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VOLUME V

Vol. IV. January, 1917

INDIANA UNIVERSITY STUDIES

Study No. 34

THE ABILITY TO READ: ITS MEASUREMENT AND SOME FACTORS CONDITIONING IT. By Melvin E. Haggerty, Ph.D., Professor of Educational Psychology, University of Minnesota; formerly Associate Professor of Psychology and Education, Indiana University.

For Sale by the University Bookstore, Bloomington, Ind. Price, 25 cents.

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Indiana University Studies
Vol. IV	January, 1917

STUDY No. 34

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Prefatory Note

THIS monograph represents the outcome of coöperative research, and acknowledgments are due to numerous persons: to Professor E. L. Thorndike thru whose courtesy the tests were printed at Indiana University; to the numerous teachers, principals, and superintendents who gave the tests in their several classes and schools, and did the initial work in scoring results; to the President and Trustees of Indiana University who bore the expense of rechecking, tabulation, and publication, to Miss Cecile White, fellow in philosophy, and Mrs. Gertrude Bell, instructor in Education, who managed the work of rescoring and did much of the actual work; to Mr. J. J. Liebenburg and Mr. Gleason Pease who made the drawings for the cuts; and to Miss Ivy Chamness, assistant editor of University publications, who edited the manuscript for publication. To all of these the writer expresses his sincere thanks, not alone for the actual service rendered, but much more for the very definite sense of professional comradeship which has grown out of these coöperative labors.

Introduction

In May, 1915, 20 Indiana cities gave the Thorndike[1] reading tests to the children of grades 3 to 8. In November, 1915, 22 cities gave to the same grades a series of tests designed to supplement the original Thorndike tests and to make them more serviceable instruments for measuring reading ability. The results from these several testings were graded in part by the teaching corps of the cities giving the tests, and were then collected at Indiana University. Here all the records were checked. In the cases of some schools, the results were found to be dependable as reported. In other cases, the work was all done over from the grading of the individual papers of the children to the computation of class, grade, and school scores.

Following is the list of cities coöperating, together with the name of the superintendent:

Alexandria	Supt. A. L. Trester
Anderson[2]	Supt. W. A. Denny
Bloomington	Supt. H. L. Smith
Bluffton	Supt. P. A. Allen
Columbia City	Supt. J. C. Saunders
Crown Point	Supt. W. S. Painter
Decatur	Supt. C. E. Spaulding
East Chicago	Supt. E. N. Canine
Elwood	Supt. J. L. Clauser
Frankfort	Supt. O. M. Pittenger
Franklin	Supt. Paul Van Riper
Kendallville	Supt. P. C. Emmons
Laporte	Supt. Arthur Deamer
Marion[2]	Supt. A. E. Highley
Michigan City	Supt. L. W. Keeler
Mt. Vernon	Supt. E. J. Llewellyn
Noblesville	Supt. E. C. Stopher
Plymouth	Supt. O. E. McDowell
Princeton	Supt. J. W. Stott
Rochester	Supt. A. C. Whitmer
Wabash[2]	Supt. O. C. Pratt
Warsaw	Supt. H. S. Kaufman

In the following pages the cities reported are indicated by numbers, but the arrangement of numbers is not according to alphabetical order.

1. Thorndike, E. L. "Measurement of Ability in Reading." *Teachers College Record*, XV, No. 4.
2. Did not give May tests.

I

Survey of Reading Conditions in Eighteen Indiana Cities

THE TESTS

Below are given the tests as they were presented to the children, except style of type. The instructions to the persons giving the tests were printed and made sufficiently clear, it was thought, to insure uniform conditions in the testing. Of this there is only relative assurance, for one does not issue instructions to teachers long until he discovers there is no such thing as a "fool-proof" set of directions. Such variations in results as are due to individual variations of method in giving the tests, however, are probably not great. The giving of the preliminary test doubtless served to correct errors for teachers as well as for the children, so that the real test was more correctly given.

With the variations in the method of computing results, the chances for error were much greater, but it was possible by checking and regrading to secure uniformity here also. In some cases, the children's papers were not returned with the class scores. Since it was impossible to check these scores, they were thrown out and not considered in the composite scores. In only a few cases was there apparent any disposition to play with the tests. In some classes the children had evidently thought the tests a joke and had given foolish answers. In a few cases, the teachers had evidently slighted the work and made up class scores which had no relation to the actual scores of the children reported. All such was either corrected or rejected. The results reported, therefore, in the following pages may be considered trustworthy measures of the reading abilities of the children tested.

Visual Vocabulary

I. PRELIMINARY TEST

Look at each word and write the letter F under every word that means a *flower*.

Then look at each word again and write the letter A under every word that means an *animal*.

Then look at each word again and write the letter N under every word that means a *boy's name.*

Then look at each word again and write the letter T under every word like *now* or *then* that means something to do with *time.*

Then look at each word again and write the word GOOD under every word that means something *good to be* or *do.*

Then look at each word again and write the word BAD under every word that means something *bad to be* or *do.*

cat, dick, rose, now, lion, lazy, honest, fred, to-day, buttercup, thief, good, then, tiger, dog, clean, daisy, before, tom, steal, yesterday, horse, william, wolf, john.

II. SCALE A

Look at each word and write the letter F under every word that means a *flower.*

Then look at each word again and write the letter A under every word that means an *animal.*

Then look at each word again and write the letter N under every word that means a *boy's name.*

Then look at each word again and write the letter G under every word that means a *game.*

Then look at each word again and write the letter B under every word that means a *book.*

Then look at each word again and write the letter T under every word like *now* or *then* that means something to do with *time.*

Then look at each word again and write the word GOOD under every word that means something *good to be* or *do.*

Then look at each word again and write the word BAD under every word that means something *bad to be* or *do.*

4. Camel, samuel, kind, lily, cruel
5. cowardly, dominoes, kangaroo, pansy, tennis
6. during, generous, later, modest, rhinoceros
7. claude, courteous, isaiah, merciful, reasonable
8. chrysanthemum, considerate, lynx, prevaricate, reuben
9. ezra, ichabod, ledger, parchesi, preceding
10. crocus, dahlia, jonquil, opossum, poltroon
10.5 begonia, equitable, pretentious, renegade, reprobate
11. armadillo, iguana, philanthropic

Understanding of Sentences

PRELIMINARY TEST

Read this and then write the answers to the questions.

Tom gave a gray cat to Mary. She gave him a black dog.

1. What was the girl's name?
2. What color was the dog?
3. What color was the cat?

Read this and then write the answers to the questions.

Your nose is on your face. Your fingers are on your hands. Your teeth are in your mouth.

1. Where are your fingers?
2. Where is your nose?
3. Where are your teeth?

Read this and then write the answers to the questions.

Dick took a bat. Fred took a ball. Will took six cents.

1. What did Will take?
2. What did Fred take?
3. What did Dick take?

SCALE ALPHA

Set *a*

Read this and then write the answers. Read it again as often as you need to.

John had two brothers who were both tall. Their names were Will and Fred. John's sister, who was short, was named Mary. John liked Fred better than either of the others. All of these children except Will had red hair. He had brown hair.

1. Was John's sister tall or short?
2. How many brothers had John?
3. What was his sister's name?

Set *b*

Read this and then write the answers. Read it again as often as you need to.

Long after the sun had set, Tom was still waiting for Jim and Dick to come. "If they do not come before nine o'clock," he said to himself, "I will go on to Boston alone." At half-past eight they came bringing two other boys with them. Tom was very glad to see them and gave each of them one of the apples he had kept. They ate these and he ate one, too. Then all went on down the road.

1. When did Jim and Dick come?
2. What did they do after eating the apples?
3. What else came besides Jim and Dick?
4. How long did Tom say he would wait for them?
5. What happened after the boys ate the apples?

Set *c*

Read this and then write the answers. Read it again as often as you need to.

It may seem at first thought that every boy and girl who goes to school ought to do all the work that the teacher wishes done. But sometimes other duties prevent even the best boy or girl from doing so. If a boy's or girl's father died and he *had to work afternoons and evenings to earn money to help his mother, such might be the case. A good girl might let her lessons go undone in order to help her mother by taking care of the baby.*

1. What are some conditions that might make even the best boy leave school work unfinished?
2. What might a boy do in the evenings to help his family?
3. How could a girl be of use to her mother?
4. Look at these words: *idle, tribe, inch, it, ice, ivy, tide, true, tip, top, tit, tat, toe.*
   Cross out every one of them that has an *i* and has not any *t* (T) in it.

Set *d*

Read this and then write the answers. Read it again as often as you need to.

It may seem at first thought that every boy and girl who goes to school ought to do all the work that the teacher wishes done. But sometimes other duties prevent even the best boy or girl from doing so. If a boy's or girl's father died and he had to work afternoons and evenings to earn money to help his mother such might be the case. A good girl might let her lessons go undone in order to help her mother by taking care of the baby.

1. What is it that might seem at first thought to be true, but really is false?
2. What might be the effect of his father's death upon the way a boy spent his time?
3. Who is mentioned in the paragraph as the person who desires to have all lessons completely done?
4. In these two lines draw a line under every 5 that comes just after a 2, unless the 2 comes just after a 9. If that is the case, draw a line under the next figure after the 5:

5 3 6 2 5 4 1 7 4 2 5 7 6 5 4 9 2 5 3 8 6 1 2
5 4 7 3 5 2 3 9 2 5 8 4 7 9 2 5 6 1 2 5 7 4 8
5 6

METHOD OF COMPUTING SCORES

Visual Vocabulary

Several points in the method of scoring should be cleared up before proceeding to the results. First as regards Scale A. Table 1 gives the scores for a class of 41 pupils.

TABLE 1.—Visual Vocabulary: 7B Class

Number of Errors per Line.

Line / Pupil	4	5	6	7	8	9	10	10.5	11	Estimated Ability
1	....	2	1	0	1	3	1	4	1	10
2	....	....	1	1	2	2	1	3	1	10
3	....	....	1	4	4	3	4	5	1	6
4	....	....	....	....	4	2	2	4	3	7
5	1	....	....	....	3	4	2	5	1	7
6	....	....	1	....	2	1	1	2	1	10
7	....	....	....	1	3	1	2	5	1	9
8	1	1	0	2	3	4	3	4	2	6
9	....	2	0	3	3	3	3	4	1	6
10	....	....	....	....	1	1	2	5	2	9
11	....	....	....	....	4	3	1	4	2	10
12	....	....	....	2	1	1	1	1	0	11
13	....	....	....	0	2	2	2	5	1	7
14	....	1	....	1	2	2	1	4	1	7
15	....	....	1	....	2	2	1	3	2	10
16	....	....	....	....	1	0	1	3	1	10
17	....	....	....	....	....	1	1	1	1	10.5
18	....	....	1	1	1	1	1	1	1	10
19	....	....	....	1	3	2	1	5	1	10
20	....	....	....	....	2	0	2	3	3	9
21	....	....	....	1	4	2	4	5	2	7
22	....	....	....	....	3	3	3	3	1	7
23	....	....	....	....	1	1	1	3	1	10
24	....	....	1	....	1	3	1	4	1	10
25	....	....	2	1	4	3	5	5	1	7
26	....	....	....	1	0	2	2	3	2	8
27	....	....	....	1	2	1	1	5	1	10
28	....	....	....	1	2	1	1	3	1	10
29	....	....	....	....	....	3	1	4	2	10
30	....	....	....	1	3	1	1	4	1	10
31	0	....	....	....	1	1	1	4	1	10
32	1	....	....	2	4	4	2	5	2	6
33	....	....	....	5	5	2	5	5	1	6
34	....	....	....	1	1	4	1	5	1	10
35	....	....	....	....	1	3	3	4	2	8
36	....	0	....	1	2	1	2	5	1	9
37	....	0	....	1	2	2	1	2	1	10
38	....	3	2	2	2	3	2	4	1	4
39	....	....	....	0	2	2	3	5	2	7
40	....	....	....	0	1	0	2	1	1	10.5
41	....	....	1	1	3	5	2	4	2	7
Totals	3	9	12	35	88	85	77	157	55	
Per ct. of error	1.4	4.2	5.8	16.6	41.9	40.4	36.6	74.7	44.7	

Class Score 7.32.

Here are shown the number of errors for each child for each line, and at the right a figure giving the line which may be considered as the estimated ability of the child in question. Thus, Pupil 1 made 2 errors in line 5, 1 in line 6, 0 in line 7, etc., and his estimated ability is line 10. At the bottom of the table the errors for the several lines are totaled and the percentage of error for each line is shown.

Each child or group is graded on the basis of 80 per cent accuracy. This allows for each child 1 error per line up to line 11. For the class as a whole, there is allowed a 20 per cent error. No line gives exactly this per cent, line 7 coming nearest with 16. 6 per cent of error. This means that the class could have done a line somewhat more difficult than line 7 within the limits of the allowable error. Just how much more difficult can be figured from a table of intermediate values given by Thorndike.[3] Referring to this table, we are told in case of 16.6 per cent error to add .32 to the value of the line. This gives for the class a score of 7.32. That is, this class of 41 pupils could have done with 20 per cent of error a line the difficulty of which was indicated by 7.32.

Understanding of Sentences

The method of scoring the individual papers in Scale Alpha was much more complicated. Many of the questions admitted of more than one answer, and there was much difference of opinion as to what answers should be accepted as adequate. No definite instructions were given the scorers on this point, and when the results reached the University, it was found that while the returns from some cities were graded by dependable methods, the returns from other cities were not. In reworking the results, Thorndike's key[4] for Scale Alpha was used and all the returns were evaluated on this basis.

Table 2 shows the record for a 4B class of 25 pupils in Scale Alpha. Reading across the top, Pupil 1 made no errors in Set A, 1 error in Set B, 2 errors in Set C, and 3 errors in Set D. Totaling the results, the record for the class is 3 errors or 4 per cent for Set A, 36 errors or 28.8 per cent for Set B, 47 errors or 47 per cent for Set C, and 91 errors or 91 per cent for Set D. Thus it is seen that the class comes nearest 20 per cent of error in Set B, but that this set is somewhat too difficult. Referring again to Thorndike's table and subtracting from the value of Set B, we get 4.58 as the difficulty which this class could have done with just 20 per cent of error. The score for this class is, therefore, 4.58.

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3. Thorndike, E. L. "Measurement of Ability in Reading." *Teachers College Record,* XV, No. 4, pp. 16-19.

4. Thorndike, E. L. "Measurement of Ability in Reading." *Teachers College Record,* XV, No. 4, pp. 49 ff.

TABLE 2.—UNDERSTANDING OF SENTENCES: 4B CLASS

Number of Errors per "Set".

PUPIL	Set A or 4	Set B or 6	Set C or 8	Set D or 10
1	....	1	2	3
2	....	2	3	4
3	....	....	3	3
4	....	3	4	4
5	....	1	1	3
6	....	1	2	4
7	....	1	1	4
8	....	....	....	3
9	....	....	1	4
10	....	1	1	4
11	....	....	1	4
12	....	2	1	3
13	2	4	4	4
14	....	1	1	4
15	....	1	1	4
16	....	1	1	3
17	....	....	2	3
18	....	4	4	4
19	....	5	4	4
20	....	1	2	3
21	....	2	....	4
22	....	....	2	3
23	....	....	1	4
24	1	4	4	4
25	....	1	1	4
Totals	3	36	47	91
Per cent of error	4	28.8	47	91

Class Score 4.58.

RESULTS

City Scores

The scores of all the grades reported by 18 cities for both the tests are shown in Tables 3 and 4. At the bottom of the table is given the median scores for all the children. All the scores on this table are translated into graphic form in Figures I and IV. In these figures the grades are arranged in order from left to right. The figures on the left ordinate indicate the successive steps of difficulty. The median score of all the children is represented by the heavy horizontal line showing an upward step at each successive grade. At the extreme right is represented the score made by 50 college students, sophomores, juniors, seniors, and graduates.

Figures I and III also show the scores of 2 cities, one of which is inferior to the median, grade for grade, and another which is uniformly superior to the median. City 14 in Figures I and III begins lower in the third grade and makes upward steps from grade to grade along the scale; but at every point remains below the median. City 13 and city 4 similarly are superior in the third grade, and by analogous upward steps maintain that superiority thruout the other grades. That these steps are not the same in degree as the steps of the median is probably due to the small number of children or the character of their selection in a single class or to the presence of a superior or inferior teacher or method in a particular class or grade. On the other hand, the conditions that place cities 13 and 4 above and city 14 below are probably general conditions affecting the school situation as a whole. In Figures II and IV, all the scores of Tables 3 and 4 are translated into graphic form. The median for each grade is shown by a heavy horizontal line, and each of the cities is represented by a short broken line above or below this median as its score demands.

TABLE 3.—Visual Vocabulary

Scores of grades 3 to 8 in eighteen cities. Also median score.

Grade	3	4	5	6	7	8
City—						
1	3.86	5.34	6.64	7.38	7.24	7.66
2	....	4.66	5.66	6.83	8.03	7.64
3	....	5.38	6.11	7.29	7.56	7.95
4	5.07	5.83	5.73	5.90	7.24	8.81
5	3.58	4.74	6.20	7.01	7.26	7.35
6	....	5.13	....	6.38	6.32	7.61
7	4.95	5.22	5.90	6.53	7.77	7.86
8	3.31	5.20	5.58	6.70	7.21	7.73
9	4.37	5.64	6.64	7.32	7.38	7.90
10	....	5.49	5.66	6.68	6.31	7.84
11	4.97	5.27	5.68	6.73	7.26	8.66
12	3.61	4.95	6.58	6.54	7.38	7.63
13	4.54	5.38	6.18	7.08	7.58	8.18
14	3.17	4.71	5.42	6.63	7.13	7.48
15	4.34	5.24	6.05	6.45	7.40	7.79
16	3.40	5.15	5.49	6.26	6.86	7.98
17	3.44	4.86	6.24	6.81	7.32	8.07
18	....	....	5.26	7.38	7.24	7.67
Median	4.00	5.26	6.00	6.66	7.29	7.91
Number of children	1,650	2,095	2,028	1,860	1,625	1,313

TABLE 4.—Understanding of Sentences

Score of grades 3 to 8 in eighteen cities. Also the median score.

Grade	3	4	5	6	7	8
City—						
1	5.48	8.00	8.33	8.70	9.00	10.00
2	....	5.40	6.76	7.36	8.98	9.06
3	....	7.20	8.56	8.71	8.96	8.47
4	6.18	6.00	8.20	8.90	9.22	9.48
5	4.91	5.70	6.86	8.91	8.18	9.00
6	....	6.36	....	8.56	8.96	9.00
7	5.46	6.36	7.16	8.90	9.22	9.40
8	4.22	5.71	7.48	8.36	8.56	8.70
9	5.00	7.18	8.36	9.00	8.50	8.80
10	....	5.48	8.56	8.36	8.82	9.48
11	6.36	7.16	8.98	9.10	9.48	9.48
12	6.00	6.64	7.32	7.82	8.56	8.36
13	5.48	8.18	8.98	9.51	9.91	10.00
14	4.40	5.62	7.32	8.00	8.00	9.00
15	4.89	6.78	7.56	7.98	7.65	8.56
16	5.38	6.56	7.16	9.08	9.14	9.18
17	5.54	5.63	7.65	8.36	8.43	8.18
18	....	....	7.16	8.37	8.62	9.69
Median	5.48	6.56	7.56	8.46	8.72	9.00
Number of children	1,650	2,095	2,028	1,860	1,625	1,313

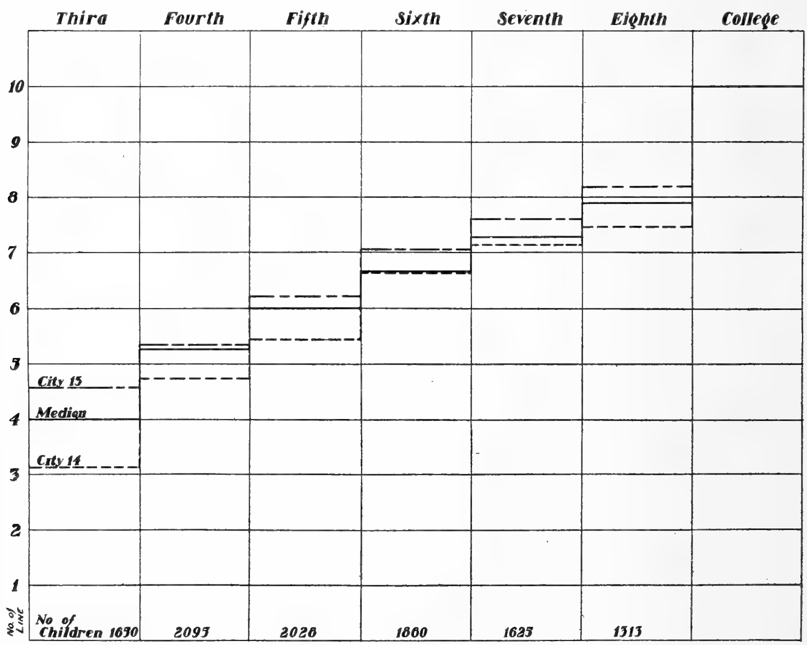


FIGURE I—Visual Vocabulary. Median score of all children in grades 3 to 8. Also median scores for each grade in cities 14 and 13. Figures on ordinate indicate steps (lines) on scale.

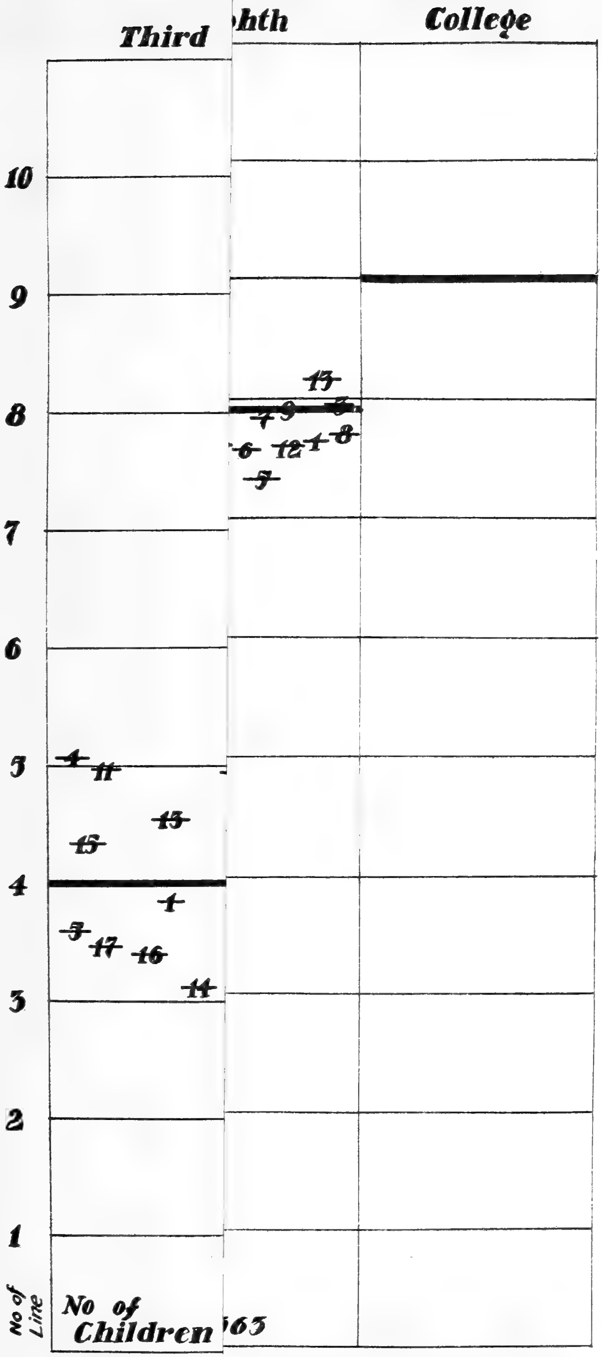


FIGURE II—ities. Figures on ordinate indicate
steps (lines) on sca

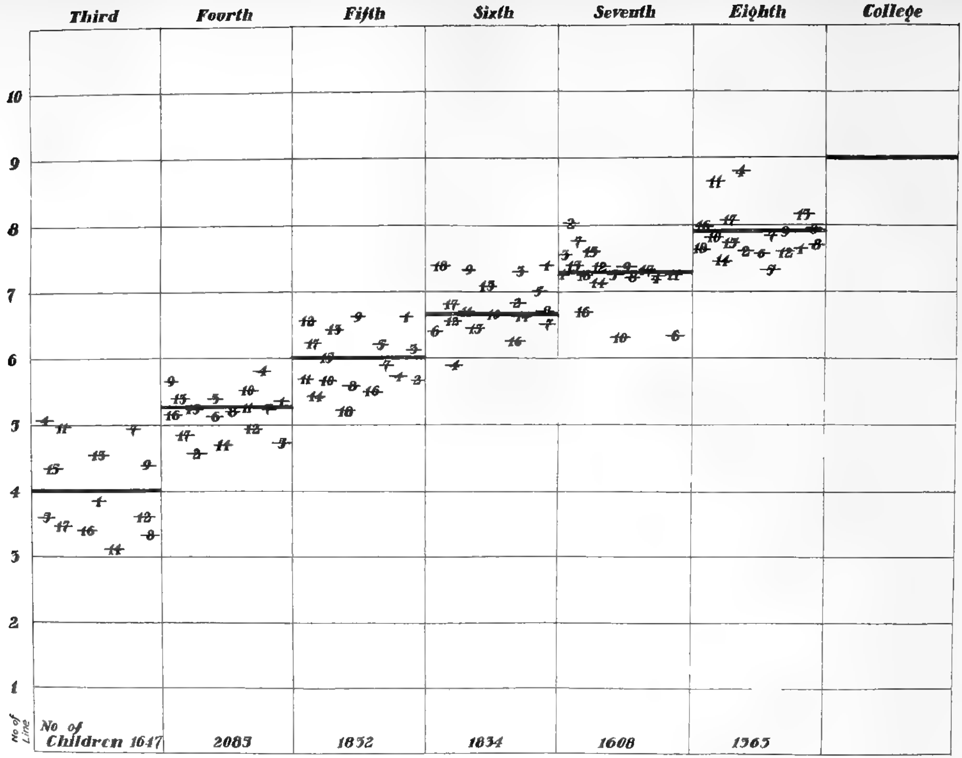


FIGURE II—VISUAL VOCABULARY. Median scores of all children in grades 3 to 8. Also median scores for each of 18 cities. Figures on ordinate indicate steps (lines) on scale. Each city is represented by its number placed in the broken line showing its median.

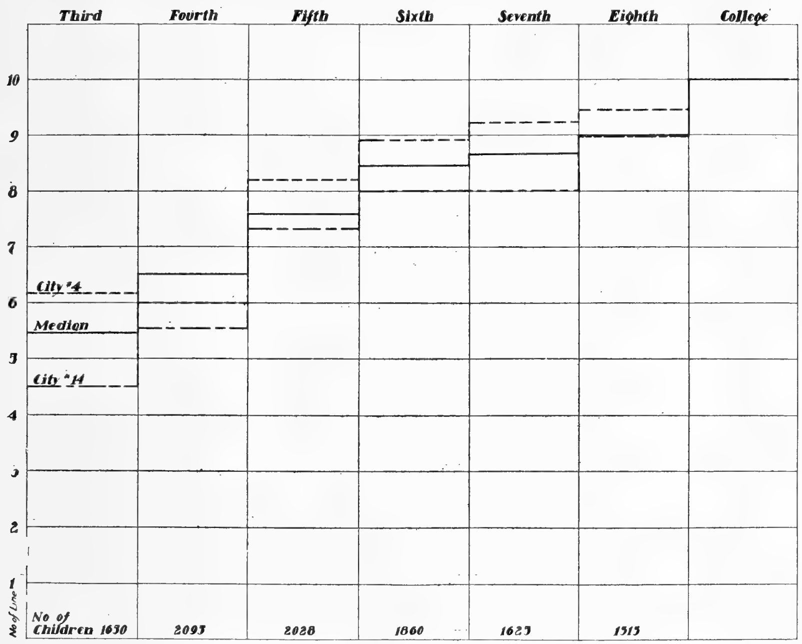


FIGURE III—UNDERSTANDING OF SENTENCES. Median score of all children in grades 3 to 8. Also median scores for each grade in cities 4 and 14. Figures on ordinate indicate steps (sets) on scale.

The Tests as Scales

The foregoing tables and figures offer very striking evidence of the scale nature of these reading tests. Figure 5 shows the median curves for the two tests together. In general, these curves are alike. They begin at a low mark on the left for the third grade and step up at each successive grade. A gradual increase of reading ability from grade to grade is exactly what we should expect for schools in general. That this increased ability is shown by linear extension along these scales is evidence that the scales are what they pretend to be, namely, scales of difficulty increasing toward the upward end. The intergrade steps for the entire group of cities is shown in the following table:

TABLE 5.—SHOWING THE INCREASE OF READING ABILITY FROM GRADE TO GRADE IN TWO READING TESTS

Grade Intervals	3–4	4–5	5–6	6–7	7–8	Average
Visual vocabulary..........	1.26	.74	.66	.63	.65	.79
Understanding of sentences	1.10	1.00	.90	.26	.28	.71

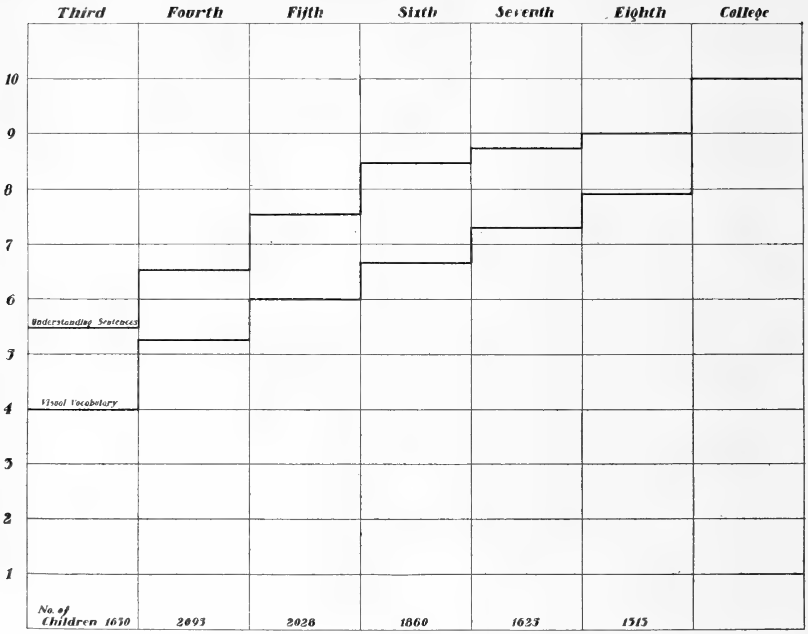


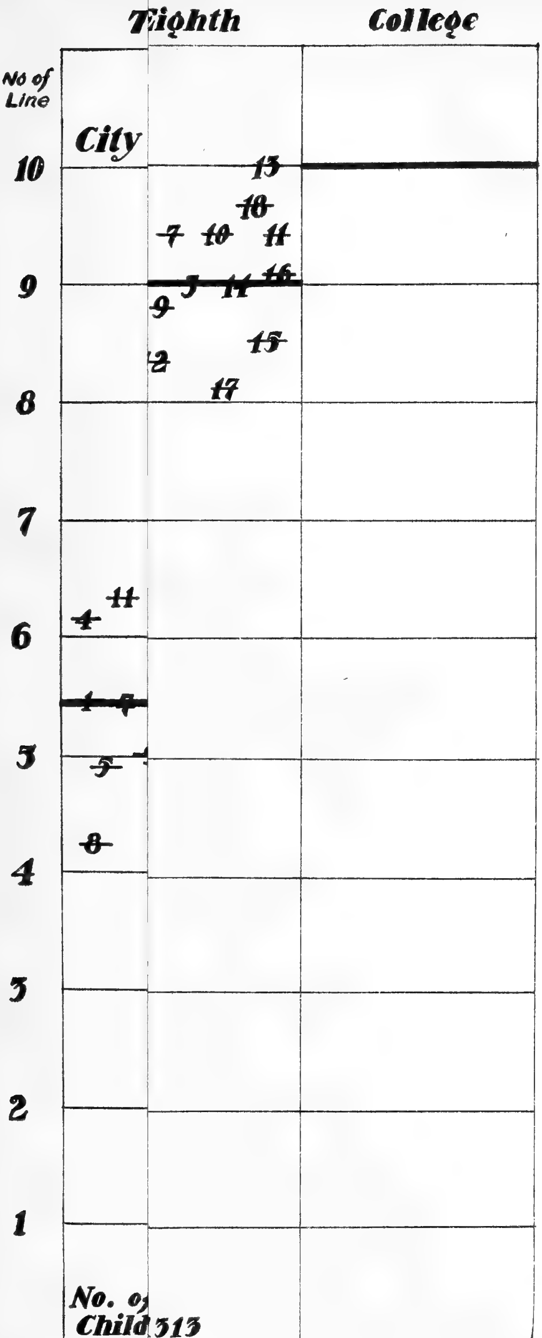
FIGURE V—MEDIANS OF BOTH TESTS. Lower line represents visual vocabulary scores. Upper line shows understanding of sentences.

For both tests the steps decrease in amount toward the upper grades. The step from grade 7 to grade 8 is about half that from grade 3 to grade 4 in visual vocabulary and about one-fourth in understanding of sentences. The average step for the visual vocabulary test is .79, and for the understanding of sentences it is .71.

What is true of the medians for the cities as a whole is, in a general way, true for each city taken separately. In the entire set of tests, there are 83 grade intervals in the visual vocabulary test, and 83 in the understanding of sentences. In the former, there are just 8 cases in which a grade shows a score higher than that of a higher grade, and in the latter there are 11 cases. These variations from the rule are doubtless due to the conditions in the several cities where the higher grades do not continue to improve in reading ability as they should.

Absence of Proper Grade Progression

While the increase from grade to grade is the common fact, the small amount of this increase in many cases is very striking.



FIGUR ch of 18 cities. Figures on ordinate indicate ste

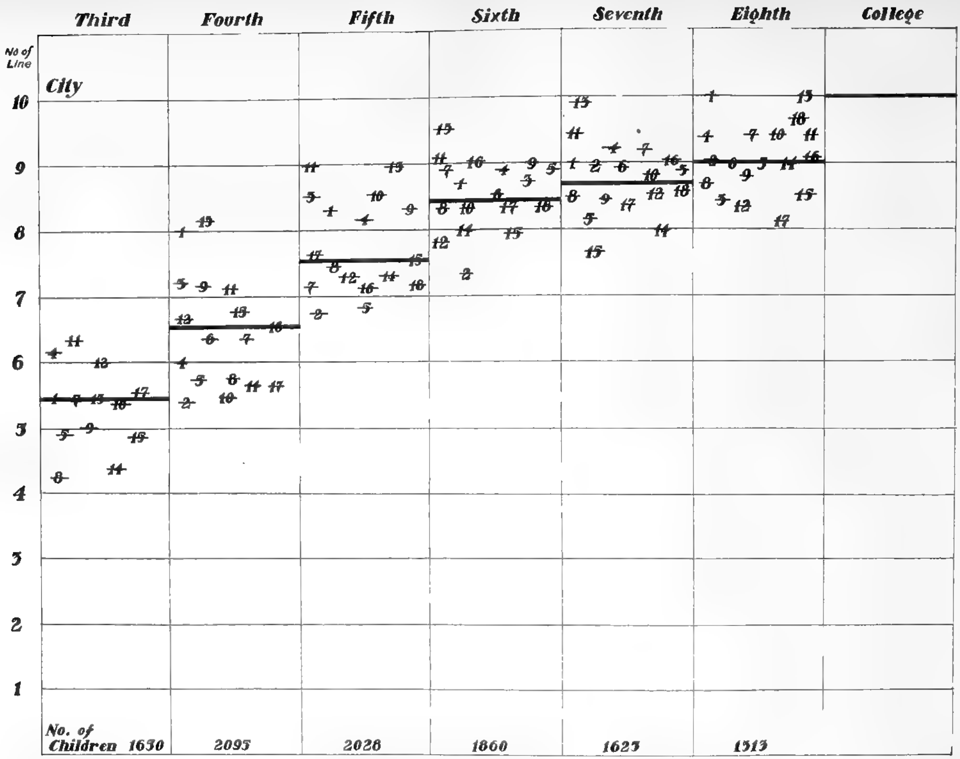


FIGURE IV—UNDERSTANDING OF SENTENCES. Median score of all children in grades 3 to 8. Also median scores for each of 18 cities. Figures on ordinate indicate steps (sets) on scale. Each city is represented by its number placed in the broken line showing its median.

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Not only in those cases already mentioned where the median score of one grade exceeds the median of a higher grade, but also in other cases where there is an approximate equality does the irregularity of grading appear. Thus the fifth grade of city 18 has exactly the median fourth grade rating in visual vocabulary. The sixth grade of city 4 is not so good as the median fifth grade, while the sixth grades of city 18 and city 1 are better than the median seventh grade. The seventh grades of city 6 and city 10 are not so good as median sixth grades, while the seventh of city 2 is better than the median eighth. Thus in city 9 the seventh grade is essentially of the same ability in visual vocabulary as the sixth; in city 11 and city 12, the sixth is the same as the fifth; in city 4, grades 4, 5, and 6 are approximately the same; in city 10, the sixth is even better than the seventh; and in city 2, the seventh is better than the eighth.

Similar facts appear in Table 4, graphically in Figure IV, showing results for the understanding of sentences. Here the eighth grade (city 2) appears slightly superior to the seventh, and the seventh slightly superior to the sixth, but the superiority of score is so slight as to be negligible. On the basis of the results of the two tests, it is clear that there is no essential grade difference in reading ability between the two groups of children constituting the seventh and eight grades of city 2. It would be interesting to know what does constitute the child's right to be promoted from the seventh to the eighth grade of that city. Similarly what do cities 9 and 10 mean by passing pupils from grade 6 to grade 7, or city 14 by passing sixth grade children on to the seventh grade, or city 12 by promoting seventh graders to the eighth grade?

Several possible reasons are advanced for the failure of pupils to continue their improvement in reading ability in the upper grades. First and probably the most mischievous as well as the most erroneous is that the pupils already read well enough. This view, tho not often openly championed, is tacitly assumed with a unanimity and complacency that is at least dispiriting. Teachers and supervisors are rightly concerned to teach the pupils in the early grades to read, but after a fair proficiency in vocabulary and sentence interpretation is acquired, the attention of teachers and pupils is turned to other things, to arithmetic, to literature, to history, and the wide range of other studies clamoring for a hearing. The teaching of silent reading as an art of understanding and interpreting printed pages is made subsidiary and incidental to work in other subjects, and in the upper grades receives almost no direct attention. Such incidental work as is given is of course valuable. The teacher in the arithmetic class finds that she must teach the pupil to read the problem in order that he may solve it; the teacher of history finds the children do not understand what they read and she must give a little help in reading. Such incidental help is, however, usually regarded by the teacher as outside the business in hand and a thing to be avoided or gotten over with the least possible time and thought. Whatever improvement in general reading ability the children acquire they get, as it were, surreptitiously, because the average teacher in the upper grades insists on assuming that the children can read. If by some chance she discovers that a child fails in geography because he can not read she is more than likely to regard it as an evidence of inefficient teaching in the lower grades rather than a legitimate problem for her to solve. In this respect she is much like the high school teacher of science who regards a student's training in English to be the exclusive business of the English department, and, like him, she makes the very serious error of believing that effective thinking can go on in other fields without adequate language training.

An adequate investigation would doubtless show that many of the failures in other school subjects are due to the inability of pupils to read, and that children learn to solve problems, to understand the history and geography texts, and to do effective work in these fields just in proportion as they acquire a mastery of the language in which these texts are written. When we consider further that the texts in school subjects which children must use in the seventh and eighth grades contain prose very much more difficult than anything the children meet in the reading work of the earlier grades, it becomes evident that the easy reliance which teachers put upon the reading ability of pupils is misplaced. Training in reading should be given on the basis of the advanced prose which children must interpret, and just because the pupils—so long as they remain in school—are passing on to more and more difficult texts, this training must be continued thruout the elementary grades and probably also thru the high school and into the college. In time many children learn to teach themselves, but the school authorities can never be certain that this will occur, and are always under *the obligation to see that the essential improvement is taking place.* This view we already have in regard to expression, in regard to the pupil's use of language in speaking and writing. It is no less imperative in reading and understanding.

A second reason given for failure to improve in the upper grades is that pupils reach their limit of improvement. There is probably no ground for this argument. There is a wide range of possibilities for increase of vocabulary, and children rightly environed and rightly taught go on acquiring new words almost indefinitely. Further, it seems possible to teach pupils of any age or grade of advancement to improve very greatly in the ability to read rapidly and understandingly when once attention is given to the question. It is easy to show that college students can be brought to a very much greater efficiency by a very small amount of practice. The plateau, if the period of decreased rate of improvement in reading ability in school children may be so characterized, is probably a purely adventitious one, the evidence of our inefficient methods of training rather than a necessary consequence either of the nature of the learning process or of the subject to be learned.

A third reason advanced by teachers is that there is no time to teach reading in the upper grades. This sets forth an administrative problem for which teachers are not directly responsible, but one demanding serious attention from those who are. Can it be possible that there is any single ability more important than the power to interpret what one sees in print? Certainly spelling and handwriting are far from being so important, and yet both get places on the seventh and eighth grade programs. And what facts or skills does a child get in arithmetic, or what knowledge does he gain in geography or history that will compensate for lack of training in the most fundamental of all the tools of knowledge, the ability to read on the level of his possible range of thinking?

None of these reasons is the real one. The pupils of the upper grades fail to improve in reading ability because the administrative officers of the school do not realize the importance of such training, and therefore do not give it adequate time on the program, and because the teachers have not yet developed the methods for teaching the art of silent reading effectively in the upper grades. Let any superintendent say that we shall continue in the upper grades to regard reading as of the same fundamental importance as we do for the younger pupils and give it adequate time recognition on the school program, and let his teachers set themselves the task of developing in their pupils the power of rapid and accurate silent reading and range of vocabulary, and these upper grades intervals will lengthen out to correspond with those lower down. It is encouraging to note that just this fortunate situation already exists in a few cities. The seventh-eighth grade visual vocabulary interval in city 4 is 1.57 steps; in city 6 it is 1.39; in city 10 it is 1.53; in city 11, 1.40; and city 16, 1.12; while in the understanding of sentences the same interval is 1 or more units in cities 1, 14, and 18, and the sixth-seventh grade interval is 1.62 in city 2 in the understanding of sentences and 1.20 in visual vocabulary. Such achievements are possible in any school of normal children.

In thus pointing out what seems to me a defect in the school regime in regard to reading I do not mean to criticize the schools unjustly, least of all to suggest that they are negligent in their attitude toward their work. It would be difficult to find a more devoted and loyal body of men and women than those in charge of the schools. If they have erred in this matter it is from the same cause that makes all of us subject to error every minute, namely the lack of scientific information upon which to found better modes of procedure. The introduction of standard tests and scales into the analysis of the reading situation offers the most promising instrument of reform. No longer need we be "unhampered by facts" as to what the situation actually is. No longer need we ignorantly put together into a class for identical instruction pupils differing in ability as much as the median of the fourth and median of the eighth grade. No longer need we call a class a seventh grade one semester and an eighth grade the next without essential improvement in their reading power. Whatever limitations of method we may still suffer we may now know in measured terms what abilities the children actually have. This scientific knowledge should be the basis of definite improvement in methods.

Overlapping

The unsatisfactory character of the grading of children is evident not only in the irregularity of the grade intervals but also in the vast amount of overlapping of ability from grade to grade. To determine just how much of this existed among the children reported in this test a large number of visual vocabulary papers (9,291 from grades 3 to 8) were grouped on the basis of the score made. The results are thrown together in Table 6 and are rep-

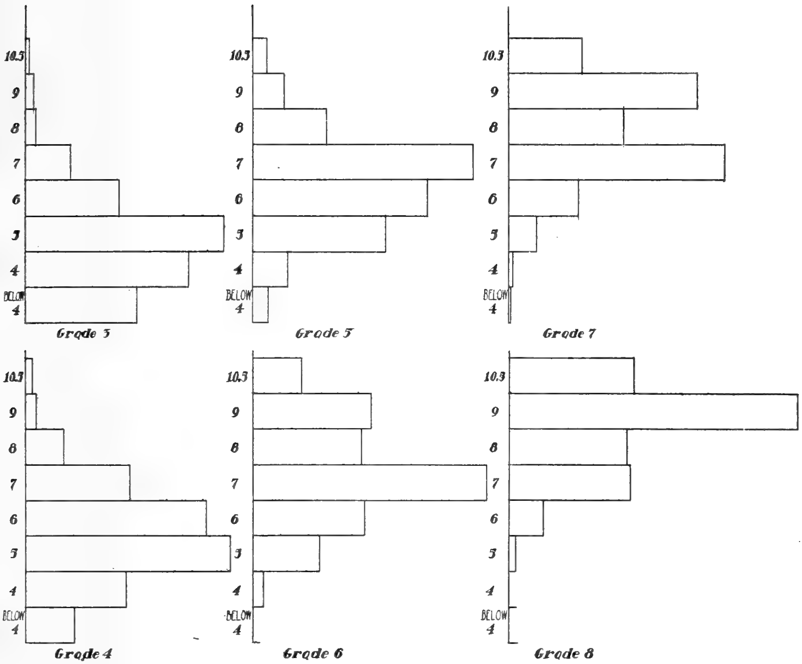

FIGURE VI—Visual Vocabulary. Showing overlapping of all grades in 14 cities. Ordinate = scale values; abscissa = per cent of pupils making each score.

resented in Figure VI. These results from the children of fourteen cities show a distribution for every half grade over five and one-half steps, and for most half grades, 7A, 7B, and 6B to 3B, over the entire length of the scale. The overlapping for three grades of one school is shown in Figure VII.

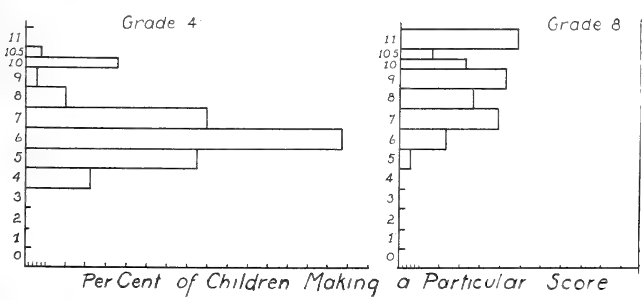

FIGURE VII—Visual Vocabulary. Showing overlapping of grades in one school. Ordinates = line value; abscissas = per cent of pupils making each score.

In computing the intergrade intervals the average was found to be .79 (see Table 5) of the distance from line to line. In the lower grades it is more; in the upper grades, less. Accepting this as a standard, it would seem that the distance between the median and the best or between the median and poorest pupils of any class should not be more than .79. A pupil varying more than this should pass to the next higher or the next lower grade. Further, the distance between the best and the poorest pupils of any class should not exceed 1.58 or approximately 1½ times the distance from line to line. Now what do we find? For the 8A's there are 20 pupils of line 6 ability, and 113 of line 10.5 ability, a distance between the best and poorest of four and one-half steps, or a little less than three times the allowable difference. That is, the 20 should be 3 grades lower than the 113. Worse still is the case of the other grades. In 8B there are 10 who are 6.9 grade intervals below the best 89; and for the succeeding half grades the distance between the best and poorest pupils is as follows:

7A:	Poorest	3—7.5	grade-intervals below best	85
7B:	Poorest	10—7.5	grade-intervals below best	57
6A:	Poorest	79—6.3	grade-intervals below best	85
6B:	Poorest	18—7.5	grade-intervals below best	26
5A:	Poorest	12—8.9	grade-intervals below best	16
5B:	Poorest	31—8.9	grade-intervals below best	15
4A:	Poorest	47—8.9	grade-intervals below best	15
4B:	Poorest	79—8.9	grade-intervals below best	5
3A:	Poorest	131—8.9	grade-intervals below best	8
3B:	Poorest	259—8.9	grade-intervals below best	1

The meaning of these figures is that in every grade there are pupils grouped together who in actual ability are from 3.1 to 4.4 grades apart.[5] If we were to classify the children represented in Table 6 on the basis of their ability as measured by the visual vocabulary scale, we should cut the table horizontally instead of longitudinally. We should make line 4, which is just third grade ability, the standard for the lowest grade. Into this group we should put all in the second horizontal row. Here would come pupils from every grade except 8A, 8B, and 6A. The next group would include all of line 5 ability, and would include pupils from every grade except 8A. Continuing in this fashion, five additional grades would be formed. Each grade would draw from every

5. The case is even worse than this, for, if, instead of measuring by the average intergrade interval, we take the seventh-eighth interval, the 20 are 3.4 times the allowable distance below the best of their grade.

half grade represented on the table. The children of any grade would be essentially of the same ability, and the steps of difficulty from grade to grade would be equal. Where we should place the pupils of the first horizontal row could only be determined by further testing. All that is clear is that they do not belong in any of the classes already suggested.

TABLE 6.—Visual Vocabulary

Showing by half-grades the number of children in 14 cities scoring each line.[6]

Line	8A	8B	7A	7B	6A	6B	5A	5B	4A	4B	3A	3B
Below 4	.....	.....	1	3	.....	.....	12	31	47	79	131	259
4	.....	.....	2	7	.....	28	28	68	101	169	165	206
5	.....	10	21	35	79	73	134	199	249	285	242	217
6	20	33	45	97	108	144	200	238	259	213	146	70
7	76	125	184	260	282	245	312	240	173	98	75	33
8	77	114	115	114	139	108	94	93	74	30	16	10
9	244	215	193	185	185	96	44	35	17	10	18	3
10.5	113	89	85	57	85	26	16	15	15	5	8	1
	530	586	646	758	878	710	840	919	935	889	801	799

TABLE 7.—Visual Vocabulary

Showing percentage of children in half-grades scoring each line in 14 cities.

Line	8A	8B	7A	7B	6A	6B	5A	5B	4A	4B	3A	3B
Below 4	.....	.....	.002	.004	.....	.....	.014	.03	.05	.09	.16	.32
4	.....	.....	.003	.009	.....	.03	.03	.07	.10	.19	.21	.26
5	.....	.02	.03	.05	.09	.10	.16	.22	.27	.32	.30	.27
6	.04	.06	.07	.13	.12	.20	.24	.26	.28	.24	.18	.09
7	.14	.21	.28	.34	.32	.35	.37	.26	.19	.11	.09	.04
8	.15	.19	.18	.15	.16	.15	.11	.10	.08	.03	.02	.01
9	.46	.37	.30	.24	.21	.13	.05	.04	.02	.01	.02	.004
10.5	.21	.15	.13	.08	.10	.04	.02	.02	.01	.01	.01	.001

Against any such radical administrative readjustment as is here suggested, it may be argued that the grounds for readjust-

6. In computing these figures lines 10 and 11 were eliminated and the children who might have been credited with these lines were distributed on the basis of their highest score on the other lines. The reason for this was the misscaling of the words of these two lines. See pp. 36 ff.

ment are not adequate. The grouping of children from 14 schools brings together children that have not been taught together, and hence the distribution and overlapping seem greater than it really is in any single city or school. The reply to this argument so far as single cities are concerned is found in Table 8 and Figures VI to IX, where the grades compared are from the same school.

The situation here is not essentially different from that shown in Table 6. The number of children is smaller, but the distribution is essentially the same, and the case holds no matter what city or what grade we choose. Everywhere children of the most diverse abilities are thrown together and called a grade.

It may be objected that the vocabulary test is inadequate as a measure of homogeneity of pupils in reading ability. Let us turn

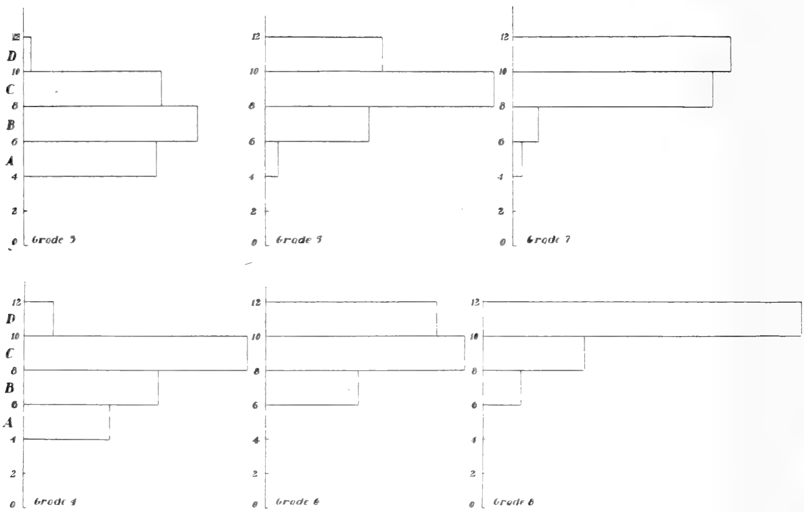

FIGURE VIII—Understanding of Sentences. Showing overlapping of all grades of one city (12). Ordinates = set values; abscissas = per cent making each score.

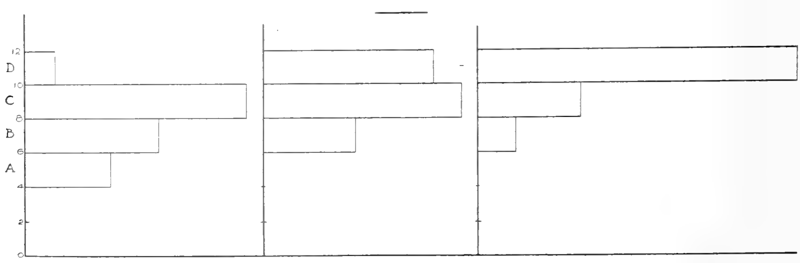

FIGURE IX—Understanding of Sentences. Showing overlapping in grades 4, 6, and 8 in one city.

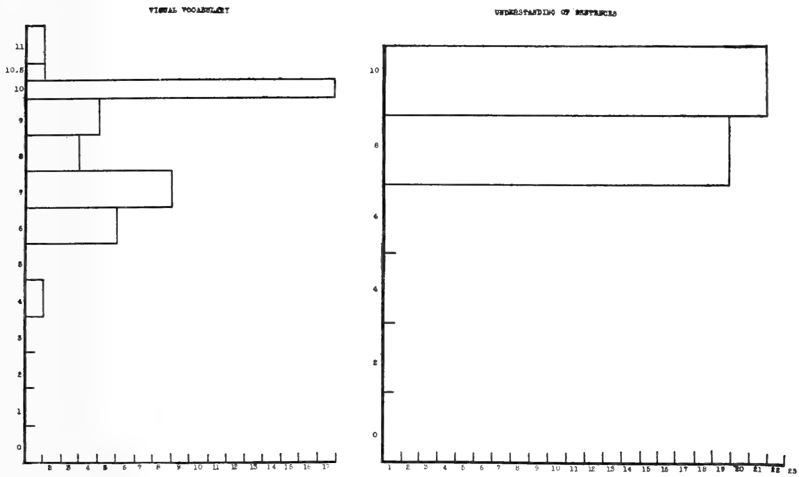

FIGURE X——SCORES OF SAME CLASS IN VISUAL VOCABULARY AND UNDERSTANDING OF SENTENCES. Showing how the individuals are better differentiated by the vocabulary scale.

to the records of the understanding of sentence scores. Table 2 (p. 12) gives a class of 25 in which 12 children made Set C or 8; 6, Set B or 6; 6, Set A or 4; and 1 who fell below the lowest mark. When we recall that the grade-interval between grades 4 and 5 is 1 or one-half the distance between Set A and Set B, and that the difference between the best dozen members of this class and the poorest half dozen is four times this inter-grade interval, the case remains about what it was under the visual vocabulary test. Nor is it improved by a study of Figure VIII where the distribution of all the grades of one city is shown in parallel figures.

In Figure IX there are shown the results for the grades of one city.

TABLE 8.—Visual Vocabulary

Showing by half-grades the number and per cent of seventh grade children of two cities scoring each line.

Line	City 14				City 9			
	7A		7B		7A		7B	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
Below 4	......	......	......	......	1	1	......	......
4	1	1	1	1	......	......	......	......
5	3	3	4	4	2	3	......	......
6	9	8	21	23	2	3	7	8
7	30	28	34	36	31	36	30	36
8	18	17	4	5	10	12	18	22
9	34	32	18	19	26	30	22	26
10.5	12	11	11	12	13	15	7	8
Totals	107		93		85		84	

TABLE 9.—Understanding of Sentences

Showing by half-grades the number and per cent of seventh grade children of two cities scoring each set.

	City 14				City 9			
	7A		7B		7A		7B	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
Below Set A	......	......	1	1	......	......	......	......
Set A or 4	1	1	7	8	1	1	1	1
Set B or 6	8	7	14	15	3	4	2	3
Set C or 8	60	56	48	52	38	44	43	55
Set D or 10	37	35	22	24	44	51	32	41
Totals	106		92		86		78	

All of the grades have children of ability 6 and 8, while each of the grades 3 to 5 contains children of the ability of Set A or 4, and each of grades 3 to 8 contains children of ability of Set D or 10. For the whole series of grades the average intergrade interval for the understanding of sentences is .7 of one step or .35 of the distance from one set to the next. In the upper two intervals it is but about one-fourth of this average. Using this average as a measure, it is seen that about 9 per cent of the eighth grade is 3 grade-intervals below the best in the grade; for the seventh grade, 20 per cent are 3 grade-intervals below the best, etc. Thus, whether we group classes and grades from a number of cities or consider the classes and grades within a single city, and whether we consider the range of vocabulary or the understanding of printed sentences, the conclusion forces itself that there is a degree of mis-grading of children on the basis of reading ability that is startling and that must be subversive of good teaching in the whole range of subjects where efficiency depends upon the ability to read.

Effective Speed

"Slow and sure" is ceasing to exert its witchery as a precept in mental control in the light of experimental results. We now know perfectly well that rapid work may be more accurate than slow work, that many of the most accurate workers are the most rapid, that many of the slow ones are the most inaccurate, that some are made more inaccurate by being slowed down, and that some are made more accurate by being speeded up. It is probable that the proper adjustment of speed and accuracy is a highly individual matter. On the physiological side, the most efficient speed for any activity involving skills or well established habits would be that speed at which interfering or distracting stimuli were most consistently inhibited. In other words, it is the speed at which the attention is least dispersed. That we are in need of extended studies in order to determine the most efficient speed for persons of any age and in various forms of activity is evident whenever one tries to say at what speed any piece of work should be done by any individual. It is not amiss, therefore, to deduce whatever evidence we can from the results of these tests regarding the relation of correct results to the speed at which the work was done. The folder containing the tests had on the first cover page a form of this sort:

Time of beginning test...............................
Time of finishing test...............................
Time for doing test...............................

Instructions were given to the experimenter for taking the time. As the papers were handed in by the pupils, he was to record the time in this fashion: 10—30—20, meaning 10 o'clock, 30 minutes, 20 seconds. This was subtracted from the time of beginning, thus giving the time of doing the test.

In compiling these results for visual vocabulary, the pupils from 14 cities in grades 4, 6, and 8 were considered. These were first thrown into groups determined by the particular score of the paper in question. Thus, all papers which were scored for line 4 were placed in one group; those for line 5 in the next group, and so on. For reasons noted on page 23 lines 10 and 11 were not considered, but the persons credited with that score were redistributed.

TABLE 10.—Visual Vocabulary

Time for doing the test shown by grades, scores, and quartiles.

Line	Grade	No. Pupils	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	Average
Below Line 4	4	126	9:15	13:22	16:34	28:23	16:28
	6	...	...	...	...	...	...
	8	...	...	...	...	...	...
Line 4	4	270	8:24	11:59	14-46	29:00	16:02
	6	18	6:47	8:47	12:23	17:41	11:24
	8	...	...	...	...	...	...
Line 5	4	534	8:15	12:00	16:03	28:07	16:06
	6	152	6:15	9:03	13:05	30:11	14:38
	8	10	5:06	7:33	9:23	13:58	9:00
Line 6	4	472	8:05	11:18	19:08	31:06	17:25
	6	252	6:27	9:51	14:54	25:52	14:18
	8	53	4:59	7:26	8:56	12:29	8:27
Line 7	4	271	7:40	11:03	17:01	30:27	16:32
	6	527	6:09	9:15	14:09	29:35	14:47
	8	201	4:48	7:12	9:13	13:20	8:41
Line 8	4	104	8:58	12:07	15:12	32:02	16:35
	6	247	6:01	9:06	14:01	26:48	13:59
	8	191	5:15	7:41	9:02	12:29	8:37
Line 9	4	27	9:05	13:16	15:12	27:26	16:15
	6	281	5:48	9:04	13:26	24:39	13:14
	8	459	4:49	7:13	9:34	14:18	8:57
Line 10.5	4	20	11:03	12:33	13:38	22:28	14:55
	6	111	5:58	9:09	13:34	24:09	13:12
	8	202	4:30	7:30	9:28	14:14	8:49

How the time distribution falls out may be seen from Table 10, where the number of pupils scoring each line, their average time, and the average time for each quartile may be seen. There are students from each grade scoring for each line except that there are no eighths of line 4 ability or below and no sixes below line 4. In general, it is seen that there is no regular increase in the average time for those who scored the higher marks. Lines 7, 8, 9, and

10.5 all show less time than line 6 for the eighths. In the sixth grade the greatest time is for those of line 8 ability, while those whose score is 10.5 use less time than do those who score lines 5, 7, or 9. Line 6 scored the longest time for the fourth grade, while lines 9, 7, 5, and 4 scored shorter times than that made by the 126 fourth graders who had less than line 4 ability. The shortest average time was made by the 20 who scored line 10.5, the highest possible score.

There is a general decrease in average time for the pupils of each higher grade scoring any line. The fourth grade requires longest, the eighth grade least, and the sixth grade is always intermediate. The time by quartiles follows this same general rule.

In examining the quartile scores the greatest difference appears. The fastest group of all is composed of fifty eighth-grade pupils who do the entire test correctly, scoring line 10.5 in 4 minutes and 30 seconds. The slowest eighth grade group, 115 in number, scored line 9 in 14 minutes and 18 seconds. The speediest group of sixth grade pupils numbering 70 scored line 9 in 5 minutes and 48 seconds, and the slowest 38 scored line 5 in 30 minutes, 11 seconds. For the fourth grade the extremes are 7 minutes 40 seconds for 67 pupils scoring line 7, and 32 minutes, 2 seconds for 26 children scoring line 8. The next slowest fourth grade group, 118 in number, scored line 6 in 31 minutes and 6 seconds. In general the fastest quartile in any grade requires from one-fifth to one-half the time of the slowest quartile. Only in the fourth does the slowest make a higher score than the fastest. The very poorest group of eighth grade pupils, 2 in number, are excelled in both speed and score by more than 400 fourth grade children, by more than 800 sixth grade children, and by almost 1,000 eighth grade children. At the opposite extreme are 50 eighth grade pupils who *excel in both quality and speed* all other children in these grades, namely 914 in the eighth, 1,588 in the sixth, and 1,824 in the fourth.

The simplest and most direct conclusion from these figures is that inaccuracy is not a necessary correlative of rapid work. Neither is slow work a guarantee of correctness. It is possible that some of those in the first quartile might have done better if they had taken more time. There is some evidence that time pays, in that the fourth grade group which took the longest time made a better record than the group which made the shortest time. Against that fact, however, is the fact that 125 fourth

TABLE 11.—Visual Vocabulary (Age of Pupils)

LINE	Grade	AGE 7½	8	8½	9	9½	10	10½	11	11½	12	12½	13	13½	14	14½	15	15½	16	16½	17	17½	18
Below Line 4	4B		2	3	11	10	12	11	7	8	6	2	2		2			1					
	4A			1	3	3	9	6	3	4	6	5	2	1	4								
	6B											1	1	1	2	1							
	6A													1		2							
	8B																						
	8A																						
Line 4	4B		1	4	20	28	35	26	19	13	12	2	6		1	1	1						
	4A	1	1	1	3	12	20	11	14	7	15	9	2		2	1		2					
	6B							1	1		3		4	2	3	1							
	6A										1	1	4			2	1						
	8B																						
	8A																						
Line 5	4B	1	6	12	53	50	52	34	27	17	12	5	3	5	4	3	1						
	4A		1	1	24	42	67	33	29	14	19	11	4	1	1			2					
	6B						1	4	2	11	17	11	10	5	4	4	1	2					
	6A								4	8	9	11	5	8	2	1	2						
	8B										1	1	1	1	1	2	1	2					
	8A															3	1	2	2				
Line 6	4B		1	7	48	48	44	17	14	10	7	5	7	2	2				1				
	4A		1	3	22	67	56	36	27	18	8	7	9	2	2	1							
	6B							5	11	30	26	21	15	11	13	1	7						
	6A					1		4	3	19	34	12	15	16	7	2	6	1	1		1		
	8B												1	3	9	10	3	2	2				
	8A													4	3	3	6		1	1	2		

Line 7	4B		3	3	22	26	15	16	4	4	2		1					1					
	4A		1	2	19	42	53	15	20	5	11	1	1	1	2								
	6B				1	1	3	13	44	38	52	32	26	11	9	6	3						
	6A						4	4	26	50	73	40	39	20	16	6	7		2				
	8B								1		1	3	16	20	29	26	17	11	9	2	1	1	
	8A											1	5	19	20	11	5	6	6	3			
Line 8	4B		1	2	10	6	2	2	5	1			1										
	4A		2	2	8	15	24	8	6	2	2	2			1								
	6B						2	6	17	22	18	9	12	6	5	6	2	1		1			
	6A								13	36	21	20	21	10	7	1	1	2		1			
	8B									1	5	10	19	21	18	18	13	8	6	2			
	8A										1	2	5	14	23	13	9	4	2	2	2		
Line 9	4B				4	2	2	1		1													
	4A			2	1	4	2	2	4		1	1											
	6B						5	11	17	21	12	14	6	4	2	1							
	6A							7	25	48	37	13	21	11	10	2	2	2					
	8B								1		11	22	30	47	42	23	28	17	10	5			
	8A									1	3	6	19	58	53	38	34	18	6	7			1
Line 10.5	4B				1	1	1	1		1													
	4A				1	3	3	2	1	2	1												
	6B						1	4	3	8	3	1	3	1	1								
	6A							4	9	19	13	15	8	4	5	3	1	1					
	8B											16	19	20	16	8	3	5	3				
	8A										1	4	11	24	34	20	15	8	4	1	1		

grade children took less time and scored equal or better than this slow group.

A question impossible to answer from these figures is, what would have been the effect on the quality of work of any group if their rate of work had been changed? Would the slow ones have done better if they had been speeded up, or would they have been less accurate? Would the rapid workers have done better if they had taken more time or would they have done about the same? From the teaching point of view these questions are highly important, for it is in changing the requirements of speed that the teacher can most easily influence the child's routine work.

What is the reason some persons require a longer time than others for a given task? One explanation is that it is a matter of temperament. Individuals are geared to go at a definite rate, some slow and some fast. A more potent reason is probably the distraction of attention, the crowding in of extraneous impulses that interrupt the main impulses and render them ineffective.

Age and Efficiency

That mere increase in age does not serve to develop a vocabulary is evident from the age-score study of the fourth, sixth, and eighth grade children. The entire distribution for these grades is shown in Table 11. Fourth grade children range in age from 7½ years to 16 years; the limits for eighth grade children are 11 and 18—a range of 9 years in the first group, and of 7 years in the latter. Sixth grade children are intermediate. Table 11 gives the scores for each half grade of the normal, accelerated, and retarded children. From this it is seen that the youngest children are in every case, except 4B, slightly superior to the oldest group of the same grade. Scarcely ever do they fall below those of normal age. On the other hand, the children who are retarded are inferior to both the normal and accelerated groups. Thus much evidence that rapid promotion does not militate against efficiency in visual vocabulary.

TABLE 12.—MEDIAN SCORES OF ALL PUPILS ACCELERATED, NORMAL AND RETARDED FOR GRADES 4, 6, AND 8

GRADE	ACCELERATED	NORMAL	RETARDED
8A	9.4	9.6	9.3
8B	9.4	9.2	8.9
6A	8.5	8.4	7.6
6B	8.	8.	7.4
4A	6.5	6.4	6.1
4B	5.5	5.8	5.6

Sex Differences

In order to study the question of sex differences the results for the visual vocabulary test were worked up in the following manner: The returns for each city were divided into two groups, boys and girls, and the average error for each sex was computed for each line and for the test as a whole. The figures are given in Table 13. City 1 reported 219 boys and 265 girls who made respectively for lines 4 to 11 average errors as follows: .41—.28, .79—.61, 1.21—.97, 1.95—1.31, 2.64—2.38, 3.05—3.06, 2.95—2.39, 4.10—3.90, 2.17—2.16. For the test as a whole, the average error was 17.87—15.61. It should be remembered that the highest average possible was 5 for each of lines 4 to 10, 3 for line 11, and 43 for the entire test. In the case of every line except 9, the boys made a higher average error than did the girls. Consider-

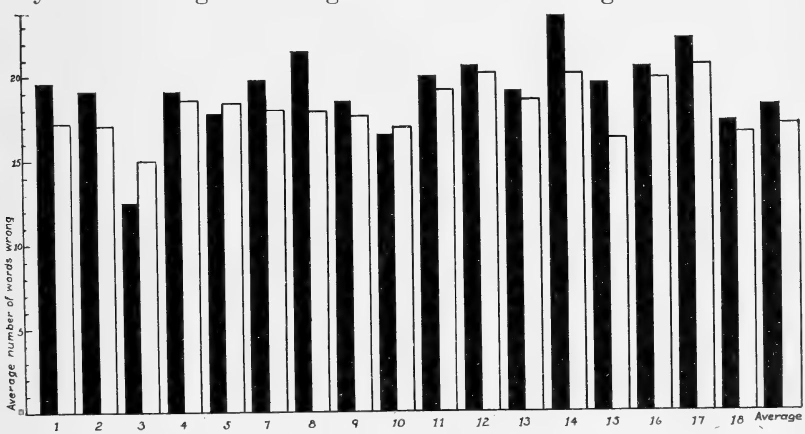

FIGURE XI—VISUAL VOCABULARY. Sex differences. Height of column proportional to number of errors. Figures on ordinate indicate number of errors. Total number of possible errors was 43. Open column equals girls; closed column equals boys. Numbers below equal cities.

ing the entire test of 43 words, the girls were superior in 14 of the 18 cities and in the test as a whole. Figure X pictures these results. The margin of superiority for the girls is not great, but it is constant and therefore significant. It tends to confirm a rather widespread common-sense notion that girls have superior language abilities.

TABLE 13.—Sex Differences

Visual vocabulary. Average error per line.

City	Sex	No.	4	5	6	7	8	9	10	10.5	11	Average by Sex
1	B	219	.41	.79	1.21	1.95	2.64	3.05	2.95	4.10	2.17	17.81
1	G	265	.28	.61	.97	1.31	2.38	3.06	2.39	3.90	2.16	15.61
2	B	135	.49	.58	1.20	1.78	2.77	3.34	3.12	3.93	1.69	17.79
2	G	176	.26	.40	.80	1.25	2.58	3.18	2.74	3.76	1.84	15.59
3	B	438	.40	.72	1.02	1.86	2.88	3.22	2.89	4.11	2.24	10.83
3	G	456	.35	.28	.53	1.00	2.03	2.65	2.25	3.28	2.42	13.18
4	B	240	.28	.39	1.19	2.02	2.80	2.97	2.67	4.10	1.86	17.74
4	G	266	.21	.40	1.01	1.89	2.73	3.26	2.43	4.26	2.27	17.21
5	B	197	.49	.73	1.29	1.96	2.25	2.91	2.51	3.61	1.87	16.36
5	G	200	.36	.67	1.20	1.87	2.54	3.33	2.57	3.58	2.12	16.87
7	B	227	.33	.60	1.36	2.18	2.69	3.19	3.08	4.04	2.10	18.11
7	G	193	.24	.55	1.24	1.88	2.45	2.62	2.71	3.97	2.32	16.32
8	B	495	.61	.99	1.54	2.44	2.91	3.47	3.20	4.02	2.01	19.89
8	G	566	.47	.91	1.38	1.94	2.45	3.03	2.28	3.33	1.79	16.58
9	B	591	.30	.51	1.17	1.79	2.90	3.23	2.71	3.72	2.05	17.02
9	G	551	.18	.48	.86	1.48	2.86	3.34	2.29	3.68	2.30	15.93
10	B	383	.23	.38	.95	1.49	2.52	2.92	2.62	3.68	1.59	15.32
10	G	410	.16	.34	.75	1.68	2.53	3.17	2.47	3.72	1.95	15.47
11	B	200	.25	.68	1.49	2.19	2.78	3.30	3.03	3.95	1.29	5.07
11	G	187	.17	.41	.90	1.46	2.46	3.78	2.37	3.69	2.20	10.79
12	B	242	.39	.63	1.23	2.51	2.75	3.23	3.38	4.16	1.30	19.56
12	G	200	.34	.76	1.24	1.89	2.82	3.33	3.07	4.10	1.43	18.97
13	B	377	.41	.68	1.27	1.77	2.67	3.52	2.90	3.95	2.02	17.57
13	G	340	.26	.53	1.13	1.77	2.53	3.35	2.31	3.99	2.19	16.86
14	B	587	.74	1.06	1.84	2.69	3.17	3.70	3.59	4.41	2.14	21.94
14	G	645	.46	.69	1.36	1.91	3.04	3.45	3.08	4.37	2.23	18.51
15	B	194	.44	.84	1.42	2.02	2.92	2.98	3.10	3.76	1.88	18.11
15	G	212	.21	.59	.92	1.60	2.52	2.78	2.41	3.40	1.75	14.83
16	B	257	.78	1.07	1.76	2.25	2.99	3.20	2.93	3.84	1.98	19.78
16	G	214	.40	.85	1.44	1.84	3.04	3.01	2.63	3.84	2.27	18.10
17	B	314	.66	1.12	1.79	2.36	3.23	3.52	3.20	4.06	2.01	20.62
17	G	298	.44	.79	1.58	2.00	2.99	3.44	2.71	3.95	2.16	18.61
18	B	126	.30	.44	.83	1.37	2.47	2.85	2.86	3.93	1.87	15.77
18	G	135	.12	.27	.61	1.05	2.31	3.09	2.55	4.23	2.15	14.98

II

Revision and Extension of Reading Scales

CORRELATION OF TWO SCALES

It has been frequently objected that the vocabulary test, the mere abilty to recognize words, is not a measure of reading ability. The objection is twofold. The vocabulary measure tests too much; it tests too little. In support of the latter contention it is pointed out that reading involves not only the recognition of words but of the relations of words in a sentence. That there is truth in this objection no one doubts. All who have tried to translate a foreign language like Latin or German know perfectly well that it is not enough to recognize the English equivalent of the foreign words, and many a person will know all the words of English sentences without understanding the sentence. "He found law dear and left it cheap" does not contain a word that is not more or less familiar to a twelve-year-old child, yet few twelve-year-olds will have any adequate understanding of the passage. The grammatical relation of the words and the range of personal experience are determinative factors lying outside the limits of mere word knowledge.

With equal justice, it must be admitted that the vocabulary test sometimes demands more than would be required from a sentence containing a word. About 900 out of 1,000 children did not know the word "philanthropic," yet it would have offered little difficulty in a setting like this:

"Mr. Rockefeller has given large sums of money to schools and colleges. He has also given money to medical research. Mr. Carnegie has given money to found libraries in cities and towns and Mrs. Harriman has given money to charitable institutions. These are but a few of the persons in our country who have given money from their private fortunes for the benefit of their fellow-men. Such *philanthropic* endeavor is one of the things which characterize our men of wealth."

In such a context "philanthropic", tho seen for the first time, would hardly offer difficulty. Clearly a child might succed with this passage, tho he had failed on the vocabulary test as such.

Despite, however, the evidently variable functions measured by the vocabulary and understanding of sentence tests, there is some relation between a person's knowledge of words and his ability to read connected discourse. Just what that relation is is best shown by the coefficients of correlation for ability in the two tests. These are shown for the several grades in Table 14.

TABLE 14.—COEFFICIENT OF CORRELATION FOR THE VOCABULARY AND UNDERSTANDING OF SENTENCE TESTS

GRADE	8	7	6	5	4	3
Coefficient of correlation................	.22	.14	.15	.34	.56	.65

According to these figures, the score in one test is a fair measure of ability in the other for the grades 3 and 4, but less so for each of the succeeding upper grades. In grades 6, 7, and 8 the relation is negligible, and the figure of .34 for grade 5 is hardly great enough to justify the estimate of reading ability on the basis of one test alone. A coefficient of .65 (P. E. .1) in grade 3 (perfect correlation would be 1.00) warrants us in regarding the score in one test as a valid measure of ability in both. The ease with which the vocabulary test can be given would make it a very important test if it also tested the more complicated reading functions, and the evidence of this very considerable amount of indirect measurements is significant. It may be possible to construct a scale for the measurement of vocabulary that will measure many of the more complicated abilities adequately. If we could construct a vocabulary scale that would correlate to a very high degree, say to .85 to .95 with an Understanding of Sentences scale, it would be sufficient to apply the vocabulary scale and get at one stroke all that we now get thru the two scales. The consequent reduction in the labor of measurement would be very great.

The construction of two scales with this high degree of correlation is not a simple task. Neither is it certain that we should not want additional scales for more technical measures, but there is good reason to believe that we could save enormously on the time now consumed in the more complicated scales.

In order to test out the validity of the scale, the scores of more than 1,000 children were computed for each word in the scale. The results are shown in Table 15. Clearly these words do not have the same values for these Indiana children as they did for the children originally tested by Thorndike.[7] Thus, among 238

7. Thorndike, E. L. "Measurement of Ability in Reading." *Teachers College Record*, XV, No. 4, p. 25.

third grade children, there were 54 who did not put the correct mark under "samuel", whereas there were only 8 who did not know "lily", supposedly of the same value. Similarly there were 102 who failed on "cowardly" in line 5, and but 7 who did not know "pansy" in the same line. "Pansy" in fact appears much easier than 4 words in line 4, ranking almost exactly with "lily", not only for grade 3 but for all grades considered.

Similar misfits appear in almost every line of the scale. Thus, in line 10, the percentages for all the grades vary from 26 to 58 per cent for the words "crocus", "dahlia", "opossum", and "jonquil", whereas "poltroon" produces 96 per cent of error. This whole line seems to be somewhat misplaced, notwithstanding the high percentage of error on the last word. The 3 names of flowers and 1 name of an animal were apparently more familiar to the children here tested than to the original group. In fact, most of the line belongs with line 8 or below so far as these children are concerned.

In spite, however, of these variations in word values, the scale was not seriously at fault so far as measuring the elementary grades was concerned. The 1,145 children gave an increasing percentage of error up to and including line 9, and then for lines 10.5 and 11. Since the median score for the eighth grade was approximately line 8, it is evident that roughly within the limits of knowledge of elementary pupils the scale is fairly adequate.

TABLE 15.—Visual Vocabulary

Per cent of error of 1,145 pupils on each word of scale.

camel	1.2	claude	12.2	crocus	25.9
samuel	7.68	courteous	33.8	dahlia	31.2
kind	8.47	isaiah	50.3	jonquil	57.1
lily	1.0	merciful	35.9	opossum	43.3
cruel	6.72	reasonable	30.9	poltroon	93.7
	5.01		32.6		50.2
cowardly	13.10	chrysanthe-mum	27.7	begonia	46.1
dominoes	12.06	considerate	51.9	equitable	80.6
kangaroo	10.91	lynx	58.7	pretentious	73.2
pansy	00.9	prevaricate	86.7	renegade	93.5
tennis	13.2	reuben	53.0...	reprobate	84.1
	10.03		55.6		75.5
during	18.07	ezra	57.6	armadillo	62.8
generous	13.7	ichabod	65.3	iguana	65.2
later	14.9	ledger	55.6	philanthropic	88.6
					72.2
modest	33.8	parchesi	88.5	....	....
rhinoceros	20.9	preceding	70.0	....	....
	20.27		67.4		

Factors in Knowledge of Words

Just why any particular word should produce a particular per cent of error is an important question. Evidently if a child has never seen a word he cannot fairly be expected to know it. True, if it contains a known phonogram or other familiar element he may work out its sound or meaning or both, but, in general, the words one knows visually are the words he has seen. If, therefore, one fails to recognize or classify a word because it is a new word that word becomes a measure of his range of reading experience, and hence a measure of the person himself. If the majority of persons of his age, race, and opportunities do know the word in question while he does not, his ignorance places him somewhere in the lower 50 per cent of his social level. How significant such a measure will be depends on how important the word is for actual life, but it is evident that such ignorance of many words in general use cannot be anything but serious.

The fortune or accident of having previously seen the word is only one of the determinative facts in word knowledge. Of two words previously seen, one may be remembered and the other not. Thus one may have seen both "camel" and "armadillo" but remember only the former because he has seen it much oftener. Practically everyone who can read at all knows "camel". Many of those who do not know "armadillo" have seen it, but not sufficiently often to fix it in mind. Just how often any word must be seen in order to be made a permanent part of any person's visual vocabulary no one seems to know, even approximately. Many words the child meets far oftener than necessary for learning. "The" is such a word, also "and", "boy", "girl", etc. Such words are vastly "overlearned". Other words are learned just sufficiently for recognition, and are soon forgotten. Still others are but partially learned and produce but a vague feeling of familiarity on recurrence. It is entirely possible to determine the number of repetitions needed by children of any age for the solid acquisition of any word. We can hardly profess to make much headway in the science of teaching reading until this is done. Practically we should need to provide for a substantial amount of "overlearning", but just the amount of such "overlearning" needed is a definitely measureable fact and should be determined.

All words will not behave alike as regards needed repetitions. Of two words presented equally often, one will be forgotten and the other remembered. Many factors such as recency, position, size of type and page, context, temporary attitude of mind, general language experience, etc. doubtless function here. But there is such a thing as difficulty inherent in the word itself, a kind of difficulty which varies from word to word, and which amid all the contextual and subjective changes remains the same. Such inherent difficulty may concern the size and form of the word, purely material features, or it may concern the nature of the idea represented. Evidently all of these variable features operate to weight the scale values of words in one or another direction, and the scale will tend to be adequate in the degree to which they maintain for children being tested the same balance as existed among the children from which the first returns were secured. Where this balance is thrown too greatly out of joint the scale will go to smash.

It would seem possible to construct a scale in which many of the variable features would be adequately accounted for. This could not be done without lengthened and intricate experimentations, and such investigation will doubtless follow the awakened interest in the possibility of measuring educational products. In the meantime, it seems worth while to use scales formed on the plan of this scale.

Extension of Vocabulary Scale

In order to extend this scale and to provide duplicate scales for further testing, ratings have been secured on a large number of words for children in grades 3 to 8. The method of securing these ratings was to test classes of children with printed words after the fashion shown in the following test:

TEST XV

Below is a group of words. Look at each word. Think what it means. If it means something to wear write the letter *w* under it. If it means something about government or courts write the letter *g* under it. If it means something you see in a factory write the letter *f* under it. If it means something about travel write the letter *t* under it.

Remember: *w*, for things to wear;
g, for government or courts;
f, for things in factory;
t, for travel.

lathe, congress, hat, coat, legislate, court, shoes, machine, senator, voyage, justice, hose, socks, iron, brass, judge, stocking, copper, lawyer, overcoat, trial, sandals, engine, moccasin, bar, journey, truck, executive, motor, gloves, argument, berth, mittens, boots, summons, pants, dynamo, national, shirt, dress, opinion, gown, witness, kimona, veil, drill, press, brooch, hammer, belt, decision, pulley, barrette, tourist, judgment, tie, shaft, plea, collar, code, skirt, piston, valve, legal, apron, anvil, sweater, representative, pilgrimage, law, sledge, jersey, planer, prosecute, waist, thermostat, vest, brief, defendant, petticoat, muffler, thermometer, mayor, gauge, guilty, scarf, derrick, trip, prosecutor, muff, boa, torts, channeller, closure, plume, recommit, cap, bonnet, advisement, ulster, alibi, counsel, cuff, majority, frock, luggage, guy, insignia, crane, uniform, minority, evidence, livery, allege, pardon, raiment, carburetor, apparel, penitentiary, badge, boiler, prison, indictment, convict, baggage, supreme, costume, battery, tour, federal, helmet, vat, circuit, habit, state, excursion, cowl, mill, theft, appeal, hood, injunction, shawl, jig, garb, arraign, hardware, tax.

Tests of this type covering about 1,000 words and 27 classes were given to grades 3 to 8 in 14 schools. The tabulated returns cover the reactions of between 1,500 and 2,500 children to each word, or a total of 1,600,000 classifications. Under the caption "Indiana-Thorndike Vocabulary Scale", 774 of these words are here arranged in groups, each group representing a distinct measure of difficulty. The zero point is arbitrarily assumed to be 5 steps below the easiest step on this scale. The units of difficulty are in terms of P. E. distances on the base of a normal probability surface. The method of scaling is that used by Thorndike in constructing the original scale. The entire group of words yields a scale of 16 steps, each step being about .3 P. E.

Altho in listing the words for this scale, the average error for all the children of all the grades has been taken as a basis, it is an open question whether words can be selected from so wide a range successfully. It might be better to consider a more limited range of grades. We might make a third grade scale based on the returns from the third grade, a fourth grade scale on returns from the fourth grade, etc. Certainly for the first and second grade tests, the reactions of first and second grade children are of much greater importance than the returns from any higher grades. However, the advantages of having a single scale to apply to a wide range of classes is great, and it seems worth while to try to make one on that basis.

It is then assumed that when words show the same average per cent of error they are of equal value. But in selecting from the entire scale the words for Scale R and Scale R2, two further cautions have been kept in mind. First, words should show a decreasing per cent of error from the lower grades up. In Table 16, which shows words of approximately the same value at three different points on the scale, "cashmere" is such a word.

TABLE 16.—WORDS OF APPROXIMATELY EQUAL VALUE AT THREE POINTS ON THE SCALE OF DIFFICULTY

Easy words giving 7 to 8 per cent of error.

	Av.	8	7	6	5	4	3
face	7.3	......	.9	1.4	6.5	10.1	31.8
hammer	7.4	......	......	.2	4.3	12.2	36.6
wave	7.7	......	1.4	2.2	4.3	11.4	35.
goat	7.1	1.1	1.9	2.7	5.1	9.1	29.3
mother	7.5	4.2	2.2	3.7	6.	9.7	24.9
picture	7.1	1.4	2.7	3.1	2.9	11.6	35.
carpet	7.0	3.2	2.0	3.7	2.5	8.3	36.3
lamp	6.8	1.8	1.0	9.2	3.1	7.8	36.3

Words of medium difficulty giving 50 to 52 per cent of error.

	Av.	8	7	6	5	4	3
cashmere	52.2	22.2	35.7	46.4	61.	76.8	89.8
tender	50.4	17.7	32.	45.2	60.7	74.3	86.6
auk	50.3	23.5	29.2	44.	44.5	79.7	92.
lynx	50.4	20.9	30.4	43.	56.8	76.5	94.3
vise	50.3	20.1	30.3	38.5	56.6	73.6	92.7

Words of greater difficulty giving 84 to 86 per cent of error.

	Av.	8	7	6	5	4	3
peritoneum	85.4	60.	79.5	82.7	90.	94.6	95.9
patella	84.	49.4	85.	82.	93.4	93.6	90.7
cormorant	85.9	65.	82.1	87.5	89.7	95.4	96.1
bittern	83.8	67.9	80.4	88.	80.5	92.5	95.5
forgery	84.4	25.	41.	61.9	78.5	88.6	93.4
cloister	85.	66.8	86.	82.4	87.	89.7	93.4
chancel	85.6	71.5	83.6	87.2	85.8	82.	94.2

Beginning with a per cent of error of 89.8 for the third grade, it decreases gradually up to 22.2 per cent in the eighth. Secondly, for 2 words to have the same value the decreasing error from grade to grade should be approximately the same for both. The cases of "lynx" and "vise" illustrate this very well. Only in the fourth and sixth grades is there a difference in error of as much as 3 per cent. A scale made of words of this type will doubtless be accurate to a very high degree for children whose previous training has been similar to that of those from whom these records were obtained.

As a matter of fact, it is not always easy or even possible to get words which behave so nearly alike as do "lynx" and "vise". Thus "tender", which has the same average per cent as "lynx", does not approximate so nearly the "lynx" value as does "vise" in grades 3, 4, 5, 7, and 8. "Peritoneum" is evidently more difficult than "chancel" for grades 3, 4, and 5, but less difficult for grades 6, 7, and 8. Some of the words seem highly erratic in behavior. Thus "corporal" was missed by 73 per cent of the eighth grade, but by only 56 per cent of the seventh; "code" was unknown to 76 per cent of the seventh and 70 per cent of the sixth; "sextet" reaped 71 per cent error from the sixth and only 66 per cent from the fifth; "artery" was known to 42 per cent of the fourth but to only 30 per cent of the fifth; and altho 66 per cent of the third knew "shin" to be a part of the body, only 59 per cent of the fourth grade were aware of that fact.

In general, however, these apparent inversions of difficulty are not the rule; in fact, they seem astonishingly rare when one considers the myriad factors which operate to produce linguistic ability. A more common limitation on the use of words for measuring purposes is the fact that they play out, as it were, at one or the other end of the scale. Thus, "hammer" has 36 per cent of error in the third grade, but produces none at all above the sixth. At the opposite extreme is "octile" with 80 per cent error for grade eight, but producing 98 per cent error in the third, far too much for practical use in measuring a class.

Indiana-Thorndike Visual Vocabulary Scale

5. arms (*b*) brown (*c*) chair (*h*) cow (*4*) dog (*4*) dress (*we*) green (*c*) hat (*we*) robin (*bi*) shoes (*we*) walk (*ft*)

10. bear (*4*) bed (*h*) bone (*b*) bonnet (*we*) bookcase (*h*) court (*g*) dance (*ft*) ear (*b*) eye (*b*) fight (*w*) fox (*4*) hop (*ft*) lark (*bi*) overcoat (*we*) ship (*s*) step (*ft*) stocking (*we*) swallow (*bi*) table (*h*) yellow (*c*)

15. ant (*i*) brother (*r*) clock (*h*) donkey (*4*) gray (*c*) gun (*w*) money (*mo*) ocean (*s*) pail (*h*) pink (*c*) pray (*ch*) pull (*ah*) reach (*ah*) shirt (*we*) skip (*ft*) sparrow (*bi*) stand (*ft*) stove (*h*)

20. boots (*we*) brain (*b*) breast (*b*) calf (*4*) carpet (*h*) cupboard (*h*) door (*ho*) dresser (*h*) eagle (*bi*) early (*t*) engine (*rf*) fare (*rf*) father (*r*) float (*s*) gloves(*we*) goat(*4*) hammer(*to*) iron(*rf*) judge(*g*) lamp(*h*) lawyer(*g*) leap (*ft*) many(*n*) mittens(*we*) monkey(*4*) mother(*r*) muff(*we*) picture(*h*) purple(*c*) rocker(*h*) rug(*h*) sister(*r*) skate(*ft*) skirt(*we*) socks(*we*) stool(*h*) track(*rf*) vest(*we*) waist(*we*) wave(*s*) window(*ho*) wink(*e*) write(*ah*)

25. apron(*we*) aunt(*r*) beside(*p*) brass(*rf*) buy(*mo*) cabinet(*h*) camel(*4*) captain(*w*) car(*rf*) cellar(*ho*) chimney(*ho*) cuff(*we*) desk(*h*) elbow(*b*) elephant(*4*) engineer(*rf*) flag(*w*) foam(*s*) gaze(*e*) gold(*c*) hall(*ho*) hatchet(*to*) hawk(*bi*) good(*we*) hug(*ah*) journey(*tr*) judgment(*g*) kitchen(*ho*) laugh(*m*) law(*g*) limp(*ft*) machine(*rf*) muffler(*we*) nine(*n*) over(*p*) owl(*bi*) pants(*we*) passenger(*rf*) pay(*mo*) petticoat(*we*) pigeon(*bi*) porch(*ho*) priest(*ch*) punch(*ah*) rub(*ah*) sandals(*we*) satin(*cl*) saw(*to*) shawl(*we*) shin(*b*) sideboard(*h*) silk(*cl*) stumble(*ft*) throw(*ah*) thrush(*bi*) ticket(*rf*) tongue(*b*) uncle(*r*) under(*p*) upon(*p*) violet(*c*) wade(*ft*) wall(*ho*) watch(*e*) west(*d*)

30. above(*p*) afternoon(*t*) before(*p*) behind(*p*) below(*p*) between(*p*) blanket(*h*) blink(*e*) boar(*4*) bobolink(*bi*) buffalo(*4*) calico(*cl*) camp(*w*) cannon(*w*) coast(*s*) conductor(*rf*) congress(*g*) copper(*rf*) crimson(*c*) croak(*m*) deck(*s*) file(*to*) flagman(*rf*) flea(*i*) fort(*w*) forty(*n*) gather(*ah*) glance(*e*) gown(*we*) grasshopper(*i*) groan(*m*) grumble(*m*) half(*n*) harbor(*s*) hymn(*ch*) justice(*g*) kidney(*b*) knife(*to*) lice(*i*) mat(*h*) mattress(*h*) mayor(*g*) moan(*m*) mule(*4*) oriole(*bi*) prance(*ft*) range(*h*) raven(*bi*) roar(*m*) scarlet(*c*) screwdriver(*to*) sell(*mo*) sink(*h*) slip(*ft*) snatch(*ah*) stare(*e*) tan(*c*) twinkle(*e*) velvet(*cl*) victrola(*h*) wasp(*i*) witness(*g*) wren(*bi*)

35. after(*p*) attic(*ho*) basement(*ho*) broadcloth(*cl*) bureau(*h*) canary(*bi*) canoe(*s*) captive(*w*) ceiling(*ho*) chest(*h*) chirp(*m*) cod(*fi*) couch(*h*) cousin(*r*) cricket(*i*) cuckoo(*bi*) davenport(*h*) dozen(*n*) evening(*t*) flannel(*cl*) forenoon(*t*) garret(*ho*) general(*w*) gingham(*cl*) grasp(*ah*) grunt(*m*) guard(*w*) hose(*we*) kangaroo(*4*) legislate(*g*) mast(*s*) merchant(*mo*) mill(*rf*) million(*n*) mock(*m*) more(*n*) morning(*t*) mosquito(*i*) moth(*i*) mourn(*m*) murmur(*m*) nibble(*m*) niece(*r*) pullman(*rf*) quail(*bi*) rhinoceros(*4*) scarf(*we*) stab(*ah*) stamp(*ft*) sweater(*we*) tax(*g*) trample(*ft*) trial(*g*) troops(*w*) Tuesday(*t*) velveteen(*cl*) within(*p*) without(*p*) worship(*ch*)

40. across(*p*) altar(*ch*) anvil(*rf*) April(*t*) argument(*g*) baptism(*ch*) boiler(*rf*) bosom(*b*) catholic(*ch*) chickadee(*bi*) chiffonier(*h*) chisel(*to*) coach(*rf*) commander(*w*) conquer(*w*) counsel(*g*) count(*n*) couple(*n*) curtain(*h*) dagger(*w*) December(*t*) defeat(*w*) defend(*w*) February(*t*) fleet(*s*) freight(*rf*) gargle(*m*) giraffe(*4*) glare(*e*) grin(*m*) grip(*ah*) guilty(*g*) gulf(*s*) gurgle(*m*) here(*d*)

hornet(*i*) hum(*m*) hurrah(*m*) January(*t*) lathe(*rf*) minute(*t*) moccasin(*we*) Monday(*t*) motor(*rf*) national(*g*) nephew(*r*) noon(*t*) November(*t*) October(*t*) on(*p*) outward(*d*) owe(*mo*) panther(*4*) plane(*to*) plume(*we*) plush(*cl*) press(*rf*) prison(*g*) pronounce(*m*) psalm(*ch*) pulley(*rf*) relative(*r*) ruby(*c*) salmon(*fi*) seize(*ah*) senator(*g*) September(*t*) serge(*cl*) several(*n*) soon(*t*) spine(*b*) toward(*d*) transportation(*rf*) trip(*tr*) trout(*fi*) veil(*we*) waltz(*ft*) Wednesday(*t*) while(*t*) whimper(*m*) year(*t*)

45. August(*t*) baggage(*tr*) beneath(*d*) brace(*to*) cargo(*s*) chandelier(*h*) channel(*s*) chant(*m*) corduroy(*cl*) defendant(*g*) double(*n*) drill(*rf*) first(*d*) forward(*d*) frock(*we*) halloa(*m*) hearth(*ho*) herring(*fi*) hoot(*m*) inside(*d*) insurance(*mo*) interest(*mo*) jackall(*4*) last(*d*) launch(*s*) lavender(*c*) left(*d*) lilac(*c*) locust(*i*) mallet(*to*) meantime(*t*) minnow(*fi*) numerous(*n*) olive(*c*) opinion(*g*) orphan(*r*) outside(*d*) patter(*ft*) percale(*cl*) pluck(*ah*) poplin(*cl*) prosecute(*g*) prosecutor(*g*) purchase(*mo*) recite(*m*) representative(*g*) right(*d*) score(*n*) shaft(*rf*) sledge(*rf*) stag(*4*) state(*g*) supreme(*g*) there(*d*) through(*p*) tread(*ft*) trudge(*ft*) uniform(*we*) waddle(*ft*) whole(*n*) worsted(*cl*)

50. advisement(*g*) artery(*b*) awl(*to*) back(*d*) balcony(*ho*) badge(*we*) barrette(*we*) billow(*s*) bishop (*ch*) brooch(*we*) carp(*fi*) center(*d*) chamois(*4*) chestnut(*c*) colonel(*w*) convict(*g*) costume(*we*) crowd(*n*) cruise(*s*) decision(*g*) during(*t*) dynamo(*rf*) each(*n*) eaves(*ho*) edge(*d*) evidence(*g*) executive(*g*) fortress(*w*) gape(*m*) garnet(*c*) gasp(*m*) gnat(*i*) group(*n*) guarantee(*mo*) gull(*bi*) gulp(*m*) hardware(*rf*) hazel(*c*) hurl(*ah*) immediate(*t*) income(*mo*) invest(*mo*) jabber(*m*) june(*t*) katydid(*i*) kimona(*we*) lasting(*t*) launch(*s*) legal(*g*) linoleum(*h*) mackerel(*fi*) military(*w*) monk(*ch*) month(*t*) multiple(*n*) numeral(*n*) overhead(*d*) ownership(*mo*) pair(*n*) pardon(*g*) pedal(*ft*) pedestal(*h*) penitentiary(*g*) perch(*fi*) piazza(*ho*) pickerel(*fi*) pike(*fi*) planer(*rf*) plea(*g*) plod(*ft*) plural(*n*) porcupine(*4*) rudder(*s*) russet(*c*) sardine(*fi*) scour(*ah*) screech(*m*) shade(*h*) shark(*fi*) singular(*n*) some(*n*) starboard(*s*) thermometer(*rf*) transcontinental(*rf*) truck(*rf*) valve(*rf*) where(*p*) whipcord(*cl*)

55. ammunition(*w*) appeal(*g*) augur(*to*) auk(*bi*) azure(*c*) berth(*rf*) betwixt(*p*) brief(*g*) cashmere(*cl*) casement(*ho*) cavalry(*w*) chambray(*cl*) circuit(*g*) continue(*t*) derrick(*rf*) diner(*rf*) drapery(*h*) embark(*s*) emerald(*c*) entrenchment(*w*) entry(*ho*) even(*n*) federal(*g*) firm(*mo*) from(*d*) future(*t*) helms(*s*) helmet (*we*) hull(*s*) hurricane(*s*) indictment(*g*) installment(*mo*) instant (*t*) interior(*p*) invader(*w*) jeer(*m*) jersey(*we*) keel(*s*) kinship (*r*) lease(*mo*) leeward(*s*) ligament(*b*) luggage(*rf*) lynx(*4*) mariner(*s*) marriage(*r*) middle(*d*) mortgage(*g*) multitudinous(*n*) nun(*ch*) opposite(*d*) overhanging(*d*) peer(*e*) percolator(*h*) piston (*rf*) plum(*c*) rampart(*w*) recent(*t*) recommit(*g*) roundhouse(*rf*) scuffle(*ft*) seldom(*t*) snipe(*bi*) summons(*g*) tapir(*4*) tawny(*c*) tender(*rf*) theft(*g*) thigh(*b*) tour(*tr*) tourist(*tr*) tweed(*cl*) vise(*to*) vulture(*bi*)

60. adoption(*r*) allege(*g*) bevel(*to*) buff(*c*) boa(*we*) bounding(*d*) brigade(*w*) campaign(*w*) canteen(*w*) carburetor(*rf*) caribou(*4*) carmine(*c*) catechism(*ch*) celibate(*ch*) century(*t*) cleaver(*to*) constantly(*t*) convent(*ch*) crane(*rf*) either(*n*) encircling(*d*) every(*n*) excursion(*tr*) exterior(*d*) fawn(*4*) finance (*mo*) forgery(*mo*) formerly(*t*) forthwith(*t*) fortification(*w*) frontal(*d*) gable(*ho*) garrison(*w*) gauge(*rf*) gazelle(*4*) gimlet (*to*) glower(*e*) gradual(*t*) henceforth(*t*) horizontal(*d*) indorse(*mo*) infantry(*w*) juggle(*ah*) lieutenant(*w*) margin(*d*) majority(*n*) minority(*n*) navigable(*s*) never(*t*) observe(*e*) odd(*n*) partridge (*bi*) patent(*mo*) pilgrimage(*ch*) previous(*t*) quartette(*n*) repeatedly(*t*) sentinel(*w*) sextette(*n*) shad(*fi*) smite(*ah*) terminal(*rf*) throttle (*rf*) turntable(*rf*) turquoise(*c*) vat(*rf*)

65. apparel(*we*) bullock(*4*) bulwark(*w*) channeller(*g*) chaplain(*ch*) cheviot(*cl*) clamor(*m*) cockroach(*i*) corporal(*w*) corridor(*ho*) cranium(*b*) descendant(*r*) diagonal(*d*) divorce(*r*) dormer(*ho*) eternal(*t*) flamingo(*bi*) frequent(*t*) gabardine(*we*) garb(*we*) grouse(*bi*) halibut(*fi*) implore(*m*) insignia(*we*) intervening(*d*) jetty(*s*) kersey(*cl*) lagoon(*s*) monasticism (*ch*) neighboring(*d*) parallel(*d*) perceive(*e*) perpendicular(*d*) plurality(*n*) prostestantism(*ch*) quadruple(*n*) quaver(*m*) raiment(*we*) rarely(*t*) ratchet(*to*) rebate(*mo*) recruit(*w*) roan(*c*) sepia(*c*) shamble(*ft*) sturgeon(*fi*) surmounting(*d*) thereabouts(*d*) thermostat(*rf*) tiller(*s*) vertical(*d*)

70. alcove(*ho*) alibi(*g*) arraign(*g*) cartilage(*b*) cerebellum(*b*) code(*g*) contemporary(*t*) creed(*ch*) decade(*t*) drugget(*cl*) duplicate(*n*) ecru(*c*) ell(*ho*) ensuing(*t*) flounder(*fi*) incessant(*t*) injunction(*g*) insolvent(*mo*) interim(*t*) livery(*we*) manoeuver(*w*) nautical(*s*) peccary(*4*) scourge(*ah*) scrawl(*ah*) smelt(*fi*) strategy (*w*) termites(*i*) transverse(*d*) treble(*n*) turbot(*fi*) wainscot(*ho*) weevil(*i*)

75. adze(*to*) belligerent(*w*) citadel(*w*) closure(*g*) contiguous (*d*) cornea(*b*) curlew(*bi*) episcopacy(*ch*) friar(*ch*) gibbon(*4*) haddock(*fi*) halberd(*w*) indemnity(*mo*) integer(*n*) legatee(*mo*) loon(*bi*) lymph(*b*) magenta(*c*) mauve(*c*) midge(*i*) negotiable (*mo*) offspring(*r*) peculation(*mo*) perennial(*t*) pirouette(*ft*) plover(*bi*) pontifical(*ch*) prate(*m*) quintette(*n*) regurgitate (*m*) sloth(*4*) ulster(*we*) vermillion(*c*)

80. conterminous(*d*) ephemeral(*t*) evanescent(*t*) litigation(*g*) octile(*n*) patella(*b*) peritoneum(*b*) sexagesimal(*n*)

Rules for Making Test Scales

In choosing words from the large scale for use in testing, the following rules should be followed:

1. Consider words of equal value when they are found in the same group.

2. Make up lines from words of the same value, using either five or ten words to the line. There should be enough lines to

cover well the upper and lower ranges of ability in the class to be tested. The probable ranges of ability for the several grades are about as follows:

Third grade—lines 5 to 15.
Fourth grade—lines 15 to 40.
Fifth grade—lines 20 to 50.
Sixth grade—lines 30 to 50.
Seventh grade—lines 35 to 50.
Eighth grade—lines 40 to 60.

3. Make out directions for the test similar to those found on page 57ff. The letter placed after each word in the scale indicates the classification demanded on the original tests and the one which the present scale value requires. The meaning of these symbols is as follows:

ah, for things done with arms and hands, like pull, take, reach;
b, for parts of the body;
bi, for birds;
c, for words about color, like red, blue, green;
ch, for words about church and religion;
cl, for clothes materials;
d, for words about direction and location, like front, east, here;
e, for things done with eyes, like see, look, read;
fi, for fishes;
ft, for things done with feet and legs, like run, jump, kick;
g, for government or courts;
h, for things found in a house;
ho, for parts of a house;
i, for insects, like fly, or ant or bee;
m, for things done with mouth and throat, like cry, talk, drink;
mo, for words about business and money;
n, for words about number, like more, five, many;
p, for place or position;
r, for words about relatives and the family;
rf, for railroad or factory;
s, for words about the sea and ships;
t, for words about time, like then, often, early;
to, for tools;
tr, for travel;
w, for words about war and fighting;
we, for things to wear;
4, for four-legged animals, like cat or dog.

Some of the words are capable of more than one classification. On the original tests there was no possibility of confusion because on the page containing the words only one classification was called for. This same condition must be maintained in further testing if the results are not to be equivocal.

4. Be careful that not too many classifications are required. Choose words from a limited number of classes, even tho you must use more words from the same class.

Scale R and Scale R2 are made up with due regard to the foregoing rules, and the two scales are of approximately the same difficulty. By giving one at the beginning of a semester, a year, a practice period, etc., and the other at the end of the time, improvement may be measured.

Sample Scales

SCALE R[8]

5. arms, dog, walk, brown, dress
10. bone, ear, bear, yellow, stocking
15. stove, reach, clock, sparrow, ant
20. gloves, stool, rug, write, early
25. thrush, over, hood, wade, engineer
30. below, scarlet, buffalo, justice, engine
35. within, gingham, sweater, dozen, evening
40. panther, catholic, conquer, freight, November
45. left, corduroy, waddle, prosecutor, inside
50. starboard, pair, legal, brooch, bishop
55. keel, tapir, opposite, tawny, instant
60. encircling, formerly, majority, sentinel, convent
65. cheviot, eternal, protestantism, intervening, perpendicular
70. alibi, turbot, strategy, cartilage, incessant
75. cornea, lieutenant, pontifical, pirouette, magenta
80. patella, ephemeral, octile, evanescent, sexagesimal.

SCALE R 2

5. robin, cow, chair, green, shoes
10. bed, eye, table, ship, overcoat
15. pink, shirt, ocean, donkey, brother
20. muff, rocker, track, many, goat
25. buy, hawk, under, throw, passenger
30. above, crimson, oriole, witness, conductor
35. without, flannel, million, morning, rhinoceros
40. baptism, coach, January, anvil, on
45. right, percale, representative, outside, baggage
50. executive, cruise, plural, decision, barrette
55. vise, ligament, helm, auk, betwixt
60. terminal, henceforth, garrison, gazelle, minority
65. kersey, rarely, monasticism, raiment, bulwark
70. arraign, manoeuver, interim, duplicate, cerebellum
75. belligerent, episcopacy, regurgitate, mauve, legatee
80. peritoneum, conterminous.

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8. It will generally be sufficient to use alternate lines and calculate intermediate values by means of Table 18.

On the basis of the percentages obtained, the words of Scale A may be rearranged in order of difficulty. In Scale A2 such a rearrangment is made with the addition of other words to make the lines of 5 words each. The steps on the scale are of approximately one-half the distance of the steps on the original Thorndike scale. Two additional classes should be added to the directions, one for words meaning "place" and one for words meaning "number". The italicized words are the ones occurring in the original scale.

SCALE A2

4. *camel*, *lily*, *pansy*
6. *samuel*, *kind*, *cruel*, monkey, goat
7. *cowardly*, *dominoes*, *kangaroo*, *tennis*, (*claude*), *generous*
8. *during*, *later*, wren, bobolink, below
9. *rhinoceros*, moth, dozen, forenoon, more
10. *reasonable*, *chrysanthemum*, *crocus*, across, minute
11. *modest*, *courteous*, *merciful*, *dahlia*, *whole*
12. *opossum*, *begonia*, each, center, porcupine
13. *isaiah*, *considerate*, *reuben*, leeward, tapir
14. *lynx*, *ezra*, *ledger*, *jonquil*, gazelle
15. *ichabod*, *iguana*, *armadillo*, eternal, *intervening*
16. *preceding*, *equitable*, *pretentious*, weevil, interim
18. *prevaricate*, *reprobate*, octile, ephemeral, evanescent
19. *parchesi*, *philanthropic*
20. *poltroon*, *renegade*

Whether such a rearrangement and supplementation will prove more satisfactory than the original Scale A must be left to further experimental work. There are apparently three things in its favor: (1) the percentages upon which it is based represent the reactions of more than double the number of children; (2) there are almost double the number of words within the same limits of difficulty; (3) the intervals from line to line are much smaller than those of the former scale.

UNDERSTANDING OF SENTENCES

Irregularity of Steps in Scale Alpha

In the original description[9] of Scale Alpha, Thorndike pointed out that the values of the several "sets" were not exactly represented by the numbers 4, 6, 8, and 10; that these designations

9. Thorndike, E. L. "Measurement of Ability in Reading." *Teachers College Record*, XV, 263.

"are not much better than convenient guesses"; and indicated a program for the revision of the scale. Our results from 10,551 children confirm his contention that the several sets arranged in Scale Alpha do form a scale of difficulty "adequate to show differences in reading ability", but suggest values very different from those given. Table 17 gives the per cent of error for each grade in each set of the scale. Basing scale values on the total per cent of error and using the same units as in the visual vocabulary revision, we get values as follows: A=4, B=10, C=12, D=16. The ratios here are 1, 2½, 3, and 4 as against Thorndike's ratios of 1, 1½, 2, and 2½ and emphasize even more strongly his statement that "intermediate sets are much needed".

TABLE 17.—Understanding of Sentences

Per cent of errors in each set.

Grade	Set A	Set B	Set C	Set D
3	7	31	45	85
4	5	22	34	78
5	2	11	21	59
6	2	8	15	51
7	2	8	13	42
8	1	6	11	34
Total..........	3	14	23	58

Test for Revision of Scale Alpha

With a view to supplying such intermediate values tests like those shown in Test S were given to about 12,000 children. Each set was answered by about 4,000 children.

TEST S

Read this and then write answers to questions 1, 2, 3, 4, 5, 6, 7, and 8. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Studies serve for delight, for ornament, and for ability. Their chief use for delight is in privateness, and retiring; for ornament, is in discourse; and for ability, is in the judgment and disposition of business; for, expert men can execute, and perhaps judge of particulars, one by one; but the general counsels, and the plots and marshaling of affairs, come best from those that are learned.

To spend too much time in studies, is sloth; to use them too much for ornament, is affectation; to make judgment wholly by their rules, is the humor of a scholar; they perfect nature, and are perfected by experience—for natural abilities *are like natural plants, that need pruning by study; and studies themselves do give forth directions too much at large, except they be bounded in by experience.*

1. How many uses may "studies" serve?
2. In how many ways may "studies" be misused?
3. In what things are learned men said to be the best?
4. What is said to be the effect of experience on studies?
5. How are "natural abilities" like "natural plants"?
6. In what way do studies serve for ornament?
7. What is said to be the humor of the scholar?
8. How may studies lend to sloth?

The tabulated returns from these tests give the per cent of error obtained by from 1,500 to 2,500 children,[10] to each of 67 questions based on 9 selected paragraphs and 16 questions of the type of "element 4" of Set D in Scale Alpha.

New Understanding of Sentence Scales

On the basis of these results, two scales, Beta 1 and Beta 2, are constructed. The interval between the successive sets on the scale is approximately .6 P. E., except in the case of the first where the interval is 1.2 P. E. Zero ability is assumed to be 10 units below the lowest set on scale Beta 1. The second set in this scale is 30 units above zero, and each succeeding step is 10 units farther away from no ability at all. Scale Beta 2 is not as complete as Scale Beta 1, but is given here inasmuch as it is fairly satisfactory in the middle regions of the scale.

SCALE BETA 1

Set I or 10

Read this and then write answers to questions 1, 2, and 3. Read it again as often as you need to.

John had two brothers who were both tall. Their names were Will and Fred. John's sister, who was short, was named Mary. John liked Fred better than either of the others. All of these children except Will had red hair. He had brown hair.

1. Was John's sister tall or short?
2. How many brothers had John?
3. What was his sister's name?

Set III or 30

Read this and then write the answers to questions 1 and 2. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

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10. In calculating percentages it is found that the values change very little after 1,500 answers have been tabulated. Very differently selected pupils might alter it more.

First, let us ask, where does book-making begin? With the printer? No, for before the printer can even think about printing, he must have his "copy". This "copy," as the printer calls it, is furnished by the publisher; and the publisher gets it from the author, who calls it his "manuscript". The author has spent many days, perhaps months, or even years, upon it, writing it out with his own hand. With pen and ink he has put his thoughts upon the paper.

1. Who is mentioned as the maker of a "manuscript"?
2. Who is it that must have the "copy"?

Read this and then write the answers to questions 3, 4, and 5. Read it again as often as you need to.

Long after the sun had set, Tom was still waiting for Jim and Dick to come. "If they do not come before nine o'clock," he said to himself, "I will go on to Boston alone." At half-past eight they came bringing two other boys with them. Tom was very glad to see them and gave each of them one of the apples he had kept. They ate these and he ate one, too. Then all went on down the road.

3. What did they do after eating the apples?
4. Who else came besides Jim and Dick?
5. How long did Tom say he would wait for them?

Set IV or 40

Read this and then write the answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Hay-fever is a very painful, though not a dangerous disease. It is like a very severe cold in the head, except that it lasts much longer. The nose runs; the eyes are sore; the person sneezes; he feels unable to think of work. Sometimes he has great difficulty in breathing. Hay-fever is not caused by hay, but by the pollen from certain weeds and flowers. Only a small number of people get this disease, perhaps one person in fifty. Most of those who do get it, can avoid it by going to live in certain places during the summer and fall. Almost every one can find some place where he does not suffer from hay-fever.

1. What is the cause of hay-fever?
2. How large a percentage of people get hay-fever?
3. What means could they take to keep from getting it?

Read this and then write the answers to questions 4 and 5. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

You need a coal range in winter for kitchen warmth and for continuous hot water supply, but in summer when you want a cool kitchen and less hot water, a gas range is better. The xyz ovens are safe. In the end-ovens there is an extra set of burners for broiling.

4. What two varieties of stoves does the paragraph mention?
5. For what purpose is the extra set of burners?

Set V or 50

Read this and then write the answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

We often think of a rich man as one who has much money, as if money and wealth meant the same thing. However, money is only one sort of wealth and some money is not exactly wealth. A twenty dollar bill, for example, is only someone's promise to pay so much gold. Wealth means land, houses, food, clothes, jewels, tools, gold, silver, coal, iron—anything that a man can have that satisfies some want. Money means something which a person can exchange for any one of many sorts of wealth. The main value of any piece of wealth, such as a barrel of flour, a house, or a cow is the direct use you can make of it. The value it has by reason of what you can change it for is of less importance. The main value of any piece of money, such as a silver dollar, a ten dollar bill, or a nickel, is NOT any direct use you can make of it. Its main value is that you can exchange it for something that is of direct use. For this reason, it is called a "medium of exchange".

1. What two things are contrasted in this paragraph?
2. How could a man be rich and still not own a single penny of money?
3. Name something that is money, but is not exactly wealth.

Read this and then write the answers to questions 4 and 5. All questions must be answered from the paragraph. Read it again as often as you need to.

It may seem at first thought that every boy and girl who goes to school ought to do all the work that the teacher wishes done. But sometimes other duties prevent even the best boy or girl from doing so. If a boy's or girl's father died and he had to work afternoons and evenings to earn money to help his mother, such might be the case. A good girl might let her lessons go undone in order to help her mother by taking care of the baby.

4. What are some conditions that might make even the best boy leave school work unfinished?
5. What might be the effect of his father's death upon the way a boy spent his time?

Set VI or 60

Read this and then wirte answers to questions 1, 2, 3, 4, and 5. All questions must be answered from the paragraph. Read the paragarph as often as you need to.

Every one of the million readers of anecdotes, or memoirs, or lives of Napoleon, delights in the page, because he studies in it his own history. Napoleon is thoroughly modern, and, at the highest point of his fortunes, has the very spirit of the newspapers. He is no saint,—to use his own words, "no capuchin", and he is no hero, in the high sense. The man in the street finds in him the qualities and powers of other men in the street. He finds him, like himself, by birth a citizen, who, by very intelligible merits arrived at such a commanding position, that he could indulge all those tastes which the common man possesses, but is obliged to conceal and deny, good society, good books, fast traveling, dress, dinners, servants without number, personal weight, the execution of his ideas, the standing in the attitude of a benefactor to all persons above him, the refined enjoyments of pictures, statues, music, palaces and conventional honors,—precisely what is agreeble to the heart of every man in the nineteenth century.

1. What other person possesses the same tastes as Napoleon?
2. Who is said to have arrived in a commanding position?
3. What must the common man do with tastes such as Napoleon indulged?
4. Who is said to have "intelligible merits"?
5. What does the "man in the street" find in Napoleon?

Set VII or 70

Read this and then write the answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Studies serve for delight, for ornament, and for ability. Their chief use for delight is in privateness, and retiring; for ornament, is in discourse; and for ability, is in the judgment and disposition of business; for, expert men can execute, and perhaps judge of particulars, one by one; but the general counsels, and the plots and marshaling of affairs, come best from those that are learned.

To spend too much time in studies, is sloth; to use them too much for ornament, is affectation; to make judgment wholly by their rules, is the humor of a scholar; they perfect nature, and are perfected by experience—for natural abilities are like natural plants, that need pruning by study; and studies themselves do give forth directions too much at large, except they be bounded in by experience.

1. In how many ways may "studies" be misused?
2. In what things are learned men said to be the best?
3. In what way do studies serve for ornament?

Read this and then write the answers to questions 4 and 5. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

However certain it may seem to be that men work only because they must, and would avoid labor except for the food, clothing, and luxuries that are its rewards, the facts may well be the contrary. It can hardly be the case that men dislike work because they wish to be utterly idle. For mere rest, mere inactivity, is not commonly enjoyed. To have nothing to do is not what men seek. Were that so, we should envy the prisoner shut up in his cell. If men had to choose between a life spent at eight hours of work daily in a factory and a life of eight hours of sitting on a throne without moving hand or foot, many of them would, after trying both, choose the former. Activity of body or mind, at which a man can succeed, is, in and of itself, rather enjoyed than disliked.

4. In what respect is a prisoner in his cell like a man with a million dollars?
5. What is stated in the paragraph to be really liked and not objected to?

SCALE BETA 2

Set I or 10

Read this and then write the answers. Read it again as often as you need to.

Robert and Helen are playing the game of Little Red Riding Hood. Robert has on Papa's fur coat. He plays he is the wolf. Grace has on a white cap.

She plays she is the dear old Grandma. She is in bed, and plays she is fast asleep.

1. What did Grace have on?
2. Who besides Grace were playing?
3. What does Robert play?

Set III or 30

Read this and then write answers to questions 1 and 2. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Hay-fever is a very painful, though not a dangerous disease. It is like a very severe cold in the head, except that it lasts much longer. The nose runs; the eyes are sore; the person sneezes; he feels unable to think of work. Sometimes he has great difficulty in breathing. Hay-fever is not caused by hay, but by the pollen from certain weeds and flowers. Only a small number of people get this disease, perhaps one person in fifty. Most of those who do get it, can avoid it by going to live in certain places during the summer and fall. Almost every one can find some place where he does not suffer from hay-fever.

1. What form of illness is described in this paragraph?
2. What is the effect of hay-fever on the eyes and nose?

Read this and then write answers to questions 3 and 4. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Every one of the million readers of anecdotes, or memoirs, or lives of Napoleon, delights in the page, because he studies in it his own history. Napoleon is thoroughly modern, and, at the highest point of his fortunes, has the very spirit of the newspapers. He is no saint,—to use his own words, "no capuchin", and he is no hero, in the high sense. The man in the street finds in him the qualities and powers of other men in the street. He finds him, like himself, by birth a citizen, who, by very intelligible merits, arrived at such a commanding position, that he could indulge all those tastes which the common man possesses, but is obliged to conceal and deny; good society, good books, fast traveling, dress, dinners, servants without number, personal weight, the execution of his ideas, the standing in the attitude of a benefactor to all persons about him, the refined enjoyments of pictures, statues, music, palaces and conventional honors,—precisely what is agreeable to the heart of every man in the nineteenth century.

3. When has Napoleon the spirit of the newspapers?
4. What things is Napoleon said not to be?

Read this and then write the answer to question 5. The question must be answered from the paragraph. Read the paragraph as often as you need to.

Studies serve for delight, for ornament, and for ability. Their chief use for delight is in privateness, and retiring for ornament, is in discourse; and for ability is in the judgment and disposition of business; for, expert men can execute and perhaps judge of particulars, one by one; but the general counsels, and the plots and marshaling of affairs, come best from those that are learned.

To spend too much time in studies, is sloth; to use them too much for ornament, is affectation; to make judgment wholly by their rules, is the humor of a *scholar; they perfect nature, and are perfected by experience—for natural abilities are like natural plants, that need pruning by study; and studies themselves do give forth directions too much at large, except they be bounded in by experience.*

5. How many uses may "studies" serve?

SET IV OR 40

Read this and then write the answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

In Franklin, attendance upon school is required of every child between the ages of seven and fourteen on every day when school is in session, unless the child is so ill as to be unable to go to school, or some person in his house is ill with a contagious disease, or the roads are impassable.

1. Name one condition that would justify a ten-year-old girl in remaining out of school in Franklin.
2. Between what years is attendance upon school compulsory in Franklin?
3. At what age may a boy leave school to go to work in Franklin?

Read this and then write the answers to questions 4 and 5. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

Nearly fifteen thousand of the city's workers joined in the parade on September seventh, and passed before two hundred thousand cheering spectators. There were workers of both sexes in the parade, though the men far outnumbered the women.

4. How many persons marched in the parade?
5. How many people saw the parade?

SET V OR 50

Read this and then write the answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

First, let us ask, where does book-making begin? With the printer? No, for before the printer can even think about printing, he must have his "copy". This "copy", as the printer calls it, is furnished by the publisher; and the publisher gets it from the author, who calls it his "manuscript". The author has spent many days, perhaps months, or even years, upon it, writing it out with his own hand. With pen and ink he has put his thoughts upon the paper.

4. What is the general topic of this paragraph?
5. Where according to this paragraph does book-making begin?

SET VI OR 60

Read this and then write answers to questions 1, 2, and 3. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

If college athletics were endowed, and those precautions taken in reference *to the expenditure of money which control in other departments the actual cost of athletics would be greatly reduced. Some believe that this saving would amount to 50 per cent of the total sum expended. No one doubts that the saving would be considerable. This statement does not imply that at present there is any gross mismanagement. It means simply that with the elimination of certain rivalries, the strict control of expenses, the more definite knowledge of resources, a real improvement could be effected in the financial administration of the work. When it is recalled that the amount now expended in the case of single institutions ranges from $25,000 a year to more than $100,000, it can easily be understood that, at all events, there is a field for the practice of economy.*

1. What does the paragraph say might be one effect of endowing college athletics?
2. How much saving might be made?
3. What three things are mentioned as possible helps in improving the management of athletics?

Read this and then write the answers to questions 4 and 5. All questions must be answered from the paragraph. Read the paragraph as often as you need to.

We often think of a rich man as one who has much money, as if money and wealth meant the same thing. However, money is only one sort of wealth and some money is not exactly wealth. A twenty-dollar bill, for example, is only someone's promise to pay so much gold. Wealth means land, houses, food, clothes, jewels, tools, gold, silver, coal, iron,—anything that a man can have that satisfies some want. Money means something which a person can exchange for any one of many sorts of wealth. The main value of any piece of wealth, such as a barrel of flour, a house, or a cow is the direct use you can make of it. The value it has by reason of what you can change it for is of less importance. The main value of any piece of money, such as a silver dollar, a ten-dollar bill, or a nickel, is NOT any direct use you can make of it. Its main value is that you can exchange it for something that is of direct use. For this reason, it is called a "medium of exchange".

4. In what does the main value of wealth lie?
5. In what does the main value of money lie?

For the successful administration of these tests, the directions on the next page should be followed.[11]

11. These tests and directions are now for sale by the Northwestern School Supply Company of Minneapolis and may be ordered thru the Bureau of Coöperative Research of the University of Minnesota. These are included in this bulletin as originally printed, except for a few changes by the author.

VISUAL VOCABULARY

Direction for Giving Test

I. *Preliminary Test*

1. See that each child has at least one, preferably two, well sharpened lead pencils.

2. Distribute to each child a copy of the test with instructions that the page should not be turned until directions are given.

3. Have each child write in the proper place his name, sex, age in years and months, city, grade, school, teacher, and the date of the test. Inspect papers to see that this is correctly done.

4. Doing the test: Direct the children to open the folder to Preliminary Test. Say to them: "At the bottom of this page are some words. The reading at the top tells you to do something to these words. Read the lines at the top and do what it says to do. Read the instructions two or three times if necessary. When you have finished, bring your papers to me so that I can see whether you have done the work correctly or not."

5. Have each child as he completes his work bring forward his finished page. Look it over at once to see if he has followed directions. Check the use of each direction. Where directions have not been followed, call the child's attention to that part before giving the Scale R Test.

II. *Scale R*

1. The preliminary test should have prepared each child to perform the Scale R Test correctly. Direct them to turn to Scale R.

2. Say to the children: "On these pages are some words. The reading tells you to do something to these words. Read the lines and *do what it says to do.* Read the instructions two or three times if necessary. When you have finished, bring your papers to me at the desk. At the signal "get ready" take up your pencil and look at me. At the signal "start," begin work.

3. Have each child as he completes his work bring his paper forward. Keep the time for each pupil. To keep time satisfactorily requires two persons, one to call the time as the papers are handed in, the other to record the time on the papers. The record can best be made by noting on each sheet in hours, minutes and seconds, as 10-15-30, the time of beginning the test and the time each individual finishes. By subtracting, the exact time occupied in the test can be determined.

Directions for Scoring

Computing Individual Scores

1. Arrange the papers from a single class alphabetically in a pile.

2. Take from the pile the first paper and read through the child's markings until you come to a line in which an error or omission occurs. Place to the left of this line a figure indicating the number of errors and omissions in that line. Read through the remaining lines and indicate in

a similar manner the number of errors and omissions. The highest numbered line which the child does with one (or no) omissions or errors is taken as his score. Draw a line under the figure on the page indicating this score. Check this score on the first cover page in the blank indicated. Then proceed in a similar manner with each of the other papers of the class.

Class Scores

1. Use class record sheet number 1.
2. Enter in the wide space at the left the name of the pupil and at the appropriate places the figures indicating the number of errors and omissions in each line.
3. Add the numbers in each column and place the sum at the bottom of the score sheet. Find the percentage of error by dividing the sum thus obtained by 5 times the number of pupils in the class. The score of the class may be taken as the line in which the percentage of error is 20.
4. If no single line gives exactly 20 per cent of error, the actual class score will be intermediate between the two lines which gives nearest 20 per cent of error. By means of Table I, this intermediate value may be calculated.[12]

For example, if a fourth grade class has only 16 per cent of error in line 25, then its rating should be somewhat more than 25. By referring to the Table, it is found that 16 per cent of error indicates an additional value of 2.3 to the value of the line. This 2.3 should be added to the 25 giving 27.3 as the ability of the class in question.

Or if a sixth grade class is found to make only 5 per cent of error in line 35 but 28 per cent of error in line 45, then the score for this grade falls above 35 and below 45. Calculating from the percentage nearest 20, namely 28, and by referring to the Table, we find that 3.9 should be subtracted from the set in question. Subtracting 3.9 from 45 gives 41.1 as correct score for the class in question. A more correct rating can often be obtained from the two scores nearest 20 per cent.

12. The figures of Table 18 are for steps of 10. Where the steps are 5, the values should be divided by 2. Where the steps are 20, the values should be multiplied by 2.

UNDERSTANDING OF SENTENCES

Directions for Giving Tests

I. *Preliminary Test*

1. See that each child has one, preferably two, well sharpened lead pencils.

2. Distribute to each child a sheet containing the test.

3. Have each child write at the proper place his name, sex, age in years and months, city, school, grade, teacher, and date of test. Make certain that this is properly done before proceeding with the test.

4. Doing the test: Have the child note the Preliminary Test. Say to the children: "On this page are some sentences. Below the sentences are some questions. You are to read through the sentences and then write correct answers to the questions. You need not write complete sentences, but your answers must be definite. Read the instructions and sentences as often as necessary. When you have finished bring your paper to me so that I can see whether you have done the work correctly."

5. Have each child as he completes his work bring his paper forward. Look it over at once to see if he has followed instructions. Do not give Scale Beta until each child understands how to do the preliminary test correctly.

II. *Scale Beta*

1. The preliminary test should have prepared each child to perform Scale Beta test correctly. Direct the children to turn to Scale Beta.

2. Say to the children: "On these pages are some selections to be read and below each selection are some questions to be answered. Read the selection and write the answers to the questions. Your answers need not make complete sentences but they must be clear and definite. Read the selections and questions as often as necessary but work continuously until you have finished. When you have finished bring your papers to me at the desk. At the signal 'get ready' take up your pencil and look at me. At the signal 'start,' begin work."

3. Have each child as he completes his work bring his paper forward. Keep the time for each pupil. It takes two people to keep the time most satisfactorily, one to call the time as the papers are handed in, the other to record the time on the papers. The record can best be made by noting on each sheet in hours, minutes and seconds, as 10-15-30 the time of beginning the test and the time each individual finishes. By subtracting, the exact time occupied in the test can be determined.

DIRECTIONS FOR SCORING TESTS

Individual Score

Read through each paper and note omission or wrong response, placing at the left an X for each error. Accept as correct for each question in each set the answers indicated at right in the following key.

Key for Scale Beta 1

Set I, Element 1. Short. 2. Two. 3. Mary.

Set III, Element 1. The author, An author. 2. The printer. 3. Went down the road or equivalent (call went on, or went on to Boston wrong). 4. Two other boys, or two boys. 5. Nine o'clock.

Set IV, Element 1. Pollen from plants and weeds, Pollen from plants, Pollen for weeds, Pollen. 2. Two per cent, 2 per cent, 2. One out of fifty, One in fifty, or equivalent. Call A small per cent, or A small number, or A few wrong. 3. By living in certain places, By going to live in certain places, By finding a place where there is no pollen from weeds. 4. Coal range and gas range. 5. For broiling, Broiling, To broil with, etc.

Set V, Element 1. Money and wealth. 2. He might have land; He could own property; He could own houses; He could have jewels, or gold and silver; Might have mines, etc. 3. Paper money, A ten-dollar bill. Call wrong any answer that confuses paper money with coin, such as "a silver dollar" "a ten-dollar gold piece" "a nickel", "a penny". 4. Call correct any answer that names a duty the boy must perform as "work to make a living for himself or his family"; "To work" is not a sufficient answer; "to help his mother" is not, but "to work in order to help his mother" or "to work because his father dies" is. Wrong responses are such as: Playing ball, etc., Going with bad boys, To work, To earn money, Have to work out to get money, Because to help their mother. 5. Right responses are such as: He would have to work all the time, He would work instead of going to school, He might have to work to support the family, He would have to go out to work, He would have to work, He would have to work afternoons evenings, It might be good effect, Work, A boy would work, He had to work afternoons and evenings, To work afternoons and evenings, Working or making his living.

Set VI, Element 1. Cost would be reduced, Cost of athletics would be reduced, To reduce the cost or equivalent. 2. 50 per cent, Fifty per cent. 3. Elimination of rivalries, Strict control of expenses, More definite knowledge of resources. (To be credited only if three are given.) 4. "In direct use you can make of it", or equivalent. 5. That you can exchange it for something you want or equivalent.

Set VII, Element 1. Three or enumeration of the three. 2. General plots, counsels and marshalling of affairs, (if two of these are given, we gave full credit, if but one, we counted it 0.) 3. In discourse (Most frequent errors here due to confusion between serve and use and ignorance of meaning of affectation.) 4. We shall envy him; Envy the prisoner; Would want to change places with him, Would want to be a prisoner. 5. Activity of body or mind at which a man can succeed.

Key for Scale Beta 2

Set III, Element 1. Hay-fever. 2. The nose runs, the eyes are sore. 3. At the highest point of his fortunes. 4. No saint, No hero, No capuchin, to be credited if two are given. 5. Three or the enumeration of the three.

Set IV, Element 1. If she were ill, If some one in her house had a contagious disease, If the roads were impassable. 2. Seven & fourteen; 7 and 14. 3. Fourteen. 4. Nearly fifteen thousand, About fifteen thousand, Fifteen thousand, There were 15,000, or the equivalent. All else wrong. 5. Two hundred thousand, 200,000. Call very many, a great many, etc., wrong.

Set V, Element 1. Be liberal; any answer noting that a gas range is cooler than a coal range, is to be called right unless the incompleteness is surely due to misreading rather than poor expression, e.g. Makes it cooler, To make it cooler, A gas range is cooler, When you use a gas stove, the kitchen is cooler, The gas is cooler. But if there is evidence that the pupil did not understand the 'what effect' or 'instead of,' etc., call it wrong. Thus Not to make the house too warm, Because it does not give so much heat, Because it makes it cooler, Gas range does not give much heat, are all to be scored wrong. 2. A coal range. 3. In the end oven, In the end ovens. 4. Book-making; the making of books. 5. With the author's "manuscript", With the manuscript; With the writer; With the author.

Composite Scores

A. Computing class scores.

1. Use class record sheet 2.

2. Copy from individual score sheet upon the record sheet the name of each pupil and the number of errors made by him in each element of each set.

3. Total the figures for each set in the broad column immediately at the right of the set in question.

4. Total these results at the bottom of the page in the line marked "Total number wrong". Divide the several totals by the product of the number of individuals times the number of questions in the set. Thus in Set I, let the total number of errors be twelve and the total number of individuals in the class 20. Since the chances of error in Set I are three, you multiply 3 by 20 which gives 60. This sixty you divide into 12 which gives .20 or 20 per cent, the per cent of error made by the entire class in Set I. Set I is then the score for the class if, as is likely, the following set gives a higher percentage of error. In any case, the class score is the number of the set which gives 20 per cent of error.

5. If no single set gives exactly 20 per cent of error, the actual class score will be intermediate between the two sets which gives nearest 20 per cent of error. By means of Table 18, this intermediate value may be calculated.

B. For two or more classes of the same grade.

1. Make table similar to one used in compiling class scores.

2. Enter in a manner similar to entering the records of individual pupils the total number of errors and omissions for each class. These figures are taken directly from the totals on the class score sheet.

3. Add the figures in each column and divide by the total number of children times the number of questions in the set in question. The score is again indicated by that set in which the per cent of error is 20.

C. For two or more grades.

The method here is the same as under A, except that the compilation includes different grades. Thus one may compute the score for all the classes of the three, four or five grades, in a building. The result is a score for the building.

TABLE 18.—To Estimate Degree of Difficulty at Which 20 Per Cent of Errors and Omissions Would be Found From any Given Percentage of Errors and Omissions Between 8.0 and 40.00

Given percentage	Add	Given percentage	Add	Given percentage	Add	Given percentage	Subtract
8.0	8.4	12.0	4.9	16.0	2.3	20.0	0.0
1	8.3	1	4.9	1	2.2	1	0.0
2	8.2	2	4.8	2	2.1	2	0.1
3	8.1	3	4.8	3	2.1	3	0.1
4	8.0	4	4.7	4	2.0	4	0.2
5	7.8	5	4.6	5	2.0	5	0.3
6	7.8	6	4.5	6	1.9	6	0.3
7	7.7	7	4.5	7	1.8	7	0.4
8	7.6	8	4.4	8	1.8	8	0.4
9	7.5	9	4.3	9	1.7	9	0.5
9.0	7.4	13.0	4.2	17.0	1.7	21.0	0.5
1	7.3	1	4.2	1	1.6	1	0.6
2	7.2	2	4.1	2	1.5	2	0.6
3	7.1	3	4.0	3	1.5	3	0.7
4	7.1	4	3.9	4	1.4	4	0.7
5	7.0	5	3.9	5	1.4	5	0.8
6	6.9	6	3.8	6	1.3	6	0.8
7	6.8	7	3.7	7	1.2	7	0.9
8	6.7	8	3.7	8	1.2	8	0.9
9	6.6	9	3.6	9	1.1	9	1.0
10.0	6.5	14.0	3.6	18.0	1.1	22.0	1.0
1	6.4	1	3.5	1	1.0	1	1.1
2	6.3	2	3.5	2	1.0	2	1.1
3	6.2	3	3.4	3	0.9	3	1.2
4	6.2	4	3.3	4	0.9	4	1.2
5	6.1	5	3.3	5	0.8	5	1.3
6	6.0	6	3.2	6	0.8	6	1.3
7	6.0	7	3.1	7	0.7	7	1.4
8	5.9	8	3.0	8	0.7	8	1.4
9	5.8	9	3.0	9	0.6	9	1.5
11.0	5.7	15.0	2.9	19.0	0.5	23.0	1.5
1	5.7	1	2.8	1	0.5	1	1.6
2	5.6	2	2.7	2	0.4	2	1.6
3	5.5	3	2.7	3	0.3	3	1.7
4	5.4	4	2.6	4	0.3	4	1.7
5	5.3	5	2.6	5	0.2	5	1.8
6	5.2	6	2.5	6	0.2	6	1.8
7	5.2	7	2.4	7	0.1	7	1.8
8	5.1	8	2.4	8	0.1	8	1.9
9	5.1	9	2.3	9	0.0	9	1.9

TABLE 18—Continued.

Given per-centage	Sub-tract	Given per-centage	Sub-tract	Given per-centage	Sub-tract	Given per-centage	Sub-tract
24.0	2.0	28.0	3.9	32.0	5.6	36.0	7.2
1	2.1	1	3.9	1	5.6	1	7.3
2	2.1	2	4.0	2	5.7	2	7.3
3	2.2	3	4.0	3	5.7	3	7.3
4	2.2	4	4.0	4	5.7	4	7.4
5	2.3	5	4.1	5	5.8	5	7.4
6	2.3	6	4.1	6	5.8	6	7.5
7	2.4	7	4.2	7	5.8	7	7.5
8	2.4	8	4.2	8	5.9	8	7.5
9	2.4	9	4.2	9	5.9	9	7.6
25.0	2.5	29.0	4.3	33.0	6.0	37.0	7.6
1	2.6	1	4.3	1	6.0	1	7.7
2	2.6	2	4.4	2	6.1	2	7.7
3	2.7	3	4.4	3	6.1	3	7.7
4	2.7	4	4.5	4	6.1	4	7.8
5	2.7	5	4.5	5	6.2	5	7.8
6	2.8	6	4.6	6	6.2	6	7.8
7	2.8	7	4.6	7	6.3	7	7.9
8	2.9	8	4.7	8	6.3	8	7.9
9	2.9	9	4.7	9	6.3	9	8.0
26.0	3.0	30.0	4.7	34.0	6.4	38.0	8.0
1	3.0	1	4.8	1	6.4	1	8.0
2	3.0	2	4.8	2	6.5	2	8.1
3	3.1	3	4.9	3	6.5	3	8.1
4	3.1	4	4.9	4	6.6	4	8.1
5	3.2	5	4.9	5	6.6	5	8.2
6	3.2	6	5.0	6	6.6	6	8.2
6	3.3	7	5.0	7	6.7	7	8.3
8	3.3	8	5.1	8	6.7	8	8.3
9	3.3	9	5.1	9	6.7	9	8.3
27.0	3.4	31.0	5.1	35.0	6.8	39.0	8.4
1	3.5	1	5.2	1	6.8	1	8.4
2	3.5	2	5.2	2	6.9	2	8.5
3	3.5	3	5.3	3	6.9	3	8.5
4	3.6	4	5.3	4	7.0	4	8.5
5	3.6	5	5.4	5	7.0	5	8.6
6	3.7	6	5.4	6	7.0	6	8.6
7	3.7	7	5.4	7	7.1	7	8.6
8	3.8	8	5.5	8	7.1	8	8.7
9	3.8	9	5.5	9	7.2	9	8.7

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INDIANA UNIVERSITY STUDIES

Study No. 35

POWER ECONOMY AND THE UTILIZATION OF WASTE IN THE QUARRY INDUSTRY OF SOUTHERN INDIANA. By GROVER C. MANCE, Ph.D.

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Submitted in partial fulfilment of the requirements for the degree Doctor of Philosophy.

Contents

PLOTS

Preface

The reasons for the preparation of this study are many. Probably the most important reason is the fact that the limestone quarry industry of Southern Indiana has reached a point in its development where it can advance only by a change in methods and by the introduction of new and up-to-date processes and of better machinery. Further reductions in the price of stone can come only from reduced cost of production, and the object of this paper is to offer suggestions that will assist in such a lowering of production cost. The stone industry of Indiana can be developed to a far greater extent than it is today, and the time is at hand for such development. Operators are already considering the installation of electrical equipment and the methods in use are constantly changing. An effort has been made to find out what has proved a success in other places, and by suggestions to help the local operator to avoid the unnecessary expense of experimenting with unsuccessful methods.

The work of which this study is the result was taken up at the suggestion of Professors Edgar R. Cumings and Joshua W. Beede, of the Department of Geology of Indiana University, and their constant interest and help have contributed very materially to the successful completion of the work.

The material has necessarily been largely a compilation of facts and suggestions collected from a great number of works, including many articles from the files of the following magazines: *Engineering Magazine, Engineering News, Engineering and Mining Journal, Engineering Record, Stone Magazine.* To this list should be added a number of papers and articles which have appeared in various other periodicals bearing less directly on this problem. It would be practically impossible to give credit separately to each firm or individual that has assisted in this work with information or material.

Many papers on quarrying, along various lines of interest, have been written, but to the best of the writer's knowledge no work has as yet attempted to deal with the engineering phases as well as with the geology of the subject, and no work whatever has been written on the engineering features of this district.

A bibliography classified by general topics is appended to this report.

The writer wishes to take this opportunity to express his obligations to the following persons and firms: to Professors Cumings and Beede, of the Department of Geology, and to Professor Brown, of the Department of Chemistry, of Indiana University, for suggestions and advice thruout the development of the study; to Mr. W. J. Huddle, of the engineering firm of Sloan Huddle and Company, of Indianapolis, who kindly offered much advice on the engineering features of the paper; to Mr. Eugene Perry of the Perry Stone Company, to Mr. Fred Mathews and Mr. E. J. Barrett of the Crescent Stone Company, and to Mr. J. H. Nolan of the Nolan and Sons Stone Company, for special data furnished by them; to all the operators and employees of the stone belt for assistance whenever asked. For special information furnished: Babcock and Wilcox Boiler Company, Skinner Engine Company, Harrisburg Foundry and Machine Company, Sturtevant Mill Company, E. I. DuPont de Nemours Powder Company, Abendroth and Root Boiler Company, Hooven Owens Rentschler Engine Company, Ball Engine Company, Power and Mining Machinery Company, Earl C. Bacon Company, Green Fuel Economizer Company, Terry Steam Turbine Company, General Electric Company, Smith Gas Power Company, Irvin C. De Haven Company, Standard Gas Power Company, Crocker-Wheeler Company, Dean Brothers Pump Company, Ingersoll-Rand Company, Kingsford Boiler Company, Harrison Safety Boiler Works, New England Gas Producer Company, American Engine and Electric Company, Lidgerwood Manufacturing Company, Deming Pump Company, Gould Pump Company.

In addition to the above mentioned firms, all of which submitted special data, there were numerous other companies that quoted prices on their products.

During the progress of the investigation the writer found the representatives of all the manufacturing firms who handle machinery applicable to the quarry industry eager to assist with information wherever possible, and the owners of quarries and mills ready to furnish any information asked. An effort has been made to give only approximate figures where the data too closely touched an operator's business affairs.

The study is a concise outline of the stone industry in Indiana as a whole; and everything has been avoided that might be construed as merely advertising the business.

Part I. Introductory

CHAPTER I

STATISTICS OF THE STONE INDUSTRY IN THE UNITED STATES

The following statistics on the stone industry in the United States were taken from the report of the United States Geological Survey, Department of Mineral Resources, for the year 1912. The total value of the stone produced in the United States for the years since 1899 is as follows:

Year	Limestone	Total
1900	$13,556,523	$36,970,777
1901	18,202,843	47,284,183
1902	20,895,385	54,798,682
1903	22,372,109	57,433,141
1904	22,178,964	58,765,715
1905	26,025,210	63,798,748
1906	27,327,142	66,378,794
1907	31,737,631	71,105,805
1908	27,682,002	65,712,499
1909	32,070,401	71,345,199
1910	34,603,678	76,520,584
1911	33,897,612	76,966,698
1912	36,729,800	78,284,572

The value of the total stone products increased $1,317,874 between 1911 and 1912, which represents a gain of 1.53 per cent. While this increase was being made in all stone products, limestone value was increasing $2,832,188, which represents an increase of 8.36 per cent. In fact, limestone and marble products were the only ones to increase in value for the year, marble showing an increase of 3.19 per cent.

The States which lead in the total value of their stone products for the years 1911 and 1912, were ranked as follows: In 1911—Pennsylvania, New York, Vermont, Ohio, California, Indiana; in 1912—Pennsylvania, Vermont, New York, Ohio, Indiana, California.

Limestone products represent 46.92 per cent of the total value of stone products for the year, granite, its nearest competitor, representing 25.85 per cent of the total value. In 1911, Indiana, ranking sixth, turned out $4,413,655, which represented 5.72 per cent of all the stone products of the United States. In 1912, the value of all stone products in Indiana was $5,091,924, or 6.5 per cent of all stone products of the United States. Thus Indiana was raised to fifth place, which rank was formerly held by California. This increase represents a gain of 15.37 per cent for the State. There were 131 plants in operation in 1912.

Limestone for building purposes, including rough and dressed stone, increased $330,096 from 1911 to 1912. In 1911 Indiana produced 64 per cent of all the limestone used for building purposes in the United States; in 1912, 69 per cent.

The table below gives the quantity and value of the Oölitic limestone produced in Lawrence and Monroe counties each year since 1900. From 1907 to 1912, inclusive, both quantity and value are given under three heads: Lawrence county, Monroe county, and the total for both counties.

Year	Lawrence County		Monroe County		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1901	....	$1,365,875	....	$421,599	....	$1,787,474
1902	....	1,207,497	....	439,902	....	1,637,399
1903	....	1,088,477	....	487,662	....	1,576,139
1904	....	1,054,302	....	589,672	....	1,643,974
1905	....	1,550,076	....	843,399	....	2,393,475
1906	....	1,460,743	....	1,162,062	9,282,004	2,622,805
1907	....	1,413,280	....	908,612	7,849,027	2,321,892
1907	....	....	....	....	256,960	110,525
1908	*5,199,996	1,498,822	3,147,097	880,218	8,347,093	2,379,040
1908	93,085	42,150	8,260	1,719	101,705	43,869
1909	6,441,483	1,678,195	2,970,388	801,436	9,411,871	2,479,631
1909	145,672	71,637	106,600	56,925	252,272	128,562
1910	5,778,660	1,841,233	3,960,148	1,265,287	9,738,808	3,106,520
1910	131,590	75,906	70,655	44,224	202,245	120,130
1911	6,612,988	2,171,148	2,915,444	859,580	9,528,442	3,030,728
1911	53,242	27,842	50,914	45,112	104,156	72,954
1912	7,066,496	2,622,648	3,375,808	824,594	10,442,304	3,447,242
1912	71,124	37,894	76,532	60,629	147,656	98,523

*From this point on the first number in quantity columns indicates cubic feet; the second, short tons.

CHAPTER II

QUARRY AND MILL OPERATION

Quarry Operations. The problem of selecting a quarry location is one attended by many chances of failure, and men who have spent their lives in the stone business are likely to make mistakes. The number of abandoned quarries in the district indicates the mistakes made by stone men in the past. The good building stone is not spread evenly over the stone belt as has been supposed by many of the operators. The stone has been laid down in large irregular lenses, and while a property in operation may give a large quantity of very good stone, a site only a short distance away may prove a complete failure. One feature that may assist somewhat in the selection of the site is the position of the quarry in the outcrop. The beds of rock which carry the building stone slope gently to the west and southwest so that in the eastern part of the stone belt the Oölitic beds outcrop at the top of the hills and ridges. As these beds are followed west or southwest they appear lower and lower down on the hillsides and soon are covered by a layer of Mitchell limestone, which is the next overlying member of the Mississippian rocks. Still farther west the stone is found in the bottoms of the valleys before it finally disappears under the overlying formations. The rock in a quarry opening which is made where the stone is near the tops of the hills and ridges will be found to be very much seamed and weathered, and the amount of waste stone that must be rejected under such conditions often makes the quarry an unprofitable venture. An example of this type of quarry is the opening made just southeast of Bloomington, where there is no protecting covering of overlying rocks, and where the stone is so seamed and weathered that the quarry has already been abandoned. Where the quarry is opened near the bottom of the valley the chance of obtaining a good grade and quantity of stone is far better.

The selection of a quarry site is determined by the amount of stripping and by the quantity and quality of the stone encountered in core drilling. The only method at present in use in the stone belt for determining these facts concerning a quarry location is vertical core drilling. This is accomplished by means of the chilled shot core drill. This drill consists of a line of hollow rods rotated by power thru a shaft and gearing, and fed forward either by a hydraulic cylinder and piston or by a screw feed. A bit is placed at the lower end of the rod and cuts an annular hole in the rock as the drill is rotated. The point or end of the bit is fed with chilled shot and is kept cool by water forced thru the rods, the stream of water removing the waste cuttings from the bit. The central piece left as the drill cuts down is called the "core". This solid core is the essential feature of this method of drilling. It is the section of rock which is formed by the hollow bit and rod as the drill advances. At intervals, usually after drilling 10 feet, the rods are withdrawn by means of a hoisting mechanism bringing with them the rock core, which is caught and held by a self-locking "core lifter". The core is then removed, the rods again lowered, and the process repeated until the desired layer of stone has been penetrated. A careful study of this "core" will show the prospector the depth of the bed, its thickness, and the character of the stone in the quarry. This helps to determine whether or not the bed will justify opening.

Since the motion of the diamond or chilled shot drill is a rotary one, it follows that where electricity is available the motor is the logical form of prime mover to use in working the drill. However, steam can be used to turn the drill thru a system of gears, and at present this method is in use thruout this district. The facts shown by the drill core should not be taken as sufficient evidence on which to open a quarry, for altho the thickness of the stripping of overlying rocks and disintegrated material can be ascertained with a fair degree of accuracy, yet if the drill were set up over a pinnacle in the rock, a false impression of its thickness would be obtained, and if the drill were driven into a seam, the quarry might be abandoned altho much good stone might really be available. Of course, a number of drillings may be made, and only by chance would the same conditions be found at each point of drilling, but it is a fact that several quarries have been opened as a result of a single boring, and many quarry sites have been abandoned on the same sort of evidence. Diagonal drilling with the diamond drill is in use in iron mining operations and is proving a success. This fact should be a strong recommendation for its use in quarry prospecting. Diamond drills can be driven at as high an angle as 72 degrees from the vertical, and if such an angle were adopted in quarry prospecting the distance between the seams as well as their width and depth could be determined with a very fair degree of accuracy. If the drill entered at this angle and at right angles to the direction or azimuth of the seams, several seams would usually be crossed by a single drilling. It would be well for the company interested in a piece of land, with the idea of opening a quarry, to look more fully into the possibilities of this form of drilling. Much valuable data on cost of drilling furnished by Mr. Gunsolus of the DuPont Powder Company will be found in connection with the part of this study devoted to the cement industry.

After the location has been determined upon, there comes the work of stripping and of levelling the floor. The disintegrated material is removed in most cases by a stream of water, the process being known as hydraulic stripping. The water is usually driven by a large reciprocating pump, the most common in use being manufactured by the Laidlaw Dunn Gordon Company or the Worthington Company. The water is distributed to the quarry in a 6-inch line, and this is reduced at the nozzle to a 1-inch or a $1\frac{1}{2}$-inch stream. The nozzle is held in position on a jack, and the operator controls the stream by means of levers on the jack. The water is allowed to flow into a catch basin where the material carried by the stream is deposited and the water can be used over and over again. These reused waters are usually heavily charged with fine material in suspension and since they are never given time enough to settle, the material must pass thru the pump many times. Under these conditions the life of a reciprocating pump is very short, since the wear on the cylinders is very rapid. In this respect the work could be accomplished better by centrifugal pumps where the clearance could be so adjusted as to handle water with any amount of dirt in it, without excessive wear on the pump. Centrifugal pumps are now constructed that will give any desired head, and since their motion is well adapted to electric drive, they should soon displace reciprocating pumps in quarry-stripping operations. The securing of an adequate water supply for hydraulic stripping is a serious problem in many of the quarries, and a catch basin is used so that as little as possible of the water is lost. Most of the work of stripping is done in the spring when the water supply is relatively large.

After the floor has been stripped of waste material the work of leveling follows. This is often accomplished by means of drilling and wedging or drilling and blasting. In the former process the holes are drilled by means of steam or compressed air drills to a depth of about 8 inches, about a foot apart in the direction in which it is desired to split the rock. In these holes steel wedges are driven between steel plates called "feathers". If each wedge is driven in turn the rock will be split very evenly. This method is also used to split up large blocks in the quarry, preparatory to removal with the derricks. Drilling and blasting can be carried on only where there is a covering of Mitchell limestone to be stripped off and a soft layer above the building stone to protect it from the jar which would tend to shatter it. In one of the larger quarries where the stripping is very thick, churn drills are used to make the holes for the blasts and steam shovels are used to remove the waste stone.

The most common type of drill is the simple steam drill in which the drill bit is fastened to the piston of the drill, and the whole machine is held in position by means of a tripod. Many modifications of this form of drill are in use, and all forms have their advocates. It has been the general idea for a great many years that electric drilling could not be made a success, but in the last few years many successful electric drills have been put on the market. The *Engineering Magazine* (December, 1911) says:

Where holes are to be drilled for blasting or plugging, reciprocating drills are used exclusively. Generally these drills consist of a piston to which the drill is fastened directly and rigidly, a valve for distributing the steam to the ends of the piston, the valve mechanism, and a means of rotating the drill to insure a round hole. Most of these types will operate on either compressed air or steam.

The uses to which rock drills are put, the class of operators who handle them, and the location of the work, all demand a machine with as few moving parts as possible, one rugged in design and construction, simple in operation, and foolproof in adjustment, and it is such a type that represents the best rock drill of today. The Sullivan tappet valve drill is a good drill for low pressures and soft rock with mud seams present, such as most open excavation work. The Ingersoll-Rand butterfly valve drill is another effective drill for this kind of work.

The Little Giant drill built by the Ingersoll-Rand Company uses a plain slide valve to distribute the air to the piston. In this drill the valve is thrown by a rocker one end or the other of which is always in contact with the piston and is moved on its pin by the curved surfaces of the piston. This rocker in turn moves the slide valve which distributes the air. This drill is also furnished with a balanced valve which is of advantage with high pressure. Another type put out by the Sullivan Company is their differential valve drill. In this drill the valve is thrown by air. The three spools on the valve differ in area, the central one being of larger diameter than those on the ends. The air and exhaust parts are so situated and proportioned that the valve is held to its seat under the total line pressure from one side only, until the proper stroke of the piston is secured. This enables the operator to adapt the length of the stroke and the force of the blow at will. In the drills just described the drill bar is fastened to the piston rod by means of a clutch. This means that the whole drill bar reciprocates with the piston. For light work another arrangement is used by the Sullivan Company in their hammer drills. In this drill the bit is held against the rock and the piston strikes the hardened end of the steel. This drill is rotated by hand.

A combination electric air drill is manufactured by the Ingersoll-Rand Company. In the electric air drill the bit is driven by pulsations of compressed air created by a pulsator actuated by a standard electric motor. The air is never exhausted, but is simply used over and over again, playing back and forth in a closed circuit. This is simply an electric drill in which the compressed air is used as a spring and cushion. This drill can be driven on about one-fourth the power consumed by the ordinary steam or compressed air drill. It seems to be the best fitted for ordinary quarry work where electric power is available, and is sure to be adopted widely in this quarry district.

After the quarry floor is leveled the tracks are put in position for the channeling machines. The channels cut by these machines are about 2 inches wide and from 6 to 10 feet deep. The first machine of this type was made by J. Wardwell in 1863, and the first Wardwell machine was bought in Indiana in 1873 by John Mathews. This machine was essentially the same as the Wardwell channeler in use today. It cost approximately $6,000, but at the present time can be purchased for about $2,000.

G. P. Merrill, in his work on *Stones for Building and Decoration* (p. 404), describes the channeling machine as follows:

> The channeler is essentially a locomotive machine driven by power, . . . moving over a steel-rail track which is placed on the quarry bed. It carries a single gang drill on one side, or two such drills—one on each side. These are raised and dropped by a lever and crank arrangement. The gang of cutters forming the drill is composed of 5 steel bars, 7 to 14 feet in length, sharpened at the end and securely clamped together. Of the 5 cutters, 2 have diagonal edges; the other 3 have their edges transverse. The center of the middle largest extends lowest, so that the five form something like a stepped arrangement, away from the center. The drill, lifted, drops with great force and rapidly creases a channel in the rock. The single gang machine is operated by 2 men, the double by 3. As it runs backward and forward over the rock the machine is reversed without stopping, and as it goes the cutters deliver their strokes, it is claimed, at the rate of 150 per minute. The machine feeds forward on the track half an inch at each stroke, cutting half an inch or more at every time of passing. The single machine will cut from 40 to 80 square feet of channel per day in marble or limestone and at a cost of from 5 to 20 cents per square foot. The double machine will do twice the amount of work. A good workman by the old

hand process would formerly cut from 5 to 10 feet; that is, a groove 1 foot deep and from 5 to 10 feet long per day. For this he would receive 25 or 30 cents per foot.

Little use is made of channeling machinery in foreign countries where most of the deep cutting is done by means of the penetrating pulley. This is a type of wire saw which is guided in its course thru the rock by means of a pulley which penetrates the rock bed.

The channeling machine in use today is simply a combination of drill bits carried in sets and acting from a single cylinder. The motive power might be steam, compressed air, or electricity. All three kinds are in use in the Oölitic limestone district. The electric channeler seems to be doing the best work or at least the most economical work. The consumption of power is less and the cost of producing it in a central plant is far lower than in the channelers carrying their own boilers. The compressed air type of channeler is probably the least economical, on account of the heavy line losses and the heavy first cost of installing the compressor machinery.

There are three principal types of channeler in use in this district: the Wardwell, the Sullivan, and the Ingersoll-Sargent. They differ chiefly in the method by which the power is applied to the drill bits. The direct-acting types are the most rapid cutters, but there is a question as to whether the added power consumption does not offset the gain in speed of cutting. The development of channeling machinery has been rapid, and the modern types will cut rock channels at a high rate of speed. Tests on an Ingersoll-Sargent machine have shown as much as 100 square feet of channel cut per hour and over 700 square feet of cut in a 10-hour day of work.

The successful channeling machine, in addition to being a rapid cutter, must have great endurance and reliability inasmuch as the constant jar to which the machine is subject will soon destroy a weak machine. Three motions are essential in a channeling machine: cutting, feed, and motion along the track. In some types of channelers these motions are controlled by three different engines; in others, cog-wheels and shafts make it possible to handle more than one motion with a single engine. The best results have been obtained in the machine with three engines.

After the channels have been run and the key block has been removed, the blocks of stone are cut loose by means of plugging with drills, and by feathering. When the block begins to loosen it is pulled over by means of a derrick and is then split up into the desired sizes for quarry blocks, by means of drills and wedges. After it is worked up to the desired sizes it is loaded on cars for transportation to the stone mills.

Swing-back channelers and gadders are machines resembling the common channeler and drill but differing in that they are arranged to cut in any plane, while the common machine can cut only a vertical channel. The fact that the strata in the Oölitic limestone district are in a horizontal position makes their use unnecessary.

If the quarry floor tends to fill with water in times of heavy rains, it is emptied by means of pumps, the single stage centrifugal pump being most commonly used.

The derricks at present in use thruout the district are handled by steam or electrical power, usually the former. The wooden derrick of a few years ago is slowly giving way to the steel derrick, and the hand-turned derrick has been almost entirely displaced by the power-swung type. Electrical power is far better adapted to handling stone derricks than steam power on account of its speed and easy control. The electric motor can be placed nearer the work than a steam-power plant, thus facilitating its control. I have seen quarries in which small steam power plants for derrick handling have been located close to the workings, when set up, but as the workings have been extended the operator thought it cheaper and less trouble to extend the lines than to move the power plant closer to the work. As each extension was made the ropes were lengthened until at the present time some derricks are operated on as much as 1,000 feet of rope. This causes a very great loss of power, and, in addition to delaying the work, is a constant menace to the workmen in the quarry. All this is unnecessary where an electric motor is used, since its position can be changed in a very short time without in any way interfering with the work or causing any great delay in the quarry operations.

The Stone Mill. The milling of stone entails considerably more work, and the operations involved are much more varied than in the quarrying of the stone. The stone mills give work to more men than the quarries, and the labor is on the average more skilled. The fact that the mills run longer and pay higher wages than the quarries makes the mill the more attractive, and less trouble is experienced in getting men than in the quarry.

The first operation on the quarry block when it arrives at the mill is sawing. The block is removed from the car by means of a guyed derrick or a traveling crane. The guyed derrick is usually controlled by power from the power plant of the mill and is of the swinging-gear type. The mast is usually supported by 6 wire ropes, 3 times its length and firmly attached to the ground. The boom should be slightly shorter than the mast, and adjusted to swing freely under the guy wires at any angle of elevation. The guy wires should be examined often, since a broken guy may cause the collapse of a derrick, endangering life as well as destroying property.

The traveling cranes in use at most of the mills are of from 20 to 50 tons' capacity and the span is from 45 to 80 feet. The most popular type is the Bedford Foundry and Machine Company 20-ton crane. In most of the mills in the district the crane motors are of direct-current types, altho a few are operated on alternating current without transformers. In many of the larger mills small auxiliary handpower cranes are in use in the carving departments. The crane is a piece of machinery that should be built for the particular service it is to perform, and any suggestion as to which kind is the best on the whole is impossible, because a crane that fits one case would not necessarily do the work under other circumstances. Crane track-runs up to 400 feet are operated in some of the larger mills. A few steam-operated cranes are still in use in the district, but these are being rapidly replaced by electric cranes.

Most of the sawing is done with gang saws. The large blocks are placed on the truck of the gang saw and cut down to the size desired. The gang saw consists of a number of mild steel blades set in a frame at distances apart to correspond with the thickness of the slabs required. The blades are held tight by wedges set at the ends. The frame is suspended by rods carried on shafts attached to the uprights of the saw. A connecting rod attaches the frame to the crank of a power-driven jack which drives the entire frame backward and forward. Sand and water are fed on to the surface of the stone, and the blades of the saw are driven downward by a screw arrangement. The more rapidly the saw is driven into the rock the rougher is the surface made, and the greater is the work left for the planer. The New Albany saw is the one most widely employed, but many other makes are also in use.

In some mills, slab-cutting to size is done by the diamond saw. This is a fixed circular saw with a number of diamonds set in its periphery. The slabs to be sawed are clamped on a traveling table that carries them under the saw. In most of the types now in use the saw travels forward into the stone. The diamond saw is more rapid in its work than the gang saw, but the cost of installation and upkeep is higher. Diamond saws are driven at speeds of from 500 to 700 revolutions per minute, according to their diameters. The types most used in this district are the Anderson, the Patch, and the Meyers saws. The gang saws are usually steam driven, while the diamond saw is more easily handled by electric motors. These motors are constructed for either direct- or alternating-current drive, but the latter is the better adapted to the work. The cost of upkeep of a diamond saw is mainly due to the loss of diamonds, which tend to loosen from their settings. The saw blades are usually set with from 80 to 150 diamonds, and the heavy work tends to loosen them.

The following description of a diamond saw is taken from the latest catalogs of a large company putting these saws on the market:

> These machines are now equipped with worm drive as planers and may be purchased with either single or double platens and for either belt or directly connected motor drive. The platens are lined every 6 inches to guide the setting of the stone. The stone need not be moved for each cut but the blade is movable so that as many parallel cuts as desired can be made at one setting of the stone. The platens can be driven at any speed from 2 to 36 inches per minute with a reverse speed of 12 feet per minute. Three sets of teeth have run over 2 years and 6 months in Indiana limestone and are still in good condition.

There are in use in the district several diamond saws called "drag saws". These are cross-cut or reciprocating diamond saws. "Drag saws" are such large consumers of power that they are being rapidly replaced by circular diamond saws.

The planer is a heavily constructed machine with a traveling table on which the stone to be planed is wedged fast. The uprights of the machine support heavy steel planes which smooth the surface of the stone as it passes. These planers are constructed with one or two platens: In the latter case they are called biplaners. The single-platen machines may cut from one side or from both sides at the same time. In some of the single-side planers the plane is supported by one side of the frame, the other side of the frame not being present. These are called "open-side planers". Planers may have their platen driven by either gear screws or worm gears, the latter giving the better satisfaction. All planers which cut from both sides are equipped with four tool heads so that the sides as well as the top of the stone can be smoothed at one trip of the platen. Bi-planers have the advantage over the others in that two stones can be worked separately and independently of each other. They are, in fact, like two single-side planers placed with their open sides together. The two planes are independent of each other in height as well as travel. In the type known as the "circular planer" the table is arranged so that it can travel either in a circle or in a straight line, thus securing planing along curved lines as well as straight travel. Any radius of curvature desired can be secured with a little adjustment. There are many special types of planers constructed for special work that need no description here.

The lathe is a machine for turning out column work and can be purchased in any size desired. The lathe for heavy column work must be very heavy in construction since it is necessary to carry very large columns on a single point of support. The column is usually quarried and roughed out by hand to within a few inches of the desired size. Steel centers are then inserted in the ends of the column. The work of turning is done by cutters made with a beveled edge out of specially hardened steel. These travel along the sides of the column as it revolves and take off the rough surface of the stone. Some lathes will turn out columns up to 24 feet in length and from 36 to 66 inches in diameter. Special attachments for fluting are used with the lathes.

The wire saw is used in only two of the mills in this district, but has a very extensive use in foreign countries. It consists of a twisted cord of steel made to run around pulleys like a band saw. The cord is composed of three steel wires twisted loosely together, but stretched tightly over the pulleys, and made to run at a high rate of speed. The swift blows delivered by the ridges in the cord wear away the stone more rapidly than the smooth blades of the gang saws fed by sand.

Pneumatic appliances are in use in all the more up-to-date mills, and the use of the hand hammer in carving limestone has nearly disappeared. The work can be done so much more rapidly and cheaply by compressed air that every plant of any size is equipped with an air compressor and air hammers. The compressed air is carried to the hammers thru flexible tubes. The hammer consists of a valve and piston arrangement, giving a striking action of over 3,000 blows per minute, the tool being inserted against the piston. The speed and force of the blows is in control of the workman. The compressed air tools have revolutionized stone-carving in the district, and at present the work can be done for less than one-fourth the cost of the same work done by hand. The amount of air used by each drill depends on the condition of the drill and the kind of work it is doing. The application of air power to the various processes of stone carving and dressing marked the greatest single forward step in the history of the stone industry. These air instruments are not only great labor savers but also great cost reducers. To quote one of the latest catalogs on stone-working tools:

> Among the essentials of a successful stone tool may be mentioned simplicity of construction, that the mechanism may not be easily deranged; perfect workmanship and selected materials, implying reliability of service; economy of air consumption and ease of management.

The Ingersoll-Rand Company has on the market a number of valveless tools designed for all grades of work from heavy cutting to the most delicate tracing. The hammer or piston performs the function of admitting and releasing pressure. There is but one hardened piece of steel to move. These instruments consume from 2 to 6 cubic feet of air per minute.

The air compressors in use are of two types: steam-driven compressors and power compressors. The former give a high power cost on account of their great steam consumption. Any power-driven unit that can be driven from the main engine of the plant is more economical of power than separate steam-driven units, since losses in transmission of power by belting or gearing are more than offset by the losses due to the use of steam in small units. Most of the compressors used with carving tools are single-stage power-driven compressors.

The wages paid thruout the district vary according to locality, but an effort has been made in the Lawrence county stone belt to reach an agreement binding each operator to adhere to a fixed scale previously agreed upon by the stone men of the district. As a result of these moves the following scale of wages was adopted by the operators of Lawrence county. This move was carried into effect on March 1, 1910, and is still (1914) in force.

MILL WORK (Cents per Hour)

Planer men	.32½	Head hooker	.25
Traveler men	.28½	Second hooker	.20
Head sawyer	.25	Car blocker	.22½
Assistant head sawyer	.22½	Tool grinder	.23
Sawyer	.20	Blacksmith	.30
Diamond sawyer	.25	Laborer	.17½

QUARRY WORK (Cents per Hour)

Ingersoll and Sullivan runners	27 ½	Laborers	16 ½
Ingersoll and Sullivan firemen	17 ½	Head powerman	27
Ingersoll and Sullivan helper	16 ½	Powermen	16 ½
Wardwell runner	25	Derrick runner	23
Wardwell firemen	17 ½	Derrick helper	19
Wardwell helper	16 ½	Stripper	16 ½
Steam-drill runner	23	Scabbler	20
Steam-drill helper	16 ½	Machinist	31
Breakers	23		

Where stone-cutters are employed they get from 50 to 56½ cents per hour.

The industry employs but few foreign laborers and this has a tendency to keep wages up. The fact that the quarries operate only about 9 months per year and the average mill not over 10 months, tends to drive away the better class of laborers who desire steady employment. Several of the operators have constructed closed mills which with the heat of the exhaust steam from their engines are able to run the year round. Such plants have but little difficulty in securing the best grade of labor in the district and this is proving a very beneficial step. In most cases the exhaust steam will heat the plant in addition to heating the feed water, provided the closed type of heater is used.

A few of the operators in the Monroe county district do not hesitate to hire laborers away from their competitors. This has a tendency to cause the men to become dissatisfied with their employment and to get the habit of wandering around. It would be a good thing for the industry as a whole if all operators would conform to a fixed scale of wages and not attempt to interfere with men in the employ of another company.

Part II. History and Description

CHAPTER III

GENERAL DESCRIPTION OF THE INDIANA STONE DISTRICT

So much of a historical nature has been written about the quarry industry of Indiana that nothing elaborate on that phase of the subject will be attempted in connection with this paper. The present sketch will depict the district as it is at the present time (1914).

The industry is at present confined to Monroe and Lawrence counties, but at an earlier period much quarrying was carried on in Owen county. The causes for the withdrawal of the industry from Owen county were many, chief among them being the fact that the stone at the northern end of the stone belt is coarser and in most cases harder than it is farther south.

The quarries of Monroe county can be readily divided into the following groups: (1) Stinesville district, with 1 quarry and 3 mills; (2) Ellettsville district, with 1 quarry and 6 mills; (3) Hunter Valley district, with 4 quarries and 4 mills; (4) Bloomington district, with 1 quarry and 7 mills; (5) Clear Creek and Sanders district, with 8 quarries and 10 mills.

This makes a total of 15 quarries and 27 mills in operation in the county at this time. Several openings have been made and abandoned in each district, but these have not been taken into account in this summation, and in fact they have only a historical interest to the quarry industry.

The quarries of Lawrence county may be grouped as follows: (1) Peerless, with 3 quarries and 1 mill; (2) Horseshoe and Oolitic, with 3 quarries and 4 mills; (3) Dark Hollow, with 2 quarries and 1 mill; (4) Bedford and vicinity, with 3 quarries and 18 mills.

The following tables will give a summary of the number of men employed in the industry in the two counties, together with the output of stone and the amount and kind of machinery in use at the present time:

QUARRIES OF MONROE AND LAWRENCE COUNTIES

a. Monroe County

	Number of Men	Average Wage	Cubic Feet of Output	Stripping, Clay (feet)	Stone	Color	Grain	Bed Thickness (feet)	Chan-nelers	Der-ricks	Power
1	22	25	300,000	8	8	Buff	Coarse	37	4	3	50
2	50	22	200,000	6	10	Buff	Fine	40	2	2	50
3	35	22	150,000	8	10	Mixed	Medium	30	5	3	150
4	65	21	350,000	5	8	Mixed	Medium	40	5	3	150
5	110	22	500,000	8	10	Mixed	Fine	45	13	6	300
6	30	21	140,000	5	8	Blue	Coarse	30	2	2	50
7	25	20	150,000	5	7	Buff	Medium	45	4	3	50
8	25	21	150,000	5	15	Buff	Coarse	40	11	5	140
9	22	21	210,000	5	10	Mixed	Coarse	55	5	3	150
10	34	22	400,000	8	18	Mixed	Fine	42	7	2	375
11	56	22	625,000	8	20	Blue	Fine	35	7	4	450
12	80	21	500,000	6	5	Mixed	Coarse	50	9	4	115
13	26	20	225,000	8	10	Buff	Fine	45	3	2	50
14	24	20	350,000	8	10	Buff	Coarse	52	5	3	100
15	30	21	350,000	14	10	Mixed	Medium	30	4	3	75
Monroe county total	634*	21 ½**	4,600,000*	7**	10**			41**	86*	48*	2,255*

*Total. **Average.

b. Lawrence County

	Number of Men	Average Wage	Cubic Feet of Output	Stripping, Clay (feet)	Stone	Color	Grain	Bed Thickness (feet)	Chan-nelers	Der-ricks	Power
1	28	22	250,000	5	18	Buff	Medium	30	6	2	75
2	25	23	400,000	6	10	Mixed	Medium	44	14	5	175
3	25	23	350,000	10	10	Buff	Fine	38	4	4	100
4	40	23	600,000	10	5	Buff	Coarse	45	8	5	225
5	150	23	1,200,000	18	25	Buff	Fine	50	16	35	400
6	45	22	400,000	10	12	Buff	Fine	38	9	17	250
7	40	23	800,000	10	12	Buff	Fine	40	14	6	200
8	30	23	250,000	6	28	Mixed	Fine	50	7	5	100
9	50	22	380,000	5	4	Mixed	Fine	54	5	3	200
10	19	22	200,000	5	18	Blue	Medium	38	3	2	100
11	20	22	200,000	5	15	Mixed	Medium	40	4	3	170
Lawrence county total	472*	22 ½**	5,030,000*	8**	14**			42**	90*	87*	1,920*
Both counties total	1106*	22**	9,630,000*	7 ½**	12**			41 ½**	176*	135*	4,175*

MILLS OF MONROE COUNTY

	Men	Wage	Boiler H. P.	Cranes	Compressors	Planers	Gangs	Diamond Laws	Lathes	Heater	Pumps	Derricks	Coal in Tons per Month
1	12	25	300	1	0	1	8	1	0	1	2	1	200
2	45	25	300	3	1	5	3	2	2	1	3	1	200
3	25	25	300	0	1	3	6	1	1	1	3	2	150
4	15	25	100	0	0	2	3	1	0	0	2	2	50
5	36	25	100	2	1	3	6	1	1	0	2	2	100
6	12	25	40	0	0	1	0	1	0	1	1	1	....
7	20	25	200	1	1	3	5	1	0	0	2	2	50
8	30	25	170	0	0	2	2	1	1	1	2	2	70
9	18	25	150	0	1	5	5	2	0	1	2	3	70
10	30	25	125	2	0	1	9	1	0	1	2	2	....
11	100	25	280	4	1	8	8	1	2	0	4	4	250
12	10	25	75	0	0	0	4	2	0	1	2	2	100
13	25	25	170	0	1	0	4	0	0	0	2	3	200
14	40	25	130	1	0	4	6	0	1	1	2	3	900
15	25	25	150	1	1	4	3	2	2	1	2	2	....
16	18	25	100	1	1	2	3	1	1	0	2	2	400
17	75	30	400	3	1	7	6	1	3	1	1	0	300
18	25	27	150	3	1	4	3	3	2	1	2	1	70
19	9	22	100	1	0	1	6	2	0	1	2	1	....
20	15	25	100	0	0	0	6	0	0	0	1	2	200
21	35	25	300	0	1	5	8	0	1	1	2	4	100
22	25	25	150	2	0	2	6	1	1	1	2	1	80
23	11	23	300	0	1	1	6	0	1	1	4	4	200
24	9	25	150	0	0	0	4	0	0	1	2	1	80
25	18	25	150	0	0	0	12	0	0	1	3	2	80
26	12	25	75	0	0	0	8	0	0	1	2	1	75
27	14	25	75	0	0	1	6	2	0	1	2	1	75
28	75	25	300	4	0	6	8	1	1	1	3	1	160
29	10	23	150	1	0	1	0	1	0	2	2	0	40
30	10	22	100	0	0	2	4	1	0	1	3	2	30
Monroe county	804	25	5,090	30	13	74	158	28	20	24	63	55	4,680

MILLS OF LAWRENCE COUNTY

	Number of Men	Wages	Boilers	Engines	Heaters	Pumps	Coal per Month	Compressors	Cranes	Planers	Gangs	Diamond Saws	Lathes	Derricks
1	40	25	250	250	1	4	200	1	3	6	7	1	1	4
2	30	29	300	250	1	4	200	1	3	3	6	2	1	2
3	28	25	450	350	1	3	200	0	2	4	9	0	0	3
4	135	30	1,000	850	2	6	450	2	8	10	12	3	4	5
5	15	25	......	......	0	3	......	1	2	3	8	0	0	1
6	15	25	......	......	0	1	......	0	1	0	9	0	0	4
7	28	28	......	......	0	1	......	1	2	7	3	2	2	1
8	55	29	150	150	1	2	100	1	5	10	6	6	2	0
9	35	30	......	......	0	1	......	1	4	9	4	2	1	1
10	22	25	150	150	1	2	110	1	2	2	2	1	0	1
11	20	27	......	......	0	1	......	0	1	2	6	1	1	0
12	28	26	......	......	0	1	......	1	2	5	4	2	1	0
13	85	29	575	500	1	3	290	1	6	10	6	2	5	1
14	60	28	300	250	1	3	200	1	5	9	6	3	3	0
15	31	27	300	150	1	2	200	1	1	2	2	1	0	1
16	100	22	500	500	1	4	300	1	5	7	21	3	3	0
17	35	25	160	150	1	2	90	1	3	5	8	1	2	0
18	22	26	......	......	0	1	......	0	1	3	3	0	2	0
19	42	25	......	......	0	1	......	1	3	6	3	3	1	0
20	40	26	......	......	0	1	......	1	3	7	4	1	1	0
21	19	27	......	......	0	1	......	1	1	3	0	1	0	0
22	55	25	......	......	0	1	......	1	4	10	6	4	0	0
23	9	25	......	......	0	1	......	0	1	3	1	0	1	0
24	65	25	......	......	0	1	......	1	3	5	8	7	2	0
25	31	25	......	......	0	1	......	1	2	4	6	1	0	1
Lawrence county	1,045	26½	......	......	......	......	......	21	73	135	150	47	33	25
Monroe county	804	25	......	......	......	......	......	13	30	74	156	28	20	55
Both counties, total	1,849	26	......	......	......	......	......	34	103	209	306	75	53	80

CHAPTER IV

MONROE COUNTY

The Stinesville-Ellettsville District. The district around Stinesville can probably boast of the fact that the first stone quarried in the Oölitic limestone belt was taken out at this point. The first operator was a man by the name of Gilbert, who quarried some stone as early as 1827 on the east side of the creek about three-fourths of a mile south of Stinesville. Most of the stone taken out at an early date was used for bridge abutments and for foundations. The industry was on a very small scale until the opening, in 1854, of the railroad, which is at present known as the Monon.

There are at present (1914) in operation at Stinesville 1 quarry and 3 mills. The quarry and 2 mills are the property of the Hoadley Stone Company, of Stinesville. The quarry is located about half a mile southwest of town on the west side of the valley. The quarry is very level topped, after the overlying Mitchell limestone has been removed. The stripping consists of about 8 feet of a sandy clay and about 8 feet of disintegrated Mitchell limestone. The upper floor of the Oölitic is also mostly waste. The stone is all buff, or, at least, all of it that is at present worked. The blue stone comes in below the level of the nearby stream bottom. The stone is very free from water and the quarry can be kept in operation most of the winter. The grain of the stone is rather coarse, but it is very even and gives a fine appearance to the finished stone. One peculiarity of the stone of this quarry is the fact that it gets harder and coarser in grain the deeper the quarry is worked. About 37 feet of good stone is obtainable, of which the upper 8 feet is a very white, chalky grade of stone.

The 2 mills of the Hoadley Stone Company stand on opposite sides of the Monon railroad about 200 yards south of the Stines ville station.

The mill of the United Indiana Quarry Company is located about one-fourth of a mile south of the Hoadley quarry. It was not in operation at the time of my last visit in July, 1914, and in fact had not been since the latter part of December, 1913. There have been no quarry operations in connection with this property for a long time, but the company has purchased 30 acres of good stone land and intends to start a quarry of its own to suppy stone for the mill.

The mill and quarry of the Romona Oölitic Stone Company are located about one-fourth of a mile north of the Hoadley quarry. This mill and quarry have not been in operation since 1910. The machinery, however, is in place, and an effort has been made to keep it in as good condition as possible. The same company has a similar mill at Romona, Owen county, which was abandoned about the same time as the property at Stinesville.

The stone plants of Ellettsville and vicinity consist of 6 mills and 1 quarry, as follows: D. K. Miers Stone Company, 1 mill; Mathews Brothers Company, 1 mill; Harding and Cogswell, 1 mill; Alexander King Stone Company, 1 mill; Perry Stone Company, 1 mill and 1 quarry; Thompson and Sandy Stone Company, 1 mill.

The mill of the D. K. Miers Stone Company is located about one and one-fourth miles north of the Ellettsville station and west of the Monon railroad tracks. The mill is the property of Perry Brothers, and is leased by the company now operating it. This mill has not been in operation since December, 1913.

The property of the Mathews Brothers Stone Company is located about three-fourths of a mile north of the Monon station at Ellettsville. The small plant operated by Harding and Cogswell is located close to Mathews Brothers and is of especial interest because of the fact that the owners are experimenting with an oil engine for the production of their power. The engine is a 40 horse-power Fairbanks-Morse kerosene oil engine and is proving very economical of fuel and lubricating oil. The cost of power at this plant will be taken up more fully in the portion of this study relating to the power problems of the district.

The mill of the Alexander King Stone Company was not in operation at the time of either visit, but the plant was opened for inspection, by the watchman. This mill is known as the Eclipse mill and is located about 200 yards north of the Ellettsville station. It is of stone construction and has been built several years, the present company securing control about a year ago. The mill of the Thompson and Sandy Stone Company is located about one-fourth of a mile north of the station at Ellettsville. The plant of the Perry Stone Company is located on the east side of the valley opposite the Thompson and Sandy plant. The valley at this point widens out, and the workings of this company are against the valley side above the drainage level.

The stone of this quarry is a very fine grade of very white, chalky stone. The stripping in the quarry is quite heavy, but the workable stone is comparatively thick and easily quarried. The seams in this quarry, altho very wide and much weathered, are few and so far apart that if the floors are worked parallel with them they in no way interfere with the workings. The situation of the quarry on the hillside above the level of the neighboring stream bed gives a large quantity of buff stone. In fact, there is practically no blue stone at all. In a few places only in the very bed of the quarry there are small quantities of blue stone. The floors along the edge of the hill are in some cases broken up by horizontal cracks which cause the blocks to split in what might be termed very irregular bedding planes. This peculiarity disappears as the floors are worked back into the hill, and is probably caused by a slight upheaval or by a tendency of the underlying stone to weather out and give a downward motion to the overlying beds, such as to have caused the breaks. The position and direction of the cracks would indicate that the last-mentioned phenomenon has occurred. A similar effect of the position of the stone on a hillside has been noticed in the Hoadley quarry at Stinesville, where a line of broken stone crosses the opening. In this line the stone is so broken that no workable pieces could be obtained. This zone of stress may be due to either of the above causes.

The Perry Stone Company had the misfortune to lose their entire quarry power plant by fire early in July, 1914, and the owners are now considering the installation of complete electrical equipment in the quarry.

Hunter Valley. Hunter Valley is a low, irregular valley located about 1½ miles northwest of Bloomington, and it is about 2 miles long by 1 mile wide at its greatest width. Its longest axis extends nearly north and south, and several small ravines entering the valley from the east and west sides cut the valley into a number of ridges and depressions extending, in general, east and west. The Oölitic limestone outcrops in all the lower portions of the valley, but on the ridges there is a very thin layer of the Mitchell limestone overlying it. Where it is exposed it is deeply seamed and weathered, and in quarrying there is a large amount of waste stone to be stripped off before the level quarry floor can be opened. Thruout the valley the amount of stripping is light and the grade of stone quarried is very good. Practically all the quarrying done in the valley is along the boundary of the Mitchell and Bedford limestones. At these points the thin feather edge of the Mitchell limestone has tended to protect the softer underlying Oölitic limestone.

There is a fair thickness of stone in all the small ridges of the valley and in some of the quarries as much as 40 feet of workable stone is obtainable. Seams in the rock are few, and where there is a sufficient covering of the Mitchell stone there has been but little weathering along these seams. The fossils in the rock are practically all small and in no way affect the value of the stone. Most of the stone quarried from the deeper beds in the valley is of the variety known to the stone trade as "blue" stone. Much mixed stone is also turned out from the upper beds where the line of separation of the "buff" and "blue" stone is very irregular. There is a marked tendency of the stone to vary in both grain and color in the different quarries, and the amount of waste in the different quarries is very unequal.

There are four companies operating in the valley at the present time, as follows: Crescent Stone Company, operating 1 quarry; Consolidated Stone Company, operating 2 mills and 1 quarry; Star Stone Company, operating 1 mill and 1 quarry; Hunter Brothers Stone Company, operating 1 mill and 1 quarry.

The Crescent Stone Company's quarry is located in the southeastern corner of the valley, and the workings have been against the eastern wall of the valley where a large amount of stone has been removed. The quarry was opened in 1893 by the Perry Mathews and Perring Company. At present the work of opening floors on the west side of the ridge which crosses their property is in progress. The new floors are southwest of the old workings and adjoin the property of the Consolidated Stone Company. The Crescent is one of the best equipped quarries in the district in power plant and general equipment. There is a substantial wooden power-house and the machinery contained is up-to-date and in good working order. The stone turned out is a good grade of quarry run, most of it buff or mixed in color. There are several worked-out floors and these are used for waste disposal. The stripping consists of about 5 feet of a loose, brown, sandy clay and about 8 feet of much disintegrated Mitchell and Oölitic stone. Under this about 40 feet of good stone is taken out in 5 channel cuts. About 55 per cent of the solid cut can be used as building stone and the rest is discarded as waste. There are about 2,500 carloads of waste in a position where it could be easily recovered if there were methods for its utilization.

The plant of the Consolidated Stone Company is directly west of the Crescent quarry and the floors of these two companies join along the southern end of their workings. The Consolidated is one of the largest quarries operating in Monroe county, and the owners are the successors to the Norton Stone Company and the

A corner in the quarry of the Crescent Stone Company at Hunter Valley, showing the method of waste disposal in use there.

old Morton C. Hunter Stone Company, the latter having been the first company to operate in the valley. The quarry working is carried on in 3 quarry floors. The south floor, which is the site of the old Norton quarry, is covered by about 8 feet of a brown, sandy clay which can be removed by hydraulic stripping. Below this layer about 10 feet of stone is lost on account of weathering of the seams. The stone of this quarry is quite fine and of uniform grain. The slope of the land at this point is gentle and the floors can be made large without excessive stripping.

The second working is located west of the west mill, and the stone obtained is a good grade of blue stone with buff and mixed stone thruout the upper 15 feet of the bed. The line of parting of the blue and the buff stone is very irregular and a large amount of mixed stone results. The stripping at this point is heavier

Looking east across the quarries of Hunter Brothers and the Star Stone Company in Hunter Valley. The waste piles show a large amount of both mill and quarry waste.

than in the other opening, and the thickness of the bed of good stone is consequently greater. The Mitchell limestone covers this part of the valley and has protected the upper layers of the Oölitic so that a comparatively level floor can be obtained. Two electrically equipped derricks are used in this working, one of steel and one of wooden construction. Purchased power is used with both derricks. The quarry opening at this point is very large, since this part of the working has been in continuous operation for a long time. Much waste stone is in sight, and its disposal is becoming a serious problem for the operators of the quarry.

The quarry north of the mills on the site of the old Morton C. Hunter quarry is being opened again, new floors are being stripped, and two new derricks are being installed at this point. In this quarry the upper layer of the stone has weathered very irregularly, owing to the fact that there is no covering of Mitchell limestone. The appearance of the surface of the rock is in marked contrast to the upper layers in the quarries already mentioned.

Hunter Brothers' mill and quarry, opened in 1893, are located about one-half mile north and east of the Consolidated Stone Company's plant. The openings are made in the north side of a ridge that nearly crosses the valley at this point. The quarry is known as the "Blue Stone" quarry and turns out a very good grade of blue stone. The stone is of very uniform grain, but is rather coarse. The surface of the Oölitic stone under the thin overburden of Mitchell limestone is comparatively smooth, and little waste stone has to be stripped off. The stripping consists of about 5 feet of sandy clay and about 3 feet of much weathered Mitchell limestone. The upper 5 feet of the Oölitic stone is waste and the average thickness of the working bed is about 30 feet. This is taken out by 4 channel cuts. The upper 2 channel cuts are buff and mixed stone, but the lower beds of the quarry are of a very uniform blue color. There are a few vertical seams, but the beds are well suited for quarrying large blocks.

The Star Stone Company's mill and quarry, opened in 1895, are located about 100 yards east and south of the Hunter Brothers' quarry. The workings are against the east side of the valley in its northeast corner. Three floors have been worked and a fourth is being stripped at the time this report is written (1914). Thirty feet of workable stone is obtained in four channel cuts. The stone turned out is a fair grade of mixed stone. The quarry face contains more blue than buff stone, but the line of parting between the two is very irregular. The upper beds uncovered by the hydraulic stripping are very uneven, and much waste stone has to be removed before the workable stone is reached. The stripping consists of about 8 feet of sandy clay, and the upper layers of the Oölite, which latter are much weathered.

There are two or three deserted quarry openings in the valley, the largest being the quarry known as the Johnson quarry. This quarry was opened in 1892 by the Chicago and Bloomington Stone Company. It is located about one-fourth of a mile northeast of the old Hunter quarry. The stone at this point is very similar to that in the Consolidated Stone Company's quarry nearby. The other openings that have been deserted are all small, the most important being the opening of the Hunter Valley Stone Company quarry, made in 1895, next to the Crescent.

Bloomington District. There are at present (1914) in operation in the city of Bloomington and the surrounding country

A large pile of mill waste at the plant of the Star Stone Company in Hunter Valley. This material could be used in a fine crusher without preliminary breaking. The pile in the background is quarry waste.

7 mills and 1 quarry. They are as follows: Central Oölitic Stone Company, with 1 mill; South Side Stone Company, with 1 mill; Nolan and Sons, with 1 mill; Hoadley Stone Company, with 2 mills; Oölitic Stone Company, with 1 mill; Bloomington and Bedford Stone Company, with 1 mill and 1 quarry.

The Central Oölitic Stone Company was organized in 1890 and the next year opened a quarry and mill on their property in the northern part of the city. The quarry did not prove a paying venture and was abandoned the following year. The mill has continued in operation since that time and is one of the oldest in this part of the stone district. A new mill building has been put up north of the old mill, and the traveling crane and the diamond saws are installed in this building, which is used at present for a loading shed.

The South Side Stone Company's plant is located two blocks west of the Monon railroad on West Second street. The plant is new and its equipment is up-to-date and in good order. The entire plant is electrically driven, and the owners feel that this form of power is very economical and satisfactory.

The mill of Nolan and Sons is located in the southern end of the city along the Monon railroad. For a small plant this mill is very well managed and equipped. The plant has been in operation for three years.

The Hoadley Stone Company has 2 very large and up-to-date mills in the city. They are both located in the southern end of the city along the Monon railway tracks.

The Oölitic Stone Company's plant is located on the rise of ground southwest of town. The mill is new and has its entire equipment driven by electrical power. The mill turns out a large amount of work in what must be called a very economical fashion.

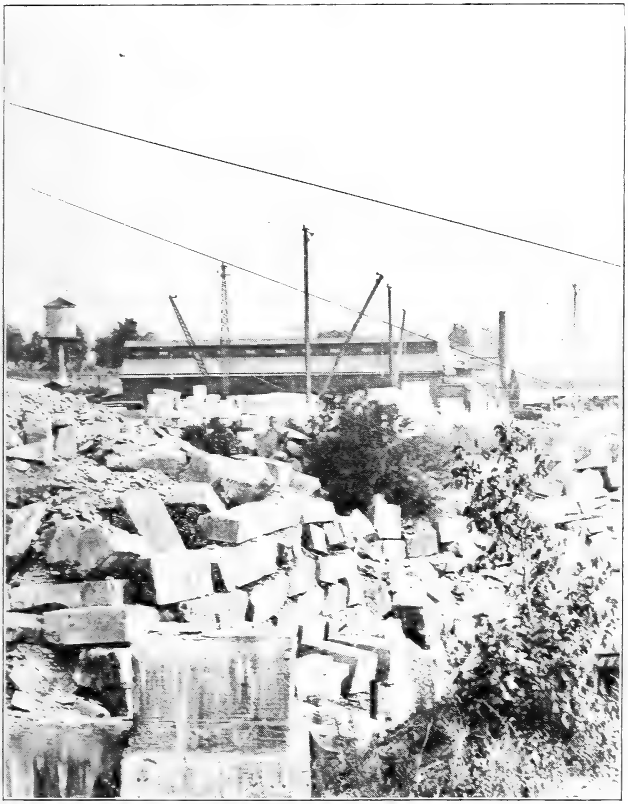
The quarry and mill of the Bloomington and Bedford Stone Company are located southwest of the city on the west side of the Monon railroad. The quarry is the only one in or around Bloomington that is at present (1914) in operation. The grade of stone quarried is good and the amount in sight is sufficient for a long run. The Oölite at this point is overlaid by several feet of Mitchell, and altho the stripping is rather heavy, the grade of the underlying stone is correspondingly good. Most of the stone quarried is buff and fairly coarse grained. The water supply at the quarry is inadequate and an effort is being made to hold the water with a small dam about 500 feet from the quarry. The water from this dam is pumped up into the old quarry working and from here the stripping pump can use it.

A quarry was opened by the Chicago and Bloomington Stone Company early last year on the high ground southeast of the city, and a large floor was stripped for quarrying. Work was carried on at this point during the greater part of the summer, and a large amount of the upper stone was removed. The grade of the stone was not very good, and the heavy cost of the stripping caused the company to abandon the quarry, at least for the present. At this point the Oölitic stone comes to the surface without a covering of the Mitchell, and, as commonly happens in such cases, the seams are weathered to such a depth that the amount of waste stone is very great.

Many other small openings in the city or close by have been made in the past, but none of them have proved a paying venture. The small openings have furnished much stone in the aggregate, but no one opening has put out any large quantity of building material.

Clear Creek and Sanders District. Under this head are included the quarries and mills around Sanders as well as all the scattering mills and quarries in Monroe county south of Bloomington. This group includes 8 quarries and 10 mills, as follows: Chicago and Bloomington Stone Company, with 1 quarry and 1 mill; Mathers Stone Company, with 1 quarry and 1 mill; Empire Stone Company, with 1 quarry and 1 mill; Reed Stone Company, with 1 quarry and 1 mill; National Stone Company, 1 quarry and 2 mills; Indiana Coöperative Quarries Company, with 1 quarry; Woolery and Son, with 1 mill; Monarch Stone Company, with 1 mill; McMillan and Sons Stone Company, with 1 mill; John Torphy's quarry, No. 18.

The first quarry in the Sanders district was opened by the company known as the Oölitic Stone Company, in 1888, and was located a little more than a half-mile west of Sanders (commonly known as Sanders or Saunders Station). The quarry is a part of the present openings of the Reed Stone Company. It was in this quarry that the stone for the Auditorium in Chicago was quarried. The next company to open a quarry in this part of the district was the Monroe County Oölitic Stone Company, organized in 1889, which opened the Adams quarry and erected a mill just west of the Reed quarry. These openings were followed in 1891 by the Bedford Quarry Company east of the Reed quarry, the opening now being part of the Reed quarry. In 1892 the Empire Stone Company followed with a quarry north of the Reed quarry. The opening of this large productive area was a great boon to the industry and marked a new era in the business. Probably no district covers a wider productive area than the one along Clear Creek and about Sanders, since the stream valley at this point cuts southwestward into the outcrop and the stone is available along the entire valley as well as along the front of the outcrop. The number of favorable locations still unworked here is probably greater than in any other part of the stone belt. The surface of the land is more level here than farther north and the openings can be made more extensive

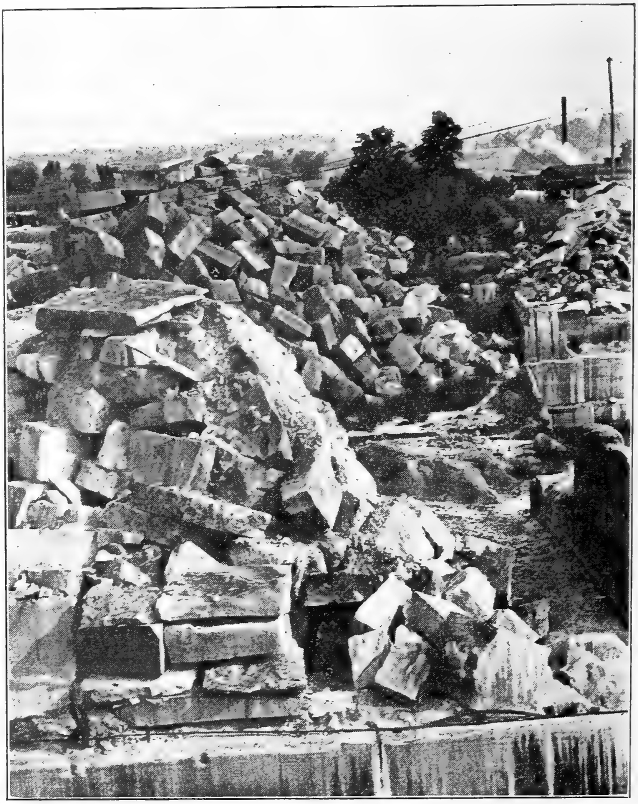


Looking north across the quarry of the Chicago and Bloomington Stone Company at Clear Creek. The old quarry floors have here been utilized for the disposal of the quarry waste. This waste is in a position where it could be easily recovered for the manufacture of fertilizing material.

without encountering so much stripping as to make the operation of the quarry unprofitable. The new railroad line down the valley has opened up a large area of stone and a greater development is looked for in the western part of this area.

The quarry and mill of the Chicago and Bloomington Stone

Company are located about three-fourths of a mile northwest of Sanders and about $1\frac{1}{2}$ miles southwest of Clear Creek. The quarry has been in operation for some time, and the opening has been extended over a large tract. The company stopped work in the quarry here on opening a new quarry just southeast of the city of Bloomington, but later in the summer of 1913 when the



Looking across the "grout" piles in the quarry of the Mathers Stone Company. The mill at the right is the mill of the same company, and the one at the left is the mill of the Chicago and Bloomington Stone Company at Clear Creek, Ind.

latter opening proved an unsuccessful venture, the company began stripping to the west of the old quarry opening and is at present (July, 1914) working a large floor there. The stripping on this new floor is rather heavy, consisting of about 20 feet of earth and the upper 10 feet of the Oölitic stone, which is waste. The channelers are at present at work on the second floor, and the thickness of the stone is not shown, but about 35 feet is expected. The seams running east and west are badly opened since there was no covering of stone to protect the Oölitic stone from weathering. The north and south seams are not so well developed, but one deep seam in this direction causes much waste and extends to a great depth, in fact below the present opened floor. The stone is rather coarse in grain, but it is comparatively uniform and very few large-sized fossils are present. The indications are that most of the stone will be buff.

The water supply of the mill and quarry is very small. The water is pumped thru about a mile and three-fourths of $2\frac{1}{2}$-inch pipe from Clear Creek, and the pump has to be run night and day to supply the workings in both this quarry and the Mathers quarry which adjoins it. The company is equipped for hydraulic stripping, but the water supply is inadequate for the pupose. A floor has been stripped in the southern part of the opening and a derrick erected, but no work was going on on this floor in 1914.

The mill of this company is located just north of the quarry opening on a switch of the Monon railroad.

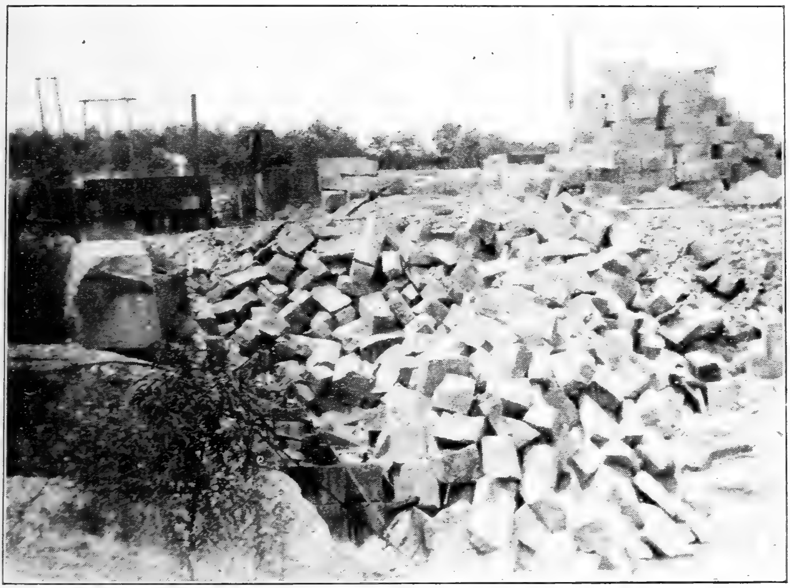
The quarry and mill of the Mathers Stone Company are located just east of the quarry of the Chicago and Bloomington Stone Company, and the two openings join each other. The opening at this point was made in 1895, but has not been continuously in operation since that time. The company is at present working on 2 floors, one at the extreme end of the old opening, and the other along the east side of the old floors. The land at this point slopes gently to the north and the drainage is in that direction; but in spite of this fact the north and south seams are but slightly opened, while those extending east and west are very greatly weathered. The south opening is nearly worked out. The stone is taken off in 4 floors, giving about 40 feet of good stone. The lower course is blue and the second floor is mixed while the top floors are all buff stone. The stone is of good quality, but contains quite a large number of fossils, which make the grain appear rather uneven. The color of the buff stone is very light, but it is of coarse grain. The stripping at this point consists of about 5 feet of residual clay and about 15 feet of waste stone, the top layer of which is Mitchell. Another opening northeast of this floor along the east side of the depression in which the quarry is located has been made and the channelers are at work on the second floor, but the stone is in large part waste on account of the fact that there is no protective layer of bastard stone over the Oölite, and consequently the latter has weathered to a great depth. The seams are numerous and reach to a depth of 2 to 3 channel cuts. The residual soil fills these wide seams and causes much labor in its removal. All the stone exposed is buff and of slightly finer grain than that taken from the other opening. The stripping consists of 8 feet of earth and the upper 10 feet of the Oölitic stone. The first bed below this waste is so penetrated by seams that a large amount of it is waste. This floor was not being worked at the time of the last visit in August, 1914.

The mill of this company is located just north of their quarry and is one of the older mills of this district.

The Empire quarry and mill are located a little more than half a mile northwest of Sanders. This company began operations in 1892, but has not been running all the time since, having had several shut-downs. The mill was built in 1904 and since that time has turned out a large amount of work. The stone at this quarry is very well protected by the overlying stone and a very thick bed is worked, in some places amounting to as much as 55 feet of good stone. The stripping consists of about 5 feet of a sandy clay and 10 feet of Mitchell limestone; the overlying stone is very closely knit and but little water has penetrated to the underlying stone so that the seams are but little weathered. The stone is taken out in 6 channel cuts of which the upper 4 cuts are buff, the next one mixed, and the lowest blue stone. The stone is rather coarse grained, with the grains very uniform in size. The company is at present working in the southeastern corner of their property along the boundary of the property of the Reed Stone Company.

The mill of this company is located at the north side of their quarry opening.

The Reed Stone Company's quarry and mill are located just south of the Empire quarry. The quarry was the first opened in this part of the district. It was first opened under the name of the Oölitic Stone Company in 1888 and was purchased by David Reed in 1890. The mill began operations in 1895 and a new quarry opening was then made farther north. Another opening was made just east of this quarry under the name of the Bedford Quarry Company in 1891 and was consolidated with it in 1900. The present operations (August, 1914) are being carried on south of the old opening of this company. The present stripping consists of about 8 feet of dirt and about 20 feet of very hard Mitchell limestone. The surface of the Oölite under the Mitchell is very even and a channeler can begin work without much smoothing. About 35 feet of very good stone is taken out. Most of the stone is blue, in fact only the top can be called buff stone. The channelers in the quarry are driven by compressed air from the power-house at the mill. Another floor farther west has been opened, but the work on this floor has been stopped because the grade of the stone at this point is not so good as it is on the main floor. The main floor is remarkably free from seams and consequently the amount of waste stone is not large. This company



An old quarry floor filled with waste.

also has a mill at Bedford, a mill at Reed's station, and a quarry at Peerless. Much stone has been discarded at this quarry and most of it is in available position. At present it is being discharged into the worked out floors of the old quarry. The waste stone will represent less than 32 per cent of the solid cut on account of the absence of weathered-out seams.

The Adams Brothers Company's mill and quarry are located just west of the Reed mill and quarry along the west side of the depression. The quarry was opened in 1889 under the name of the Monroe County Oölitic Company, and has been in active operation ever since. The stone from this quarry is of a very fine grain and uniform texture. About 8 feet of earth is being removed by hydraulic stripping, and under this there is about 18 feet of Mitchell limestone which acts as a protective covering for the underlying stone. The stone is being taken out in 4 floors of about 10 feet each. The quarry has very few seams, and those that are present extend east and west. The stone is

The waste piles of the National Stone Company's quarry at Clear Creek, Ind. In this case the waste has been stored well back out of the way of future operations.

about half and half buff and blue, with a comparatively straight line between the two. The mill is one of the old type, having stood since 1889, the time of the opening of the quarry.

The National Stone Company quarry and mills are located about a quarter of a mile west of the Adams quarry. There is quite a rise of ground between the two quarries, and the National is on a switch which comes up the valley of a small branch of Clear creek from the new belt line. This quarry was opened in 1901, and has been in continuous operation ever since. The quarry is one of the largest and most up-to-date in the district. The stone from this quarry is a medium coarse stone of very uniform grain and is very free from seams in the bed. At present, work is in progress on two beds along the southern edge of the quarry opening. There are 5 floors or about 50 feet of good stone. Three floors are buff, one mixed, and the lower floor is blue stone. The stripping consists of about 6 feet of sandy loam and about 5 feet of the overlying limestone. The surface of the Oölite is comparatively smooth, and but little waste in the quarry results from mud seams, especially on the east floor. Of the two, the west floor is much more seamed, owing to the fact that the overlying limestone is not present and the upper surface of the Oölite has been much affected by weathering.

In the west opening the stone is not as thick as in the east opening, for the upper floor is almost all waste and much of the second floor is lost owing to mud seams. The seams all run east and west. The company is about to install a new electrical equipment for the entire plant.

The quarry of the Indiana Coöperative Quarry Company known as the Red Hog quarry is located southwest of the National quarry on the opposite side of the depression and across the Bloomington-Bedford pike. The quarry was not in operation in August, 1914. The stone at this point is under a rather heavy overburden and is cut by a considerable number of seams. The stone taken out is fine grained and of uniform texture, and is overlaid by about 8 feet of dirt and about 10 feet of waste stone.

The Clear Creek mill of the McMillan Stone Company built in June, 1904, is located about 2 miles southwest of the Clear Creek station and about one-half mile northeast of Victor. This company has interests at Peerless and also in Bedford. The mill is one of the most up-to-date in this section. There are several abandoned quarries near this mill, but the grade of the stone is not high and the amount of waste stone encountered in the quarries made it more profitable to secure the stone elsewhere. The old Crown quarry is just south of the mill, and the Eagle and the Clear Creek quarries are east of the mill.

The quarry known as Quarry No. 18, located one-half mile southeast of the Victor postoffice, was first opened by the Johnson and Mathews Stone Company of Bloomington in 1897. It was so named on account of the fact that it was located on the site of the eighteenth drill core taken out in this vicinity. The stone lies at the very top of the hill overlooking the creek and so but little overlying stone has to be removed. The stone is very coarse grained and all of a buff color. The mill is at present owned and operated by John Torphy of Bloomington. At the time of my last visit the quarry had been leased, and is operated by another company. The stripping consists of about 8 feet of earth and about 10 feet of Mitchell limestone. The salable stone is taken off in 5 channel cuts and there are about 50 feet of good stone, but the number of seams present causes a large amount of the stone to be rejected as waste. The fact that the stone is so far above the drainage level accounts for the seams being weathered to so great an extent.

Woolery and Son have opened a small mill on their farm 1 mile southwest of Clear Creek.

The plant of the Monarch Stone Company of Clear Creek is located about 1½ miles south of the Clear Creek station, on the switch leading to the National quarry. The company owns stone land and a mill, but at the time of my visit they were doing no quarrying. The mill is an open mill of the old type and was built in 1902.

CHAPTER V

Lawrence County

General Description. The stone industry operations in Lawrence county differ quite notably from those in Monroe county. The size of the quarry openings and the size of the mills is generally greater, and the work is carried on on a much larger scale. There has been a tendency toward consolidation of ownership in this district, not seen in the northern part of the stone belt.

The operators of this district have been more ready to adopt new methods and more up-to-date machinery, and, as a result, the district as a whole appears to be more advanced than the Monroe county district. Altho the first openings were made in the northern end of the district, the southern end was opened very soon afterward, and in a short time it had surpassed the northern end and has ever since kept its leadership. The Bedford district saw the first electrical power; and the first diamond saws and first electric channelers were put in use in the Bedford quarries. The labor question has grown to greater proportions in Lawrence county, and several attempts at organization have been made. There is at the present time a well-organized labor union.

The stone operations of Lawrence county are all located close to the city of Bedford. Several mills are located in the city, but the quarries are from 2 to 5 miles outside the corporation limits. The majority of the mills and quarries are reached by the Monon railway, either by its main line or by the Switz City branch. Several others are on the Southern Indiana and the Baltimore and Ohio Southwestern Railroad.

The stone in the different districts varies extensively in color, texture, thickness, hardness, and coarseness. The kind and amount of stripping varies thruout the district, but there is a tendency for the stone to appear higher on the hillsides, the farther east the quarry is located.

The first developments of the lime and crushed stone industries were located in the Horseshoe and Oölitic district. The Ohio and Western Lime Company has 6 kilns at the old P. M. and B. quarry, now the property of the Indiana Quarries Company; and the Indiana Products Company has a crushed-stone plant in the town of Oolitic.

Peerless District. Peerless* is about 4 miles north of Bedford on the main line of the Monon railroad. The quarries lie on the hill about half a mile east of the station. The first quarry opened in this district began operations in 1890 on the bluff southeast of Salt Creek, and is still operated by the Reed Stone Company. The quarry opening is located at the top of a north and south ridge, and the stone is not protected by any overlying formation. As a result, the upper bed of the Oölite is very much weathered. Some of the seams are weathered to a great depth. These weathered seams run both north and south and east and west. Both sets of seams are open because the quarry lies in such a position against the hill that the land has had a drainage both to the north and to the west. Some of the larger of these seams penetrate to the bottom of the workable bed. Much waste stone results from these greatly weathered seams, and the cost of quarrying this waste stone is practically as great as the cost of stripping a comparatively thick bed of Mitchell where the latter is present. The rock at this point is overlaid by about 4 or 5 feet of a residual clayey loam. The loam fills the fissures in the rock and necessitates much labor in its removal from the quarry workings. The fact that both sets of seams are weathered makes channeling difficult and the benefit of this stripping is more than counterbalanced.

The stone is fairly uniform in texture and grain, and practically no blue stone was seen in the opening. There is a slight tendency toward cross-graining in the stone, but not enough to interfere with the work or in any way to hurt the value of the stone. Three floors were being worked (July, 1914), but a large amount of the top floor was rejected. The thickness of the opened bed did not exceed 28 feet. The surface of the rock was very uneven, and much leveling was necessary before the channelers could be placed in operation. Much waste stone is stacked about the quarry and its disposal is becoming a difficult matter.

About 100 yards directly east of the Reed quarry is the opening of the W. McMillan and Sons' quarry. The opening is a large one and much good stone is being taken out. The workable bed in this quarry is thicker than in the quarry farther west. The bed of good stone is about 44 feet thick and is taken out in 5 floors. The lower $3\frac{1}{2}$ floors contain much blue stone, and the irregularity of the dividing line is responsible for quite a quantity

*Often called Peerless Station.

of mixed stone. The stripping consists of about 6 feet of red clayey loam, which has resulted from the disintegration of the limestone, and the upper channel cut which is also rejected as waste. The work is being carried on on 4 separate floors and a new one is being stripped.

The Peerless mill of the same company is located just east of the quarry opening and is operated in connection with the quarry. This mill is very well equipped, and was running full time when visited.

The third quarry of the Peerless district is the property of the Ingalls Stone Company of Bedford and is located on the site of the old Thornton quarry, about a quarter of a mile southwest of the quarries of the Reed Stone Company and the McMillan Stone Company. This is about a quarter of a mile southeast of Peerless. The stripping in this quarry is heavier than in the other quarries, but no Mitchell limestone appears on top. The thicker layer of stripping gives few seams, but still many north and south seams as well as east and west ones are present. There is a layer of impure Oölitic limestone along the west side of the quarry that acts as a protection to the underlying stone. The bed of workable stone at this point is about 38 feet thick and is taken off in four channel cuts. The stone is all a fine-grained buff stone, but in some places there is a marked cross-bedding. This quarry was first opened in 1895 by the Bedford Steam Stone Works. The quarry is equipped thruout with electrical machinery, and power is purchased from the Southern Indiana Power Company. The company is called the Indiana Limestone Company. The present opening is north and east of the old opening and the stone is thicker and less seamed than in the old quarry. The stripping consists of 10 feet of earth and the upper 10 feet of waste stone. The ground slopes to the north and west so that both sets of seams are developed.

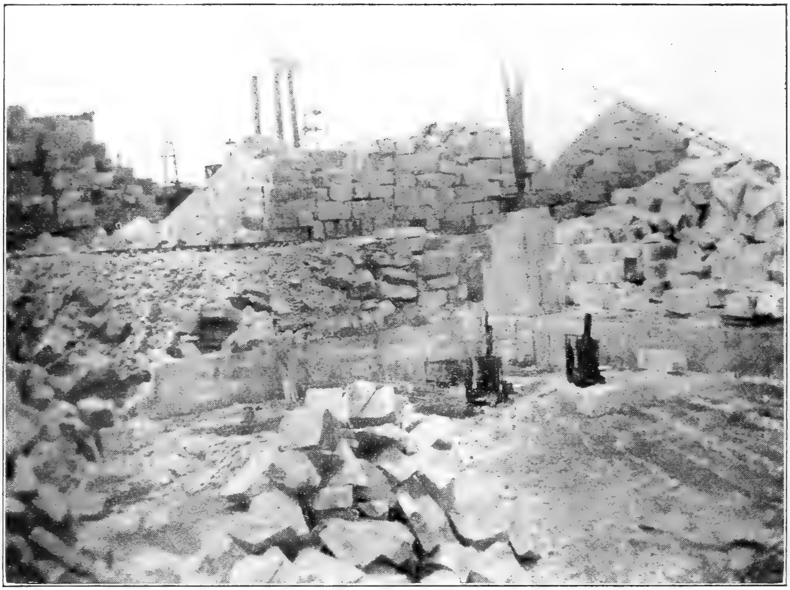
Horseshoe and Oolitic. About a mile due west of the quarries at Peerless and across the Valley of Salt Creek, a high ridge stands out above the valley. This ridge is known as Buff Ridge and the quarries located along it are sometimes known as the Buff Ridge quarries. These quarries are among the largest and oldest in the entire district. The most northerly opening is the quarry of the Furst-Kerber Company with their mill No. 2 located at the same place. The quarry has been in operation only a few years, but in spite of this fact a large amount of stone has been taken out. The thickness of the workable stone is about 45 feet and it is taken out in 5 channel cuts. The stripping consists of about 10 feet of earth and about 5 feet of the overlying Mitchell limestone. In addition to this, quite a large amount of the first floor is spoiled by mud seams which are very pronounced in an east and west direction, which represents the general drainage slope. A large quantity of clayey earth has to be removed from the quarry working on account of the large mud seams which penetrate the beds to a considerable depth. The stone is quite coarse in grain, but very uniform in texture and color. Practically the entire output of the quarry is a good grade of buff stone. As the quarry working is opened farther west, the blue stone begins to appear, and if the work is carried still farther west a large quantity of mixed and blue stone may be looked for. The stripping is constantly growing heavier, and as the opening goes farther back into the hill, the disposal of this waste stone will be a serious problem. The quarry has a complete outfit of electrical equipment and the work is carried on in a very up-to-date manner. The old power plant burned down late in March, 1914, and the new plant had been in operation but a short time when the last visit was made. This plant represents the best practice in the district, and the use of all forms of recording instruments aids the engineer in getting the best possible results from his machinery and in detecting any unnecessary loss.

The Furst-Kerber Mill No. 2 is located by the quarry of the same company and is one of the best-equipped mills in the district.

The next of the ridge quarries is the old P. M. and B. (Perry Mathews and Buskirk) quarry, at present the property of the Indiana Quarries Company. This is one of the oldest as well as one of the most famous quarries in this part of the State, and indeed in the United States. It was opened in 1889 and has been in operation ever since. It is located 1 mile north of the village of Oolitic and about 3½ miles northwest of the city of Bedford. The hill quarries are connected by a switch with the Monon railroad at Horseshoe. This quarry opening is the largest in the Oölitic stone belt of Southern Indiana. The quarry at one time consisted of a number of separate openings, but the floors have been extended till they have joined and the new floors have been extended north of the old openings. The Hoosier quarry, opened in 1885, is a part of the worked-out quarry, as is also the old Buff Ridge quarry, opened in 1891. At present the work is being carried on on 5 separate floors at different parts of the quarry. The workable stone is in most parts of the quarry about 50 feet thick, but this thickness varies with the location and amount of stripping that is taken off. The number of seams present is small and the new floors which are being opened under a thicker cover of the Mitchell limestone are quite free from any open mud seams. The bulk of the stone quarried is buff, but the

Waste piles in the P. M. and B. quarry of the Indiana Quarries Company at Buff Ridge. The amount of waste stone taken out in this quarry is probably greater than in any other quarry in the belt. Some of the waste is at present utilized in the manufacture of lime.

amount of blue increases as the openings are carried to the west and north. The grain of the stone is uniformly fine, altho there are places where a more crystalline and coarser stone appears. The stripping varies in different parts of the quarry but on the north side of the old workings where a very extensive new floor is being opened the covering consists of about 8 feet of clayey loam and 25 feet of Mitchell limestone. The top of the Oölite under this thick cover is very even and the channelers can operate on it without difficulty. The overburden of rock at this quarry is being removed by means of churn drills, explosives, and a steam shovel, the only place in the stone district where such a method is followed. In many places where the two formations are closely knit the explosives would tend to injure the underlying stone; but in this quarry the effect on the underlying Oölitic stone of the use of explosives in removing the Mitchell does not appear to be serious. The waste removed is dumped into the



Looking northeast in the P. M. and B. quarry of the Indiana Quarries Company. This view shows how the storage of the waste stone often interferes with the quarry operations when the quarry is to be enlarged.

old workings by means of a dinkey engine and dump cars. This method solves the problem of waste disposal, but the waste could not easily be recovered for use if it were ever to become of value. Probably there is no quarry in the district where more waste is to be seen piled about the openings, but some of this vast amount of rock is at present being utilized for the manufacture of lime by the Ohio and Western Lime Company, which has 4 kilns in operation in the old workings of the quarry. The waste is turned over to the lime company at 15 cents per ton, the quarry company furnishing derrick and switch connections for the lime company. Two churn drills and a 90-ton Bucyrus steam shovel with the necessary dump cars are kept constantly at the work of stripping new floors. The openings probably cover 50 acres and the large number of switches laid gives the quarry the appearance of a small railroad yard.

The Hoosier Quarry. About a half-mile west and south of the P. M. and B. quarry and over a low ridge of hills lies the Hoosier quarry, also the property of the Indiana Quarries Company. This quarry is probably the oldest in the district to remain in active operation to the present time. It was opened in 1879 and has been the property of several different companies since that time. This quarry also consisted of a number of openings that have since run together. The stripping here is lighter than in the other quarry, but the thickness of the valuable stone is less, the floors at present operated not giving over 35 to 38 feet of good stone. The stripping consists of about 8 feet of earth and a thin edge of the Mitchell limestone. The seams in the quarry are developed in both directions but only the east and west ones are widely opened by weathering. The upper surface of the Oölite in this quarry is very irregular and much of the upper layer is rejected as waste. The stone quarried is a fine-grained buff stone. The blue stone comes in at the bottom of the quarry, but the opening is so far above the valley drainage that the amount of blue stone is very small.

The company has 2 large mills in connection with this quarry, one located near the center of the working and the other, a new mill, at the southwest end of the workings near the town of Oolitic. The old mill of the company, located near the central part of the present quarry opening, is built of stone. It has not been in operation for the past two years. This mill is one of the few mills where wire saws are still in use in the district. The only other company using them is the McMillan Company in their mill at Peerless. These saws consist of a cord of twisted wire drawn tightly over pulleys. The quarry blocks to be cut are placed in a row in line with the stretched wire and the pulleys force the wire down on the stone while a line shaft drives the pulleys. The cuts made in this way are not as regular as those made by other types of saws because the wire tends to be forced out of a straight line as it encounters rock of varying hardness. The consumption of power by these saws is small, but their rate of cutting is slow.

The Reed Stone Company has had a mill in operation at

Reed's Station for a number of years but at the present time (1914) the mill is shut down, and a large amount of the machinery is being removed to their plant at Bedford. The company will probably not reopen this mill, since the work can be carried on more economically in a larger plant, and they will probably center their interests at the Bedford plant.

There are a number of abandoned quarry sites in and around Reed's Station, but no active quarries at this time, and the outlook for opening any at this point is not bright. This district was first opened by David Reed in 1882, the first quarry operating under the name of the Bedford Quarry Company. Another opening was made in 1885 by Crim Duncan and Company, and was known as the Robin Roost quarry. All these properties were located on the west side of Goose creek and well above the water level. The stone quarried was a good grade of buff stone, but as the quarry face was worked back into the hill the cost of stripping became so great that it became necessary to abandon the undertaking.

The mill of the Indiana Bedford Stone Company is located just west of the village of Oolitic, across Goose creek. It is one of the older mills of the district and has been in operation since the Robin Roost quarry near it was opened in 1885. The present company has operated the mill since 1894. The old quarry has long been abandoned, but the mill is still in operation and has just been equipped with electric motors.

Dark Hollow. Dark Hollow is a depression running northwest from Salt Creek valley where it makes a sharp turn west between the village of Oolitic and the city of Bedford. It is located about 2½ miles west and about the same distance north of Bedford, making the quarry belt about 6 miles from the city. The location is ideal for quarries, inasmuch as the Harrodsburg stone outcrops in the very lowest portions of the valley, while the Mitchell covers the hilltops around the depression. The Oölitic limestone outcrops along the sides of the hills and it is along these outcrops that the quarries are located. The stone opened up in this valley is remarkable for its fine grain and extremely light color. The finished stone is so light that at a distance it looks white. The valley is occupied by two companies, the Consolidated Stone Company, holding most of the openings, and the George Doyle Stone Company, holding two openings along the southwest wall of the hills; and this has tended to spread the workings along the hillsides until the valley is practically surrounded with workings.

The Consolidated Stone Company's quarries are all located along the northeast side of the "hollow" and are very extensive. Work had been done on three ledges, at the time of my visit, and several more ledges were either in the process of opening or were partly worked out. The amount of waste stone around the openings tends to hamper the work, and at one point a very

A view in the quarries at Dark Hollow, Ind. These quarries have been in operation a long time and a large quantity of waste stone has accumulated.

large heap of waste that had been piled on the hillside was being rehandled to make room for the opening of a new floor. It would be good business policy for the company to install a cableway and stack the waste in the lower part of the valley. The valuable stone is about 40 feet thick at this point, and the stripping consists of about 10 feet of earth and about 8 to 12 feet of Mitchell limestone. The stone is removed in 5 channel cuts on most of the floors, altho on one floor but 4 cuts were made and about 35 feet of good stone was removed. The upper surface of the Oölite is smooth and the amount of the stone that must be rejected as waste is small. The stone is uniformly fine grained and the larger part of it is a very light buff. A small amount of blue stone appears in the lower beds, especially if the floor is near drainage level in the valley. The line of meeting of the buff and blue stone is more regular than usual and the amount of mixed stone is consequently small. The quarries are all electrically equipped. The north floor is taken off in 5 channel cuts, making about 40 feet of good stone. The stripping consists of about 13 feet of earth and from 4 to 6 feet of limestone. The upper floor is mostly waste. The 2 lower floors show traces of blue stone. The next opening southeast of this is 6 channel cuts deep and the grade of the stone is better. The 2 lower floors are to a large extent blue, and the line joining the buff and blue stone slopes up to the east at an angle of about 25 degrees. This slope is in the same direction as the slope of the hill. The stripping here is thicker, reaching as much as 14 to 16 feet of Mitchell limestone. Hydraulic stripping is carried on on these floors. The upper bed of the rock is much seamed, but the seams do not penetrate deeply. The east and west seams are the most prominent, but this can usually be accounted for by the direction of the drainage slope. Stripping thruout the quarry is done by means of a large pump located on Salt creek one quarter of a mile east of the quarries. The pump is one of the largest in use in the district, and the water leaves the pump under a pressure of 160 pounds per square inch.

The Consolidated mill is located along the west side of the valley near the quarry. It is a mill of the old type with open yard.

The other company operating in the valley is the George Doyle Company, of New York. Their quarry, which is worked well back into the hill on the southwest side of the valley, has about the heaviest stripping seen anywhere in the stone belt. The overburden consists of 6 feet of clay, 6 feet of coarse blue limestone, 8 inches of shale, and 22 feet of Mitchell limestone. The quarry shut down in May, 1914, and all the work in progress in July, 1914, was a small amount of hand scabbling. There is about 50 feet of good stone in the quarry, half blue and half buff, but the heavy overburden makes its development expensive; the stone is taken out in 6 (sometimes 7) channel cuts. It is very free from seams or waste rock.

The superintendent says that the older workings have at least 35 feet of hard stone stripping, which is more than is worked at any other point in the district. The newer openings farther north have less stripping, but the thickness of the stone is considerably less.

Bedford District. The city of Bedford has long been the center of the Indiana limestone industry. It is located near the center of the older part of the stone belt and at the present time is the home of more stone mills and handles more cut stone than all the rest of the stone belt.

Three quarries and 18 mills are in active operation in and around the city. They are as follows: Ingalls Stone Company, McLaren Mill; Ingalls Stone Company, Main Mill; Reed Stone Company, Mill "A"; J. P. Falt Stone Company; Ingalls Stone Company, Climax Mill; John Rowe Cut Stone Company; Furst-Kerber Stone Company; Shea and Donnelly; Bedford Cut Stone Company; Bedford Steam Stone Works; Indiana Quarries Company, Salem Mill; Henry Strauble Stone Company; Morton Brooks Stone Company; Consolidated Stone Company; W. McMillan and Sons Stone Company, Hoosier Mill; Bedford Stone and Construction Company; Stone City Cut Stone Company; E. F. Giberson and Company; Bedford Stone and Construction Company, Quarry; Imperial Stone Company, "Blue Hole Quarry"; Norton Stone Company, Quarry.

All the mills mentioned above are located in the city of Bedford and are grouped along the railroads. There are 3 quarries.

The Bedford Stone and Construction Company's quarry is located about 2 miles east of the city. The same company operates a mill at the edge of the city. The quarry yields 4 floors of a fine grade of stone. In all, 54 feet of usable stone is being removed. Half of the lower floor is of blue stone, but the line of parting of the buff and blue stone is fairly regular so that only a small amount of mixed stone results. The stripping consists of about 5 feet of dirt and 2 feet of much disintegrated Mitchell limestone. The mud seams are not opened badly by weathering at this point where the present operations are going on. There appears to be a large amount of good stone in sight and a great amount of good stone is still available in the quarry.

The quarry operated by the Imperial Stone Company is the quarry that has always been known under the name of the "Blue Hole" quarry. It is located in the eastern edge of the city of Bedford. This quarry is one of the oldest quarries in the stone belt. It was first opened by Nathan Hall in the early 'sixties. The good stone is rather thin at this point, altho the new opening is not cut thru to the bottom of the workable stone as yet. The present floor has light stripping along its western edge where the stone is overlaid by but 5 feet of dirt. At the extreme eastern edge of the opening the Mitchell limestone has reached a thickness of about 20 feet. Two floors have been removed and most of the stone is blue in color.

The quarry of the Norton Stone Company is located about 2 miles southwest of Bedford. This quarry was first opened in 1888 by Cosner and Norton, and has been in operation most of the time since. The stripping consists of about 5 feet of dirt and about 15 feet of waste rock. About 40 feet of stone is taken out. The quarry is more than half blue stone, but the line of parting is regular, so that but a small amount of mixed stone results.

Part III. Quarry Economics

CHAPTER VI

POWER AND MACHINERY

General Discussion. The quarry industry as carried on in the Oölitic limestone belt of Southern Indiana offers a fertile field for research long the lines of increased economy in production. The first tendency of unthinking people is to feel that whatever other of our natural resources need conserving, this is surely not necessary in the case of building stone. The popular belief is that building stone and building materials are unlimited in amount or at least as abundant as the rocks of the earth's crust. This is far from true because some rocks are totally unfit for building materials, and many more, altho used in quantities, are not ideal building stones.

Altho the stone industry is one of the very oldest, in fact the first industry mentioned in history, still its development has progressed more slowly than almost any other of our great industries, and today it is carried on along much the same lines that have been followed for decades. The early operators who began production of building stone in this district introduced very wasteful methods, feeling that the supply of first-grade stone was unlimited. At that time the abundance of material, its cheapness, and the narrow field of the output made it necessary to take out only the best stone. There has been a tendency to retain these methods to the present time, and it is only in the last few years that a more careful study and a broader knowledge of conditions has shown the fallacy of this practice. The amount of first-grade buff stone in sight is very limited, and the production of a sufficient quantity to meet the increasing demand for this high-grade building stone is becoming a serious problem to the quarry men and mill operators of the district.

The problem of transporting the stone long distances has always been a deterring factor in the broadening of the industry, and has tended to confine the interest of the operators to a small section of the country.

As railroad transportation facilities in this country have increased, the market for the output of Oölitic limestone has been extended, and today the stone is carried to all parts of the country, some of it even being exported. The growth of the output has not been followed by a corresponding development in the methods of production. The tendency of the operators in this district has been to continue with the old methods and machinery. Only the growing demand for a fine grade, easily workable stone has caused the operators to realize that there are possibilities of development which might be attained by a careful study of the industry, far in advance of the methods now in use. Within the last few years competition has become so keen that the operators are at present confronted with the alternative of decreasing the cost of output or giving up the more distant markets. The cost of production can be lowered only by more careful handling of the waste products and by a lower cost of power. The more progressive operators of the district have begun to realize the wastefulness of present methods, and are trying to introduce more up-to-date and efficient methods.

The Southern Indiana stone belt is blessed with large deposits of one of the best known and most valuable building stones in the United States. The stone has all the requirements of a perfect building stone. In structure, composition, color, durability, ease of quarrying and dressing, and in fact all the properties that go to make up an ideal building stone, it ranks among the best in the world. One of the many properties which tend to make the stone popular with the building trade is the fact that when first taken from the quarry the stone is very soft and easily workable, but upon exposure tends to become hard and very resistant to the elements. The stone is easily carved and will retain the carving in a good state of preservation longer than any other stone of equal softness.

The principal losses accompanying the production of building stone in this district may be grouped under four heads as follows: (1) losses incident to the production and use of power; (2) losses of second-grade stone, due to the present methods of grading; (3) losses of lime, cement, and fertilizing materials; (4) losses of human labor.

Probably the largest loss, taking the district as a whole, is that resulting from the present methods of power generation and distribution. This loss may be due to any one of the following causes: inefficient power-plant equipment, out-of-date methods, and obsolete machinery. The methods at present in use are very wasteful. This condition is in part the result of the proximity of the stone belt to the coal fields. The price of coal is so low that little care is practiced in conserving it. If the price of coal had been higher in the district, this sort of waste would have been done away with much sooner.

The value of a treatise on the question of power generation lies in its ability to suggest methods of saving money for the owners by improving the methods of operation and increasing the efficiency of the equipment. The fundamental object of any power plant is the conversion of energy from one form into another at the least possible ultimate cost. This involves not only the cost of converting the energy into the form desired, but also the cost of the distribution and application of the energy. The most efficient plant thermally in the conversion of energy from one form to another is not necessarily the most economical commercially, since the various other items involved in effecting this transfer may more than offset the gain over a thermally less efficient plant. Competition or a desire to increase the profits of production makes every progressive operator watch for ways and means of reducing the cost of his product. The primary object of this study is to outline as thoroly as possible the present practice thruout the district, and, wherever possible, to suggest methods for betterment. The criticisms may seem severe in some cases, but they are only made where justified, and then only with a view of making the operators see the wastefulness of their methods. The cost of power is a non-productive factor and frequently runs so high that it endangers and sometimes actually destroys the profits. Few managers and operators have the time or the inclination to go deeply enough into the subject of power generation to judge rightly the returns from power costs. In 9 out of every 10 mills and quarries of this district the cost of power is above what it could be made with a little careful oversight of this large factor in the expense account. Even with present equipment a marked saving could be made by more careful management and a closer oversight.

Present Practices and Machinery. The power problem of the Southern Indiana quarry district can be best understood by first familiarizing ourselves with the methods now in use for the production of power.

The buildings in use for the housing of the power-producing machinery in the district are in most cases temporary wooden structures. Usually the power-house is built as a lean-to against the side of the mill and in a majority of cases is too small for proper attention to be given to the machinery inclosed. Ventilation and light have often been sacrificed in an effort to cut down first cost. In many cases the machinery is not thoroly protected from the weather or from meddlesome persons, who may visit the plant while it is not running, and valuable machinery has thus been damaged. A few operators have used stone or brick in the construction of their power-houses, and a number of the others have substantial wooden buildings for the housing of their power machinery. As a rule, the quarry power plants are not as well protected as the power plants of the mills. One noticeable feature of the district is the scarcity of power plants equipped with good floors, in which any attempt at cleanliness is made. Light and space are prime requisites in any power-house and thoro cleanliness is essential to economy in power production. One of the first laws of good engineering practice is that a clean machine will outlast a dirty one and a clean power-house means a marked increase in the useful life of the machinery in it.

The present outlook would be improved if the following suggestions were kept in mind by the operators: The power buildings in which engines, boilers, and accessories are placed need not be elaborate or expensive but should be so constructed that they protect the machinery and its attendants from the weather while the plant is in operation. They should also protect the machinery from meddlesome persons while the plant is not in use. The buildings should be so located and arranged that additional machinery can be installed at any time with a minimum amount of expense. All power buildings should be of fireproof material. Brick or stone walls with a wooden roof covered with tar and gravel have met with wide approval as a good and economical form of building. Buildings should be made large enough so that the machinery in them is not cramped, and when several machines are placed in a single building they should be so placed that any machine can be quickly stopped. Provision should be made in planning a power-house for ample room around the machinery for taking it apart; for example, the removal of piston rods without taking the cylinders from their foundations, or the removal of the boiler tubes for repairs. In fact, as much space as can be spared should be provided for the power-house, and its arrangement should be given very careful consideration.

Power. The power machinery used thruout the stone belt consists of engines, boilers, stacks, feed pumps, and water heaters. In most of the mills electrical equipment and air compressors are also included. The first piece of apparatus to be considered is the boiler.

Boilers, altho of many types, can be classed under two main heads, as follows: Fire-tube boilers, in which the water is con-contained in a cast-iron shell, and tubes extend lengthwise thru this shell to conduct the hot gases from the furnaces to the stack; and water-tube boilers in which the water is in the tubes and the hot gases from the furnace are forced to pass back and forth across and among the tubes by means of baffle plates. In the smaller power plants the fire-tube boiler is most widely used on account of its lower first cost, cheaper foundations, and easier attention, etc. As the size of the plant increases the water-tube boiler tends to replace the fire-tube boiler on account of its longer life, greater overload capacity, quicker steaming, and greater safety. The disadvantages of the two types can be summed up as follows: Fire-tube boilers are liable to leak at the ends of the tubes; they fluctuate rapidly in the pressure supplied; they are not easily examined; and it is necessary to reduce the pressure as time goes on. Water-tube boilers have small steam space, are not easily cleaned, and are liable to prime.

Another type of boiler that is very efficient but not much used in quarry work is the internally fired boiler, known as the Scotch Marine boiler. These boilers give a greater evaporation of water per pound of fuel burned than either of the types above mentioned. They cost less for foundations, and, altho higher in first cost, soon make up for this in the lower fuel consumption during service.

The most satisfactory all-round boiler for a quarry or mill equipment and the one that is used almost exclusively in this district is the well-known horizontal return-tubular boiler. The most widely used makes are the Atlas, Chandler Taylor, and the Erie City boilers. They range in size from 40 horse-power up to 200 horse-power, with pressure allowances from 75 pounds up to 125 pounds per square inch, according to the age of the boiler.

The boilers as a rule show the results of hard usage, due mainly to two causes: First, there is a tendency to overload a boiler where it is furnishing steam for steam pumps or drills. The boiler is usually pushed to furnish steam for as many pieces of apparatus as are needed in action at once. In the second place, labor conditions make for poor handling. The wages of the average fireman of this district will not attract a competent man, and as a result there are very few licensed firemen in the district. The prevalent idea seems to be that anyone who can shovel coal and see a steam gauge and a water-glass will do for a fireman. This results in a shortening of the useful life of a boiler and a large increase in the amount of coal necessary to do the work. At some plants I have seen fires under boilers that showed a thickness of ash on the grate under the fire of 6 or 7 inches. In many of the plants the boiler tubes are not kept properly cleaned and the boiler settings thoroly tight. Every fireman should have it carefully impressed on his mind that any soot accumulation in the tubes or in the combustion chamber of a boiler acts as a non-conductor of heat and that ash accumulation on the grate reduces the steaming capacity. Effective steaming depends on keeping the tubes clean of soot and scale and the grate free of ash and clinkers.

Many boilers in use at the present time have passed the age where they can be used economically. Few operators seem to appreciate the fact that a small saving in fuel will soon make a new boiler a more economical proposition than the continued use of the old equipment. At one plant visited, there were two boilers in operation which had been used continuously for over 25 years. Both were in a very unsafe condition and the waste of fuel in their use would have been great enough to cover all fixed charges on a new boiler equipment. At another plant an old worn-out boiler had caused three extensive shut-downs during the last year while repairs were being made. At still another plant I found the fireman carrying a very thick layer of ash and clinker on the grate under the fire. When asked why he said that the grate was in such a condition that a large amount of his fire would be lost if he were to rake it clean.

A comparative study of the amount of coal shipped in and the output of power by the plant will readily show that the plant with modern boiler equipment is a saving investment in the long run. I have made an extensive study of the cost of power in a number of plants in this county and find that up-to-date boiler equipment and careful attention are the most important factors in lower power costs.

The most reliable boiler feeder is a direct-acting single or duplex pump. In most plants the single-acting Dean pump is used and a second pump or injector is held in reserve. As a rule, the pumps in use are in good condition.

Feed-water heating is practised by practically every owner, and in any form is a very economical practise. In many cases old boilers have been utilized as feed-water heaters. In some cases the tubes have been removed from the old boiler and a large exhaust pipe has been carried thru the boiler shell. This method utilizes a small portion of the heat in the exhaust steam, but there is a distinct saving in the small rise in temperature of the feed water. In some cases the exhaust steam is passed thru the tubes while the shell is filled with the feed water. These as a rule do not give a high temperature to the feed water, but any rise in temperature is a saving of fuel. Many of the plants are equipped with regular water-heaters. Among the types represented are the Cookson, Cochrane, and Wicks heaters. All these types seem to be giving entire satisfaction to the owners, and the number in use is constantly increasing. In all cases where no effort is made to heat the plant with the exhaust steam from the boilers, the open types of heaters are used, but where the operator has an enclosed plant and wishes to make a long run thru cold weather, the closed types of heaters are used with steam connections to heat the plant. Much of the exhaust steam from the pumps is still allowed to escape, since the exhaust from the engines is usually enough to heat the supply of feed water used.

The guyed steel stack is used almost exclusively thruout the district and seems to give entire satisfaction. It is in fact the best type for quarry and mill service, since few operators would be justified, with the present outlook of the business, in making the additional outlay necessary for brick or self-supporting steel stacks. In most cases the stack equipment is sufficient for the boilers in use, but in one case, where a water-tube boiler of the Atlas type is in use, it is not giving satisfactory results on account of the insufficient draft. The operator who installed it failed to realize that a water-tube boiler needs more stack draft than a fire-tube boiler of the same size. This difficulty has since been obviated and more satisfactory results are being obtained. Few cases are on record where stacks have been injured by winds, since most plants are in protected locations and few of the stacks are of great enough height to be troublesome in the wind. Wherever stacks have not appeared to be giving draft enough the difficulty has nearly always been found to lie in the connections and breechings rather than in the stack.

The most common type of engine in quarry service is the simple Atlas engine. These engines are usually of the older types and are in most cases in poor condition. Most of the mills are equipped with Corliss valve engines, among which the Atlas and Hamilton-Corliss are the most common. There are a few automatic engines in use in the district, and in every case save one they were reported to be giving entire satisfaction. The automatic engines are best adapted to mill work, where they can be used direct connected to the generator, for the generation of electricity. There will be a tendency to increase the number of automatic engines as the amount of electrical equipment increases, for they are proving far more satisfactory in this work than the slower engines. The direct-connected generator gives better satisfaction than the belt-driven types. The automatic engine is best fitted to handle the sort of load that is necessary in mill work. Where most of the machinery is handled from a line shaft, the slower Corliss engines seem to be better adapted and are doing the work in a satisfactory manner wherever they are installed.

The steam lines are protected by covering in only a few cases, and in many plants are so long as to cause a serious loss of power on account of radiation between boiler and engine. The main work of the quarry engine is derrick handling, and as a rule this work is very hard on an engine. In many cases these engines are only protected by a roof and in a few cases they are entirely exposed to the weather. There appears to be a marked tendency among the quarry men to replace the steam engine used on derrick work by motors and thus concentrate the power in one large engine. This is a wise move, inasmuch as the cost of driving several small units is far greater than the cost of generating all the power in a single unit.

Wherever there is complaint against driving machinery from a line shaft, the loss of power can nearly always be traced directly to the shafting, where the cause of loss is usually found to be in improper alignment of the shafting or worn bearings. The power losses due to poor shafting and belting often represent a large percentage of the power generated by the engine, and in every such case the tendency is to lay the blame on the engine, without having first made the proper tests to determine the real cause of the losses.

The electrical equipment of the mills is almost entirely Westinghouse or General Electric Company machinery. Wherever electrical equipment has been installed it has been found to be far more economical than the old line shafts and belting with their accompanying losses of power. The electrical equipment in use thruout the district is in good condition and is giving satisfaction. The electric motor seems to be better fitted for derrick handling than any other form of power unit and its efficiency has also been proved in driving mill machinery. As has already been said, the direct-connected generator is doing better work than the belt-driven generator wherever it has been installed, and its greater efficiency seems to justify the greater first cost of installation.

Compressed air is in use in most of the mills for decorative work, and practically all of this equipment has been furnished by the Chicago Pneumatic Tool Company, of Chicago and New York, and the Ingersoll-Rand Company of New York. The use of compressed air in this line of work has been an important factor in the decrease of the amount of skilled labor employed in the stone-cutting business. One laborer working with compressed-air tools can do as much carving as five men working under the old system. Where compressed air is used in the operations of channeling and drilling, the machinery employed is on a much larger scale, and the equipment is usually of types furnished by the Sullivan Machinery Company or the Ingersoll-Rand Company. There are two companies using compressed air for channeling purposes in the district at the present time, but in both cases it has been found to be an uneconomical procedure. This subject will be further discussed in another part of this study under the head Power and Machinery.

The Ideal Quarry Power Plant. The quarry owner will always be found ready to talk of the quality of the stone and of the methods of its production, distribution, and use, but when the quarry power plant is mentioned his information fails. Few of the men who are bearing the expense of power-plant operation can tell where the money spent for coal goes, and even if they have tried to determine it, few have been able by such study as they could give to the problem to check the unnecessary drain from this source. Mr. D. M. Myers in his paper on "The Mechanical Engineer and the Factory Power Plant" says:

As regards his power plant equipment, the operator must strictly specify and obtain three things if he is to have the ideal power plant. These are as follows: (1) No shut-downs or delays, or at least as few as possible. (2) An efficient power equipment with minimum bills for fuel, labor, maintenance, repairs, and interest charges. (3) Any changes made for improvement must pay for themselves in a comparatively short time, including all charges for installation and delays. Of course, all the above conditions cannot be realized, but they at least offer an ideal to be aimed at. If the suggestions above were followed there would be fewer high-priced equipments, giving poor satisfaction, and fewer complaints about the high cost of power production.

The selection of the boiler equipment for a steam powerplant is a matter which should be given the most careful consideration and attention. While some purchasers take the time to go carefully over the factors which enter into the make-up of a good boiler, the majority are inclined to accept as satisfactory those boilers with which they have had some experience. There are many owners who buy the boiler which is cheapest in cost, after little or no investigation, taking for granted the representations of the salesman. Many purchasers of the latter class often consider carefully the comparative economy and reliability of engines and their auxiliaries while at the same time their boilers may be extremely wasteful in operation and deficient in the essentials of simplicity, economy, and adaptability to the service for which they were intended. High-grade engines add materially to the first cost of a plant, while high-grade boilers cost but little more than those of the poorer sorts. Careful boiler selection results in a far greater saving than can possibly be obtained by installing more efficient engines with poor boiler equipment.

The special requirements of each individual case should be carefully studied before determining the general type of boiler to be used. After this has been determined, the most important features to be considered are safety, efficiency, durability, and accessibility of parts. Of almost equal importance are the skill, experience, reputation, and financial standing of the company putting out the boiler.

The life of a boiler depends upon the attention it receives and the conditions under which it operates. In figuring the cost of power one of the largest items to be considered is the depreciation or the rate of decrease in value of a piece of machinery on account of age and wear. If thru careful handling the life of a piece of machinery can be materially lengthened, the accompanying cost of power will be reduced in proportion.

Few power users realize the great fuel economy possible with proper boiler equipment. They spend their time and money in the selection of engines of low steam consumption, when in reality the most important part of a steam power plant is the boiler equipment and its proper operation. Boiler operation represents the largest share of the operating expenses of any power plant. The best efficiences can be secured only in plants where skill, good judgment, and continued vigilance are practiced. The development of the steam boiler has reached a point where the same evaporation rate can be reached by all if the proportions of grate and heating surface are correct and the operating conditions are the same. The present method of boiler rating is very misleading, since any rate based upon the square feet of heating surface regardless of its position cannot be accurate. The ability of a surface to transmit heat to the contained water depends upon its position with regard to the grate and the point of maximum combustion. The proper ratio of grate area to heating surface for boilers using the local grades of bituminous coals should be about 1 to 45.

Some of the principal factors governing the selection of a steam boiler are: space occupied, weight, capacity, first cost, adaptability to the particular condition under which it is to operate and the location of the plant in which it is to be placed. It is necessary to determine which are the best proportions for the boiler for the use to which it is to be put.

Even in small plants expert advice should be obtained and followed. Mr. H. C. Meyer in his work on *Steam Power Plants* (pp. 1, 2), says:

> No better service can be done the non-expert about to construct a steam plant than to advise him to engage at the outset of the project some capable engineer to design the plant and superintend its installation. . . . It is the practice of many engineers in steam plant construction to invite bids on apparatus described very generally in the specifications and intended to perform a service under the conditions named, the idea of the engineer being to allow each bidder to proportion the parts of the apparatus he is to furnish and to quote a price on it. When bids are received under these conditions, it generally follows that there are many variations in the sizes of the machinery offered by the different makers to do the same work, and the lowest in price may not be the best adapted for the conditions. . . . The expert engineer, of course, is able to detect and reject bids on deficient apparatus.

While an engine may give the required power, its cylinders may be so small that it requires an excessively large amount of steam to run it, or a boiler may be so small that an abnormal amount of coal must be burned in order to generate the steam required of it. Non-expert purchasers are liable to accept machinery which is not the best adapted to the service for which it was intended.

Professor G. F. Gebhardt in his book *Steam Power Plant Engineering* (first edition, p. 681), gives the following description of the horizontal tubular boiler:

> These [boilers] are the most common in use and are constructed in sizes up to 200 horse-power. They are simple and inexpensive and, when properly operated, durable and economical. . . . The grate is independent of the boiler and the products of combustion pass beneath the shell to the back end, returning through the tubes to the front, and into the smoke connection.
>
> The tubes are from 3 to 4 inches in diamater and from 14 to 18 feet long and are expanded into the tube sheets. The portion of the tube sheet not supported by the tubes is secured against bulging by suitable stays. Access to the interior is obtained through manholes.

The following suggestions were made by Mr. G. W. Bissell in his paper on "Selection of Power Plants and Equipment for the Quarries of Iowa," and are published in the *Iowa Geological Survey,* Vol. XVII, pp. 151-183:

> For the local coals as fuel the boiler should be relatively long and should be set high above the grate and should have liberal grate area and stack capacity. All boiler tubes for the use of local coals should be at least 4 inches in diameter, on account of the excessive accumulation of soot. Twelve square feet of heating surface should be allowed for each boiler horse-power desired. One square foot of grate surface should be allowed for every 40 square feet of heating surface. That would require 33 square feet of grate area for a 100 horse-power boiler. A 72-inch boiler should be at least 36 inches above the fire.

In this respect most of the boilers of this district are at fault since few of them are more than 30 inches above the grate. The coals of Indiana coal fields are slightly lower in volatile matter, and the amount of soot is not quite so high, nevertheless the above suggestions may well be followed here, since the differences are not great enough to materially affect the result.

The following table (from Bissell's paper on "Selection of Power Plants" in Vol. XVII of the *Iowa Geological Survey,* p. 158), contains approved dimensions for fire-tube boilers for use in ordinary quarry service:

		48 in.	54 in.	60 in.	66 in.	72 in.
Diameter of boiler		48 in.	54 in.	60 in.	66 in.	72 in.
Number of tubes		24	36	44	54	68
Diameter of tubes		4 in.	4 in.	4 in.	4 in.	4 in.
Thickness of shell		$\frac{5}{16}$ in.	$\frac{5}{16}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.	$\frac{3}{8}$ in.
Thickness of head		$\frac{7}{16}$ in.	$\frac{1}{2}$ in.	$\frac{1}{2}$ in.	$\frac{1}{2}$ in.	$\frac{9}{16}$ in.
Braces above tubes		12	20	30	30	40
Braces below tubes		4	4	4	4	8
Size of steam pipe		3 $\frac{1}{2}$ in.	4 in.	4 $\frac{1}{2}$ in.	5 in.	6 in.
Size of feed pipe		1 $\frac{1}{4}$ in.	1 $\frac{1}{4}$ in.	1 $\frac{1}{2}$ in.	1 $\frac{1}{2}$ in.	1 $\frac{1}{2}$ in.
Size of blow-off pipe		2 in.	2 in.	2 in.	2 $\frac{1}{2}$ in.	2 $\frac{1}{2}$ in.
Heating surface	16 ft.	520 sq. ft.	715 sq. ft.	864 ft.	1042	1325
	18 ft.	585 sq. ft.	805 sq. ft.	972 ft.	1270	1490
Rated horse-power	16 ft.	43.3	59.5	72	87	110
	18 ft.	48.7	67	81	90	124
Grate surface	16 ft.	14 sq. ft.	18 sq. ft.	21.6 sq. ft.	30 sq. ft.	33 sq. ft.
	18 ft.	15.8 sq. ft.	22 sq. ft.	24.3 sq. ft.	33 sq. ft.	39.6 sq. ft.
Diameter of 60-foot stack		24 in.	27 in.	30 in.	33 in.	36 in.

The following are standard specifications for a boiler 72 inches by 18 feet, working pressure 125 pounds, as given by Professor Bissell (*loc. cit.*, pp. 159, 160):

Type.—Horizontal return-tubular.

Dimensions.—72 inches in diameter, 18 feet long from outside to outside of heads, with smoke extensions 18 inches long continuous with the shell. Thickness of the shell, $\frac{3}{8}$ inch; thickness of head, $\frac{1}{2}$ inch.

Material.—Best open hearth flange steel, having a tensile strength of not less than 57,000 nor more than 62,000 pounds, and ductility corresponding to 56 per cent reduction of area and 25 per cent of elongation. All plates in finished boiler to show stamp with name of maker, quality, and tensile strength.

Riveting.—Triple-riveted butt joints for longitudinal seams and single-riveted lap joints for girth seams.

Tubes and braces.—68 tubes 4 inches in diameter, 18 feet long, best lap welded or seamless drawn, carefully and properly expanded with Dudgeon expander, and beaded at each end. Braces: 40 braces above tubes and 4 below tubes; the former crowfoot form, flat or round, of not less than 1 square inch in area at smallest section, the latter 1$\frac{1}{4}$ inches in diameter, with upset ends for 1$\frac{1}{2}$-inch thread at front and crowfoot connections at back, with turned bolt 1$\frac{1}{16}$ inch in diameter. No brace less than 3 feet 6 inches long.

Details of the tube sheet layout to be according to practice recommended by the Hartford Steam Boiler Inspection and Insurance Company.

Supports.—2 lugs on each side. Front lugs to rest on cast iron plates, others on rollers and plates to permit of expansion. All plates 12 by 12 by 1$\frac{1}{2}$ inches. Rollers 1 inch diameter, and 9 inches long, 3 at each plate. Or 2 suspension loops on each side, of 1$\frac{1}{2}$-inch round iron securely riveted to shell. Columns and double channels for overhead suspension, with equalizing I-beams at back end.

Construction.—No dome. Shell in 3 rings, each ring formed from a single sheet, horizontal seams above the fire and to break joints. Heads machine-flanged, rivet holes drilled or punched and reamed, tube holes drilled or bored.

Openings.—2 manholes, 11 by 15 inches in top of shell, 10 by 15 inches in front head, under tubes 1½-inch feed-water pipe, internal from front head over tubes. Blow-off flange 2½ inches. Steam nozzle 5 inches, near back end, safety valve nozzle 4 inches, near front end. Both nozzles flanged and fitted with companion flanges for screwed pipes of same size as nozzles.

Castings.—Fronts. Ornamental three-quarter arch for overhanging extension. Fronts designed to allow not less than 42 inches between grate and boiler shell and to have fire-door frames for 8-inch wall. Tight-fitting fire, ash pit and smoke extension doors, saddle for breeching connection, with balanced butterfly damper. 8 wall binders, binder rods, anchor rods for front, soot door and skeleton frames for fire-brick arch at back. Uptake 14 by 60 inches. Rocking dumping grates of approved design to work from front of boiler.

Fittings.—8-inch brass steam gauge, combination water column, 4-inch pop safety valve, 1½-inch check and stop valves and 2½-inch asbestos blow-off cock.

Inspection and Test.—Before shipment test with cold water at 175 pounds per square inch and furnish certificate of inspection from the Hartford Steam Boiler Inspection and Insurance Company, and insurance policy in the same company for one year.

The above specifications can be used with slight changes in ordering a boiler at the present time. Alterations in the size can be made to suit the case in hand. In ordering a boiler care should be taken to be sure that the boiler is large enough to supply steam for all the units that will be necessarily in operation at one time. A boiler should always be made as accessible as possible so that it can be readily cleaned. The boiler should preferably be hung on columns by means of equalizing levers and hangers, so as to keep the shell free from strains due to the settling of the brick work.

The advantages of the return-tubular boiler over the other types are a large heating surface in a small space, and a large overload capacity. It requires little overhead room and it first cost is low. It is a quick steaming boiler and needs little repair.

For the larger mills where electrical equipment is to be used thruout, the water-tube boiler is probably better on account of its ability to stand a higher pressure and its ability to steam economically on a varying load.

Many types of these boilers are on the market and each seems to have a large group of supporters, but the one that has an established reputation which has been maintained for a long time is the Stirling boiler.

The following specifications for a water-tube boiler are taken from the general specification sheet of a company manufacturing water-tube boilers, and were submitted by the company as a specimen of the form used in their order department. The boiler specified is of 250 horse-power.

SPECIFICATIONS FOR A WATER-TUBE BOILER

Each boiler to have:

Tubes, Drums.—4 in. diam. lap-welded charcoal iron; 12 tubes wide; 11 tubes high; 16 ft. long; 2 ft. 36 in. dia. longitudinal drums. Shell ⅜ in. thick, heads ½ in. thick. Longitudinal seam double-riveted lap joint, girth seam single-riveted. Flanged steam outlet 8 in. by 15 in. One mud drum 12 in. diam.

Heating and Grate Surface.—2,527 sq. ft., including tubes, headers, drums. 54 sq. ft. *Grates.*—Furnace 8 ft. 4 in. wide by 6 ft. 6 in. long. Standard, unless otherwise specified. Opening in grate bars as required.

Fittings.—2 pop safety valve 4 in. diam. to be set at 160 lbs. One each 2½ in. globe and check valve for feed. One 3 in. blow-off valve. One ¾ in. globe valve for cleaning hose. One steam gauge with 12 in. dial. One cast-iron water column with three try cocks. One glass water gauge fitted with chain shut off, operating from floor. All necessary piping and fittings to connect with drums.

Testing.—When erected the boiler will be tested to 250 lbs. hydrostatic pressure. Safe working pressure 160 lbs. per sq. inch.

Tools.—One set Fire tools consisting of poker, slice bar, and hoe. One steel wrench for bolts on headers. One length of hose with pipe for blowing soot from tubes.

Space.—Space occupied, including brick work: Length 18 ft. 9 in.; width (single) 11 ft. 2 in.: battery 21 ft. 6 in.; height to outlet flange 17 ft. 3 in.

Weight.—Approximate shipping weight of each boiler 50,000 lbs.

Brick Work.—Estimated quantity of brick for the setting of each boiler above the foundation: 14,800 red brick; 2,650 fire brick; to be provided by the purchaser.

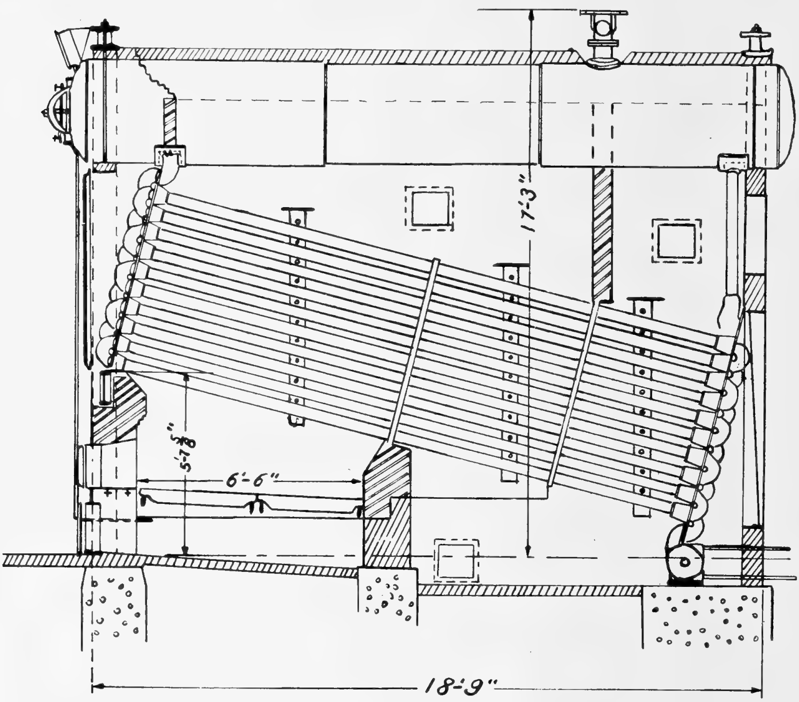
Foundations.—Excavating and foundation to be furnished by the purchaser and must conform to drawings furnished by us in all essential points. The depth must be governed by condition of the site. We will not be responsible for any defects caused by settling of foundations.

All previous conditions or agreements between the parties hereto, either verbal or written, are hereby abrogated and cancelled, and no changes or modifications shall be binding on the party of the first part unless in writing and signed by an executive officer of the company—this constituting the entire agreement between the parties hereto.

Delivery.—To be delivered f.o.b. cars, at our plant. Shipments subject to strikes, accidents, failure to receive material, or causes beyond our reasonable control. The transferring of material from cars to place of erection to be done by purchaser who will also furnish appliances and ordinary labor for the erection, unless otherwise agreed in writing.

Erection.—We will, if desired, supply the services of a man, to superintend the erection of the iron work, his wages at the rate of six dollars per day, traveling expenses and board from plant and return to be paid by the purchaser.

Boiler Power. Altho it is a misnomer to speak of the horse-power of a boiler, it has come to be very general among engineers to rate boilers on the amount of steam they are capable of furnishing. The ability of a boiler to generate steam depends upon the area of its effective heating surface. Heating surface has



WATER-TUBE BOILER

been defined as boiler surface, either shell or flue, which has hot gases on one side and water on the other. The surfaces which have steam on one side and water on the other are called superheating surfaces. A boiler horse-power is taken as the equivalent of the evaporation of 34½ pounds of water per hour from a temperature of 212 degrees Fahrenheit to steam at atmospheric pressure. This is sometimes stated as the evaporation of 30 pounds of water at 212 degrees Fahrenheit to steam at 70 pounds pressure. These figures of course depend upon the kind of engine in which the steam is to be used. The amount of steam mentioned above will develop about 3 horse-power in the best compound condensing engine of today, but only about one-half a horse-power in a small non-condensing engine. A very common method of rating the horse-power of boilers is on the area of the heating surface. Ten to 12 square feet of heating surface is considered as equivalent to a horse-power. The power of a boiler to evaporate water depends on the rate at which coal can be burned on the grate and the area of the grate. With natural draft, from 20 to 45 pounds of coal per hour can be burned per square foot of grate area. When forced draft is used these figures can be increased.

The efficiency of a boiler and its grate is expressed as follows:

$$\text{Efficiency of boiler and grate} = \frac{\text{Heat absorbed by boiler per pound of coal as fired}}{\text{Calorific value of one pound of coal as fired}}$$

The fact that different firms use different heating area ratings is likely to confuse purchasers, but a careful study of the size and position of these surfaces will avoid this difficulty.

Cost of Boilers. Figures on the cost of boilers are hard to give with accuracy since the great variation in types and arrangement makes a single statement based on the horse-power rating misleading. In fact, the cost does not increase in the same ratio; and so many other considerations enter into the calculation that only approximate prices can be given. The wide variation in the cost of boilers is partly accounted for by the fact that the horse-power basis differs with different manufacturers. Gebhardt in *Steam Power Plant Engineering* (first edition, p. 96), quotes a price of $1 per square foot of heating surface for all boilers of over 100 horse-power. He also quotes the following method from C. H. Benjamin (*Engineer* [U. S.], Nov. 15, 1902):

(*A*) Cost in dollars = 500 + 9.2 × rated horse-power.
(*B*) Cost in dollars = 500 + 8.5 × rated horse-power.
(*C*) Cost in dollars = 100 + 6.5 × rated horse-power.
(*D*) Cost in dollars = 100 + 5 × rated horse-power.

(*A*) Horizontal water-tube boilers, 125 pounds pressure, 10 square feet heating surface per horse-power.

(*B*) Vertical water-tube boilers, other conditions same as in (*A*).

(*C*) Horizontal return tubular boilers, 12 square feet heating surface per horse-power.

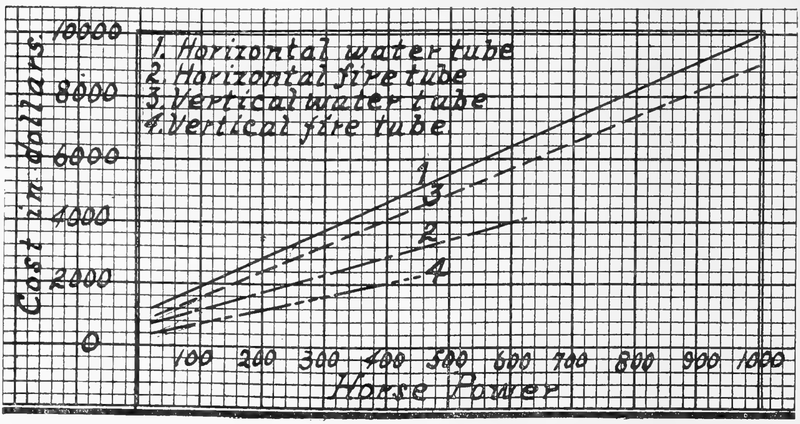
(*D*) Small vertical fire-tube boilers.

The cost of Scotch marine boilers rated on a basis of 8 square feet per horse-power may be estimated by means of formula (*A*).

Cost of Boiler Settings. Gebhardt gives the following cost of boiler settings:

> Horizontal water-tube: Cost equals 400 + 0.8 × rated horse-power.
> Return tubular: Cost equals 300 + 0.7 × rated horse-power.

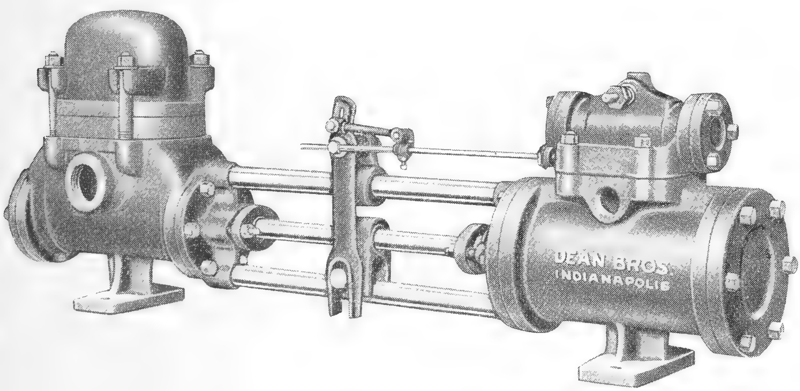
The only form of stack in use in the district is the guyed steel stack, and for all kinds of service it is the best as well as the lowest in first cost. There is a tendency here, as elsewhere, not to allow sufficient draft to burn properly the coal on the grate; and a large loss of coal is the result. Any unburned gases that



Plot 2 gives the approximate cost of boilers and is taken from the same source as Plot 1 (p. 89).

escape from a chimney are money out of the owner's pocket. The best practice is to have ample draft and control it by dampers, instead of running the risk of having insufficient draft in unfavorable weather. Ordinarily the draft should be one-third more than enough for the usual run in order to give a sufficient draft for overloads or times of poor draft. The breechings should be large and free from obstructing turns or unnecessary dampers. Lack of adequate draft can more often be traced to defective breechings than to lack of stack capacity.

The most reliable method of boiler feeding is by means of a direct-acting single pump. A second pump or an injector should always be held in reserve. The single pump is usually superior to the duplex pump because the single pump is far more economical of steam and has fewer parts to keep in running order. In all duplex pumps each steam piston is controlled and reversed by a connection with the opposite piston rod. Two cylinders and pistons cannot be packed so that friction will be equal in each, hence the result is that one cylinder is interrupted and reversed before it has had time to complete its stroke. In other words, one cylinder is constantly short stroking. Another thing in favor of the single pump is the fact that it has fewer ports and less steam space to be heated and filled with waste steam. In specifications of pumps for feed-water work the amount of water necessary should be specified since the term horse-power in referring to a boiler is a very indefinite term. The accompanying cut represents a simple Dean Brothers pump. This pump is the most widely used thruout the stone district.



Feed-Water Pump

The following suggestions concerning pumps are of importance:

1. A pump should be subjected to a pressure test of at least 200 pounds per square inch before purchase.

2. It should show a suction of at least 25 inches of mercury.

3. The piston of a pump used for feeding water to a boiler should not run over 50 feet per minute.

4. If possible avoid all right-angle turns in the suction pipe.

5. The pump must not be more than 20 feet above the water supply. For hot water it must be below the water supply.

6. See that all water entering a pump is thoroly strained.

7. Avoid leaks in the suction pipe.

8. A check valve and water cock should be placed in the discharge pipe.

9. Be careful to keep the pump well packed and the packing even.

It would be more economical for the pump user to employ a power pump, where electrical energy is available, because the steam-end pump at its best is very wasteful of steam. An engine that consumed over 35 pounds of steam per horse-power hour would be considered very inefficient, but the ordinary steam-end pump with its slide valves taking steam under full pressure thruout the entire stroke, and exhausting at full pressure, uses over 100 pounds of steam per horse-power hour. A belted power pump takes less than one-fourth the power necessary for a steam-end pump.

The use of feed-water heaters is one of the most economical practices connected with power plant operation. The heat utilized in heating the feed water for a boiler is a clear gain and in the course of a year represents a large part of the cost of coal. The boiler water can be heated to 200 or even 210 degrees Fahrenheit by means of the exhaust steam from the engine and pumps. At the present time the waste heat in the exhaust steam from the engines is used, but a large amount of heat is being lost in the exhaust steam from the pumps.

Altho feed-water heaters act to a great extent as water purifiers, their greatest advantage lies in their ability to make use of a certain amount of heat that would otherwise be a total loss. For every increase of 10 degrees in the temperature of the feed water there is a gain of approximately 1 per cent in the saving of coal. In other words, at least 12 per cent of the heat of the coal can be utilized in first-class heaters. For every pound of exhaust steam utilized in the feed-water heater 6 pounds of feed water can be heated from a temperature of 50 degrees Fahrenheit to a temperature of 210 degrees. In addition to saving a large portion of the heat generated under the boiler, the smaller the difference in temperature between the steam and the feed water, the less will be the strain on the boiler shell on account of unequal expansion and contraction, and thus the life of the boiler will be lengthened. The cost of water-heaters is a very insignificant item when compared to the saving effected. In fact, it has been said that 6 boilers with the best methods of feed-water heating will furnish as much steam as 7 boilers of the same size heating their own supply of water. The open heater is more efficient than the closed heater, because the steam which furnishes the heat comes into intimate contact with the water to be heated, and the resulting temperature of the latter is higher than can be obtained with closed heaters, in which all heat transfers must be effected thru metal partitions that offer resistance to such transfer. One advantage of the closed feed-water heater is the fact that the boiler-feed pump can be eliminated and an injector can be placed in the pipe leading to the heater thus feeding the boiler thru the heater. The saving will be the difference between the cost of a feed pump and an injector. In most quarry and mill service the open heater will be the best adapted to the work.

In the selection of an open heater the following considerations should be taken into account:

1. There should be ample arrangements for the storage of the heated waters until withdrawn by the feeding pump; there should be the necessary arrangement of pipes to keep the water hot until it is used.

2. A separator or separating chamber for the removal of the oil contained in the exhaust steam must be an integral part of the heater.

3. The reservoir should be provided with blow-off, overflow, and water glass. The feed pump connection should be a few inches above the blow-off.

4. There should be a large heating and purifying chamber containing pans, trays, or trough, so arranged that the cold feed water must flow over all of them in order that the exhaust steam may come in contact with the water on every tray. The trays should be easily removable for ready cleaning.

5. All grease should be removed from the water.

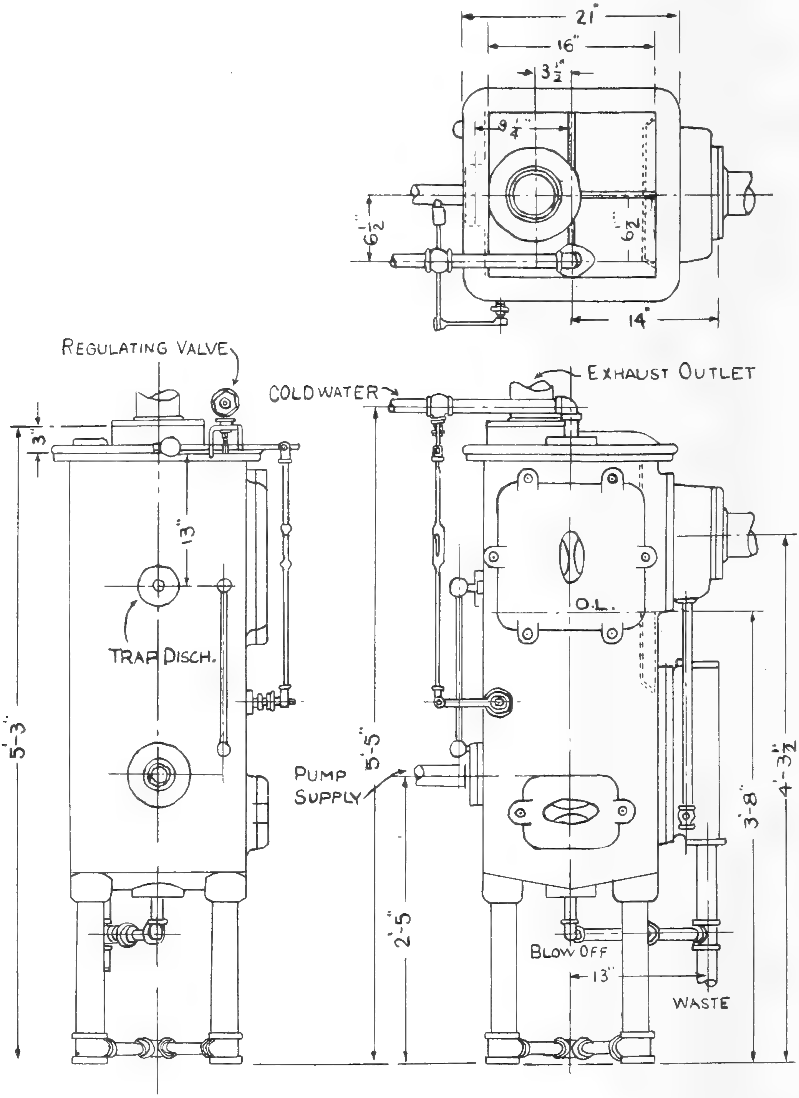
6. A filter bed should be provided thru which the water must pass after it has been heated.

7. Suitable cut-out valves should be supplied to the water lines.

The general proportions of open feed-water heaters vary greatly with the different arrangements of the storage chamber and the trays and pans, so that it is difficult to give a definite size of heater to be used with any particular boiler capacity. There is a tendency among manufacturers of feed-water heaters to overrate the capacity of their heaters. Care should therefore be exercised in buying, to make sure of the proper size of heater for the boiler equipment of the plant. Professor Gebhardt in *Steam Power Plant Engineering* (first edition, p. 425), gives the following formula for determining the size of shell needed for a given horse-power:

$$\text{Area of the shell of heater} = \frac{\text{Horse-power}}{a \times \text{length in feet}}$$

In this formula a = 2.15 for very muddy water; a = 6 for slightly muddy water; a = 8 for clean water.



Cochrane Feed-Water Heater and Purifier

The accompanying drawing, submitted by the Harrison Safety Boiler Works of Philadelphia, Pa., illustrates the Cochrane feed-water heater. The firm is one of the oldest in the business, and the Cochranes in use in this district are giving complete satisfaction.

The economical transfer of steam from the boiler to the engine or pump that is to use it is often accompanied by a very material loss, in fact, a greater loss than the ordinary observer would suspect. Where steam leaves the boiler as simple saturated steam, the amount of condensation in an unprotected steam line represents a high percentage of the steam generated, and also causes trouble on account of the large amount of water in the lines. A series of tests made by Professor C. L. Norton of the Massachusetts Institute of Technology shows that the yearly cost of maintaining 100 square feet of piping at a gauge pressure of 100 pounds per square inch is for bare pipes $225 while the cost for insulated pipes at the same cost of fuel would be from $25 to $35.90. These figures are based on the price of coal in Boston, but the percentage would be the same for any point. With superheated steam the line losses are reduced to a minimum, but since superheated steam would necessitate new engines, its use at present appears to be out of the question. This point could be looked into with profit by any owner who may be considering the project of installing new machinery, or who may be planning a larger power plant. For anyone about to erect a power plant no better work on pipe covering can be found than Paulding's *Steam in Covered and Bare Pipes.* All steam containers should be covered, since careful insulation will eliminate from 80 to 90 per cent of the heat loss per annum. This loss can be figured as three British thermal units per square foot per hour per degree of difference in temperature between the uncovered pipe and its surroundings. The actual loss depends upon the diameter of the pipe, its position (whether horizontal or vertical), the nature of the surface, and the velocity of the surrounding air currents. Professor Gebhardt, in *Steam Power Plant Engineering* (pp. 550-553), gives the following example to show the method of calculating the loss of heat in an unprotected pipe, as compared with the loss in the same pipe when it is insulated:

Required the saving per annum due to covering a pipe 10 inches in diameter and 100 feet long; steam pressure 150 pounds, average temperature of the air 76 degrees Fahrenheit; cost of covering applied 65 cents per running foot; efficiency of the covering 85 per cent; cost of coal $2.50 per ton; plant to operate 14 hours per day and 300 days per year.

The temperature of steam at 150 pounds pressure = 366 degrees Fahrenheit.

Difference of temperature between the steam and air = 366 — 76 = 290 degrees Fahrenheit.

Loss per square foot per hour, bare pipe = 3 × 290 = 870 B.T.U.

Loss per square foot per day, bare pipe = 870 × 14 = 12,180 B.T.U.

Loss per square foot per year, bare pipe = 12,180 × 300 = 3,654,000 B.T.U.

100 lineal feet of 10-inch pipe has an external surface of 282 square feet. Therefore the loss per year from the bare pipe is 282 × 3,654,000 = 1,030,000,000 B.T.U. (approx.)

Assuming a net available heat of 10,000 B.T.U. per pound for the coal, the equivalent coal consumption is 51.5 tons, valued at 51.5 × $2.50 = $128.75.

The covering will save 85 per cent of this, or $109.50 per annum.

The pipe covering applied will cost 100 × $0.65 equals $65.

In this case the covering will pay for itself in considerably less than a year.

The figures can be changed to fit any case in the district, and I have figured the cost and saving by covering the pipe in at least two of the mills and find that at the lower price of coal here, the saving due to insulating pipes will pay the cost of such insulation in about 16 months for the commonly used 6-inch pipe.

Another thing to be avoided is short turns in piping, for altho little is definitely known concerning the friction of steam in pipes, it is known to have a great effect on the condensation of steam passing thru the pipe, and it is therefore an economical proposition to have feed pipes as nearly straight as possible. Another practice is to give the pipes different colors according to the kind of material carried. This practice is employed in a large plant that I visited at Crawfordsville, Ind., and, in addition to giving the power-house a neat appearance, it makes the work of fitting easier.

Coal and Firing. The cost of coal from the local coal fields is so low that the choice of a coal worth considering in a discussion of power generation in the Southern Indiana quarry district is narrowed to the coal of the local fields. The better grades of coal from the eastern fields cannot compete on account of the high cost of transportation as compared to the short-haul freight on local coal. Coal at the mines can be bought (1914) at from 90 cents to $1.35 per ton, according to the grade and size. The kind of coal in use in most of the quarries is that furnished by an Indiana company at $1.10 per ton for run-of-mine, and $1.35 to $1.45 for lump coals. The freight rate per ton for the coal laid down at Bloomington is 55 cents with an additional 5 cents per ton for switching to the various quarries when such switching necessitates setting the cars on private switches. The subject of coal composition and heating value is narrowed by the few coals available, but a few analyses of coals will be of interest in this connection. The U.S. government maintains, under the supervision of the Bureau of Mines, a coal-testing plant at Pittsburgh, Pa., where any coal submitted in carload lots by the mine owners will be tested free of cost. A number of the local mine owners have availed themselves of this offer, and the literature concerning these tests is available for free distribution by the Bureau of Mines at Washington, D.C.

ANALYSES OF INDIANA COALS

(*Bulletin* 22 of the U.S. Bureau of Mines, 1913)

PROXIMATE ANALYSIS

	Brazil	Linton No. 1	Linton No. 2	Ayrshire	Dugger	Terre Haute	Boonville	Hymera
Moisture	16.91	13.58	10.30	11.13	12.15	9.55	9.62	12.03
Volatile	26.85	32.07	36.31	35.11	33.48	36.19	36.14	35.65
Fixed C	38.87	46.20	41.64	46.78	43.23	46.65	41.22	41.44
Ash	17.37	8.15	11.75	6.98	8.14	10.61	13.02	10.88

ULTIMATE ANALYSIS

	Brazil	Linton No. 1	Linton No. 2	Ayrshire	Dugger	Terre Haute	Boonville	Hymera
Sulphur	1.98	.91	4.23	1.64	1.41	3.72	4.43	4.27
Hydrogen	5.48	5.65	5.38	5.65	5.46	5.49	5.33	5.50
Carbon	52.97	63.53	61.00	66.94	64.92	64.08	60.70	60.73
Nitrogen	1.01	1.42	1.06	1.34	1.38	1.08	1.20	1.08
Oxygen	21.28	30.34	16.58	17.45	18.69	15.02	15.32	17.54

HEATING VALUE

	Brazil	Linton No. 1	Linton No. 2	Ayrshire	Dugger	Terre Haute	Boonville	Hymera
Calories	5,291	6,344	6,233	6,684	6,534	6,533	6,179	6,218
B.T.U.	9,524	11,419	11,218	12,031	11,761	11,759	11,122	11,192

The Brazil coal is described in the report as being Brazil Block bottom bed, screenings thru 1½-inch bar screen.

Linton sample No. 1 is from Black Creek mine, bed No. 4, run of the mine.

Linton sample No. 2 was taken from the White Rabbit mine bed No. 5, run of the mine.

Ayshire sample was from mine No. 4, bed No. 5, lump.

Dugger sample was from mine No. 4, bed No. 4, lump.

Terre Haute sample was from Deep Vein mine, bed No. 4, lump.

Boonville sample was from Electric mine, bed No. 5, run of the mine.

Hymera sample was from mine No. 33, bed No. 5, run of the mine.

It will be seen that in average composition these coals will run about 12 per cent moisture, 32½ per cent volatile matter, 44 per cent fixed carbon, and 11½ per cent ash. The heat generated in the combustion of coal comes from the carbon, hydogen, and sulphur, tho the sulphur is usually present in such small quantities that it has little effect on the heating value. In the burning of a fuel these substances unite with oxygen from the air to produce carbon dioxide, water, and sulphur dioxide. If the supply of oxygen is insufficient, the carbon forms carbon monoxide instead of carbon dioxide. The following heat values are given for these reactions:

One pound of carbon burned to carbon dioxide, 14,500 B.T.U.
One pound of carbon burned to carbon monoxide, 4,400 B.T.U.
One pound of hydrogen burned to water, 62,100 B.T.U.
One pound of sulphur burned to sulphur dioxide, 4,000 B.T.U.
One pound of carbon monoxide burned to carbon dioxide, 4,330 B.T.U.

From the above data it will be seen that the ultimate analysis of a coal is necessary for the calculation of its heating value. There are several formulae in use for calculating the heating value of a coal from its proximate analysis since the latter is much easier to determine than the ultimate analysis; but none of these formulae is satisfactory, for they usually give results which vary more or less from the true value. If oxygen is present in the coal, it is considered to be in combination with some of the hydrogen, and the heat of this combination is lost and must be subtracted when the determination of the heat value of the coal is made.

The following formula is given for the determination of the heating value of a coal from its ultimate analysis:

$$\text{Heating value in B.T.U. equals } 14{,}500\ C \text{ plus } 62{,}100\ (H-\frac{O}{8}) \text{ plus } 4{,}000\ S$$

In this formula the letters C, H, O, and S represent the weight of carbon, hydrogen, oxygen, and sulphur in a pound of fuel. It will be readily seen that the weight of the carbon has been multiplied by the heating value of one pound of carbon burned into carbon dioxide, plus the weight of the sulphur, multiplied by the heating value of one pound of sulphur burned into sulphur dioxide; and to this is added the amount of heat generated by the combustion of the hydrogen not already united with the oxygen present. The amount of this hydrogen is determined by subtracting one-eighth of the amount of the oxygen present from the hydrogen present. This is done because the hydrogen and oxygen unite by weight in the ratio of 8 parts of oxygen to 1 part of hydrogen. Therefore for every 8 parts of oxygen present 1 part of hydrogen is made useless for heating. For example, take a coal of the following composition: moisture 17 per cent, sulphur 2 per cent, hydrogen 6 per cent, fixed carbon 55 per cent, and oxygen 20 per cent. The computation would be as follows:

$$(62{,}100 \text{ times } (.06-\frac{.20}{8})) + (14{,}500 \text{ times } .55) + (.02 \text{ times } 4{,}000) = 10{,}242.5 \text{ B.T.U.}$$

This heating value is only realized when enough oxygen is furnished to the fire to completely burn the carbon into carbon dioxide. Whenever the supply is insufficient the carbon passes off in the form of carbon monoxide, and only about one-third of the theoretical heat of the carbon is realized. This is the strongest reason for good draft and good draft equipment. In fact, the analysis of the flue gases from any boiler plant will show the presence of carbon monoxide, and the amount present will be a direct measure of the heat that is being derived from the coal burned.

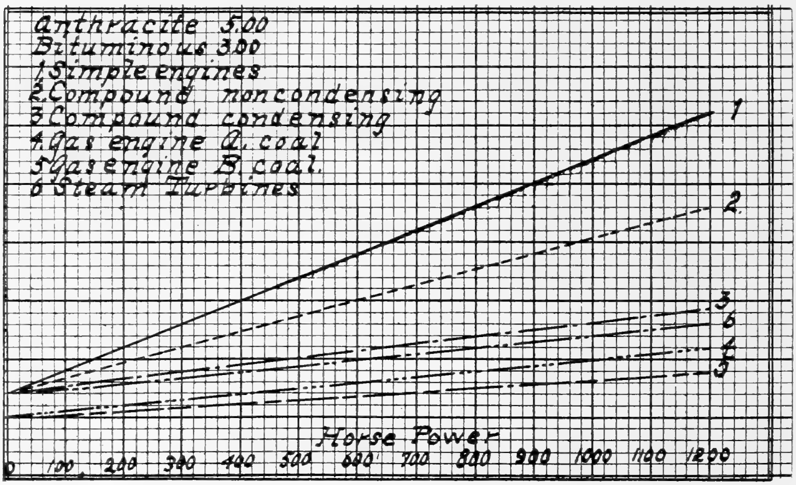
The air required for the combustion of a pound of coal can be figured from the example given above as follows:

Twelve parts by weight of carbon unite with 32 parts of oxygen; 8 parts by weight of oxygen unite with 1 part of hydrogen; and 1 part of sulphur by weight unites with 1 part of oxygen.

Therefore the coal of the analysis used in the other problem would need

$(\frac{32}{12}$ times .55) plus .02, plus (8 times $(.06-\frac{20}{8}))$ equals 1.7667 pounds of oxygen

Since air contains about 23 parts of oxygen by weight, in 100 parts, the air required would be 1.7667 times 100 divided by 23, equals 7.68 pounds of air per pound of coal burned. Since 1 pound of air at 62 degrees Fahrenheit has a volume of 13.14 cubic feet it would require 7.68 times 13.14, equals 100.915 cubic feet of free air per pound of coal burned. Since these ideal results cannot take place in the exact amounts as given for the reason that the oxygen cannot all be brought in contact with the



Plot 5 is given to show the fuel cost of different types of equipment. The cost of bituminous coal is taken as $3 per ton. The plot is reproduced from Roger's *Industrial Chemistry.*

combustible material to be burned, it is customary to figure 12 pounds of air per pound of coal burned, or in general 160 cubic feet of free air.

Method and care in firing are very important in realizing all the heat possible from the fuel burned, for altho a plentiful supply of oxygen is necessary to the proper combustion of the coal, an excess of air will cool the hot gases below their ignition points, and cause them to pass off without being burned. Stoking may be done either by hand or by mechanical stokers. The latter are much more economical in large plants, but most of the small plants of the stone district employ hand-stoking. The spreading method of stoking is the one in common use. The following rules for hand-firing have been formulated by the Coal Stoking and Anti-Smoke Committee of the Illinois Coal Operators' Association for hand-firing with Illinois and Indiana coals:

1. Break all lumps, and do not throw any in the furnace that are larger than your fist. The reason for this is that large lumps do not ignite promptly and their presence also causes holes to form in the fire, which allow the passage of too much air.

2. Keep the ash pits bright at all times. If they become dark this is evidence that the fire is getting dirty and needs cleaning. If this is not done, imperfect combustion and smoke will result. If the furnace is equipped with a shaking grate, it should be operated often enough to prevent any accumulation of ashes in the fire. Do not allow ashes to collect in the ash pits, since they not only shut off the air supply, but they may also cause the grate to be burned.

3. In firing do not land the coal all in one heap, but as it leaves the shovel spread it over as wide a space as possible. A little practice will enable one to catch the proper motion to give the shovel in order to make the coal spread properly.

4. Place the fresh coal from the bridge well forward to the dead plate, and do not add more than three or four shovels at a charge. If this amount makes smoke it should be reduced till smoke ceases, which means, of course, that firing will be at more frequent intervals than formerly in order to keep up steam. This rule is applied in cases where the boiler is worked at a large capacity. In cases, however, where a small capacity only is required, firing by the coking method, wherein the fresh coal is placed at the front of the fire, and pushed back and leveled when it has become coked, is the best.

5. Fire on one side of the furnace at a time so that the other side containing a bright fire will ignite the volatile gases from the fresh charge.

6. Do not allow the fire to burn down dull before charging. If this is done, it will result not only in a smoky chimney, but also in an irregular steam pressure.

7. Do not allow holes to form in the fire. Should one form fill it by leveling and not by a scoop full of coal. Keep the fire even and level at all times. As far as possible level the fire after the coal has become coked.

8. Carry as thick a fire as the draft will allow, but in deciding

on the proper thickness, judgment must be exercised. If the draft is weak, a thin fire will be in order, but if strong, a thicker fire should be carried.

9. Regulate the draft by the bottom or ash pit doors and not by the stack dampers, because, when the stack damper is used it tends to produce a smoky chimney since it reduces the draft, while the closing of the ash pit door diminishes the capacity to burn coal. If strict attention is given to firing according to the demand for steam, there will be no occasion to have recourse to the dampers except when there is a sudden interruption in the amount of steam being used.

10. A good general rule is to fire little and often, according to steam demands, rather than heavy and seldom. The former means economy in fuel and a clean chimney, while the latter signifies extravagance in fuel and a smoky stack.

The part of the heat of the fuel that can be utilized in the boiler varies with the care given the firing, and engineers state that the boiler that can utilize 80 per cent of the heat is exceptional and 75 per cent represents very good practice. The only boiler plants in the district that reach anywhere near this figure are the larger plants in the better mills of the district. Many of the plants in the older mills and quarries are probably not utilizing over 50 per cent of the heat in the fuel consumed. The losses of heat from a boiler furnace are summed up by Gebhardt in *Steam Power Plant Engineering* (p. 45), as follows:

1 Loss in dry chimney gases.
2. Loss due to incomplete combustion.
3. Loss of fuel through the grate.
4. Superheating the hygroscopic moisture in the air.
5. Moisture in the fuel.
6. Loss due to the presence of hydrogen in the fuel.
7. Unburned fuel carried beyond the combustion chamber in the form of soot or smoke.
8. Radiation and minor losses.

These losses refer only to boilers in continuous operation. In most plants where the load is such that additional boiler equipment must be held in reserve to handle peak loads the loss is much greater.

As a steam plant increases in size, the question of draft always arises, and the relative value of mechanical draft and natural draft has to be considered. There is no question but that with a larger boiler equipment the steaming power of the plant to meet varying loads is increased by mechanical draft. Mechanical draft saves coal and labor cost, but when the life of the installation is compared with the life of a good stack or chimney, the saving is not so apparent. In every form of mechanical draft, power is necessary to drive the machinery, and the machinery works under conditions that cause it to wear out rapidly. Mechanical draft is of two classes: forced draft and induced draft. Both forms have their advantages. In forced draft the air is driven in under the fire to cause the draft, and in this case the gases in the firebox are under higher pressure than the air of the boiler-room and the doors of the furnace must be kept shut or the draft turned off. If the setting of the boilers becomes defective, the boiler-room is filled with smoke which has escaped from the furnace. In induced draft the fan is placed in the stack or the breechings, and sucks the hot gases out of the furnace and tubes. In this case the pressure is lower, and there can be no escaping gases while the fan is running, but the disadvantage of this type of draft lies in the fact that the fan is handling very hot gases which tend in a short time to destroy it.

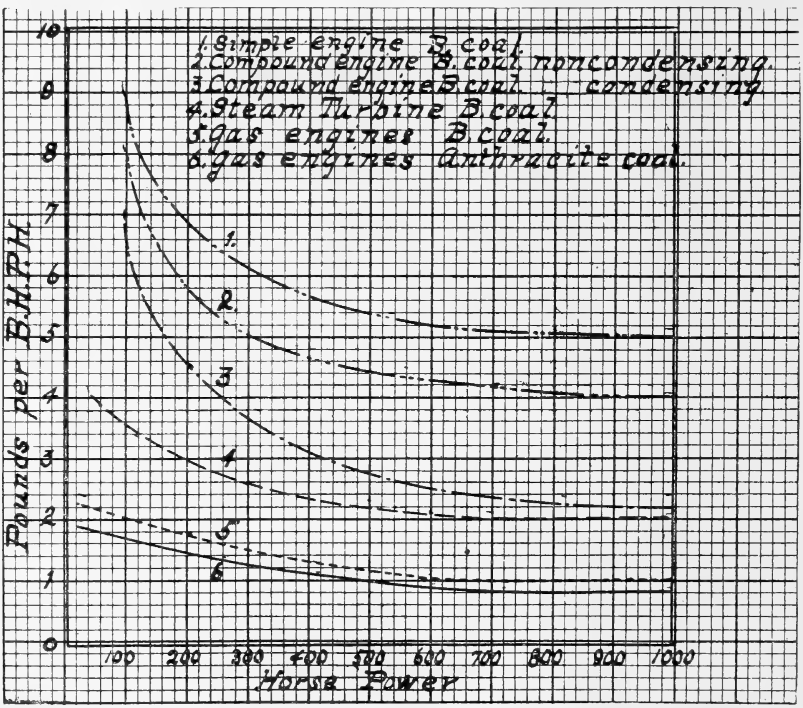
Another consideration is the fact that in induced draft a larger fan is needed to handle the gases after they have been heated in the furnace. Hot gases occupy much more space than the same weight of cold gases. Altho it will require a much larger fan, it will not require increased power in the same ratio, on account of the fact that hot gases are lighter and consequently less power per volume is necessary to handle them.

The power consumption of mechanical draft is usually figured at from 1 to 5 per cent of the total capacity. The cost of installation is from one-fifth to one-third the cost of an equivalent brick stack. In considering this low figure, the life of the equipment must be kept in mind because the cost of upkeep and the life of the apparatus are important factors.

The largest item in the waste heat from boiler and furnace equipment is the heat lost in the hot gases passing up the stack. The following table shows the percentage of the heat of combustion present in the flue gases at various temperatures, under average conditions:

Flue Gas Temperature	Heat Wasted (per cent)
200 degrees Fahrenheit	6.0
300 degrees Fahrenheit	10.6
400 degrees Fahrenheit	15.3
500 degrees Fahrenheit	19.9
600 degrees Fahrenheit	24.5
700 degrees Fahrenheit	29.2
800 degrees Fahrenheit	33.8

The above figures are based upon 26 pounds of air per pound of coal burned, the air being taken in at a temperature of 70 degrees Fahrenheit. It has been calculated that for each increase of 10 degrees in the temperature of the feed water a saving of 1 per cent in fuel can be realized, with a decrease of 20 degrees in the temperature of the escaping flue gases. This saving can be effected by the use of economizers. In the modern types of



Plot 4 gives the approximate fuel consumption of the different types of power-producing equipment.

economizers, a series of cast-iron tubes thru which the hot gases must pass is inserted in the flue between the boiler and the stack. The feed water is led thru these tubes under a pressure that allows it to be heated well above the boiling point, and it is then fed to the boiler at temperatures higher than could be realized with feed-water heaters. The main criticism against economizers is the fact that they interfere with the draft, but with the installation of mechanical draft this objection disappears since high enough draft pressures can be produced with mechanical draft.

Coal handling in the quarry belt is carried on in a very wasteful manner. The power plants of a few of the larger mills are equipped with stokers, but in general hand-firing is practiced. In many of the smaller plants no switch arrangements have been made to bring the coal as near as possible to the boiler plant, and much hand-shoveling and wheelbarrow work is necessary. Of course, with the modern steam quarry machinery this extra handling is necessary, since it would be impossible to deliver the coal directly to the units using it. In figuring the relative cost of electrical and steam equipment, few of the operators take into account the losses resulting from the present methods of handling coal. Coal is brought to the quarry or small mill and dumped in carload heaps. The loss in heating value of coal stored in this way represents a noticeable percentage of its heat value. In addition to this, much of the coal is scattered and lost. I have seen quarries where the entire surface of the quarry opening was covered to a greater or less extent with fine coal. The saving in this regard alone would represent 1 per cent of the power cost for steam channelers, not to mention the saving in the cleanliness of the stone. A fair figure for the saving in cost of labor and fuel that could be realized in a quarry running 4 channelers, a stripping pump, and 2 derricks, if motors were used instead of steam units, would be 10 per cent of the power cost.

As the size of power plants increases, the saving in the use of coal and ash handling machinery becomes more apparent, and after the size of the boiler equipment passes 500 horse-power, hand-handling of the coal is out of the question.

So much has been written on the selection of a suitable engine for almost every line of work that no attempt will be made here to discuss the relative values of the different types. So many factors enter into the selection of an engine that no two operators have the same conditions on which to figure. The factor of first cost is usually the determining one, and in many cases the only one that counts. In all cases where it is possible, the factor of cost per horse-power used should determine the choice. Engine building has developed until the steam consumption of any given type of engine is the same, regardless of what company builds it. The following table from Meyer's *Steam Power Plants* (p. 49), shows the steam consumption of the various types of steam engines:

Type of Engine	Pounds of Steam per Horse-Power per Hour	Steam Pressure, Pounds
High-speed simple	32	80–100
High-speed compound non-condensing	24–26	150–110
High-speed compound condensing	19–21	150–110
Corliss simple non-condensing	26	80–100
Corliss simple condensing	21	80–100
Corliss compound non-condensing	20–22	150–110
Corliss compound condensing	14–15	150–125

It would be safe to say that the coal in use in the district would, with favorable boiler equipment, evaporate 6 pounds of water per pound of coal; so that the annual fuel cost of an engine could be calculated by the following formula:

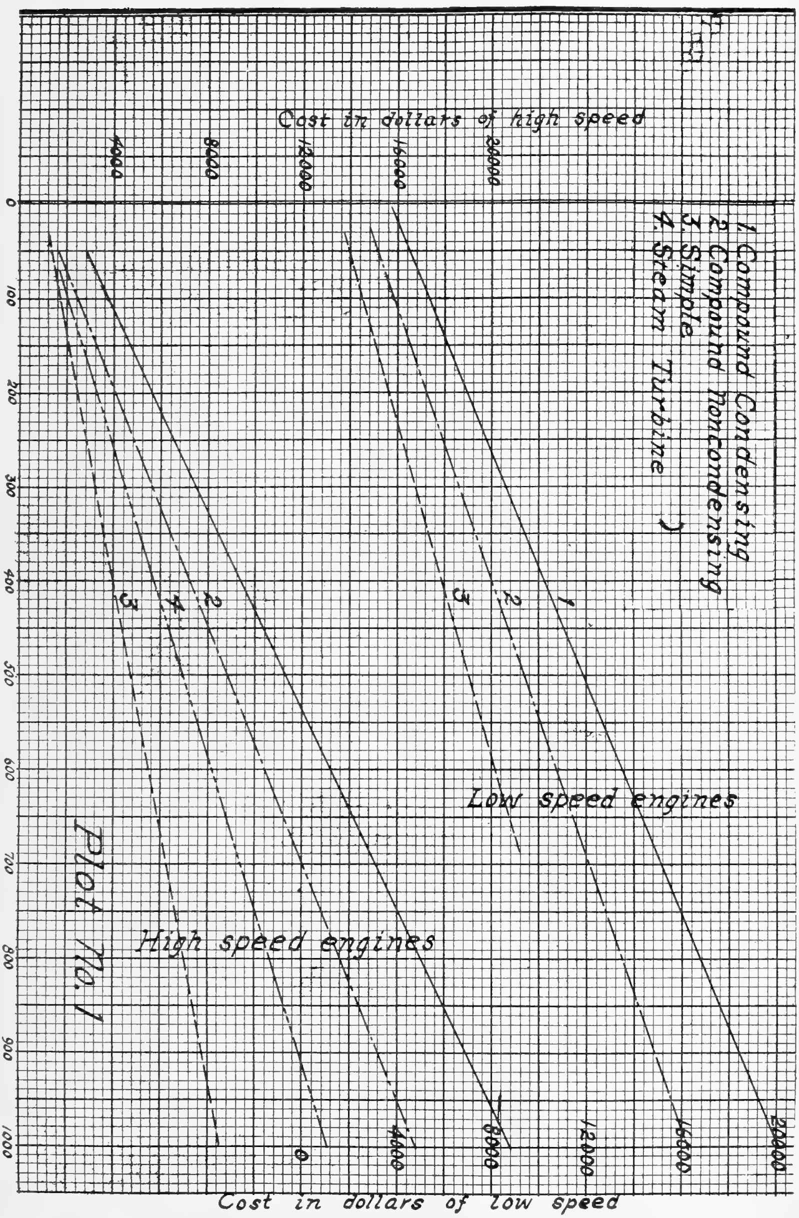
Annual fuel cost equals P $\times$ H. P. $\times$ h $\times$ c divided by (6 $\times$ 2,240)

In this formula, P equals the pounds of steam used by the engine per horse-power per hour. H.P. equals the average horse-power developed. h equals the number of hours during the year that the power is used. c equals the cost of coal in dollars per long ton of 2,240 pounds.

The amount of detail included in full specifications for a steam engine might seem unnecessary to some persons, but this detail is made necessary by the large number of manufacturers in the field and the numerous types of engines produced. To do a given amount of work, an engine should be selected with about double the power required to drive the machinery, because this margin is necessary in order to allow for the loss of power in the form of friction and other losses in belts, shafting, etc., and losses due to wear in service or to neglect.

Transmission. When properly cared for, the leather belt is one of the most generally satisfactory means of power transmission in the long run; but in a few instances rope drive is in use in the stone belt and is giving very good satisfaction. Narrow, double belts are preferable to wide, single belts. A belt speed not to exceed 3,000 feet per minute gives good results, but where higher speeds are desired rope transmission should be used since ropes can be driven at least one-half faster than belts.

The following is a satisfactory method of determining the horse-power of leather belting: Multiply the diameter of the



Plot 1 shows the approximate cost of engines. The lower set of lines represents the cost of high-speed engines with the cost in dollars laid off on the left, while the upper set of lines represents the cost of low-speed engines with the cost in dollars laid off on the right hand of the page. The drawing is taken from Roger's *Industrial Chemistry*.

pulley in inches by the width of the belt in inches and this product by the number of revolutions per minute and divide this number by 2,860 for single belts and 1,720 for double belts.

The following table, furnished from the catalog of one of the manufacturers of shafting, shows the horse-power that can be transmitted by various sizes of shafting running at various speeds.

HORSE-POWER OF SHAFTING

Diameter of Shaft (Inches)	Revolutions per Minute						
	100	125	150	175	200	250	300
$1\frac{3}{16}$	2.4	3.1	3.7	4.3	4.9	6.1	7.3
$1\frac{7}{16}$	4.3	5.3	6.4	7.4	8.5	10.	13.
$1\frac{11}{16}$	6.7	8.4	10.	11.7	13.	17.	20.
$1\frac{15}{16}$	10.	12.5	15.	17.	20.	25.	30.
$2\frac{3}{16}$	14.3	17.8	21.	25.	28.	35.	43.
$2\frac{7}{16}$	19.5	24.4	29.	34.	39.	49.	58.
$2\frac{11}{16}$	26.	32.5	39.	43.	52.	65.	78.
$2\frac{15}{16}$	33.8	42.2	51.	59.	67.	84.	101.
$3\frac{3}{16}$	43.	53.6	64.	78.	86.	107.	129.
$3\frac{7}{16}$	53.6	67.	79.	94.	107.	134.	159.
$3\frac{11}{16}$	65.9	82.4	98.	115.	121.	165.	196.
$3\frac{15}{16}$	80.	100.	120.	140.	160.	200.	240.
$4\frac{7}{16}$	113.	142.	171.	199.	228.	285.	342.
$4\frac{15}{16}$	156.	195.	234.	273.	312.	391.	469.
$5\frac{7}{16}$	208.	260.	312.	364.	416.	520.	624.
$5\frac{15}{16}$	270.	337.	405.	472.	540.	675.	810.

The principal cause of loss of power in shafting is improper alignment and poor bearings; and much of this loss could be avoided by proper care at the time of the installation.

When we come to figure the cost of power transmission it is readily seen that electrical transmission is far cheaper after it is once installed. The best arrangement for power transmission to the different machines of the mill or quarry is by electric wiring, and the use of an alternating current motor at each machine. The mills are rapidly adopting this arrangement.

The use of electric motors of all types in the mills and quarries is increasing, and with the effort of central power plants to furnish current to a number of plants in the district the use of alternating current motors especially has become widespread. The relative value of the two types of equipment (direct and alternating-current motors) in plants where the current has to be carried but a short distance is still a question, but where the current is transmitted any considerable distance the alternating current is undoubtedly the better. The advantages of the use of alternating current lie in the fact that there is less heating, and that no high voltage is carried thru sliding contacts. Probably the best results are obtained in this type of work by three-phase sixty-cycle motors. Many of the operators who were using direct-current motors and generators in their plants, and have since begun to purchase power from the local power companies have installed motor-generator sets instead of putting in alternating-current motors. In most plants the alternating-current motors have been installed with the stone-working machinery, but small motor-generator sets are used to furnish direct current for the motors on the cranes.

A type of machine that should be of interest to the manufacturer who uses but a medium amount of power is the self-contained engine and boiler equipment known as the locomobile. The engine of this equipment is set upon the boiler with the cylinders projecting into the smoke box so as to minimize piping and radiation losses. These engines are built in units up to 800 horse-power. They are widely used in Europe but are just beginning to be developed in this country. One German firm alone has built over 1,000,000 horse-power of these machines. The following description is taken from the catalog of an American manufacturer of locomobiles:

It consists of a compound engine mounted on an internally-fired boiler, the engine cylinders being inclosed in the smoke box which also contains a superheater, a reheater, and all high pressure piping and valves as well as the intermediate piping. A special casing compels the hot gases to traverse the superheater and reheater before emerging into the smoke box proper on their way to the stack. The engine drives a pump which feeds the boiler through a tubular heater in the exhaust line. The engine exhausts into a suitable condenser equipped with an air pump also directly driven from the main engine. The boiler is of the internally-fired type and the machine does not need elaborate brick work further than a firm foundation. The engine is of the tandem compound center crank type.

Among the advantages claimed for this type of power generator are the following:

1. Small floor space.

2. Cheap foundations as compared to the ordinary boiler and engine plant.

3. Economy in fuel consumption in small plants. Tests have been made on a locomobile of medium power which showed a coal consumption per horse-power per hour as low as $1\frac{3}{4}$ to $2\frac{1}{2}$ pounds; and steam consumption as low as 9.2 pounds per horse-power hour.

4. Dependability and easy supervision.

5. Universal application and universal fuel.

In this engine, steam is generated at a pressure of 175 to 225 pounds absolute, and is superheated to 800 degrees Fahrenheit, before it is admitted to the high-pressure cylinder. Exhaust steam is reheated to a temperature of 500 degrees Fahrenheit before it is admitted to the low-pressure cylinder. The feed water is heated by an economizer placed in the breeching. Some of the larger units on test have shown a coal consumption as low as 0.8 pounds per horse-power per hour and many tests have shown as low as 1 pound per horse-power per hour. The lowest steam consumption recorded is about 7 pounds per horse-power.

The fact that the locomobile uses superheated steam and runs condensing even in comparatively small units, accounts for its economy over the simple steam engine and boiler plant.

With regard to the coal consumption and steam used per horse-power per hour the following letter from one of the largest manufacturers of locomobles in this country will probably be of interest. For the sake of comparison I am introducing with it an extract from a letter from one of the large engine manufacturers which gives the steam and coal consumption of a high-grade automatic engine for the same service:

Dear Sir:

In reply to your letter of the 7th stating that you are figuring on an ideal plant for furnishing power for a small stone mill, in any work where economy is desired and over a wide range of load, a locomobile is very well adapted. We are enclosing herewith some power plant tests which we have run on this unit and the coal consumption is the same at three-fourths load and rated load, while at one-half load and one and one-fourth load the increase is very slight, being about 3 per cent more at one and one-fourth load and less than 15 per cent at one-half load, while with the ordinary plant the percentage of increase in steam consumption or coal consumption is very much greater at fractional loads. Would say roughly that with coal having 14,000 B.T.U. and not more than 40 per cent volatile matter we can produce a horse-power with a locomobile on $1\frac{1}{2}$ pounds per I.H.P. per hour between three-fourths and rated load when operating condensing. The amount of coal used for banking the boilers at night would be approximately 10 per cent of the amount used during a 10-hour run.

Locomobiles cost from $60 per horse-power in the 75 horse-power units to $47.50 per horse-power in units of 600 horse-power. That is, a 75 horse-power locomobile would cost $4,500 while a 600 horse-power unit would cost approximately $28,500. The two letters can be compared by adding one-third to the horse-power consumption to give the kilowatt consumption. This method of figuring will give a comparatively accurate result. The second letter is as follows:

Dear Sir:

We have you favor of the 29th inst., and would state that a 100-kilowatt single-cylinder engine, with 120 pounds steam at throttle, will give a steam consumption per indicated horse-power per hour at full load of 26 pounds, and at one-half load of 28 pounds.

Inasmuch as you will have boiler and line losses, and the steam will come to the engine somewhat wet, and inasmuch as you have the friction loss of the engine and the factor of generator efficiency to be taken care of, 6 or 7 pounds of coal per kilowatt hour is as low as you should figure.

It takes about 600 pounds of coal to bank a 150 horse-power boiler all night, and this should be added in.

With good oiling system, the engine should not consume more than one dollar's worth of engine oil per month; and the cylinder oil should not cost more than 30 cents per day.

If you are going up into the larger sizes, if you installed a compound engine you could cut about 1½ pounds off the coal consumption per kilowatt hour.

Another economical type of engine for ordinary power generation is the oil engine. In this type of engine oil is burned in the cylinders the same as gas is burned in the gas engine. Several general types are in the field; the main difference between them lies in the method of preparing the oil charge for ignition and firing the charge.

Oil engines offer a cheap method of producing power in medium-sized plants, but the one drawback is the dependence of the operator on the prices fixed for oil by the company controlling the output in this country.

The only oil engine plant in operation in the stone belt at the present time is the one run by Harding and Cogswell at Ellettsville. The engine in use is a 40 horse-power Fairbanks-Morse and is giving excellent satisfaction. The cost of power in this plant will be taken up in the part of this study which deals with the cost of power.

Another type of prime mover that is of interest in connection with any discussion of power, especially power in large plants, is the steam turbine. Steam engines are of two general classes:

reciprocating engines and turbines. Either of these types may be run either condensing or non-condensing. In the reciprocating engine, the moving parts, including the piston, connecting rods, etc., stop and reverse their direction of motion twice during each complete revolution of the flywheel. That is, the piston is constantly passing the same point but reversing its direction of travel. In the turbine all the moving parts are rotating with a constant motion. The term non-condensing, when applied to an engine, indicates that the steam from the cylinders is exhausted against a back pressure equal to the pressure of the atmosphere, which is approximately 14.7 pounds per square inch. This back pressure can only be reduced by exhausting the steam into as high a vacuum as can be maintained by the engine pumps. This gives an added pressure on the pistons equal to the amount of vacuum that can be maintained. The saving due to the use of condensers on small power units is not enough to justify the expense of installing condensers, but as soon as the plant reaches a fair size they are an economical proposition. In the steam turbine the steam is driven against the blades of a fanlike rotor by means of a single set of nozzles, in the single-stage turbine, or thru a series of nozzles, in the multi-pressure types. The low first cost and adaptability of the turbine to driving generators make it an ideal prime mover in such plants.

Producer Gas and Producer-Gas Machinery. There are three principal natural fuels: coal, oil, and gas. Of these we are most familiar with coal for the reason that its use as a source of power has been known longer and the deposits are more widespread. Oil carries the most stored energy, but the supply is more limited. Gas is the most convenient, but the supply of natural gas is already decreasing and its use is confined to small areas where it occurs. The experiments with natural gas as a source of power have led to the production of artificial gas.

The use of steam machinery as a means of power generation is admitted by everyone who has gone over the figures to be a most extravagant waste of our coal resources. With the country-wide cry for a better conservation of our natural resources, the coal situation has occupied the attention of thinking people more than any other issue. It would seem that if any considerable portion of the heat in our coals which is being lost by our present methods of power generation is to be saved, it will have to be by some other method than by improving steam power machinery. The generation and use of steam in engines as a source of power has been understood for a long time, and many of the best engineers have studied the development of the boiler and engine until this type of power plant is now comparatively near the highest point of development that can be hoped for. And in its present high state of development, it stands condemned as most wasteful. The following figures as to the percentage of the heat of the coal that can be turned into mechanical energy in the steam plant should be of interest in this connection. These figures are taken from Gebhardt's *Steam Power Plant Engineering* (p. 4):

	B.T.U.
Heat value of 1 pound of coal	14,500
Boiler and furnace losses, 50 per cent	7,250
Heat of the steam 50 per cent	7,250
Heat equivalent of one horse-power hour	2,545
Heat used to develop one horse-power hour (50 pounds of steam per horse-power hour, pressure 80 pounds gauge, feed water 62 degrees Fahrenheit)	57,500

	Per Cent
Percentage of the heat in the steam realized as work $\frac{2,545}{57,500}$	4.4
Percentage of heat value of the coal realized as work $\frac{2,545}{57,500 \div 0.50}$	2.2

The above is given as an average output for a small steam plant.

The dissipation of the heat of the coal in a large steam plant has been figured as follows:

	B.T.U.
Lost in ashes	135
Lost in radiation from boiler	675
Carried off in stack gases	2,970
Carried off in auxiliary exhaust	190
Lost in radiation and leakage in main pipes	210
Lost in radiation and leakage in small pipes	30
Lost in radiation and leakage in engine pipes	280
Rejected to condenser	7,737
Total loss in one pound of coal	12,227
Converted into power	1,273
Coal value	13,500
	= 9.43 per cent.

The above figures show what has been done toward developing the steam engine into an economical power producer. It seems therefore that the time has come to begin casting about for some more economical type of power unit. The rapid development of the gas producer and gas engine seems to promise the most reliable substitute for the steam plant. It is confessed by every good engineer that the steam plant that can utilize 12 per cent of the energy in the coal is exceptional, and this can only be reached in the best equipped and most modern large-unit plants.

It has long been observed that when coal is thrown upon a hot fire a portion of it bursts into flame, or goes off as gases and smoke. This portion is known as the volatile matter of the coal. The solid portion remaining behind has been called coke, and this part consists largely of carbon but also contains the ash or non-burning part of the coal. When coal is treated in retorts for the coal gas, the coke remains behind as a by-product. It was found that this coke, or at least the carbon in it, could be burned into carbon monoxide provided the supply of oxygen was kept low enough so that the formation of any considerable quantity of carbon dioxide was impossible. This led to the modern process of producing gas from coal by passing a moderate supply of air with or without steam thru a thick fuel bed at a high temperature. In this way the combustible matter of the coal can be driven off as gas, without the production of coke. This gas is called producer gas and the apparatus used is called a gas producer. There are at present manufactured in this country three distinct types of gas producers: the suction producer, the pressure producer, and the down-draft producer. There are also combinations of the up-draft and the down-draft producer, called double-zone producers. In the suction producer the draft of air thru the producer is produced by the suction of the engine cylinder. In this type the supply of air is liable to be enough to interfere with the production of a satisfactory gas and so steam must be added to the draft. The necessary steam is generated at atmospheric pressure by the hot gases leaving the producer and is drawn into the producer with the air supply. As this mixture of air and steam comes into contact with the highly-heated lower part of the fuel bed, the oxygen of the air and the oxygen of the steam combine with the carbon to form carbon dioxide. As the carbon dioxide passes up thru the higher parts of the fuel bed it is reduced to the monoxide, and the hydrogen in the steam passes on with the carbon monoxide formed.

In the pressure producer the air is driven into the producer under pressure and the gas is stored in tanks for use in the engine.

The air blast is heated by an economizer which receives its heat from the hot gases as they leave the producer. The storage of the gas before it is used in the engine makes it possible to remove tar or other impurities, and hence bituminous coals, lignite, or peat can be used.

In the down-draft producer the gases are drawn downward thru the coal bed instead of upward as in the other types. In this way the tar and tarry vapors which would distill off of the new coal as it is fed to the fire are drawn down into the hot fuel bed and burned into fixed gases which can be delivered to the engine in gaseous form. The down-draft producer is well adapted to burning low-grade coals in which the loss of the tar would be serious. In large installations where by-products recovery is practicable, the other types can successfully compete with the down-draft type.

I will not attempt here to go into the details of construction of the different types of gas producers. The development of the gas producer has been rapid and there is already an extensive literature of the subject. The work of the United States Bureau of Mines on the gas producer and its development in this country has done much to give us a better understanding of its operation. The following publications of the U. S. Bureau of Mines, Washington, D.C., treat of various phases of the producer-gas problem and are for free distribution: namely, *Bulletins* 4, 7, 13, and 31, and *Technical Papers* 9 and 20.

Producer-gas installations in the United States at the present time number over 1,000, ranging in power from 15 horse-power up to several thousand. The total horse-power is over 300,000. During the period from 1909 to 1912 the number of producer-gas plants of over 500 horse-power rating which were using bituminous coal increased 118 per cent and the toal horse-power increased 89 per cent.

Producer gas is in reality a mixture of gases, and may be classed under the three following heads: air gas, mixed gas, water gas. The first of these results when the gas producer is blown with dry air; mixed gas results when the producer is blown alternately with air and steam; and when the producer is blown with steam, water gas results. In all cases the amount of carbon in the coal is the factor that chiefly determines the value of the gas. The incomplete combustion of a pound of carbon into carbon monoxide yields 4,450 B.T.U., and the gas formed carries with it to the engine the additional 10,231 B.T.U. that would have been given up if the combustion had been complete and the entire product had passed off as carbon dioxide. This represents 70 per cent of the heating value of the coal and with dry-air blast the other 30 per cent is dissipated in the producer. When this is done the temperature of the fuel bed is raised accordingly, so that when steam is introduced into the bed the steam is decomposed into oxygen, which combines with the carbon of the coal, and hydrogen, which passes in this form to the engine. Here it is again burned into steam. Thus much of the 30 per cent which remained behind in the fuel bed when the air blast was running is saved by the steam blast. The steam also reduces the temperature of the fuel bed and lessens the amount of clinkering.

The successful gas producer should have the following features:

1. A deep fuel bed carried on top of a deep bed of ashes; the first to make good gas, and the second to prevent waste of fuel.

2. Blast carried by conduits thru the ashes to the incandescent fuel.

3. Accessibility of the ash bed and proper arrangements for the removal of the ashes.

4. Level, grateless support for the burden, insuring uniform depth of fuel at all points, and consequent uniformity in the production of gas.

The following table showing the distribution of the heat of the coal when used in producer-gas power plants and steam plants is of interest. The coal used was of 13,000 B.T.U. thermal efficiency.

	Steam Plant	Gas Plant
Heat lost in ashes	2.00	1.10
In radiation and cooling	4.60	18.60
Heat lost in smoke	24.60	none
Heat lost in engine radiation	3.30	4.30
Heat lost in exhaust	53.50	23.70
Heat lost in water jacket	none	33.50
Lost in auxiliaries	7.30	none
Total heat losses	95.30	81.20
Net efficiency of the plant	4.70	18.80

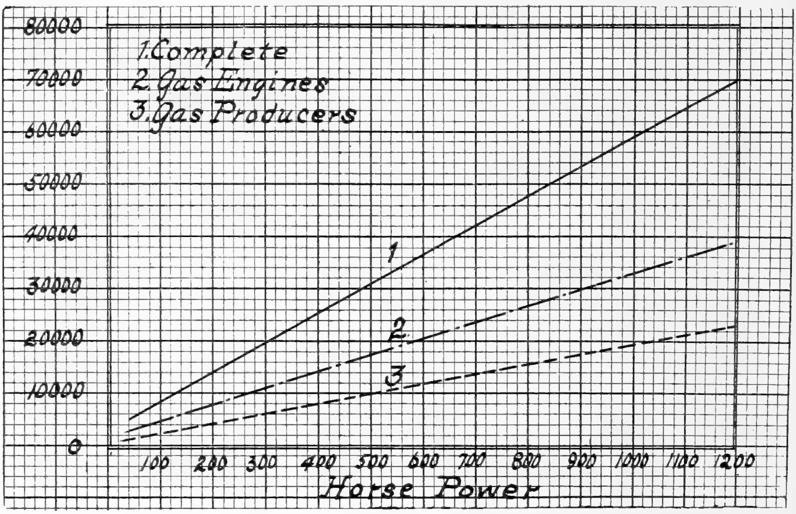
This table was taken from a catalog of producer-gas equipment, but it is corroborated by numerous tests.

The amount of gas produced from a pound of coal differs according to the kind of coal, the type of producer, the number of pounds of fuel gasified per square foot of fuel bed, and the regulation of the draft. The quantity of gas obtained per pound of bituminous coal under average conditions is given in *Bulletin* 13 (U.S. Bureau of Mines, 1913), as 60.5 per pound of coal as fired. The heat value of producer gas as compared to natural gas is on the average about one-fourth to one-fifth, or about 125 B.T.U. per cubic foot under standard conditions. The following is an average analysis of producer gas made in a downdraft producer:

	Volume Per Cent
Carbon dioxide (CO_2)	9.23
Oxygen (O_2)	.16
Ethylene (C_2H_4)	.04
Carbon monoxide (CO)	17.53
Hydrogen (H_2)	11.85
Methane (CH_4)	1.08
Nitrogen (N_2)	60.11
Total	100.00

Producer gas, in addition to being of value as a means of power production, is useful in the manufacture of iron and steel, annealing, enameling, brazing, soldering, drying, japanning, galvanizing, evaporating, tempering, and case hardening. In addition to its numerous other uses, it is of value in lime, cement, and brick kilns. In the burning of lime the application of producer gas enables the operator of the kiln to secure the long, soft flame characteristic of wood firing, and at the same time escape the localization and intensity of oil or natural gas. Troublesome overburning and underburning is eliminated and the quality of the lime produced is constant. It eliminates the difficulty of having ash in the product, which results from coal firing. It allows the use of larger kilns than could be used with short-flame coals. With no ash the clinkering and irregularities of operation arising from its fusion with the lime are absent, while the cost of attendance is reduced to a small fraction of that of coal firing. Producer-gas firing is readily controlled and gives a long, slow flame with medium heat, which is ideal for lime burning. The fact that producer gas can be obtained from any grade of fuel makes the operator independent of the fuel supplies of the locality.

In by-product recovery the nitrogen of the coal is converted into ammonia, which is taken up in dilute sulphuric acid, forming ammonium sulphate. A ton of coal under average conditions will yield from 60 to 80 pounds of commercial sulphate. This sulphate is worth about 30 cents a pound. The immense amount of nitrogen lost from our coals as now fired, that could be made available for fertilizing material if it were recovered as a by-product, is appalling, and shows very poor economy.



Plot 3 is given to show the approximate cost of gas producers and engines and the combined cost of engines and producers.

Cost of Power. The cost of power in the power plant of a quarry or mill, altho of interest, is an item not generally known by the operators, especially those operators who have small plants. The factors which enter into a calculation of this cost are so many and so varied that few of the operators care to go to the expense of making the tests necessary to determine them. The various expenses incurred in the operation of a power plant can be grouped under two heads: fixed charges and operating costs. Under the first head come: (1) interest on investment; (2) depreciation in value of machinery; (3) insurance; (4) taxes. Operating costs include: (1) labor or attendance; (2) fuel and water; (3) oil, waste, and supplies; (4) repairs and maintenance.

Fixed charges are those costs which are independent of the output of power of the plant. In other words, they go on whether the plant is in operation or not. The cost per kilowatt hour due to fixed charges, of course, decreases with an increase of output, but the total charge does not vary. The rate of interest varies with different conditions, but for all calculations the rate will be placed at 5 per cent, since this represents a fair average.

Depreciation is the loss in value of a piece of apparatus with increase in age. The methods of determining depreciation are almost as numerous as the number of operators trying to determine it. The main object of setting aside this fund or charging it against power cost is to have available a sufficient sum of money to replace the machinery when it wears out or becomes obsolete. Power machinery decreases in value from its cost price to scrap value during its useful life, and if the price of new machinery is to be available at the end of that time, it must be charged against the power and set aside during the time the machine is in operation. The figure for depreciation used in the following calculation is 8 per cent. Of course, the rate will vary with the normal life of the apparatus, that is, the time it should run and give good service if properly cared for. The data of the following table on the average life (in years) of power-plant and stone-working machinery were collected from various articles on depreciation and from the observations of mill and quarry operators in the stone district:

Buildings	25	Heaters, open	20
Stacks, brick	40	Heaters, closed	15
Stacks, guyed sheet-iron	12	Belts	5
Boilers, water-tube	25	Generators, direct current	18
Boilers, fire-tube	18	Generators, alternating current	20
Pumps	15	Motors, direct current	18
Piping	18	Motors, alternating current	20
Engines, high-speed	15	Diamond saws	6
Engines, low-speed	20	General stone machinery	20

The figures given above are only relative and are based on data given by men who have not made a practice of collecting such data. They would therefore be subject to considerable variation.

While no definite rule can be applied covering charges for taxes and insurance, they have been lumped at 2 per cent on the investment.

Under the head of labor must be charged all wages paid to firemen and engineers and for any extra coal handling, etc.

Fuel and water costs represent the cost of these materials laid down at the plant ready for use.

Oil, waste, and supplies include all supplies used about the plant that are not directly chargeable to repairs and maintenance.

Power costs thruout the stone belt, taking into account the above factors, vary widely. The figures cannot be brought down to a definite cost per horse-power per hour, until the load factor of the plant is determined. The load factor is the yearly output of power divided by the rated horse-power, times 24, times 365. In fact, if an operator knew the exact amount of power used per year, the problem would become the very simple one of dividing the yearly cost of power by the horse-power used. Where electrical equipment is in use these figures are easily calculated. Where calculations were made the cost of power in this district was found to vary from 1.65 to 4.23 cents per horse-power per hour. Calculations were made on a few plants only, and are given merely to show in a general way what the present situation is. These figures when calculated on the Kilowatt basis become from 2.21 to 5.67 cents per kilowatt per hour. A number of manufacturing companies that specialize in the types of power machinery used in quarry and mill work were asked to submit figures on the cost of power in plants where their machinery is in use at the present time. In answer to a letter asking for data on the cost of power in a 100-kilowatt plant, or plants of nearly that power, the following data were submitted on the cost of power in a quarry at present in operation in the Oölitic stone belt in Kentucky. Altho the plant is larger than the one I suggested, the data will show what good practice in the stone belt could accomplish. The figures given represent a low power cost in this kind of service, but this results from the high average load, the low cost of labor, and the fact that no machinery is held in reserve. The letter mentioned is as follows:

It would require a 16 by 20 "J" Corliss engine direct connected to a 200 r.p.m.; a 200 K.V.A., 60-cycle direct-connected alternator and belted exciter for same, a water-tube boiler with 2,000 square feet of effective heating surface in the tubes, a feed-water heater, two boiler-feed pumps, a guyed steel smoke stack, etc., and our estimate of cost is as follows:

The engine delivered and erected	$3,400
Foundation for engine	275
One direct-connected alternator, 200 r.p.m. and exciter delivered and erected	2,600
Switchboard and cables to connect switchboard to alternator and exciter	900

One boiler with hand-fired grate, and smoke stack, all erected and bricked up	$3,200
Piping, heat, pumps, pipe covering, etc	2,000
Total estimated cost	$12,375

In a general way the plant as above with one boiler would cost at the present time $80 per kilowatt actual energy at 80 per cent power factor at full load.

If they want a spare boiler the same will have to be added, $3,200.

Our estimate of cost of operation as follows, based on 10 hours per day, 300 days per year, average load of 150 kilowatts, being 450,000 kilowatt hours per year at 50 pounds of feed water per kilowatt hour, being 22,500,000 pounds of water evaporated per year. Assuming the coal to be of pretty good quality (13,000 B.T.U.) they ought to evaporate 7 pounds of water per pound of coal, which would mean an annual coal consumption of 1,607 tons.

1,607 tons of coal at $2 per ton	$3,214
One engineer, who will do his own firing, $75 per month	900
Part of one man's time to wheel coal and ashes	150
We assume that water will not cost anything	
All waste, and engine room supplies	300
Repairs	75
Overhead expenses, being 8 per cent depreciation, 5 per cent interest, 1 per cent insurance, 1 per cent taxes, total 15 per cent of $12,000	1,800
Total annual operating expenses	$6,439

The above gives a cost per kilowatt hour of 1.43 cents.

If the annual load is reduced to 115 kilowatts, 10 hours per day, 300 days per year, the above estimate would change only on the coal cost and result in a cost per kilowatt of 1.65 cents.

Cost of labor, etc., is estimated on Kentucky conditions. If a brick stack is required instead of one of sheet steel, additional cost for the one-boiler plant would be approximately $1,000, and for two boiler plants it would be about $1,700 over the cost of the steel guyed stack, and a concrete stack would probably figure out a little less than brick.

The above estimate is based on using the Ball non-releasing gear Corliss engine.

The following figures as to cost of investment, coal consumption, and other costs were submitted by one of the small operators of the stone district for a calculation of the cost of power. The cost is very low on account of the low first cost of the plant, due to the fact that much first-class machinery was purchased second hand in perfect condition at a very low price and that the repair bills had been exceptionally low since the plant began operation. The plant is kept in good condition and has been in operation for three years.

The average load is figured at 40 horse-power per hour with a 10-hour day run for 200 days per year, which would be equal to 80,000 horse-power hours per year. With a yearly power cost of $1,817.75 as shown in the data submitted, the cost per horse-power per hour will be 2.27 cents or 3.04 cents per kilowatt per hour. The yearly cost of $1,817.75 can be itemized as follows:

COST CHARGEABLE TO DEPRECIATION

	Cost	Age	Depreciation (Per cent)	Depreciation	Condition
Building	$400	3	4	$16	New, good.
Boiler	$1,800	5	10	180	Good. Second hand
Engine		9			Fair.
Foundations	600	3	10	60	New, good.
Pumps	100	6	10	10	Second hand.
Piping	100	3	10	10	New, good.
Stack	60	3	8	4.80	New, good.
Heater	85	3	6	5.10	New, good.
Dynamo	265	3	6	15.90	New, good.
Switchboard	115	3	5	5.75	New, good.
Wiring	75	3	5	3.75	New, good.
Belting	160	......	25	40	New, good.
Shafting	75	8	4	3	Second hand.
Total	$3,835			$354.30	

TOTAL YEARLY COST

Cost chargeable to depreciation (as above)		$354.30
Interest (5 per cent)		191.75
Taxes and insurance (2 per cent)		76.70
Operating charges—		
Labor, one man at $12 per week	$500.00	
Coal, 400 tons at $1.65 per ton	660.00	
Oil	10.00	
Repairs (none except for belting)	......	
Waste	25.00	
		$1,195.00
Total all charges		$1,817.75

The following figures were submitted for the power plant of a small mill in which the only electrical equipment was a direct-current dynamo driving the cranes. The plant has a full load capacity of 175 horse-power, but the calculations have been made on three-fourths load.

Cost of equipment new—		
Building, just power-house	$600.00	
Boiler, water-tube, 153 rated	1,850.00	
Foundation for boiler	160.00	
Brick work for boiler	500.00	
Iron work for boiler	250.00	
Stack delivered and erected	350.00	
Heater, one piece cast iron with oil separator	155.00	
Pumps	140.00	
Piping and erection of pumps and heater	250.00	
Engine, 14 x 36, 100 r.p.m.	1,600.00	
Freight and hauling	100.00	
Foundation for engine	400.00	
Belts and shafting	400.00	
Dynamo and wiring for same	675.00	
Total cost of plant		$7,430.00
Operating cost—		
Coal, 120 tons per month, 10 months, $1.55 per ton	$1,860.00	
Labor, engineer $15 per week, fireman $10 per week	1,000.00	
Waste and supplies	200.00	
Repairs	100.00	
Total		$3,160.00
Fixed charges—		
Interest at 5 per cent	$371.50	
Depreciation at 8 per cent	594.40	
Insurance at 1 per cent	74.30	
Taxes at 1 per cent	74.30	
Total		$1,114.50
Yearly cost of power		$4,274.50

Figuring on three-fourths load as 130 horse-power for 10 hours per day and on 200 days per year, the cost per horse-power per hour would be 1.65 cents. This would be equivalent to a cost of 2.21 cents per kilowatt hour. This figure is low, since there are few mills that could figure on a load factor as high as three-fourths load. In most cases it would not in all probability go over 50 per cent, and in such cases the costs would be 2.44 cents per horse-power, or 3.27 per kilowatt per hour.

In connection with the cost of power in small units other than steam units, the cost of power in the small oil-driven plant now in use in one of the small stone mills is interesting. The engine as before stated is a 40 horse-power Fairbanks-Morse engine, and, according to the owners, cost approximately $1,400 installed. The fuel used cost 7½ cents per gallon, and the consumption was about 11½ gallons per day of 10 hours. The cost of power on such a basis is as follows:

Fixed charges—		
Interest at 5 per cent	$70.00	
Depreciation at 8 per cent	112.00	
Insurance and taxes at 2 per cent	28.00	
Total fixed charges		$210.00
Operating costs—		
Cost of fuel at 7½ cents per gallon, 11½ gallons per day, 200 days per year	$172.50	
Repairs, 3 per cent on investment	42.00	
Supplies	25.00	
Labor of one man, part-time office work	100.00	
Total operating cost		$339.50
Total power cost		$549.50

A 50 per cent load factor for 200 days of 10 hours each gives 40,000 horse-power hours, or a cost of 1.37 cents per horse-power per hour. This is about 1.7 cents per kilowatt hour.

These figures compare favorably with figures given on a 20-kilowatt oil plant by R. L. Streeter in the *Factory Magazine* where the total cost of the installation was given as $2,200 and total power cost as $973, giving a cost of 2.1 cents per kilowatt hour.

The same authority gives the cost of a 100-kilowatt plant as $13,100, with total power cost as $3,810 or a cost of 1.69 cents per kilowatt hour.

Many of the plants are growing in size, and as the machinery in use at the present time gives out, the owners are casting about to determine the approximate cost of power with a larger plant or trying to determine when the saving will justify scrapping the machinery now in use. For this reason I will try to outline roughly the cost of power plants of 250 and 500 kilowatt capacities.

A 250-kilowatt oil engine plant can be installed for approximately $31,000 with a total power cost of $7,000 per year, or about 1.6 cents per kilowatt hour.

A steam plant of the same size would cost about $16,000 with a total power cost of $10,000 per year, or about 2 cents per kilowatt hour.

The same authority divides these costs up as follows:

Engine and foundations	$5,980.00
Boilers and pumps	5,770.00
Generator and switchboard	3,250.00
Stack, etc	1,000.00
Total	$16,000.00

Fixed charges at 14 per cent	$2,240.00
Labor	1,890.00
Fuel, oil, waste, etc	4,990.00
Repairs	880.00
Total	$10,000.00

The cost per kilowatt hour was calculated on a 66 2-3 per cent load for 300 days of 10 hours each, as 2 cents per kilowatt hour.

I corresponded with a number of the manufacturers of power machinery, and they submitted the following figures on installations of this size:

Water-tube boiler with stack, including transportation to Bloomington, Ind., and complete erection of the same	$4,550.00
Engine with foundation and pumps delivered	5,170.00
Water heater, piping, etc	750.00
Generator switchboard and wiring	5,100.00
Total	$15,570.00

With the lower cost of coal and labor in Bloomington and the shorter run of the stone mill, and 2,000 working hours per year, the total power cost would not exceed $6,290 per year.

At 500 kilowatts the steam plant would cost about $31,000, with a power cost of about $12,000 per year, and the oil engine with generator would cost about $58,000 with a power cost slightly under $10,000 per year. The high cost of bituminous-gas producers makes their use poor economy in small installations, but by the time 500-kilowatt plants are reached they begin to compete successfully with the steam and oil plants. A large producer-gas machinery manufacturing company submitted the following figures on a plant of 500 kilowatts, with four engines, including three of 200 horse-power and one of 100 horse-power:

Installation complete		$45,450.00
Fuel, including lay-over periods, 1,600 tons at $1.50 per ton	$2,400.00	
Fixed charges at fifteen per cent	6,817.50	
Repairs	500.00	
Total power cost	$9,717.50	

Figuring on a three-fourths load, which would be possible in a large plant, the cost of power would be about 1.28 cents per kilowatt per hour.

Since it will be some time before more than a very few of the mills exceed this power consumption, the power problem beyond this point must include the centralization of the power plants and the distribution of the power electrically to the various mills and quarries. Mr. H. St. Clair Putnam in his address before the conference of governors of the United States held at Washington in May, 1908 (*Report of the Conference of Governors,* p. 293), said:

> Electrical transmission of power is the new art which now is resulting in another and radical change in methods of utilizing our power resources, permitting, as it does, development whether by water power or by steam at points most convenient and economical, and transmission to the consumer in form adapted to great variety and convenience of use. This new development in applied science calls for reappraisement of the sources from which our power is derived. The size of the power plant is no longer limited to the requirements of the individual user, but the power for entire communities can be supplied from a single station.

There has been much talk of centralizing the power plant to the extent of having a single plant supply power to the several quarries and mills which are in the same neighborhood, and in many cases this could be carried out economically. The cost of a 1,000 horse-power steam plant with a compound engine and water-tube boilers would be about as follows:

Three 250 horse-power B. and W. water-tube boilers	$10,550.00
Two 500 horse-power compound engines	22,000.00
Foundations for engines and boilers	4,000.00
Stack (steel)	1,200.00
Two 375-kilowatt generators	10,000.00
Exciters for same	800.00
Switchboard equipment and wiring	3,300.00
Piping and installation	2,200.00
Pumps, including condenser and pump equipment	2,100.00
Water heaters	650.00
Superheaters	2,300.00
Incidentals	5,000.00
Total without building	$64,100.00

POWER AND OPERATING COSTS

Fixed charges—		
Interest at 5 per cent	$3,205.00	
Depreciation at 8 per cent	5,128.00	
Taxes and insurance, 2 per cent	1,282.00	
Total		$9.615.00
Operating cost—		
Coal, 5,000 tons at $1.55 per ton	$7,750.00	
Labor	3,640.00	
Repairs	1,100.00	
Oil, waste, etc	1,350.00	
Total		$13,840.00
Total power cost		$23,455.00

Figuring on a 75 per cent load 10 hours per day for 300 days in the year, the cost of power per horse-power per hour would be about 1 cent, and if the run were but 200 days per year with the smaller operating cost of a shorter run it would make the cost about 1.3 cents per horse-power per hour, since the fixed charges would remain the same.

With steam turbines and mechanical draft, and with coal and ash handling machinery, the total investment would be about $63,500, but the total cost of power would be cut to about $21 per horse-power per year, or, if figured on the same basis as above, the cost would be about .93 cents for the longer run and about 1.3 cents for the short year.

It is of interest to compare the approximate figures on the cost of power with a producer-gas plant with the above figures for a steam plant. With the grade of bituminous coal available in the stone belt the cost would be approximately as follows:

Investment cost—	
Bituminous gas producers, figured at $23 per horse-power	$23,000.00
Two 500 horse-power gas engines	38,000.00
Accessories, including draft equipment at $9 per horse-power	9,000.00
Two 400-kilowatt generators	10,000.00
Exciters for the same	800.00
Switchboard equipment and wiring	3,300.00
Foundations	3,000.00
Incidentals	5,000.00
Total	$92,100.00

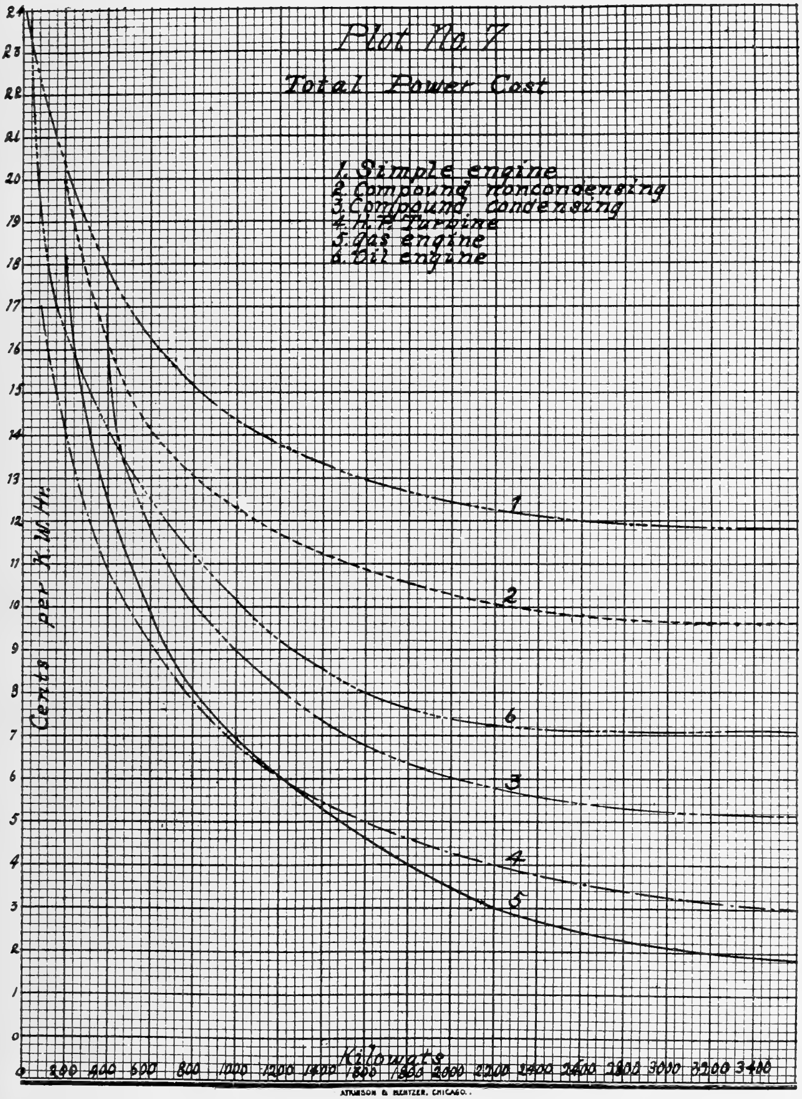
Fixed charges—		
Interest at 5 per cent	$4,605.00	
Depreciation at 8 per cent	7,368.00	
Insurance and taxes at 2 per cent	1,842.00	
Total		$13,815.00
Operating cost—		
Coal, 1,500 tons at $1.55 per ton	$2,325.00	
Labor	3,100.00	
Repairs	920.00	
Oil, waste, etc., including incidentals	1,000.00	
Total		$7,345.00
Total yearly power and operating cost		$21,160.00

Figuring as before on a 75 per cent load for 10 hours per day for 300 days in the year, the cost of power would be .94 cents. Or if the running time were reduced to 200 days, the cost of power would be about 1¼ cents per horse-power per hour.

These figures show that in installations of this size the cost of power is in favor of the gas producer, and as the size of the units increases the difference becomes constantly greater in favor of the gas equipment. Up to this point the value of the by-products from the coal formed in the manufacture of producer gas is hardly great enough to warrant the installation of the expensive machinery necessary for their recovery, but as soon as the size of the plant passes beyond this point, recovery of by-products can be carried on economically.

The power problem in the quarry district is a larger one than the simple matter of installing better small plants and handling them more carefully, altho, as will be seen by the figures already quoted, quite a portion of the present waste could be eliminated even in this way. The greatest saving in the cost of power would result from the production of the power in large central plants and its distribution to the quarries and mills of the district by electrical transmission. The large plant when properly constructed and handled is always a more economical source of power than even the best handled small plant. The stone belt of Southern Indiana is a reasonably compact district, and the problem of a large central plant is therefore a simple one.

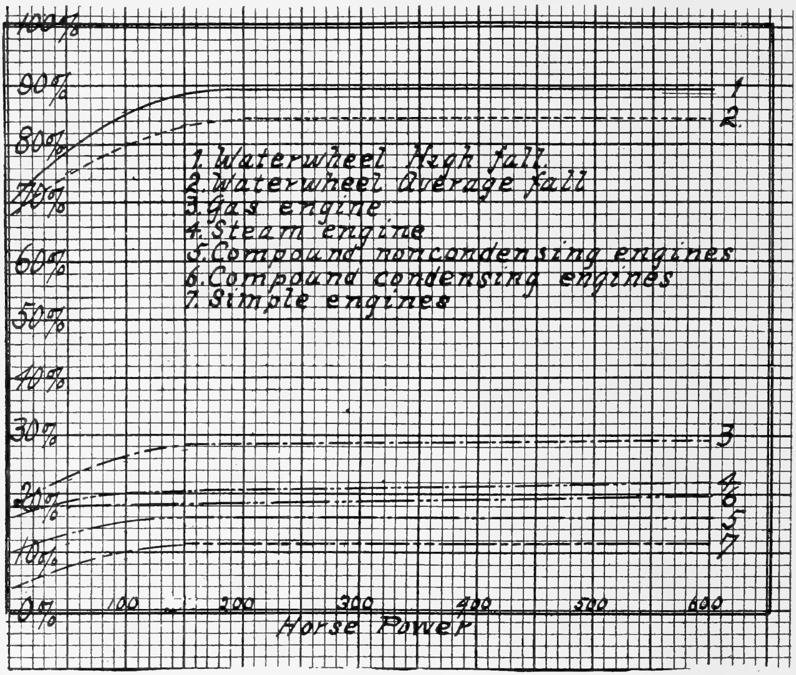
In the treatment of the development of power in central plants three types of plants present themselves for considera-



Plot 7 is given to show the relative total cost of power with the different types of power plant equipment. This plot is the general summation of the data on power costs that I have been able to collect.

tion, as follows: (1) hydro-electric plants, (2) steam-electric plants, (3) producer-gas electric plants.

There is no question as to the low cost of power generated by hydro-electric plants, but when the cost of transmission and the heavy overhead charges are taken into account the economy is not so evident. The use of water power as a solution of the power problem in the stone belt is out of the question. The only available water power is the White river at Williams and this power site is already in use. The amount of power that can be developed at this point is given in the thirty-fifth annual Report of the Indiana Department of Geology and Natural Resources



Plot 6 shows the relative efficiency of different types of power equipment.

(p. 52), as 332 horse-power. This is not enough power to assist materially in the quarry power plants, and at the present time most of the water is used as cooling water in the condensers of the steam plant erected at this place.

From a purely thermal standpoint and as a means of conserving our natural resources, the producer-gas electric plant is much better than the ordinary steam-electric plant for power purposes. If fuel consumption were the only consideration there would be no question as to its superiority over the steam plant, but this item is only one of many to be considered. Up to the present time it has been the commercial efficiency of the steam plant that has allowed it to compete successfully with the gas and the hydro-electric plants. In the consideration of producer-gas installations there are two factors that count against it strongly when an operator or a group of manufacturers is deciding on the kind of power plant to install. First, the gas engine is a comparatively new power unit, and the natural conservatism of the men often causes them to decide to stick to the old way of doing things. This does not mean that the gas producer and gas engine are an untried project, for in fact in foreign countries, especially in Germany and England, they are taking the place of steam plants wherever large power plants are being built. In this country the Bureau of Mines of the United States government has made very extended tests and has indicated its satisfaction with this type of power plant. This would not be so if these installations were not a success in every way. In the second place, the higher first cost is a deterring factor because it is hard to interest capital in making a large investment when a smaller one would do the work, even if higher ultimate returns could be shown for the former. But as the competition in power becomes more keen and the cost of coal increases, gas installations are sure to displace steam plants.

Further figures would probably be of no interest to the stone operators, but I desire to say that among the letters received from the manufacturers of large power-plant machinery, I have figures on steam plants including Sterling boilers with chain-grate stokers and coal and ash handling machinery, economizers and superheaters, and turbo generators with high vacuum condensers, ranging in size from 2,300 to 2,500 kilowatt capacities, in which the power cost was as low as .47 cents per kilowatt hour. I also have received similar figures from producer-gas plants of this size which claim a power cost of .43 cents per hour without by-product recovery.

The power problem of the stone belt is so closely related to the similar problem in the coal mining district of the State, which is located comparatively near the stone belt, that the ideal solution seems to be one common to both industries. Power production at the present time in both districts is costing too much, and this fact is becoming more and more plain to both groups of operators. Large power plants could be located in the coal fields at the mines and the power used in the stone district carried over in the form of high voltage current The ideal power units for such plants would be gas produc.ers and gas engines with by-product recovery. In this type of installation any and all grades of coal, even to slack, could be used and much waste could thus be eliminated. The by-products, consisting of ammonium sulphate and tar, would sell for enough to cover the cost of mining the coal and the charge for power would only have to be enough to cancel the fixed charges. This would not need to be an exceptional plant since there are numerous plants in Europe that depend entirely on the sale of their by-products for their profits. A good example of the economy of by-product recovery is the plant at Dudley Port, South Staffordshire, England, where a Mond by-product plant practically pays for the coal in by-products. Ammonium sulphate recovered from a ton of their coal was worth $2.25, while the tar sold for $0.19, or a return of $2.44 per ton of coal.

The power from such a central plant located in the coal fields could be used in the stone belt as far as it was desired, and the remaining power developed would find a ready use in the mine work.

This method of power production is almost sure to come in the future, and why not try to hasten the day? The conservation of the coal is becoming a problem of vital interest and if we can develop a horse-power on one-fifth the coal with a gas engine that it takes to develop it with the steam power plant, why not develop it with the gas engine even if the greater power-plant cost makes the saving at present in favor of the gas slight?

The gas engine is the engine of the future, and with its firm establishment in this country a price for power of 1 cent per kilowatt per hour will not be considered low. The field is open, and the company with the necessary capital and proper business management that locates a plant of this kind in this field will find that an excellent dividend will result because the demand for power is growing fast and to all appearances must continue to grow for a long time to come.

Part IV. Utilization of Waste

CHAPTER VII

Quarry Waste

General Discussion. The largest industries of the country have all been developed by improved methods of the utilization of waste. The success of the Standard Oil Company and the meat-packing industries is directly traceable to their close utilization of the waste products of their business. The stone industry has been one of the most backward of all industries in its use of the waste stone that results from the operation of quarry and mill.

During the operations of quarrying the loss of stone will reach from 30 to 50 per cent of the solid cut, and one operator who was working a quarry where there was no adequate covering over the building-stone layer estimated that as high as 60 per cent of the solid cut of his quarry was wasted. The quarry in which 70 per cent of the solid cut can be put on the market is an exceptionally good quarry. The probable average of waste for the whole quarry district is 38 per cent to 45 per cent of the solid cut.

The causes of this great amount of waste stone are many, but the most important may be grouped under the following heads: (1) the texture of the stone, (2) mud seams and joints, (3) the character and amount of the overburden, (4) irregularities in the stone, (5) crackings in the stone due to geologic causes, (6) carelessness in the handling of the stone in the quarry, (7) variations in the color of the stone.

The general texture of the stone is granular and a wide variation in the coarseness of grain may occur even in a single quarry. This variation may appear in the different beds or even in different parts of the same bed. Stone of too coarse texture has to be discarded because there is no demand for the coarse-grained stone in the trade. On the other hand, when the grain of the stone is very fine it may be harder and more difficult to work. It follows therefore that the medium-grained stone is the most desirable and gives a larger profit to the quarryman. In many places the stone contains small crystals of calcite, and when these crystals are numerous they produce what is known as "glass seams".

When these occur the stone is usually rejected. The presence of large fossils also causes the rejection of the stone.

When the stone in the quarry has been covered by nothing but the loose material resulting from the disintegration of the upper part of the formation, the stone will be traversed by a number of deep mud seams ranging up to 10 feet wide and 25 feet deep. These seams are the result of the action of water which enters the ground and, becoming charged with the organic acids of the soil and the carbonic acid gas of the air and soil, dissolves the limestone along the natural joints of the rock formation and the connecting material from between the grains for some distance into the blocks. These seams may be developed in either direction, depending on the direction of the surface drainage at the given point. In many of the quarries where the surface drainage has been at an angle with both sets of seams it will be found that both sets are developed. The most of the quarry openings have been made along the edge of the outcrop of the overlying Mitchell limestone and then the quarry is worked back under the Mitchell stone. In such cases the seams will be less enlarged, and the thicker the overburden the fewer will be the number of mud seams and the less open will they be. All stone formations contain joints, but the stone of this district is especially free from them and large blocks can be quarried in many of the quarries.

The overburden in the quarry usually consists of a few feet of loose material resulting from the disintegration of the rock strata at that point, and the overlying limestone of the Mitchell formation. When this limestone layer is lacking, the amount of waste due to weathering of the building-stone layer is greatly increased, and, in fact, the amount of waste resulting from the fact that the stone has no good cover may make it unprofitable to operate such a quarry. The result of thick stripping of the underlying stone is very noticeable in such quarries as the old P. M. and B. quarry operated by the Indiana Quarries Company and the George Doyle quarry in Dark Hollow where upwards of 30 feet of Mitchell limestone is removed. In these quarries the seams are hardly noticeable, and none of the joints has been opened and filled with mud as is the case in many quarries where little rock stripping is necessary.

In many of the quarries there occur structural irregularities known as stylolites, usually called "crowfeet" or "toe-nails". These irregularities are the only representatives of bedding planes or horizontal joints. They usually are responsible for the loss of from 3 to 6 feet of stone on either side of the seam.

In at least three of the quarries the stone shows a tendency to split up in irregular blocks as soon as quarried, and this splitting results in the loss of many valuable blocks of stone. The cracks seem to be present in the stone before it is quarried, but do not open until the stone is removed from its bed. This condition probably results from geological movements within the earth, and the resulting stress set up causes the stone to crack or at least develop lines of weakness. In one quarry all these cracks were in a horizontal plane and may have been caused by a settling of the formation as a result of the removal by erosion of the underlying beds since the trouble existed only along the edge of a hill and the cracks decreased in extent as the operations were carried farther into the hill.

The present methods of handling stone in the quarry result in much waste that could be avoided. Most of the operations in the quarry are performed by unskilled labor, because the quarry work is less desirable than the mill work. As a result the quarry laborer is underpaid and careless. The channeler, drill, and scabbling machine each cause some waste, and if the work is not well done the irregular breaking of the blocks will represent another important source of waste.

The Oölitic limestone is of two shades of color known to the trade as "buff" and "blue" stone. The difference is caused by a chemical change in the small amount of iron compounds present in the stone. The original color of all the stone was blue, but the oxidation into ferric compounds of the iron which was present originally in the form of ferrous compounds has caused the blue shade to turn to a light grey or greyish brown known as buff stone. When the quarry block is entirely buff or entirely blue, it can be sold at full price; but the line of separation between the buff and blue stone is usually very irregular, and consequently there are blocks in which the colors are both present with the result that this mixed stone has to be sold at a much lower price, some of it being rejected altogether. There is a growing tendency in the stone trade to disregard the difference in color of the stone, for the stone will take on a uniform color after a longer or shorter period of exposure to the atmosphere. If a block of blue stone be exposed to the sunlight and atmosphere for a month it is difficult to tell whether it was originally buff or blue without chipping into it. A building made of the mixed stone, altho presenting a peculiar appearance at first, will soon become uniform in color, and the fact that it was mixed stone will be difficult for even a stone expert to determine. A building made entirely of blue stone will slowly change to the same color as a building of buff stone, so that the grading of the stone on this basis is unnecessary if the trade were educatedto this fact.

In the mills less waste occurs, but even here the amount sometimes reaches as much as 20 per cent of the weight of the quarry block purchased. Estimates by the different mill operators place the amount all the way from 8 per cent up to 22 per cent, but Mr. Ernest Hunter, then superintendent of the Oölitic stone mill of Bloomington, gave me figures of actual weights of rough stone shipped in and the sawed stone shipped out which show that fully 20 per cent of the quarry block is wasted at the mill. This percentage of waste increases with each additional operation that the stone undergoes, and in the case of decorative work is far greater than the above figure. This waste is greatest where planer and lathe work is done and where the stone is turned out as columns.

Since a conservative estimate of the quarry waste would be 40 per cent and of the mill waste 17 per cent, the part of the stone finally reaching the building trade is about 50 per cent of the solid cut. The 1912 Report on *Mineral Resources* of the United States Geological Survey (p. 745) places the output of the Southern Indiana quarry district at 10,442,304 cubic feet, so that at the rate of waste given above the total waste of the district must be close to 10,000,000 cubic feet of stone per year. Of this vast waste-pile, at present about 18,000 cubic feet is converted into crushed limestone and about 8,500 cubic feet is made into lime. Allowing that as much more is sold for other purposes, it will be readily seen that the present utilization of the waste stone of the district amounts to nothing as compared to the amount available. To this vast accumulation of any year must be added the amount of waste that has accumulated during the last twenty-five years of active operation of the quarries of this locality.

The present method of waste disposal is to dump it into the old workings or give it to the railroads for hauling it away. Such a large amount of waste has accumulated at some of the quarries that the disposal of the present waste is a serious problem, and in many cases waste-heaps of other years have to be moved so that new floors may be opened. The present method is to pile the waste by means of a derrick in large piles at the sides of the opening. When therefore the floor has to be extended to the point where the waste-pile is located, the pile must be moved to make room, and is usually thrown back into the worked-out floor. Since most of the quarries are located on the hillsides a better method of disposal and one which would not interfere with the later recovery of the stone would be the use of cable-ways and overhead cars for running the discarded blocks to a place well removed from the quarry and to a point where there was no quarryable stone to be covered.

The usual price of the waste stone loaded on the cars at the quarry is 15 cents per ton, the price paid by the limestone and lime plants of the district. The charge of the railroad for moving cars in the stone belt when the product is to be rehandled is $2 per car, making the product cost about 20 cents per ton delivered at a central point. This is not, however, a fair estimate since almost any of the quarries or mills would contract to give away their waste if the contracting company would promise to take care of the entire output of waste stone.

The waste stone or at least a part of it might be taken care of by some one or more of the following methods: (1) more careful grading of the stone and the use of a large amount of the rejected blocks in rougher buildings; (2) the production of ground limestone for fertilizer and for use in the manufacture of glass; (3) the production of lime; (4) the production of Portland cement; (5) the production of crushed stone for road metal, for flux in the steel industry, and for crushed rock concrete.

In the case of the last four uses above mentioned the Mitchell limestone of the overburden would be just as useful as the waste Oölitic stone, and in the case of road metal and crushed rock concrete, it would on account of its greater hardness be better than the softer Oölitic stone. The cost of stripping could be entirely met by the use of the stone in any one of the last four ways.

The amount of waste that could be utilized for these purposes would be increased by the amount of Mitchell limestone taken off as stripping, and the utilization of this stone would make profitable the operation of quarries which have been abandoned on account of the high cost of stripping this stone.

Stone Grading. The present methods of grading stone are very unsatisfactory since there are no hard and fast rules to follow and the selection of the different grades of stone is left to each individual quarryman. This allows a wide variation in what is called "A1" stone; for what one quarryman with a good quarry would call second-grade stone might be exactly the same kind of stone that another operator would be putting on the market as "A1".

If a selection is to be made on the basis of grain or color alone there will be about as many grades of stone as there are quarries in the district. Bids are made on the basis of a single sample, with the result that, since the quarrymen are in the habit of sending out selected stone, as samples, in most cases they are unable to furnish any large amount of stone that is strictly like the sample submitted. This causes a tendency on the part of the builders to become altogether too stringent in their specifications, and much dissatisfaction results. The stone trade would be greatly benefited if every operator would exercise more care in the selection of his samples. It would be a benefit if the present method could be done away with and a single standard grade of stone be adopted. In other words, if all the stone could be sold as a single grade, it could be put out at a higher price than is now charged for the lower grades, and the larger output would give a greater profit than the present system. The following table gives in general the grades recognized and the average prices paid for each grade:

QUARRY BLOCKS

"A1" buff	25 cents per cubic foot.
"A1" blue (fine-grained)	25 cents per cubic foot.
Trade buff	20 cents per cubic foot.
Trade blue	20 cents per cubic foot.
Mixed stone, part buff and part blue	13 cents per cubic foot.

To these prices must be added 5 cents per cubic foot if the blocks are scabbled. The higher grades of stone are the ones shipped long distances, the New York market especially demanding the best grade.

Every mill operation the stone undergoes increases its price. The cost of some of the simpler operations is as follows (per cubic foot):

Sawing on two sides	15 cents.
Sawing on four sides	30 cents.
Sawing on six sides	45 cents.

Planing—Charge made according to the surface area planed and the shape and weight of the stone.

The above figures were submitted by Mr. William Johnson of the Chicago and Bloomington Stone Company and Mr. S. C. Freese of the National Stone Company.

During the earlier years of the stone industry in the Southern Indiana stone belt only the finer grades of stone were made use of and large quantities of quarry blocks were discarded as waste. At the present time these are utilized more and more, but there is still a large amount of stone piled on the waste-heaps that could be used if the selection of the stone were carried on more carefully.

It has been suggested that a large amount of the waste quarry blocks and even a large amount of the waste of the mills could be utilized if a machine for cutting the stone in small sizes, say brick size or cement-block size, could be perfected. It seems possible that an arrangement of small circular saws might be made that would turn out this stone in small rectangular blocks, such as would be suited for use in cheaper buildings. In fact, a very cheap product could be put on the market in this way and its development would assist materially in the solution of the problem of waste stone.

Another method of utilizing much of the rougher block stone would be to use the poorer grades of stone in the upper parts of buildings. The wearing and lasting qualities of this stone are equal to those of the better grades, and the only reason for its rejection is the fact that its appearance is not as attractive as that of the better grades. If the lower parts of the building were finished in the fine grades of stone and the higher stories were made of the poorer grades the cost of the building would be materially lessened without lowering its durability, or in any way impairing its appearance. No person at the street level can distinguish the grade of stone used in the second story of a building.

In the following chapters I shall attempt to show the economic value of the waste stone as a means of fertilizing acid soils and as a flux in the manufacture of glass. These two industries are growing rapidly and should offer a broad field for the disposal of much of the accumulating waste heaps.

CHAPTER VIII

Ground Limestone

Use in General. Trace the history of agriculture back as far as possible, and you will find that man has been familiar with the use and value of calcium compounds in the treatment of certain soils which had failed to produce their usual crops. The Roman farmer dug marl to use in treating his fields before he planted them, and whether he originated the practice or whether the idea was handed down to him by earlier agricultural peoples is still a matter of doubt. Nor were the Romans the only people of that early date who practiced the liming of their lands when the soil failed to produce. The custom has been followed in China for long ages, except that there it was muck dressing that was practiced, but since the beneficial part of the muck was its calcium carbonate content, the process was essentially the same.

We have records to show that the farmers of England have made a practice of spreading chalk or marl on their soils for nearly two centuries, and we are also in possession of the observations made on the results achieved. Dr. C. G. Hopkins in his work, *Soil Fertility and Permanent Agriculture* (p. 160), says:

> An English record of 1795 mentions the "prevailing practice of sinking pits for the purpose of chalking the surrounding land therefrom." . . . On the famous Rothamsted Experiment Station it has been found that the fields that had received liberal applications of this natural limestone a century ago are still moderately productive, while certain fields remote from the chalk pits which show no evidence of such applications are extremely unproductive.

There are according to Hopkins no early records which state that the easily pulverized limestones and marls were burned to improve their fertilizing value. The burning of limestone to quicklime was probably first practiced with the idea of finding an easy method of pulverizing the resistant rocks so that they could be successfully applied to the soil. The treatment of soils with ashes may also have been in part responsible for the idea of burning limestone before using it.

The early farmers of England, as might be expected, appear to have been the first to make use of chalk on the soil in order to increase its productivity. This is easily explained by the great deposits of chalk outcropping on the southern counties. That the generous applications of calcium carbonate-bearing compounds were of value to the lands and were concerned in their increased productivity is shown by the fact that the limed fields are still distinguishable by their greater productivity.

Following a rather extended use of lime and calcium-bearing compounds on the soil, there was a long period during which the use of lime fell into disrepute. The cause of this disfavor was the fact that the use of quicklime had become more general than the use of chalk or limestone and the further fact that this dressing had been used in too large quantities. In fact, we are only now coming back to the use of this helpful form of soil dressing. Some works on agriculture written as late as the early 'eighties are inclined to treat the use of lime on the land as an unnecessary waste of time and money. This attitude resulted from the fact that the chemical action connected with the transfer of nitrogen from the atmosphere to the soil was not thoroly understood. F. H. Storer, professor of chemistry in Harvard University, in his book on *Agriculture*, published in the late 'eighties, said (Vol. II, p. 139): "In some parts of the world landlords have often absolutely forbidden their tenants by contract from using lime." Professor Hopkins (*op. cit.*, p. 162) quotes the old German proverb: "Lime makes the fathers rich but the sons poor."

Probably no scientific investigation ever did more to show the value of lime on land than that which resulted in the discovery of the bacteria that have the power of changing the nitrogen of the air to nitrates, or, as the process is commonly spoken of, the fixation of nitrogen.

The average composition of the air by volume is usually given as follows:

Oxygen	20.61
Nitrogen	77.94
Carbon dioxide	.05
Aqueous vapor and other gases	1.40

Plants need all of these constituents for their proper growth and development. But one of the strange phenomena of nature is the fact that while plants can appropriate the oxygen and carbon dioxide directly from the air, the nitrogen is not directly available, altho it constitutes over three-fourths of the entire atmosphere. It has long been known that in some peculiar way the nitrogen of the air was on some kinds of soils and with some crops finally transformed to an available form, but the process of transformation was a mystery. Science has now demonstrated that certain soils and the roots of certain plants form the home of species of bacteria that have the power to take up the nitrogen from the air and give it up in the form of nitrates to the soil. In this form it is known to be one of the most important of plant foods. Along with these discoveries it became known that these organisms thrive better in normal or slightly alkaline soils, and that when a soil becomes markedly sour or acid, their development is arrested and in fact a point is quickly reached where they cease to live. The scientists discovered the fact that these microscopic organisms live in tubercles upon the roots of various members of the family of plants known as legumes (clover, peas, soy beans, cowpeas, etc.). These tubercles can be easily seen on the roots of these plants, varying in size with the different kinds of plants; but the organisms themselves are far too small to be visible to the naked eye. As the nitrates are formed the plant draws upon them for its own food, but when the crops are harvested and the roots remain behind or when the crop is ploughed under, nitrates remain in the soil and increase its fertility. A chief reason for the use of lime or limestone upon the land is to neutralize the acids that may be present in the soil. These acids are always present to a greater or less degree, since they result from the decay of any form of organic matter. The most common acids present in soils are carbonic acid and nitric acid, as well as the various organic acids, such as lactic acid, acetic acid, etc. The reaction between these acids and a base or basic salt gives a salt, and leaves the soil free of acid. To supply this base, quicklime is often used, but it is now known that finely ground limestone will serve as well in reducing the acidity of the soil, and is far less destructive of the organic matter contained in the soil.

The burning of limestone into lime is a process of driving off the carbon dioxide contained in the calcium carbonate of which the limestone is formed, and takes place according to the following reaction:

$$CaCO_3 = CaO + CO_2$$

In other words, the calcium carbonate is broken up into calcium oxide, which is the quicklime, and carbon dioxide, which is driven off as a gas. The calcium oxide thus formed reacts with the waters of the soil, and slaked lime or calcium hydroxide is formed according to the following reaction:

$$CaO + H_2O = Ca\,(OH)_2$$

When this water-slaked lime comes in contact with the air it tends to take up carbon dioxide from the air and to change back to calcium carbonate. The reaction takes place as follows:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

In addition to the fact that the crushed limestone is as effective as lime on the soil, since both do the same work thru the same chemical reactions, the quicklime is far more destructive of the organic matter that might be present in the soil. The use of crushed limestone is accompanied by less inconvience than the use of the lime. The latter is injurious to the skin and must be handled with care. The burned lime, in addition to being a powerful chemical agent in the destruction of animal matter, tends to increase the solubility of the phosphorus and potassium in the soil. Altho this may give larger crops at the time of dressing the soil, it tends presently to cause a rapid impoverishment of the field. Since the main object of the use of lime or limestone on land is to correct the acidity of the soil and thereby increase the amount of nitrates present, the use of ground limestone is just as effective as lime dressing and is less expensive. Where the soil is especially rich in organic matter, as in the case of peaty and other swamp soils, the quicklime is probably the better dressing because such a soil can spare a large amount of its organic matter without becoming impoverished. There are types of soil also that contain large amounts of phosphorus and potassium which become available very slowly, and in such cases the use of lime will hasten the liberation of these necessary plant foods. Professor Hopkins says (*op. cit.*, p. 164):

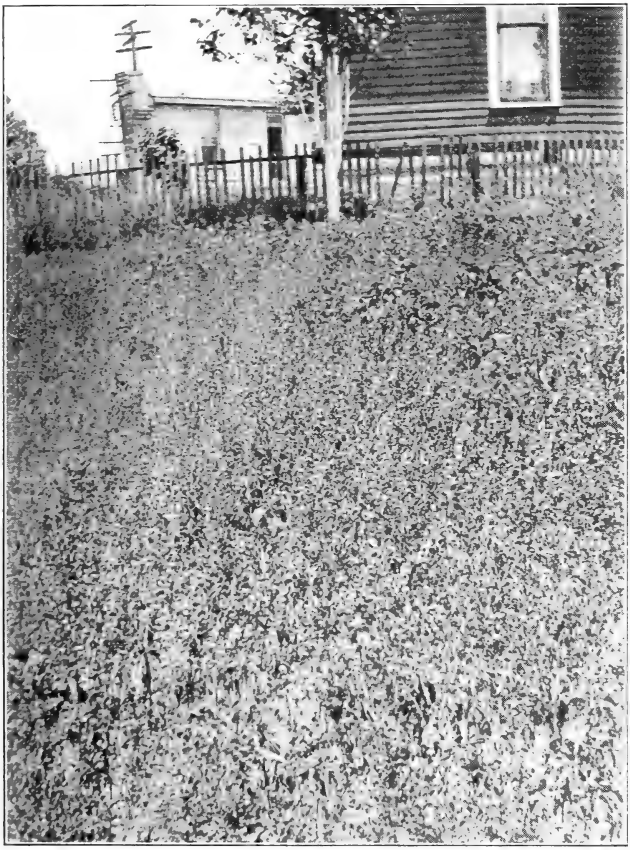
Of course, the landowner must be governed somewhat by the cost of the material. As a rule, fine-ground limestone will be both the best and the most economical form of lime to use, wherever it can easily be obtained. If caustic lime is used, we should make special provision to maintain the humus in the soil by making even larger use of farm manure, legume crops, and green manures.

It might be expected that burned lime would produce a greater increase in the crops for the first year or two than would be produced by ground limestone, more especially where the mineral elements, phosphorus and potassium, are not applied; for . . . ground limestone produces only the milder action, chiefly of correcting the acidity of the soil and thus encouraging the multiplication and activity of the nitrogen-gathering and nitrifying bacteria; whereas, the burned lime not only produces this same effect, but it also acts as a powerful soil stimulant, or soil destroyer, attacking and destroying the organic matter and thus liberating plant food from the soil, usually resulting in more or less waste of valuable nitrogen and humus.

There are at least ten chemical elements essential to the life and growth of plants: oxygen, carbon, hydrogen, potassium, magnesium, calcium, iron, sulphur, phosphorus, nitrogen. The question of soil fertility can in fact be narrowed down to only two of these elements, since all the others can be obtained from the air and almost any soil that can be called in any way normal. These two are phosphorus and nitrogen. In some cases potassium must be added, but such cases are the exception. Since the air contains an inexhaustible supply of nitrogen and this by properly controlling the acidity of the soil becomes available thru the action of nitrifying bacteria, the problem of soil fertility is largely a matter of securing lime or limestone and phosphorus-bearing compounds. In the few cases where the element potassium is necessary, it can usually be obtained by treating the soil with gypsum. Since nearly all soils contain more or less clay or waste from feldspathic rocks and this contains the necessary potassium, the calcium of the gypsum will slowly replace the potassium in the clay, giving rise to potassium sulphate from which the potassium is available for the plants.

The farmer of Indiana should no longer waste his earnings on prepared fertilizers. It is time that he learn what is necessary in a fertilizer and prepare it himself for the soil on which it is to be used. Prepared fertilizers must contain the necessary elements for a number of different soils, and thus the farmer who purchases them must often purchase a large amount of material which cannot possibly be of any use on his particular soil. An attempt should be made to educate the farmer to a point where he will be able to determine what fertilizers his soils need and from this knowledge buy the raw materials and mix his own fertilizers. The State of New York maintains a bureau of soils for the testing of the soils of the State, and any farmer who cares to submit a sample of his soil can have it tested free of charge. With the analysis he also receives advice as to the kind and amount of fertilizer to use in the treatment of his land. This State could find no more effective means of helping her agricultural population than by maintaining a bureau where free analysis and advice could be obtained. This idea has lately been taken up by a number of States, and in the future every large commonwealth will furnish free of charge all the available scientific aid possible.

The physical effects of the use of ground limestone on different soils are very peculiar. When the ground limestone is added to a clay soil it makes the soil more mellow. In fact, the richer a soil is in limestone the more readily the soil crumbles and the more readily can the rainwater percolate thru it. The cause of the compactness of a clay soil is the fact that such soils are composed of very small particles which fit very closely together. Water passes between these particles with difficulty, but when the



The result of the use of limestone fertilizer on a field of clover on the farm of Perry Blackburn at Oolitic, Ind. The field was not entirely covered and the clover at the left of the picture had no dressing.

limestone is added, the lime cements a number of these small particles together to form much larger composite granules, thereby increasing also the size of the spaces between the granules. When once thoroly dressed with crushed limestone a clay soil will remain in a friable condition for a number of years, and the effects pass away very slowly. On the other hand, when a sandy soil is dressed with ground limestone, the soil becomes more compact and has a greater ability to retain moisture. This effect of ground limestone is readily shown by the appearance of the soil after a long drought. On fields that have been treated the soil is markedly more moist than on fields that have not been treated. This is well shown by a series of experiments which have been carried on by Mr. Perry Blackburn on his farm near Oölitic, Ind., during the last two years. The writer visited the farm early in June after that section of country had undergone a severe drought, and examined a field which had received a partial dressing of rather coarse limestone early in the spring. The line of division between the dressed part of the field and the portion which had received no limestone was very marked, as shown in the picture. The clover on the part of the field that received the limestone dressing was on an average 6 inches taller, the roots were on an average 4 inches longer, and the soil markedly more moist than on the portion which had been left without dressing. In the picture it will be seen that the part of the field on the left which received no limestone is hardly covered by the crop and the clover present is short and undeveloped, while on the right where the limestone dressing was applied the clover is much thicker, taller, and more advanced in its growth.

The statements of those interested in commercial fertilizers that lime and limestone are not fertilizers have tended to keep many farmers from the use of these soil correctives. In the strict sense of the word limestone is not a fertilizer, since it does not contain any one of the three essential foods of plants: phosphorus, nitrogen, or potassium. Materials that act in a secondary way have been called soil amendments by Professor Vivian in his work on *The Fundamentals of Soil Fertility.* The chief value of these amendments lies in their ability to correct conditions in the soil that keep plant foods from becoming available. The condition most easily observed and the most widespread is soil acidity, which causes the death of the nitrifying bacteria. Probably no one man has done more toward the development of the theory of raw fertilizers than Professor C. G. Hopkins, and the results of his experiments in the use of ground limestone and ground rock phosphate leave no doubt that the grinding of limestone and rock phosphate will soon become a great industry. The results of these experiments are published in pamphlet form and can be obtained from the Illinois Experiment Station. Some of the results of these experiments are outlined below for the benefit of those who may be unable to obtain the circulars mentioned.

In November, 1903, a farm of about 300 acres in Illinois was purchased at less than $20 per acre. It was abandoned prairie land, which was thought to be almost worthless, but by scientific employment of a small quantity of farm manure and ground rock fertilizers it was brought back to a point where the yield of wheat on a 40-acre field was 35½ bushels per acre. During the 10 years that the experiment was in progress a 6-year rotation system was used; 1 year each of corn, oats, and wheat, and 3 years of meadow and pasture with clover and timothy. During the 10 years 2 applications of 2 tons per acre of ground limestone and 2 applications of 1 ton each of ground rock phosphate were made. These applications of fertilizer occupied 12 years and cost $18 per acre, or a cost of $1.50 per acre per year, and this outlay resulted in an increase of 24 bushels per acre over the amount that was raised on an adjoining strip of land with liberal applications of farm manure. The differences in the clover crops were even more marked than the differences in the wheat crops. The following are given as the best directions for the southern counties of Illinois, and most of Southern Indiana closely resembles Southern Illinois in the conditions of its soils. The directions are as follows:

First, apply 2 to 5 tons per acre of ground limestone.

Second, grow clover or cowpeas.

Third, apply from 1,000 to 2,000 pounds per acre of very finely ground natural rock phosphate, to be plowed under with the clover or cowpeas.

During the last 8 years 318 tests to determine the effect of the lime or ground limestone on crop yields in Southern Illinois were made. These included 79 tests on legumes (clover, cowpeas, and soy beans), 122 tests on corn, 55 tests on oats, and 62 tests on wheat, these crops being grown in the rotations usually practiced. As an average of all tests the yield per acre was increased by ½ ton of hay, 5 bushels of corn, 6.6 bushels of oats, and 4 bushels of wheat. The data at hand and here reported are amply sufficient to justify the conclusion that, in practical economic systems of farming on the common prairie and timber soils of Southern Illinois, limestone at less than $1 per acre per year will produce ½ ton more of clover or cowpea hay, 5 bushels more corn, 6 bushels more of oats, and 4 bushels more wheat than would otherwise be obtained. The only reason that the same statistics are not available for the soils of Indiana is the fact that the farmer has been too much inclined to let well enough alone and practice the system of farming followed by his father before him. He must realize that economic conditions have changed and that what would bring success on the virgin forest soils of a century ago will lead to disaster at the present time.

Probably no better and more convincing data can be furnished at the present time than the following taken from the work of Professor Hopkins in *University of Illinois Experiment Station Circular* No. 157 (1912) on "Soil Fertility". He says (p. 10):

> As an average of the first 2 years' work on two different experimental fields (Ewing and Raleigh) where the initial application was 5 tons per acre, the average increases were ¼ ton of hay, 9¼ bushels of corn, 8.9 bushels of oats, and 3½ bushels of wheat; and, as the increased farm manure or increased crop residues from these larger crops are returned to the land, the effect becomes more marked in subsequent years.
>
> On the Vienna experiment field in Johnson county, about 9 tons per acre of ground limestone were applied 10 years ago. At a cost of $1.25 a ton, this would amount to $11.25 and the returns for this investment have thus far amounted to 90.3 bushels of corn, or to 42.2 bushels of wheat, or to 3⅓ tons of clover. Any one of these will pay for the limestone three times over, and, in addition, two-thirds of the legume crops have been plowed under as green manure, and at the end of 9 years with no further application, the land treated with limestone is producing 5 bushels more wheat, 9.3 bushels more of corn, and 1.4 tons more clover hay per acre than the land not so treated. Indeed, as an average of the last 2 years, this old worn hill land has produced larger crops where the limestone had been applied than the average yield for the State of Illinois for each of the crops, corn, wheat, and hay.

Since this study is not supposed to go deeply into the agricultural phases of limestone as a fertilizer, except to show what a broad market could be opened up by a proper process of education of the farmer, an outline of the kinds of soil that need this dressing, with their distribution, is all that will be attempted in this connection. But the time is ripe and the field for experiment is broad and must be covered before we can say we know the possibilities of raw fertilizers and the principles that govern their use.

What Soils Need Limestone Dressing. The idea that, since the soils of much of Monroe and Lawrence counties are on the limestones and in fact are residual soils from the decomposition of limestones, they do not therefore need limestone dressing is responsible for the fact that the farmers of these counties have allowed these vast deposits of limestone to go unutilized. In fact, the operator of the only crushing plant in the district says he has sold less than a carload of crushed stone in these two counties since opening his plant over a year ago. No idea could be farther from the truth. Limestone, while only slightly soluble in pure water, is dissolved very rapidly in water containing only a small percentage of certain acids, and even carbon dioxide in solution. Thru the long ages that these soils have been exposed to the leaching action of rainwater charged with the acids formed by the organic remains present in the soil, there has been a steady loss of the calcium carbonate present, and an increase in the quantity of acids in the soil. The fact is that there are no soils in the entire State which are any more acid than many of the hillsides of the Southern Indiana driftless area. Probably the best indication of the effect of crushed limestone upon these soils can be seen in the condition of the fields which lie along roads that have received a surface of crushed limestone. The dust from the roads has been blown over the nearer parts of the fields, while but little of it reached the remoter portions. The stand of grass or crops is always better on the portion that has received even this small amount of limestone. Another example of the effect of limestone can be seen along the stream valleys that receive their drainage from hillsides formed of limestone above the level of the stream, as compared with the stream valleys farther east where no limestone is close to the surface in the adjacent hillsides.

Acid soils represent more than three-fourths of the entire area of the State. Practically all soils west and south of a line passing along the boundaries of the following counties are strongly acid: the southern boundary of Newton and Jasper counties, the western and southern boundaries of White and Carroll counties, the southern boundary of Howard and Grant counties, the western and southern boundaries of Delaware and Randolph counties. In addition to this area, there is a smaller area in the northwestern part of the State, including most of Porter, Laporte, Starke, Pulaski, Marshall, St. Joseph, and Elkhart counties, that is characterized by acid soils.

In addition to these larger areas, there are many smaller areas in the northern and eastern sections of the State that have acid soils. The larger area includes what is known as the driftless area of Southern Indiana. The entire southeastern section of Illinois south of Danville also is acid and might provide a market for crushed limestone from this section, if it were not for the fact that this industry has been so highly developed in the latter State and that the cost of the product is kept so low by regulation of freight rates and by convict labor.

Test for Soil Acidity. Every farmer can easily make his own tests and satisfy himself as to the acidity of his soil without skilled advice. One of the best and easiest methods of testing the acidity of a soil is by what is known as the litmus paper test. The test is made in the following manner: Take a fair average sample of the soil to be tested. To make an average sample take a small portion from several points in the field to be tested, mix carefully and reject one-half the pile, cut thru the middle. Mix the remaining half carefully and reject one-half, repeating the process until only a small portion remains. Moisten the sample with pure water and press together upon a small piece of neutral litmus paper. The presence of acid will cause the litmus paper to turn to a reddish pink color. Allow a little time for the action to take place. Be careful not to touch the paper with the fingers after it has been moistened, since perspiration is acid in reaction and will affect the paper. Another method of applying the test is to scrape away a little surface soil and press the paper to the moist earth uncovered. Cover the paper and leave for a few minutes. To obtain good results only the best grade of neutral litmus paper should be used. People are often misled in making this test by the direction to use "blue litmus paper which can be bought at a low price at almost any drug store". In fact, the ordinary blue litmus paper is not sensitive enough to detect a quantity of acid which would entirely prevent the growth of clover. Any druggist can procure the best grade of neutral litmus paper at only a slight additional cost. This small extra cost represents the difference between success and failure in the tests. A good crop of clover which stands well and continues its growth thruout the season is a pretty good indication that enough lime is present in the soil for present purposes. But where the clover fails to grow or where it only makes growth for part of the season, limestone can be applied with good results, and in fact its use is imperative for the best results.

Lime or Crushed Limestone. When a soil is "sour" the acidity may be corrected by either caustic lime or crushed limestone since both react with the acids of the soil to form salts. The reactions are illustrated by the following equations:

$$CaO + 2HNO_3 = H_2O + Ca(NO_3)_2$$

In other words, calcium oxide (quicklime) plus nitric acid equals water and calcium nitrate.

$$CaCO_3 + 2HNO_3 = H_2O + CO_2 + Ca(NO_3)_2{}^*$$

This means that calcium carbonate (crushed limestone) plus nitric acid equals water, carbon dioxide gas, and calcium nitrate, the same compound that came from the caustic lime. The function of soil conditioning already mentioned is performed equally well by both, but they differ in their effect upon the organic matter present in the soil. Caustic lime is better than ground limestone only when the soil contains an abundance of organic matter or some form of phosphorus which is not readily available. It should always be borne in mind that caustic lime, altho giving good results for a year or two, tends in the end to impoverish the soil.

Probably no more convincing experiments have been carried on along the line of the relative values of burned lime and crushed limestone than those of the Pennsylvania and Maryland Experiment Stations. The results of these experiments are summarized in *University of Illinois Experiment Station Circular* No. 110, p. 6, as follows:

> Four plots were treated with burned lime (slaked before being spread) at the rate of 2 tons per acre once in 4 years. Four other plots were treated with ground limestone at the rate of 2 tons per acre every 2 years. A 4-year rotation was practiced consisting of corn, oats, wheat, and hay, the hay being mixed timothy and clover, seeded on the wheat land in the spring. . . . Seven products were obtained and weighed each year: namely, corn, corn stover, oats, oat straw, wheat, wheat straw, and hay.
>
> After 20 years results had been obtained (1882-1901). . . showing that with every product a greater total yield had been obtained from the plots treated with limestone than from those treated with burned lime. . . . Furthermore, with every product whose total yields for the last 8 years was greater than for the first 8 years the limestone produced a greater increase than the burned lime; and with every product whose total yield for the last 8 years was less than the total yield for the first 8 years, the decrease was less where limestone was used. . . . This . . . demonstrates the tendency of burned lime to exhaust or destroy the fertility of the soil.

The actual figures of the above experiments are, to say the least, startling, and the effect upon the soil shown by careful chemical analysis bears out the statements already made. The nitrogen present in the soil treated with crushed limestone

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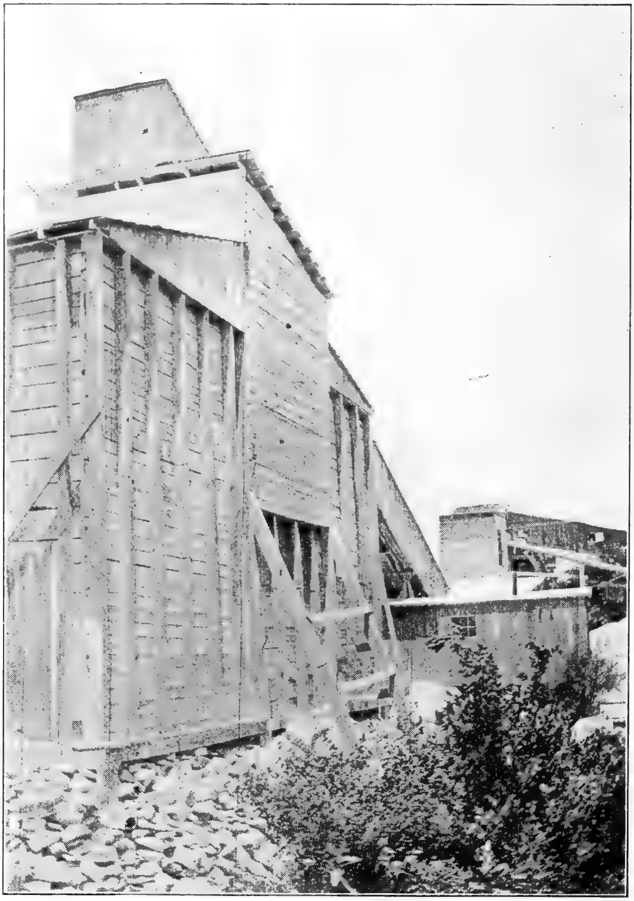
*It is not meant to imply that soil acidity is really due to nitric acid.

was, according to Hopkins, greater than the amount present in the soil treated with burned lime by an amount equivalent to the amount of nitrogen present in 37½ tons of farm manure. Or, it represents the equivalent of more than 2 tons per acre per year of farm manure. The analysis also showed that the amount



The plant of the Bedford Stone Products Company at Oolitic, Ind. This is the first plant erected in the stone belt for the purpose of crushing the waste stone for fertilizing purposes.

of organic matter present in the first case exceeded the amount present in the second case in about the same ratio as the amount of nitrogen. This alone should demonstrate that ground limestone is the proper form of neutralizer, as well as being the form provided by nature.

Amount of Limestone to Use. The amount of crushed limestone necessary to correct the acidity of a soil depends on a number of things, among which are the location of the field, whether hillside or flat land, the degree of acidity, and the fineness of the limestone used. Hillsides lose their lime faster than flat land, but the accumulation of acid is also slower than on flat land. If a rather coarse limestone is used the hillside will need most limestone. The degree of acidity determines the amount of limestone that will be used up soon after its application, and so determines the amount that will be left in the soil to correct any acidity that may occur later. The finer the limestone is ground, the quicker will be its action and the sooner will it be used up and dissolved. Accordingly a ground limestone that contains both coarse and finely ground stone is the best. The larger lumps present may remain several years before being entirely dissolved and used by the soil. The best average quantity to use is about 2 tons per acre every 4 years, unless the soil shows an acid test in the meantime. If it does, increase the number of applications rather than the amount used at one application. This amount should keep almost any soil "sweet". A large percentage of the acidity of the soil comes from the capilarity of the soil, which causes the waters of the soil to rise bringing with them the acids of the subsoil. If the subsoil is very acid the amount of limestone should be increased. The time of year for spreading crushed limestone makes little difference, but the spring, before the the spring rains, is probably the best.

Cost of Crushing Limestone. Cost data on the cost of crushing stone are very difficult to obtain with any great degree of accuracy on account of the number of factors to be reckoned with. Data are, however, available for certain plants already in operation on a given kind of stone. One such plant operating in the Oölitic stone belt is located at Oölitic, Ind., and the operating company is the Stone Products Company of Bedford, Ind. The superintendent, Mr. E. W. King, has furnished the following data:

The plant has been in operation a little over one year and in that time the business has made a steady increase. The demand for the crushed product is growing till the operators are thinking seriously of the feasibility of enlarging the plant so as to increase its output. The present plant represents an investment of approximately $7,000 and the following figures represent fairly well the cost of turning out a ton of the product in a mill of this size.

Labor at the mill	$0.08
Total labor charge, including sales	.31
Power	.06
Upkeep	.05
Stone	.15
General expense	.05
Total cost per ton for present output	$0.70

With an additional 10 cents per ton added to cover depreciation of machinery, the total cost will be 80 cents per ton. The price charged for the product free on board the cars at Oolitic, Ind., at present is $1.18 per ton. The present equipment could be made to produce 75 tons per day if the demand were large enough, but at the present time the output is considerably below this figure, since the market has not as yet been worked up to its greatest development. The plant is equipped with storage bins for 10 tons only, and this hampers the output, but the company has already made plans to enlarge this part of their plant, and by so doing a larger amount of the crushed product can be handled. Any increase in the output will not be accompanied by a corresponding increase in the cost of production, because the fixed charges on the equipment which represent a large part of the cost of production will not be increased. The per ton cost of production therefore decreases with the increase of the output. The product is at present sold for agricultural purposes during the summer months and for use in fluxing, and in the glass industry during the winter.

The machinery in use at the plant consists first of a Forster type crusher manufactured by the McLanahan Machine Company of Hollidaysburg, Pa. This reduces the stone to 1½-inch size after which it is carried by a belt conveyor to a pulverizer in which it is reduced to 20-mesh. The crusher, according to the statement of the superintendent, is not giving satisfaction on account of the high cost of upkeep, and the owners are thinking seriously of installing a gyratory crusher of the Gates type. Power for the machinery is purchased from the Southern Indiana Power Company, and the investment mentioned included the cost of wiring and of motors.

The stone for the plant is purchased from the mill and is of the smaller sizes so that the crusher can handle it without further breaking. The quarry company furnishes this material free on board the cars at 15 cents per ton. The company has a large belt conveyor to carry the waste from a nearby scabbling machine to the crusher.

The preparation of the limestone for fertilizing purposes consists simply in pulverizing the stone until it will pass a certain mesh screen. The size of the largest lumps that will be of value upon land is still an open question, but the general idea is that the larger the lumps the more slowly does the sweetening process take place, but the longer can its results be noticed. The stone is usually fed to a large crusher called a breaker, which reduces it to a certain defined size. The largest piece that will pass a given ring is the size by which the product is known. It is then crushed fine in some form of pulverizer, and screened. The fine product is stored, while the material too coarse to pass the screen is returned to the pulverizer and worked over again.

Rock breakers are of three general types: (1) jaw breakers, in which the motion of the crushing parts is reciprocating; (2) gyrator crushers, in which the motion of the crushing parts is rotary and spiral; (3) roll crushers, in which the motion of the crushing parts is rolling.

The jaw breakers are of two types according to whether the greatest movement comes on the smaller lumps fed or on the larger. The first kind is known as the Blake type of crusher and the latter kind is known as the Dodge type. Very complete descriptions with sectional drawings of all types may be found in the work of Professor R. H. Richards, of the Massachusetts Institute of Technology, entitled *Textbook of Ore Dressing.*

Gyratory crushers are classified on the same principle as the jaw breakers. The type most widely used and the one that will give the best results in the crushing of limestone for fertilizing material is the Gates or the McCully type of breaker. The rolling crushers are known as Forster crushers.

The jaw breakers are usually selected where the output of the plant is small, on account of their small first cost and the fact that the cost of upkeep depends to a large extent upon the output. The cost, per unit of output, of crushing a small quantity is in favor of the jaw crusher. In the selection of a jaw crusher, great care is necessary on account of the great strain that the machine must withstand. The following points should be kept in mind when a selection is to be made: The frame should be heavy and cast in as few pieces as possible. Foundations should be low and very massive on account of the great jar. The machine should be low and the size of the jaws ample for the amount of rock fed. Larger jaws will accommodate larger lumps, and the power expended per ton crushed is the same regardless of the size of the crusher. Larger crushers also cost less for upkeep than smaller ones. The average rate of crushing with a crusher of this type, working in hard limestone, is about 8 tons per horse-power per hour, with the output reduced to 1-inch size. This amount increases rapidly as the output is turned out in large sizes. Professor Richards, *Textbook of Ore Dressing* (pp. 16, 17), gives the following amounts per horse-power per hour:

13 tons to 1½-inch size.
16 tons to 2-inch size.
19 tons to 2½-inch size.
21½ tons to 3-inch size.
28½ tons to 3½ inch size.

The estimated cost of preliminary breaking with a Blake type jaw crusher can be best obtained from the following table taken with slight modification from Richard's *Textbook of Ore Dressing* (p. 22):

Size of mouth in inches	10x4	10x7	15x9	20x10	30x13
Tons per 24 hrs. to 2-inch size	92	120	192	360	600
Horse-power	5	8	12	20	40
Cost of breaker	$275	$500	$750	$1,050	$2,250
Operating cost (in cents) per ton					
Oil	0.020	0.020	0.020	0.020	0.020
Interest and depreciation	0.097	0.135	0.127	0.095	0.122
Power	0.705	0.865	0.811	0.721	0.865
Labor	4.348	3.333	2.083	1.111	0.667
Wear	0.815	0.815	0.815	0.815	0.815
Repairs	0.462	0.462	0.462	0.462	0.462
Total cost (in cents) per ton of rock crushed	6.447	5.630	4.318	3.224	2.951

Machines of this type are more widely used for crushing stone for road metal than in regular crushing plants because they produce less fine material then is produced by the gyratory crushers of the larger sizes. A jaw breaker uses more power per unit of output than the gyratory crushers on account of the large weight of the reciprocating parts and the fact that they are in the act of crushing only half the time, while the action in the gyratory crusher is continuous. The cost list given in the above table was calculated as follows by Professor Richards (*op. cit.*, p. 21):

1. Sizes, capacities, power, and original costs are taken from catalog figures [of the different companies putting out these machines].

2. Oil, costing 35 cents per gallon, is estimated to be used at the rate of one quart per 24 hours, on a 30x13-inch breaker breaking 600 tons in 24 hours to a maximum size of 2 inches. The cost per ton is $35 \times \frac{1}{4} \div 600 =$ 0.015 cent. The cost per ton for a 10x4-inch breaker, estimated to use one-half pint per 24 hours, breaking 92 tons to 2-inches is $35 \times \frac{1}{16} \div 92 =$ 0.024 cent. The average of these two figures is about 0.020 cent.

3. Interest and depreciation at 10 per cent per annum. For a 10x4-inch breaker this would be $27.50 per year. On a basis of 308 operating days per year 92 tons being crushed per day, the cost would be $\frac{\$27.50}{308 \times 92} = 0.097$ cent. Other sizes can be calculated in the same way.

4. Power is estimated to cost $40 per horse-power year of 308 operating days or $0.1298 per day. For a 10x4-inch breaker using 5 horse-power and breaking 92 tons per day, the cost per ton would be $\frac{0.1298 \times 5}{92} = 0.705$ cent. Other sizes are figured in like manner.

5. Labor. It is assumed that the breaker is fed by a sloping chute and can therefore be fed by one man at a cost of $2 per 12-hour shift, or $4 per 24 hours. The cost per ton for the 10x4-inch breaker would be $\frac{\$4.00}{92} = 4.348$ cents. Other sizes can be figured in a similar manner.

6. Wear is estimated at 0.815 cent per ton, which is the average of the gross cost per ton at 18 mills.

Repairs other than wearing parts. The maximum figure recalled by the author was $155 per year. These repairs were required by a breaker breaking 109 tons per day or 33,572 tons per year of 308 days, making the cost per ton $\frac{\$155.00}{33,572}$ or 0.462 cent.

Altho this table is taken from average conditions and average hardness of rock, it can be considered as a conservative set of figures for the conditions that exist in the limestone belt of Southern Indiana, and any estimates based on it will be certain to be high enough.

Jaw crushers are on the market in all sizes up to the giant Ferrel crusher, which is designed for very coarse breaking in order to eliminate the necessity of sledging. This machine will handle 350 tons per hour crushed to 16-inch size.

Another recent improvement in jaw crushers to reduce the rock more effectively in a single machine is the machine known as the "Sturtevant Roll Jaw Crusher". This machine has a grinding as well as a crushing effect on the rock, and its output is much finer than that of the ordinary crusher.

Gyratory breakers are the standard type for work such as grinding rock fertilizer, where a considerable output is to be handled and the mill is to be kept in continuous action. This type of crusher will be found in all the larger crushing plants such as those operated at cement mills and ore plants. The table below, taken with slight modification from Richards' *Textbook of Ore Dressing* (p. 39), and recommended as correct by the leading manufacturers of today, will give a fair idea of the cost of crushing with crushers of this type.. The figures in the following table are calculated by the same method as that used in the case of jaw crushers:

Breaker number	0	2	4	6
Size of mouth in inches	4x30	6x50	8x68	12x88
Tons broken in 24 hours	72	228	720	1,500
Horse-power required	3	8	16	32.5
Cost of breaker	$375	$760	$1,800	$3,300

Operating cost (in cents) per ton

Oil	0.020	0.020	0.020	0.020
Interest and depreciation	0.169	0.108	0.081	0.071
Power	0.541	0.456	0.288	0.281
Labor	5.556	1.754	0.556	0.267
Wear	0.971	0.971	0.971	0.971
Repairs	0.308	0.308	0.308	0.308
Total cost (in cents) per ton	7.565	3.617	2.224	1.918

It will be seen by a comparison of the two tables that as soon as the output passes the 200-ton per day mark it is cheaper to use a gyratory crusher; and that the 10x4-inch jaw crusher is only slightly cheaper in operation than the crusher of the gyratory type with the same output. It must also be remembered that the higher cost has been included in the calculations, or at least that the interest on the larger outlay has been accounted for.

The Sturtevant Mill Company, of Boston, and Ferrel and Bacon, of New York, deal in the jaw breakers while the Power and Mining Machine Company, of Milwaukee, Wis., handle the McCully type of gyratory crushers. All these companies have furnished figures on the cost of crushing with their special type of machinery.

Following the coarse crushing the product is fed to some sort of pulverizer. The most common form in use is what is known as rolls. These are heavy metal cylinders held together by powerful springs or by gravity and rotated at such high speed that their centrifugal force tends to hold them together and at the same time to impart a heavy blow to the stone as it passes between them. The closeness of approach of the rolls is regulated by shims or compression bolts. The larger the roll the greater its capacity since with the same speed of rotation its peripheral velocity is greatly increased. The cost of rolling 100 tons per 24 hours would be as follows, on the basis of ten horse-power:

Power 1.30 cents per ton; attendance, 1.50 cents per ton; wear on roll shells 0.02 to 4.00 cents per ton; repairs, oil, babbitt, etc., 0.37 to 0.60 cents per ton; total 3.19 to 7.40 cents per ton.

The above calculation is given by Richards (*op. cit.*, pp. 69, 70).

Several special types of machinery are in use for the final reduction of the product after it has passed the crusher, and probably better results can be obtained from a hammer-bar pulverizer or a set of ring rolls than can be secured from the common type of rolls. The hammer-bar pulverizer depends on a blow struck in space to effect the crushing. The harder the impact the finer will be the product. The mill works on the principle that a weight placed to swing freely on a revolving shaft will stand at right angles to the shaft when the shaft rotates rapidly, and that the faster the rotation of the shaft the harder will be the blow that can be struck by the weight before it will be forced back. The stone is fed into this machine and struck by the first set of weights and thrown against the retaining case of the machine from which it rebounds in the way of the next set of weights to receive a greater impact due to its own motion as well as the motion of the swinging weight. These mills are rotated at speeds from 700 to 1,500 revolutions per minute. The lower walls of the mill may be made of cast-iron screens so that the pulverized material can escape, while the uncrushed stone is carried around again till it is reduced to a size that will pass the screen. The advantage of these mills is that the screening and pulverizing can be done in one machine. One drawback to their use is the large amount of power used to drive them. The cost of pulverizing with such a mill is about 10 cents per ton for limestone when the output is about 200 tons per day. This figure will be increased for smaller output and decreased for increased output. The high speed of rotation of the machine tends to drive out the crushed product by air pressure, the swinging parts acting as fans. Many of these machines are coming into use for this work and all seem to be giving satisfaction.

The ring-roll mill is a mill in which the rollers are placed inside a ring or cylindrical case and the crushing force comes between these rolls and the inside surface of the mill. The rotation of the ring imparts a motion in the same direction to the rollers, and since they are held firmly to the inside of the ring the material in passing between the ring wall and the roller is brought under great pressure. Much of the force applied is due to the centrifugal force of the rotating parts, and this force keeps the material confined to the outside of the ring and tends to draw it under the rolls. The great advantage of the ring-roll mill lies in the fact that there are few wearing parts. The mill is very accessible, and the speed is slow enough so that there is little vibration, and the parts can be so well balanced that elaborate foundations are not necessary. Another advantage is the fact that the consumption of power per unit of output is comparatively small. These machines will handle about 1 ton per horse-power per hour in limestone crushing. For the larger units they are built in duplex, that is, with two identical machines on a single shaft; this has the advantage of less cumbersome parts and less vibration with less cost of repair because the smaller parts of the two mills cost less than the larger parts of a large single mill.

The cost of handling limestone thru such a machine from 2-inch size or finer, down to a size to pass a 20-mesh screen, can be calculated with all investment charges, including interest, depreciation, wear and tear, and repairs, at about 8.455 cents per ton in a plant handling 200 tons per day; and this figure will be decreased with an increase of output and increased with a decrease of output. The Sturtevant Mill Company is putting these mills on the market and the above figures were taken from their catalogs.

The cost of screening and elevating the crushed stone is a more difficult proposition on which to make calculations, because conditions differ so much in various plants. It is therefore almost impossible to give anything more than the most approximate calculations. Screens are named from the motion they have: as, shaking screens or riddles, rotating screens or trommels, and inclined separators. These do not need defining since the names are self-explanatory. Of these the trommel is the type most used in fertilizing plants, altho the Newaygo separator of the Sturtevant Mill Company, which is an inclined separator, is rapidly coming into use. The chief advantage of the latter lies in the small amount of power consumed, the largest sizes taking less than one horse-power. The vibration in this type of screen is imparted to the wire cloth by a number of small hammers while it is held taut. The inclination of the screen allows a coarse wire to be used even when a fine product is desired. In the trommel the material is fed in at one end and the coarse particles pass out of the other end while the fine material passes thru the sides. These screens are rotated and slightly inclined. The greater the inclination the finer the screening that can be done. They use but little power and are rotated from 16 to 20 times per minute. Screening is improved by faster rotation and greater slope; but the decrease in output of screened material under these conditions is very rapid and the limit is soon reached. Plates with slits are often recommended in place of wire cloth, and are more lasting, but the percentage of openings is necessarily less, and the screening is slower. The cost of screening will, when all charges are taken into account, be about 1 cent per ton when the output handled is 200 tons of limestone per day to 20-mesh. Another thing to be taken into account when deciding which type of screen to purchase is the size of machine necessary to do the work. The trommel must necessarily have a larger screening surface than a vibrating screen, for only a small portion of its screening area is in use at once while the entire surface of the vibrating screen can be in operation at one time. The other types of screen can for present purposes be considered simply as modifications of those already mentioned, and therefore need no detailed description.

Elevating the product is necessary in practically every plant, unless the location selected is such that every movement of the product from one machine to the next can be controlled by gravity. Plants where this condition prevails are very few for the reason that such a favorable location would in most cases make the switching of the stone to the plant and its removal from bins to cars a serious problem. The most common type of apparatus used in carrying the crushed material from one point to another is the belt conveyor. In this apparatus a belt is run over wheels arranged to cause the upper surface of the belt to be concave so that the product will remain on the belt. Rough belts or belts with cleets are sometimes used. The capacity of a belt conveyor is determined by its velocity and width. They are in operation up to 40 inches in width with a speed of 650 feet per minute. Such a belt will handle about 1,220 tons per hour. As the elevation increases an elevator becomes necessary, and the bucket elevator is the only one giving satisfaction in this kind of work. This consists of an endless belt running over two pulleys, one above and one below and having buckets riveted to it. The buckets act as scoops as they pass thru the material and carry a quantity along the belt in each bucket. Bucket conveyors are run at speeds up to 400 feet per minute, but slower speeds give longer life and fewer repairs.

Bins are the one problem that needs to be figured on closely by any company about to start a plant, because the capacity of the storage bins limits the running time in case of a dull market. Bins are expensive at the best, and if extra large ones are put up the first cost of the plant is so high as to seriously interfere with the profits of the new venture.

Bins are usually of wood construction and elevated so that the material may be delivered from them by chutes. They must be roofed and must not be leaky.

The following letter received from one of the leading firms handling crushing machinery in reply to a letter asking the cost of crushing in plants of a certain size shows that even the large manufacturing companies dealing in crushing machinery will not give any but approximate figures:

Dear Sir:

The necessary equipment of your plant would include a crusher, set of rolls, screens, elevators, transmission machinery and power, but we can give no figures as to cost till a stated project is laid before us and our engineering department has gone into the matter. If you care to fill out the enclosed blank we will gladly make an estimate.

The blanks were filled out and sent and the following data were submitted, including a plan of a 10-ton per hour plant:

DEAR SIR:

The machinery required will be as follows, together with weights and prices:

EQUIPMENT	POUNDS	COST
One crusher No. 4	23,000	$1,134
One fine crusher	4,000	1,000
One 10x6 bucket elevator 38 ft. 6 in	1,700	201
One No. 3 screen	1,600	350
Pulleys, 5 in all	....	90
Shafts, boxes, and set collars	....	23
Belts, 4 in all	....	55
Total cost of plant without buildings and bins	....	$2,853

These figures lack the freight, cost of installation, and the work of building plant and bins. To the above figures should be added the following:

Freight	$ 205
Building	850
Installation	300
Bins	250
Total	$4,458

This would be a fair estimate on a small plant that would handle about 100 tons per day. The power necessary to drive such a plant would be about 40 to 45 horse-power. The cost of crushing in such a plant should not exceed the following figures:

Interest and depreciation, 6 per cent and 9 per cent respectively	$ 668.70
Taxes and insurance, 2 per cent	89.16
Labor	2,230.00
Power at 2 cents per kilowatt hour	1,848.00
Wear and repairs	420.00
Oil and waste	35.00
Total year's operating expense	$5,290.86

With a total year's output of 30,800 tons the cost per ton of the product turned out of the mill should be about 17.5 cents. To this must be added the cost of advertising, and of the office and sales force. With these put at 30 cents per ton, it still brings the cost of the product well under 50 cents per ton.

Another firm suggested the use of a jaw crusher and a swing-hammer pulverizer, but the cost of the pulverizer made the entire investment a little higher than the above estimate.

The following figures are for a large plant turning out from 20 to 25 tons per hour. The prices are subject to the discounts given by the firm, and are for the material free on board cars at the manufacturing plant:

One steel breaker for heavy duty, set to crush to 2-inch size and handling 25 tons per hour; size 20x20 inch; horse-power 18; speed 150 revolutions per minute; weight 12,500 pounds	$1,407
One No. 2 ring-roll mill, horse-power 75; speed 325 revolutions per minute; weight 45,000 pounds	8,857
Four separators, weight 7,200 pounds ($479)	1,916
One elevator, horse-power 10; weight 2,200 pounds	395
Pulleys, belts, and supports	325
Building and bins, including labor	2,000
Freight, foundations, and cartage	950
Total outlay	$15,850
Fixed charges—	
Interest at 6 per cent	$ 951.00
Depreciation at 9 per cent	1,426.50
Taxes and insurance at 2 per cent	317.00
Total fixed charges	$2,694.50
Operating charges—	
Labor at $2.00 per day	$5,544.00
Power at $40.00 per horse-power per year	4,320.00
Wear and repairs	810.00
Oil and waste	98.00
Total operating expense for 1 year of 308 days of ten hours each	$10,772.00

The total yearly output is 77,000 tons. The cost is slightly under 14 cents per ton. To this must be added the fixed charges of about 3 cents per ton which brings the total cost up to approximately 17 cents per ton. This figure is sufficiently high because the liberal discounts and the fact that the estimates on the other costs are very conservative would tend to reduce the cost in case of the actual construction of such a plant.

Breakers of the type included in the above estimate are made in capacities of from 6 to 40 tons per hour, and the prices range from $715 to $2,572. In cases of large output, roll jaw fine crushers are often used, following the breakers, before the product is fed to the ring-roll mill. This materially increases the output of the plant. They range in capacity from 1 to 12 tons per hour and cost from $429 up to $2,858. These machines can be used on rock of a large size without previous crushing, but are slower in action than a breaker.

Ring-roll mills are made to handle outputs from the small requirements of a laboratory up to those of large machines with an output of 40 tons per hour, and costing up to $8,857.

Vibrating screens cost from $400 to $600, according to the fineness of the product desired. Their capacity approximates 6 tons per hour for limestone reduced to 20-mesh.

The estimate of one of the leading firms on the cost of wear and upkeep on the machinery of a limestone crushing plant is about one-third of a cent per ton for the material turned out. This cost per ton is divided as follows:

Crusher, including new plates and jaws	0.03 cent.
Ring-roll mill	0.08 cent.
Elevator	0.007 cent.
Screens	0.05 cent.
Amount for belts, etc	0.20 cent.
Total cost	0.367 cent

Since the average farmer would rather purchase a ready-mixed fertilizer than to trouble to mix it himself, it might be good economy to construct a mixing plant in connection with a crushed limestone plant in this district, and to that end the proposition of getting raw rock phosphate was taken up with several of the dealers in the phosphate belt of Tennessee, which is the nearest available deposit of this raw material. The owners of these deposits quoted prices averaging $6 to $6.50 per ton, laid down in Bloomington in small lots, and these prices would probably be reduced to at least $5 per ton on a large contract with a plant which was handling a large part of their output. These figures are on a phosphate rock that carries from 11 to 14 per cent phosphorous, or in other words represents about 25 per cent available phosphoric acid.

The proportion usually recommended for treatment of ordinary soils is two parts of limestone to one of ground phosphate rock. At this rate the mixture could be turned out ready for use at about $2.25 per ton. Allowing a fair profit to the operator, it could be sold f.o.b. Bloomington at about $3.50 per ton. This would bring it to almost any part of the State at less than $5 per ton. The Indiana railroad commission has fixed the rates on natural fertilizer, such as crushed limestone, at a very low figure, in most cases not over 70 to 80 cents per ton.

For lands known to be lacking in potassium, gypsum could be mixed with the fertilizer. The average cost of gypsum in this country last year (1913), was, according to the report of the Bureau of Mineral Resources, about $2 per ton, and the amount used on land as fertilizer was about 55,000 tons. The three could be mixed as follows for land deficient in potassium: four parts of crushed limestone, two parts of phosphate rock, and one part of gypsum. This mixture could be put on the market at the same price as that mentioned above. Deposits of gypsum occur in large quantities in Northern Ohio, and the cost at this point would undoubtedly be considerably lower than the $2 per ton mentioned above.

The total output of phosphate rock from the Tennessee fields was approximately 450,000 tons last year (1913), which represents about 14.5 per cent of the total output of the United States. The deposits are very large, and this valuable mineral fertilizer should have a much broader use in the treatment of worn-out soils than it has at the present time. The use of crushed limestone in the treatment of acid soils has increased so rapidly that the figures given for any one year are far below those of the next year. The latest figures available are 200,000 tons for the year 1912.

CHAPTER IX

LIME

Origin and Nature of Limestones and Lime. The generally accepted theory with regard to the origin of limestones is that most of them at least are of organic origin, altho some geologists still hold that the formation of the massive beds of limestone deposited in the earlier geological periods was by a purely chemical process. Limestone, or at least the chemical compound, calcium carbonate, which constitutes the main part of limestone, may occur in a great number of forms in nature. Common limestone, marble, aragonite, calcite, and travertine are all forms that are composed almost entirely of calcium carbonate, while the rock known as dolomite is composed of calcium and magnesium carbonates.

Pure calcium carbonate is composed of 44 per cent carbon dioxide and 56 per cent calcium oxide. These two chemical compounds can be separated by means of heat, and this is the chemical reaction utilized in the manufacture of lime. The carbon dioxide, being a gas, is driven off by heat, and the calcium oxide, a white solid, known as quicklime, remains in the kiln.

Calcium, the metallic constitutent of limestone, is very abundant in nature; in fact, only oxygen, silicon, aluminum, and iron are more abundant. An estimate of the amount of limestones in the earth's crust by T. Mellard Reade places it as equivalent to a layer around the earth with a thickness of 528 feet. Van Hise estimates the amount of calcium carbonate in solution in the waters of the oceans as equal to 160,000,000,000,000 metric tons. Calcium cannot exist in nature as the metal or the oxide on account of its great affinity for water. Water changes it immediately to the form known as slaked lime or calcium hydroxide. The hydroxide in turn is acted upon by carbon dioxide to form calcium carbonate. The formation of quicklime and its return to the form of carbonate again takes place according to the following reactions:

$$CaCO_3 + \text{heat} = CaO + CO_2$$

This means that when calcium carbonate or limestone is heated it gives up carbon dioxide and becomes calcium oxide or quicklime. Quicklime, when acted upon by water in the process commonly known as slaking, gives the following reaction:

$$CaO + H_2O = Ca(OH)2$$

$Ca(OH)2$ is the substance commonly known as slaked lime or the milk of lime. This slaked lime, on exposure to the air when wet, takes up carbon dioxide from the air and again forms calcium carbonate as shown by the following reaction:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

Altho the chemical explanation of the above changes has been known but a few decades, nevertheless the fact that such changes took place was known even in the early ages when the Egyptians were engaged in building their great works. In fact, some of their mortars are still to be seen and they are known to be very similar to our present common lime mortars. All the great structures built before the time of the Roman Empire were constructed with lime mortars, but the Romans used a cement made from volcanic ash in many of the great structures built under the Empire. The use of this cement was soon abandoned and the mighty castles of the Middle Ages were constructed with lime mortars.

Limestones are widely distributed and they differ materially from one locality to another. They are found interbedded with other sedimentary rocks and often grade into them without any perceptible line of change. In purity they may vary from rocks containing but 45 per cent calcium carbonate to limestones which contain as high as 99 per cent calcium carbonate. The limes of commerce are produced by calcining almost any of these limestones, the resulting lime varying in use with its varying purity. The one impurity most often found is magnesium carbonate, and when the percentage of this runs above 20 per cent the rock is called dolomite. Following magnesium carbonate the most common impurities found are silica or sand, alumina or clay, and iron.

A limestone composed of nearly pure calcium carbonate will furnish a high grade of quicklime. This product is known as white lime, hot lime, or fat lime, while the product from a limestone containing magnesium is called a cool lime, brown lime, or lean lime. In scientific language the former is called a high calcium lime, while the latter is known as dolomitic or magnesium lime.

The limestones of both the Mitchell and the Salem formations are very free from magnesium carbonate, and, in fact, are among the purest limestones of this country, so that any lime burned in this district would be classed as a high calcium lime. In other words, it would be composed of almost pure calcium oxide.

In the *West Virginia Geological Survey*, Vol. III, p. 324, Professor Grimsley describes lime oxide as follows:

> Lime oxide when pure is a white solid, without crystal form, infusible and non-volatile at temperature below 3,000 degrees Centigrade. The commercial oxide is more or less tinged with color due to impurities present.
>
> The metallic lime [calcium] free from oxygen may be made by electrolysis of fused lime chloride, or more readily by heating seven parts of the iodide of lime with one part of sodium in a crucible. The metal is yellow in color, soft, with a specific gravity of 1.578. It is said to be both malleable and ductile and does not tarnish in dry air. If heated in a current of air or oxygen the metal burns into lime oxide with a very brilliant light.
>
> Lime oxide in a very pure form may be obtained by heating the nitrate of lime $Ca(NO_3)_2$.

White lime slakes readily and rapidly with the evolution of much heat and becomes a perfectly white paste. Any impurities present tend to retard this chemical action. The presence of magnesium makes the process much slower, and less heat is evolved. Limes containing less than 10 per cent of MgO show no effect, but as soon as the amount goes above this figure the slowing up of the reaction is noticeable.

The presence of aluminum and silicon oxides in a limestone tends to color the lime produced a gray color, but when present in small quantities they only make the action of the lime less vigorous; that is, these impurities do not ordinarily exert any chemical influence or in any way change its physical properties. They have a diluent action the same as sand when mixed with lime to produce mortar. If this alumina or silica be present in finely divided particles it will be susceptible to chemical combination with the lime if the temperature employed in burning the lime be high enough. As these constituents increase the limestone is called argillaceous or arenaceous and from this it grades into shales or sandstones according to whether the diluent is clay or sand. The presence of these impurities in a small proportion produces on higher heating a hydraulic lime; that is, it gives a lime that possesses the property of setting under water. When the quantity of clayey impurity in a limestone reaches 6 per cent it begins to produce hydraulicity, but below this percentage its only noticeable effect is a retardation of slaking. In fact, many limestones containing between 6 and 12 per cent of clayey impurities make good cool, slow-slaking limes, but the risk of overburning them is very great. This is not true of white limes. When they are overburned they form a hydraulic cement, and must be finely ground to be of use. From the above discussion it will be seen that the difference between common lime and a hydraulic cement is only in the amount of clayey material or alumina present, and the percentage of alumina present is the only difference between the hydraulic cement and a true Portland cement. In fact, these products form a series with the hot or white limes at one end and true Portland cement at the other. The dividing lines are more or less arbitrary, and depend upon chemical composition. The following divisions are commonly made: (1) common or fat lime, (2) hydraulic limes, (3) hydraulic or Roman cement, (4) Portland cement.

The main difference between limes on the one hand and cements on the other is that cements are burned at a much higher temperature, contain a much higher percentage of alumina and silica, and must be thoroly pulverized before water will have any great effect upon them.

The presence of iron or sulphur in a limestone in any amount spoils it for the manufacture of lime. The iron in addition to coloring the lime dark has a fluxing effect. The sulphur darkens the lime and forms sulphates of calcium or magnesium. Organic matter when present in a limestone does not interfere with its lime-making properties because it is completely removed in the process of calcination which the limestone undergoes.

Mortars made from hot limes harden more quickly than those made from magnesium limes, and tests made at the end of 30 or 60 days show the mortars made from hot limes to be harder and more resistant than those made from lean limes. This superiority does not appear to persist, for tests made on mortars after they have been set a year or more shows their resistance to be about equal.

When water is added to lime, calcium oxide hydrates and changes to calcium hydroxide. On exposure to the air the excess of water is given up. It has been generally held that the set of the lime is complete when all the water disappears from the lime, but it has been determined by Chatelier (*West Virginia Geological Survey*, Vol. III, p. 328), that the slaking of lime takes place in four stages:

1. Simple absorption of water.
2. The mixture is warmed by contact and by heat of the chemical action taking place, and a portion of the added water is evaporated.

3. The mass cools and moisture is fixed by the silicates, although some of the free lime remains unslaked.
4. The unslaked lime removes this water from the silicates and becomes completely hydrated.

The time taken for a lime to set depends on a number of factors. Among them is the amount of impurities present, the amount of water used, the air temperature, and the thickness of the lime layer. Fat or hot limes set much more rapidly than lean ones, and when a mason has been taught to use one it is difficult for him to handle the other. After the set has started, any movement of the plaster tends to weaken the bond and injure the work. After the first set the lime hydrate takes up carbon dioxide from the air and forms carbonate of lime, as shown earlier in this study. This process is a slow one and in the case of some limes it may be years before the lime has finally returned to the state of a carbonate. The rapidity with which this change takes place depends on the amount of exposed surface of the mortar, the thickness of the layer, and the porosity of the mortar. As this action goes on, a crust of the carbonate forms over the surface of any considerable mass of mortar and protects the soluble hydrate within from being dissolved or changed, and therefore this final condition of a carbonate may never be reached.

In regard to the final reaction of the lime with the sand in a mortar, S. W. Beyer says in his paper on the "Physical Tests of Iowa Limes" in Vol. XVII of the *Iowa Geological Survey* (p. 104):

> Long contact of lime hydrate with finely divided silica is known to cause a reaction by which the silica combines with the lime forming a stable silicate of lime. The extent to which this reaction progresses depends on the physical and chemical qualities of the siliceous impurities in the lime or of the sand used with it. If these are very fine, chemical action is favored. Silicates, such as clay or feldspar, for example, are more susceptible to attack by the lime than is quartz sand. Hydraulic limes are apt, therefore, other things being equal, to give a more durable final product than the purer limes. In the same way, muddy or clayey sand used with lime, although less desirable at the start, will likely contribute to the durability of the mixture in time, because of the development of these stable compounds by the caustic action of the lime. In the case of silicates, it is probable that other elements, especially alumina, also enter into combination.

Lime has many uses in the various industries, but by far its most important use is in the production of lime mortars for structural work, interior walls, and plastering. In these uses the lime cannot be used alone on account of the great shrinkage of the lime paste in setting, and its own lack of inherent strength when set. It is also cheaper to add some foreign substance, which material can always be cheaper than the lime itself. The most common material used for filler in mortars is sand. Any type of sand grain is superior in hardness to the set lime, and when the lime mortar cements these hard grains together the resulting mortar is hard and durable. In the production of mortars any inert substance which does not shrink nor deteriorate may be used. Ground or rough crushed limestone may be used and will give equally good results. Crushed stone, being rough edged, gives the lime more chance to adhere, and thus the resulting mortar is very durable. Dolomitic limes are more durable and show less shrinkage than high calcium limes. (See also Beyer, *loc. cit.*)

A long series of tests of the proper percentage of lime and foreign material for the strongest mortar, and the type of lime best adapted to the manufacture of mortars has been conducted by the Iowa Geological Survey and the results of these tests are published in the seventeenth annual Report of that Survey for the year 1906 (pp. 106-146).

Lime Burning. The reaction by which limestone or carbonate of lime is broken up into lime oxide or quicklime and carbon dioxide takes place above the temperature of 850 Centigrade or 1,562 Fahrenheit. This reaction will go on to completion only in a current of heated air to carry away the carbon dioxide as fast as formed. Dr. Thorp in his *Outlines of Industrial Chemistry* says (p. 175):

> Calcium carbonate begins to decompose below a red heat into calcium oxide and carbon dioxide, but the decomposition is not complete until a bright red heat (800 to 900 Centigrade) is reached. The temperature should not rise above 1,000 to 1,200 Centigrade, as there is danger of overheating the lime. [For successful burning], it is essential that the gases escape freely from the kiln, the draught usually being sufficient to remove them as they form. This escape may be accelerated by blowing steam or air into the kiln during the burning, or even by wetting the carbonate as it is introduced.

The amount of heat required to produce this change of limestone to quicklime is 373.5 calories for one kilogram of calcium carbonate changed. This amount of heat is equivalent to 747 B.T.U. These are the figures given by Gruner, while Eckel gives the heat requirements as 784 B.T.U. The above figures are quoted from Vol. III of the *West Virginia Geological Survey* (p. 358).

Lime kilns are of two general classes: periodic and continuous.

After a charge has been calcined, the periodic kiln is allowed to cool before it is emptied and recharged. With the continuous kiln this delay is not necessary. The calcined material can be withdrawn and fresh material can be added without loss of time or the great waste of heat, which are necessitated by the periodic kilns.

Kilns are fired by two general methods. In the first case, with what is known as "short flame burning", the material to be calcined is charged in alternate layers with the fuel. In this method the limestone is in close contact with the fuel, and is, of course, more or less contaminated with ashes after burning. In what is known as the "long flame" method of burning, the fuel is burned on a separate grate and only the flames and hot gases pass into the shaft of the kiln. With this method no ashes are left in the product and a purer lime is produced. With the long flame method there is a materially greater loss of heat but the purity of the product more than counterbalances the extra loss. With any of the various forms of kilns other fuels than coal can be used such as natural gas, producer gas, or oil. Any one of these fuels has the advantage over coal, of cleanliness and regularity. The fact is becoming generally recognized that producer gas as a fuel for lime burning is the ideal fuel because the heat can be applied more closely to the charge than is the case with any other fuel and the product will be more even and cleaner than with any other fuel.

Continuous kilns are preferred where fuel is expensive, and and where regular output is desired. Where close figures are necessary on the cost of fuel the periodic kiln is out of the question. The continuous kiln is a tall, narrow furnace or shaft, built of brick or iron plates, and varies in size. Such kilns are usually 35 to 45 feet high by 6 to 8 feet in diameter. The limestone is fed in at the top and is calcined as it passes down thru the kiln, the lime being taken out at the bottom. The burning goes on without interruption even during the process of charging or removing the lime.

In this country a great many long-flame periodic kilns are now in use, the main reason for their installation being their cheapness and simplicity of construction, but they are very expensive in their use of fuel. With these kilns an arch of large blocks of limestone is built about 3 feet from the bottom of the kiln, openings being left for the flames to pass thru. On top of this arch small lumps varying in size from a cocoanut to an orange are piled till the kiln is full. The fire is then built and the temperature of the whole mass is slowly raised during 6 or 8 hours till a full red heat is obtained. This heating must be slow in order to prevent the arch from crumbling. The high temperature is maintained for about 2 days, after which the fire is allowed to burn out and the kiln to cool. The material is removed and the kiln recharged, much time being lost in the process.

The first method of burning lime and one occasionally used at the present time for fertilizing lime was to pile together heaps of logs on which blocks of limestone were piled. The whole mass was fired and the overburned or underburned blocks were thrown aside and the remaining material used. This method was followed by the heap or ditch method in which the limestone was piled in long heaps on a bed of wood and long openings for draft channels were left thru the piles. These huge heaps were fired as the smaller heaps had been fired before, but the burning took a much longer time. These ditches were modified into trenches upon hillsides where the material to be burned slid down thru the trench much as it does in the lime kilns of today; the burned product came out at the lowest level. This type of kiln required four times as much wood fuel as the amount of lime burned, but the small cost of wood in the earlier days made this method practicable. Next came the stone-pot kilns which were square chambers of stone about 18 to 20 feet high and about 12 feet square. These would produce as much as 800 cubic feet in 24 hours. They were the forerunners of the modern type of intermittent kiln, and many of them are still in use. The modern lime plant has 3 floors. The top one is for charging the kilns, the middle one for charging the fires, and the bottom one for removing the burned product. The upper floor is connected with the inclines to the quarry up which the limestone is drawn in cars to be dumped in the top of the kiln. The second floor is on a level with the coal bins and is usually level with the ash dump. The lowest floor is at the ground level so that the product can be loaded in cars.

Under present conditions one ton of coal will burn from 3 to 5 tons of lime, the problem being to keep the fires at their greatest efficiency and to force or draw the hot gases up into the kilns. These things can best be done by means of forced or induced draft put on the fires. There are four methods of securing better draft on lime kilns at present in use, and they are as follows: (1) air jets, (2) steam jets, (3) the Eldred process, (4) suction process.

In the first process, jets of air are forced under the grates and the fire boxes are kept tight on the same principle as forced draft under a boiler.

In the second method, steam jets are inserted up thru the grate bars to give the necessary force to the upward currents of gas.

The Eldred process is a combination of the two methods in which steam and air jets are forced into the kiln and suction fans take away the waste gases.

The fourth method is to apply suction fans at the top of the kiln to draw off the waste gases as fast as they are formed.

There is no question as to the fuel economy with any of these methods for increasing the draft, but as to their relative value expert engineers are not at all agreed. Of course, the use of reinforced draft in the manufacture of lime is a source of danger if not properly handled since careless handling is sure to give an inferior product and the danger of overburning is much greater. A carelessly burned product, in addition to being inferior for use, is also inferior in its keeping properties. These difficulties would be lessened if the lime were hydrated before it is put on the market

One hundred pounds of good limestone will yield from 56 to 58 pounds of lime, but the shrinkage in volume does not exceed 15 per cent and is usually much less. There is little difference in the hardness of lime and limestone, but the lime is much more porous and when acted upon by water it falls into a powder.

Pure lime is infusible at the temperature of the oxyhydrogen flame and is therefore used in the production of the calcium light. For light pencils the lime must be very pure since any impurities cause it to fuse and form a glass slag. Lime is a powerful base and reacts with acids to form salts of calcium.

With the development of the use of gas producers and producer gas in all lines of industry, the increased use of gas in the manufacture of lime is only a matter of time. Several types of gas producers are in use at the present time. The Morgan system is one of the oldest of these. It consists of a cylindrical steel-plate shell which extends into a water-filled ash pan. The fuel is automatically fed in at the top of the producer and scattered over the entire fuel bed. A jet of air and steam is introduced thru a central tuyère in the bottom of the producer. All the operations are continuous and automatic and the ashes are removed under water. This producer is capable of a very steady and uniform flow of gas and is admirably adapted to the manufacture of lime.

At the lime plant in New Milford, Conn., a two weeks' run showed a saving over old methods of 40 per cent in fuel, and an increase of 20 per cent in capacity of the kilns. The cost was lowered from 25 cents to 17.2 cents a barrel ot 300 pounds, and the capacity of the two kilns equipped with this apparatus increased from 65 to 80 barrels to a kiln daily.

The above is quoted from *Rock Products*, Vol. IV (p. 41), and Vol. III of the *West Virginia Geological Survey* (p. 367).

Professor G. P. Grimsley in his comprehensive work on "The Limestone and Lime Industry of West Virginia" in Vol. III of the *West Virginia Geological Survey* (pp. 373-375), describes five general kilns at present in use in the industry in that State as follows:

The S. W. Shoop kilns [manufacured by S. W. Shoop and Company of Altoona, Pa.] . . . are known as center draught kilns and rest on a foundation of common brick or stone. The stack . . . is made of $\frac{3}{16}$-inch steel, 12 feet in diameter and 25 to 30 feet high and rests on a rock foundation. The inner cylinder is made of fire brick supported by a back wall of red brick. The inner diameter of the cupola is 5½ feet near the fire boxes and 8 feet near the top. This leaves a space about 18 inches below, between the brick cylinder and the steel cylinder, which is filled with ashes or earth packed solid. The shape of the interior of the cupola is conical to about the middle and then becomes a cylinder. The barrel below the furnaces to the cooling pot is lined with fire brick so that the lime is partially cooled before reaching the cooler pot which is made of ¼-inch steel and about 4 feet long, bolted to a base 5 feet square so that it may be easily repaired. The opening of this pot is closed by shears readily operated to discharge into the car below. Fire brick pillars at the furnace openings into the cupola prevent the lime dropping into the fire boxes and choking the draught.

The following explanation and claims are made by the designer of this kiln (S. W. Shoop) for the natural draught.

"The kiln is constructed with two chambers or ash pits to each side under the firing doors. One is located centrally underneath the other, with foundation on the floor line connected with flumes around the cooling formation of lime chamber, which gather the heat and hot air from the cooling lime and distribute it underneath the grate bars. The velocity that this heat gathers passing through these flumes is almost equal to forced draught, and making it the strongest natural draught kiln constructed. Not only are there advantages derived through draught, but a large saving in fuel is affected by the utilization of this hot air.

"Taking into consideration that it requires about 12 pounds of air (or 50 cubic feet) to consume 1 pound of coal, and that this air flowing under the grate bars in the ordinary style of kiln at an average of 70 degrees Fahrenheit has to be raised to a temperature of nearly 2,000 degrees Fahrenheit, there is economy in collecting and utilizing the waste heat from the cooling lime. By the introduction of a small jet of steam underneath the grate bars in connection with this hot air, there is an excellent force draught for coal."

The Keystone lime kiln made on the Broomell patents is another popular steel-clad kiln built on a somewhat different plan from the Shoop kiln. The supporting base of the kiln is heavy steel, reinforced by vertical, double-angle iron posts. . . . The steel-cooling cone within the supporting basal cylinder is made of heavy boiler plate suspended from a heavy cast-iron bed plate and can be readily removed for repairs. At the bottom of the cooling cone are patented draw gates opened and closed by hand wheels which project outside of the supporting base so that the workman can turn the gates without coming in direct contact with the hot lime and dust. The heat for the kiln is generated in 4 independent furnaces, each 24 inches wide, 30 inches high, and about 4 feet long. The furnaces can be used with forced draught under the grate bars by forcing a mixture of steam and hot air through an inserted steam pipe. . . . Induced draught is obtained by using an iron cover with a door and attaching a suction fan to the top of the kiln.

The shell of the kiln is composed of heavy steel plates bolted together, and the interior is lined with fire brick supported by common brick. Near the top of the kiln . . . is placed a heavy steel cone to protect the brick, and above this cone is a large storage space, the full diameter of the kiln. The rock is heated in this space by the heat passing through the kiln, and its temperature is gradually raised as the rock passes down to the burning zone.

These kilns are usually placed in a row or battery with 3 feet of space between them, and any kind of fuel may be used. The most popular size kiln is the No. 3 which is described as follows by the company:

Diameter of shell outside	11½ feet.
Diameter of brick lining inside	6½ feet.
Diameter of cooling cone at the top	7 feet.
Diameter of cooling cone at the bottom	2 feet.
Height of cooling cone	7 feet.
Total height of kiln	48 feet.
Shipping weight of kiln	44,000 pounds.
Weight of special brick	14,800 pounds.
Fire brick required	8,463 pounds.
Common red brick	15,700 pounds.
Capacity	90 to 140 barrels (200 pounds) per 24 hours.

The O'Connell kiln patented in 1899 has boilers set in the arches of the kiln, and the fire box of the furnace opening into the body of the kiln supplies the necessary heat for the kiln and also provides a means whereby steam generated in the boiler may be used to aid combustion. By this plan the fuel used for burning lime produces also steam to run the blowers and conveyors, elevate the stone, and operate quarry pumps and other necessary machinery. It is claimed to save 20 per cent of the fuel ordinarily used for burning the lime.

The horizontal circular kiln invented by Hoffman, used especially for the manufacture of brick in Europe, is also used for burning lime. . . .

It consists of an arched circular room divided by moveable partitions into sections (usually 12 in number). The limestone is placed in these sections and fired through openings in the roof into the first section, and when the lime is burned the fire is added to the next section and so on around the circle. The air enters the section in which the lime is being removed and cools the burned lime, becoming heated in the section where the full fire is maintained and then reaches the sections charged but not burned giving off its heat and passes from the last section out through a chimney at the center of the kiln. Dampers serve to regulate the air current and sections not in use can be shut off, as all are connected with the central chimney by openings which can be readily closed.

In England, according to Frasch, the Hoffman kiln produces daily 1,200 to 1,500 cubic feet of lime with a consumption of only 5 pounds of slack coal per cubic foot of lime. In Germany the saving of fuel in the Hoffman kiln is almost 75 per cent over the old methods. The lime is said to slake more easily and cannot be stored for so long a time as that made in other kilns. The saving in fuel in Hoffman kiln over the best constructed draw kilns is said to be about 40 per cent. This form of kiln could be used with economy where the lime is hydrated before being placed on the market.

Rotary kilns are in use in a few instances, but not enough data are available to determine their economic value. The figures on the cost of lime burning with oil fuel, and a rotary kiln are as follows:

Average output	25 tons per day.
Fuel consumption	40 barrels (42 gallons).
Stone	98.5 per cent $CaCO_3$.
Labor cost	$22 per day.
Oil consumption per 100 pounds of lime	26.2 pounds.

This represents a total cost of about 9 cents per bushel.

The cost of lime manufacture differs markedly in different sections of the country. Some of the most important factors in the cost of lime, or the factors which chiefly cause variations in cost of production, are different labor costs, variations in fuel cost, and the cost of quarrying the rock.

The following figures are given as the average cost with a two-kiln plant having a daily capacity of 500 bushels. The expenses run as follows:

Interest on plant and land	$1.60
Repairs, taxes, etc.	1.30
Quarry cost of quarrying 30 tons of rock	7.00
Fuel cost (coal $1.25 per ton)	5.00
Additional labor cost	12.00
Total cost of 500 bushels	26.90
Cost per bushel	5.4 cents.

These costs for the Southern Indiana district would be, with up-to-date-plants:

Interest on plant and depreciation	$2.00
Repairs, taxes, etc	1.30
Quarry cost or cost of waste stone (15 cents per ton)	4.50
Fuel cost (coal $1.50 per ton)	6.00
Labor cost	10.00
Total	$23.80
Cost per bushel	4.8 cents.

There are approximately 27 bushels to the ton of quicklime. A fair estimate of the cost of lime burning in the quarry district of Southern Indiana with the cheap waste limestone as a raw material would be not to exceed $1.50 per ton after all expenses are included.

In slaking a high calcium lime there is an increase in weight of about 40 pounds to the bushel. Quicklime weighs about 75 pounds per bushel.

Uses of Lime. Lime probably has a greater number of uses than any other mineral product. Approximately one-half of the lime burned in this country is used for structural material, and the remaining half is used for chemical purposes. Different grades of lime have different uses, and, in fact, most grades of the product have some special use to which they are best adapted. Some uses require a high calcium lime and some require a slow-slaking lime such as results from the burning of dolomitic limestones. The principal uses of lime as a structural material are in lime mortars, and plasters, in gauging Portland cement mortars, concrete, and gypsum plasters, and as a whitewash. Both quicklime and hydrated lime can be used for these structural purposes. The chemical uses of lime are given in the government reports on the industry as follows:

Agricultural industry—
- As a soil amendment (either calcium or magnesium lime can be used).
- As an insecticide (either).
- As a fungicide (either).

Bleaching industry—
- Manufacture of bleaching powder, "chloride of lime" (calcium).
- Bleaching and renovating rags, jute, ramie, and various paper stock (either).

Caustic alkali industry—
- Manufacture of soda, potash, and ammonia (calcium).

Chemical industries—
- Manufacture of ammonia (calcium).

Manufacture of calcium carbide, calcium cyanimide, and calcium nitrate (calcium).
Manufacture of potassium and sodium bichromate (calcium).
Manufacture of fertilizers (either).
Manufacture of magnesia (magnesium).
Manufacture of acetate of lime (calcium).
Manufacture of wood alcohol (calcium).
Manufacture of bone ash (either).
Manufacture of calcium carbides (calcium).
Manufacture of calcium light pencils (calcium).
In refining mercury (calcium).
In dehydrating alcohol (calcium).
In distillation of wood (calcium).

Gas manufacture—
Purification of coal and water gas (either).

Glass manufacture—
Most varieties of glass and glazes (calcium).

Milling industry—
Clarifying grains (either).
Manufacture of rubber, glue, pottery, and porcelain (either).
Dyeing fabrics and polishing material (either).

Oil, fat, and soap manufacture—
Manufacture of soap, glycerine, candles (calcium).
Renovating fats, greases, tallow butter, etc. (either).
Removing the acidity of oils and petroleum (either).
Lubricating greases (either).

Paint and varnish manufacture—
Refining linseed oil (either).
Cold-water paints (either).
Manufacture of varnish and linoleum (either).

Paper industry—
Soda method (calcium).
Sulphite method (magnesium).
For strawboard (either).
As a filler (either).

Preserving industry—
Preserving eggs (calcium).

Sanitation—
As a disinfectant and deodorizer (calcium).
Purification of water for cities (calcium).
Purification of sewage (calcium).

Smelting industry—
Reduction of iron ores (either).

Sugar manufacture—
Beet root (calcium).
Molasses (calcium).

Tanning industry—
Tanning cowhides (calcium).
Tanning goat and kid hides (either).
Water softening and purifying (calcium).

The uses of lime in the agricultural industry are many, but by far the largest part used is as a soil amendment, and this use is thoroly discussed in the portion of this study dealing with crushed limestone as a fertilizer. It was there shown that crushed limestone would do the same work as lime and at a much smaller cost. The only case in which lime is better adapted to soil treatment is that of a soil very high in organic matter, as in the case of drained lands where the soil is of a peaty nature and a part of the organic matter in the soil can be sacrificed for quicker returns.

Lime is used in the preparation of nearly all of the insecticides and fungicides used for protecting plants. Lime and iron sulphate, commonly known as copperas, and water are much used as a spray under the name of Bordeaux mixture. This mixture is used to kill fungus growths on vines and trees. A mixture of about 20 pounds of sulphur, 15 pounds of common salt, 35 pounds of lime, and 50 gallons of water will make when boiled a spray that will destroy scale and other insects without doing damage to the trees at any time of the year. Many other mixtures of this type are known.

Slaked lime, when treated with an excess of chlorine gas, forms calcium oxy-chloride ($Ca(OCl)_2$), commonly known as "bleaching powder", much used in bleaching vegetable fibres in the textile and paper industries.

Quicklime is used in the manufacture of the alkaline hydroxides, such as sodium, potassium, and ammonium hydroxides. The carbonate of the substance, when treated with quicklime and water, gives calcium carbonate and the hydroxide of the substance, as for example:

$$CaO + Na_2CO_3 + H_2O = CaCO_3 + 2Na(OH)$$

This means that quicklime plus sodium carbonate plus water equals calcium carbonate plus sodium hydroxide.

Calcium carbide, much used in the production of acetylene gas, is made from a mixture of 100 parts of lime and 70 parts of coke. This mixture must be heated at the temperature of the electric furnace for some time, and as a consequence plants for its manufacture must have cheap sources of power. The carbide breaks up slowly in the air, but rapidly when treated with water according to the following reaction:

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$$

The manufacture of acetate of lime from which pure acetic acid is prepared, and the purification of wood alcohol and acetone are carried on along the same line. Milk of lime is used to take up the acid from the impure wood spirits, while the alcohol and acetone are carried over and condensed. Much lime is used in these reactions. The only method of obtaining wood alcohol of high purity is by distillation over lime.

In the manufacture of soaps the lime is used to obtain the alkaline hydroxides from the carbonates, as described earlier. The action of the lime on tallow or on a grease forms organic salts of calcium. The calcium is easily replaced by sodium or potassium, from some of their compounds, to form the soluble soaps of commerce. Saponification with lime is a necessary step in the manufacture of candles, glycerine, and the explosives derived from glycerine. The milk of lime is used also to remove any trace of acid that might be present in the pure products.

Lime plays a very important part in the manufacture of paper. The first use of lime in this industry is in the cleansing of the materials and the removal of foreign substances. This method is employed in the case of rags, straw, etc., that are to be used in paper manufacture. If wood pulp from soft woods is to be used, the pulp is boiled in a solution of sodium carbonate which has been rendered alkaline by the addition of pure lime oxide. In the sulphite process the wood of spruce, hemlock, etc., is boiled with sulphurous acid and milk of lime until the tars and oils are removed and the pulp softened. The paper pulp is usually bleached with chloride of lime before rolling. It will thus be seen that lime plays one of the most important parts in this industry.

The uses of lime in sanitation are so numerous and so well known that space will not be given here to a discussion of them.

Lime is used in sugar manufacture in the process known as "Defecation". The lime here removes the excess of organic acids and coagulates the albumen and mucous. Lime, altho only slightly soluble in water, is more soluble in sugar water, and the lime unites with the sugar to form an insoluble compound in which form it can be washed with alcohol and water. The calcium from this sugar of lime compound can be removed by passing carbon dioxide thru the solution.

Lime is used in tanning hides, in which process a strong solution of milk of lime is used to remove the hair from the hides. The lime also dissolves the fatty matter and the coriin, loosening the fibres which swell the hides. The length of time that the hides undergo this liming process determines the pliability of the leather formed. The addition of sodium sulphite to the lime gives a paste that will remove the hair in a few hours if spread on the hair side and rolled in.

I have attempted to outline here only a few of the more important chemical uses of lime. A discussion of these industries can be found in any of the later textbooks on industrial chemistry.

It will be seen from the lists given at the beginning of this section that high calcium limes are far more important and have a much more extensive use in the manufacturing industries of the country than the magnesium limes or those burned from dolomite.

The demand for these manufactured products is sure to increase very rapidly in this country during the next few years and the demand for lime will increase accordingly. The price of high-grade, high-calcium limes is sure to increase with the increased demand for them in the new manufacturing projects that are sure to spring up in the next decade.

The vast diversity of the uses of lime is sure to keep the demand constant even if the different industries make varying demands for it. The ability of lime to correct soil acidity has been thoroly treated in that part of this paper treating of the use of lime and limestones on acid soils.

The Hydration of Lime. When a magnesium lime is packed for shipment its slow-slaking properties and the small amount of heat given off in slaking make it possible to keep it a long time and to ship it in paper sacks without fear of their destruction or danger to property near it. This is not true of the hot, high-calcium limes. Their great affinity for water has always made them dangerous to property and has caused them to spoil in storage or transit. In most industries the hydrate of lime is as useful as the pure quicklime and much easier to handle, being also less liable to spoil. This demand for a compound easily handled and shipped led to the placing of lime hydrate on the market. In any process by which quicklime and water are brought together, the same chemical reaction results, namely:

$$CaO + H_2O = Ca(OH)_2$$

When the oxide leaves the kiln it is in lumps about one-fourth larger than the lumps of limestone from which it was burned. These lumps on slaking fall into a fine white powder known as the hydrate of lime. The reaction is accompanied by the generation of an amount of heat that under some conditions is sufficient to cause combustion. When this reaction has been completed and the resulting lime hydrate has cooled and dried, it can be stored or shipped without any danger to property or to itself. The lime hydrate contains about 25 per cent of water and has a specific gravity of about 2.08 while limestone is about 2.8. The specific gravity of pure lime oxide may be as high as 3.1.

The burning of the lime has much to do with the rapidity with which it slakes. Lime burned at temperatures under 1,000 degrees Centigrade will slake quickly, while limes burned at higher temperatures may take hours to slake thoroly. When a hot lime and water are mixed, temperatures as high as 310 degrees Fahrenheit may be reached; this temperature is often sufficient to cause combustion.

To slake the lime properly the water must be added slowly. About one-third of the amount of water necessary to slake the lime should be added first, and after the heat is generated the rest of the water may be added. If the lime is mixed with a large amount of cold water the product will be very granular. The weight of high calcium limes is increased about one-third in slaking. One bushel of good lime will when slaked make about 2½ bushels of slaked lime with a weight about one-half as great per bushel.

The old method of lime hydration practiced by masons and plasterers consisted in pouring the necessary amount of water over the lime in a water-tight box lined with sand and lime paste. The lime was spread over the bottom of the box in a layer about 8 inches thick and enough water added to make a thick paste. A layer of sand was then spread over the lime to keep in the heat. This method when properly carried out by an experienced man gives a good product, but careless work usually injuries the lime and makes it inferior as a building material. The new method of lime hydration at hydrating plants and the marketing of the product already slaked do away with the danger of careless slaking; and the resulting product gives much better satisfaction as a building material.

Many processes are now in use for slaking lime. Several of them are operated under patents and the product sold under various names, such as lime hydrate, limoid, cream of lime, etc. The process consists essentially of the following operations: first, crushing the lime lumps with some type of crusher to give a uniform size of lump so that the water will act upon it rapidly; second, hydrating the lime, which is accomplished by placing a weighed portion of lime in a hydrating pan holding 1,000 to 2,000 pounds. Scrapers in the pan level the lime down to a depth of about 8 inches. The pan rotates under a number of stationary ploughs which are so arranged that the lime is thoroly turned over and mixed every half-revolution. An automatic sprayer which contains a predetermined amount of water is located over the pan and sprinkles the water evenly over the surface of the lime. As soon as the water and lime are thoroly mixed the pan is emptied and a new charge placed in it. The process of hydrating with a high calcium lime does not require over half a minute per charge. Following the process of hydration the product is screened to remove particles of limestone, underburned lime, and unslaked lumps. The product screened to about 40-mesh is stored in bins ready for bagging and shipment.

The equipment of a small hydrating plant should include two elevators, one to take the lime from crusher to bin and one to take the slaked lime from the hydrator to the storage bin, as well as a hydrator, a crusher, and screens.

The above process is known as the batch process. Other methods use machinery which is continuous in operation, the most common being the rotating cylinder, containing screens for discharging the product as fast as it is hydrated. Water and jets of steam are sprayed into the cylinder and accelerate the process. The lime is fed in at the higher end of the cylinder and travels slowly toward the lower or discharge end. The usual capacity of these cylinders is about 8 tons of hydrated lime per hour. They require about 5 horse-power to operate them.

The lime-hydrating industry is one that is sure to grow in this country inasmuch as the product has many advantages over quicklime for every use in which the caustic properties of the lime are not a necessity. The main advantages are as follows:

1. Hydrated lime will keep better than quicklime.
2. It can be shipped in paper bags instead of barrels.
3. The impurities have been removed in the hydrating plants.
4. It is ready for immediate use. No slaking or seasoning is necessary.
5. Less is needed to produce an equally strong mortar.

6. It can be mixed dry with sand or cement, thus necessitating less labor.

7. There is less danger in packing and in handling.

With these advantages favoring it, the use of lime hydrate cannot but develop very rapidly, and plants for the hydration of lime will be a paying investment. Mixtures of lime hydrates and Portland cement are already much used in making concrete walls. It is also recommended in the production of concrete building blocks, where it is claimed to improve the water-resisting qualities and give a lighter shade to the blocks.

Lime hydrate is used with kerosene and copper sulphate or Paris green as a spray, and as such it is recommended as a very good insecticide.

Sand-Lime Brick. The manufacture of building bricks from mixtures of sand and lime has been carried on for a number of years in regions where the soils are sandy and clays are lacking; but these mortar bricks are very unsatisfactory, and the industry has never reached large proportions. With the patent of Dr. W. Michaelis for hardening sand-lime brick by high-pressure steam, the industry of making sand-lime bricks has developed to a great extent. The patent, taken out in 1881, lapsed before any great use was made of it, but since 1900 a large number of plants for the manufacture of sand-lime brick by this method have begun operation in Germany. The first plant to operate in this country was started at Michigan City, Ind., in 1901, and at the present time about 100 plants are in operation in this country.

Sand-lime brick, or "Kalksandstein" as it is called by the Germans, is a mass of sand grains cemented together by a hydrated calcium silicate. The union, instead of depending on the lime as a cement, depends upon the formation of this silicate by the high temperature which the brick undergoes in the process of manufacture. This industry is sure to grow and with it such a demand for lime as to cause a rise of prices in the future.

The Lime Industry in Southern Indiana. The reasons why the lime industry has not been developed in the stone belt of Southern Indiana are many. In regard to this I may quote from the paper on the "Lime Industry in Indiana" by W. S. Blatchley, in the twenty-eighth Annual Report of the Indiana Department of Geology and Natural Resources (pp. 219-220), as follows:

The average of 8 analyses of specimens from 8 of the leading quarries of Bedford stone showed the following percentage composition: Calcium carbonate, 97.62; magnesium carbonate, .61; iron oxide and alumina, .36; insoluble residue, .91. These analyses show the fitness of the Bedford Oölitic stone for making a very pure quicklime; and the practical burning of the lime at Salem, Bedford, and other points proves that fitness. For some reason, however, the lime industry in the Oölitic stone district is not as flourishing as it should be. Abandoned kilns are found in a number of localities in the area, notably in Monroe county, near the old University building at Bloomington, and at Ellettsville; in Lawrence county, 2 southeast of Bedford, and 3 south of the same place along the Monon railway, and in Owen county at Romona.

Professor T. C. Hopkins in his report on the Oölitic stone industry, in the twenty-first Annual Report of the Indiana Department of Geology and Natural Resources (p. 337), says:

To see the great quantity of waste rock on the dump piles about the quarries one wonders why more of it is not burnt into lime, and no satisfaction could be obtained to that query when put to the quarrymen. One said it did not make good lime. Another that the lime was too hot, and some had not thought of it, did not know that it had ever been tried or would make lime at all.

One needs only to look at the average analysis quoted above to see that it would make a rich, fat lime, as remarked earlier in this paper. Quoting from the same source (p. 337):

The reason that more of it has not been burnt may be due to a number of causes [as follows]: 1. Freight rates, the cost of bringing in the coal and shipping the lime. 2. A prejudice in the local markets against rich lime. 3. Want of a large market, as they are situated in the midst of the Mississippi Valley, with large deposits of limestones on all sides. 4. The lack of some enterprising person to push the business into prominence, as all the stone dealers are interested in the sale of building stone and not lime.

Considering the force of these reasons for the lack of development of the industry in this district, at the time of writing the present report, it will be seen that not all of them are now effective. In the first place, more railroads have penetrated the stone belt and are competing for the business. This has had a tendency to lower freight rates. The quarry operators and the railroad managers have come to realize that their interests are mutual, and so are better acquainted with conditions and will coöperate to make rates that will allow the industry to develop. In the second place, the development of the process of hydrating lime at the manufacturing plants has done away with the objections to hot limes by making them easy and safe to handle. With this objection removed, the rich lime will be more popular in the market than the lean limes now used. In the third place, the markets of the Central West are being supplied with limes from Ohio which must cross Indiana in transit, thus placing on them higher freight rates than would be placed on Indiana limes. In fact, Ohio limes are being used at the present time in the stone belt of Indiana. This is more to be lamented when it is known that most of the Ohio limes are dolomitic limes and the Indiana limes are superior for most uses if put on the market in the form of lime hydrate.

The last reason is probably still the most effective in holding back the industry, but this cannot long stand in the way, for the stone industry is filling up with a younger generation of progressive business men who find the profits of the industry not large enough to satisfy them, and realizing that a more careful utilization of the waste heap can add to their profits, they will develop any industry as soon as convinced that the returns are proportionate to the capital invested.

The 1913 output of lime in Indiana was 96,359 short tons valued at $323,905, while her neighboring State, Ohio, produced 497,693 tons, valued at $1,976,316. To make up the difference of 401,000 short tons of output so that Indiana would take rank with her neighbor, it would be necessary to burn in the State 8,000,000 cubic feet of limestone more than is burned at the present time. It will be seen from these figures that if the waste limestone that accumulates in the quarry district every year were used in the manufacture of lime, Indiana would take rank as one of the greatest lime producing States in the Union. Approximately 18,000,000 cubic feet of limestone is burned per year in the State of Pennsylvania in order to produce their lime output of about 852,000 short tons.

The price of lime in Indiana averages about $3.50 per ton, and calculated on this basis the waste from the quarries in a single year would be worth nearly $1,250,000 if the product were in the form of lime. Of course, these figures are only approximations, since any such an increase in the output of the State would cause a drop in the price paid per ton, but with the increase in demand for a high-calcium lime in the chemical industries of the country due to the changed conditions of manufacture in Europe, the producer of this kind of lime can look for a strong demand and good prices for a long time to come. In Ohio the price of lime remains about $4 even with her large production.

At the present time there is only one lime plant in operation in the Southern Indiana quarry district. This plant was the property of the Ohio and Western Lime Company of Bedford, Ind., until the latter part of 1914, when it was purchased by the Indiana Quarries Company. The plant is located on the site of the old Perry Mathews and Buskirk quarry of the Indiana Quarries Company on Buff Ridge, and the limestone for burning comes from this quarry. While the plant was operated by the first company the operators were paying 15 cents per ton for the waste stone and the quarry operators were furnishing derrick and switch connections for the lime company. Since the same company is now operating both quarry and lime plant, the industry will be sure to develop. In reply to a request for information concerning the plant under its new owners, the following information was promptly furnished. The equipment of the plant consists of four kilns, two of stone and two of steel construction. The plant furnishes employment for 15 men at an average wage of 22½ cents per hour. The yearly output of the plant is about 225,000 bushels of lime and the coal consumption is about 5,200 tons. The cost of production of the lime is figured at about 10 cents per bushel. The plant represents an investment of approximately $25,000.

CHAPTER X

PORTLAND CEMENT

History of the Industry. The cement used by the ancient Egyptian builders was a type similar to our present lime mortars. There is no reason to believe that they were familiar with any form of hydraulic cement. The first use of this type of cement is attributed to the Roman builders who used it in the great engineering works of the early Empire. This cement was made by burning a volcanic ash found abundantly in the vicinity of Naples and called Pozzuolana. The product was called Puzzolan cement. This type of cement differed very much from our modern Portland cement both in composition and method of production. A very similar cement is produced at the present time from blast-furnace slag. Following the fall of the Empire even this type of cement was forgotten and the great buildings of the Middle Ages were laid up with plain lime mortars.

In 1756 John Smeaton, an English engineer, began a series of experiments with hydraulic cements for use in the construction of the Eddystone lighthouse. When the results of these experiments were made public in 1791 a number of men began experiments and in 1796 a patent was given in England to a man by the name of Parker. The product was also patented in France about the same time and both products were very similar to our present Rosendale cement.

According to Eckel (*op. cit., infra*), the first compound approximating the composition of our present Portland cement was manufactured in England under a patent granted to Joseph Aspdin of Leeds, England, in 1824. No formula was given with the application for the patent, so the definite composition of this cement is unknown, but to it was given the name of Portland cement on account of its close resemblance to the well-known Oölitic limestone of Portland, a well-known building stone. Aspdin's cement was made from a mixture of chalk and clay and was burned at a higher temperature than is necessary in the manufacture of hydraulic cements. The method was to pulverize and then calcine a quantity of limestone in a furnace, then mix it thoroly with an equal amount of clay in water, making a thick paste. This mixture was then dried and calcined, and after the carbon dioxide was driven off the mass was again powdered. The resulting compound had the ability to harden under water.

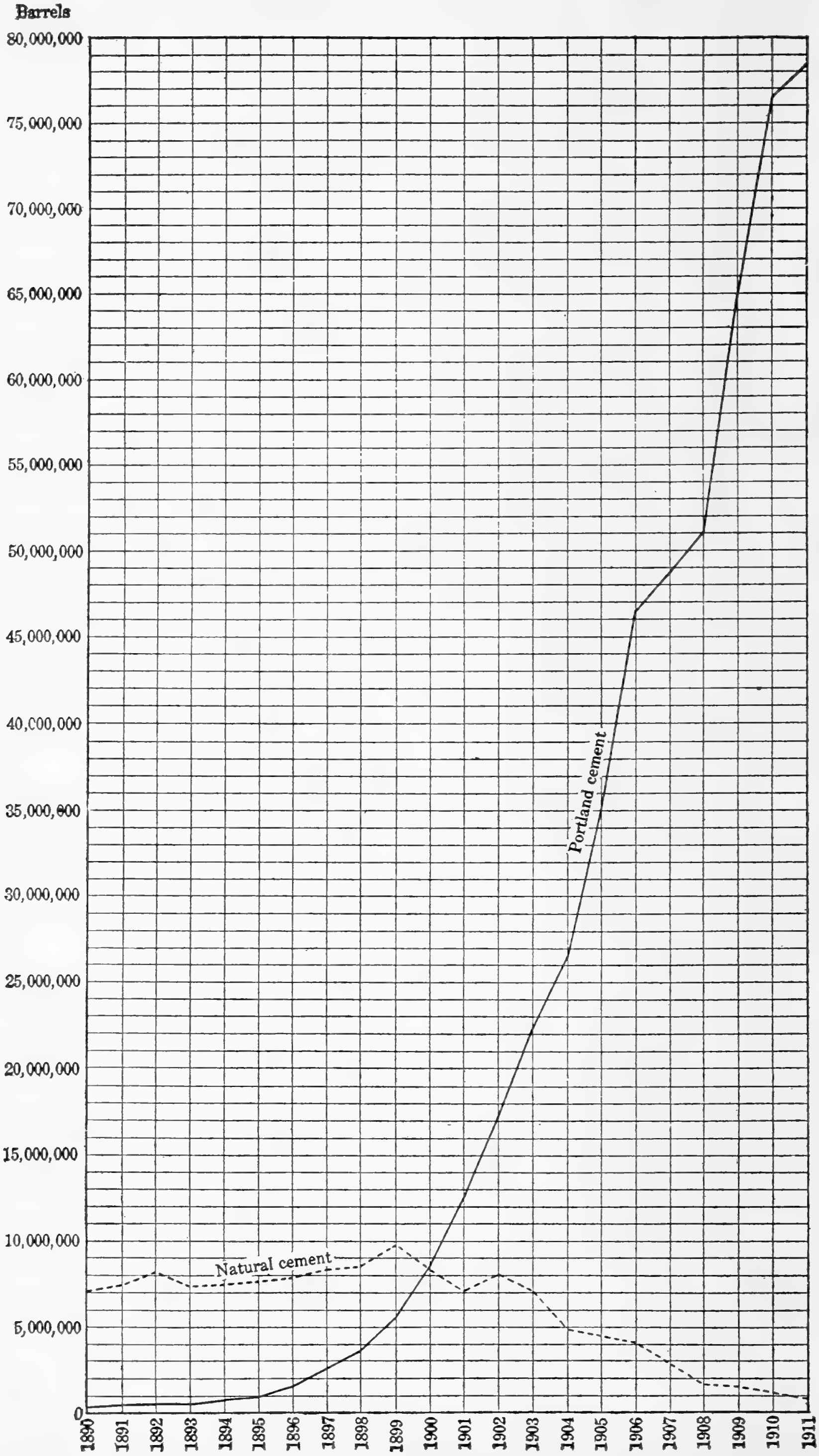
The Portland cement industry began its development in France in 1850, in Germany in 1855, but was not taken up in this country until 1872 when the first mill was built at Coplay, Lehigh county, Pa. The present Coplay Cement Manufacturing Company is a direct outgrowth of this modest beginning.

The real history of the industry in this country dates from about 1880 when it was first realized that the methods in use in Europe where fuel was expensive and labor cheap were not fitted to the industry in this country where fuel was cheap and labor expensive. Up to this time the manufacturer in this country had followed closely the methods in use in Europe. From this time methods began to diverge, and in time the American methods were to completely outstrip those in use in Europe. The first step came when it was known that dry materials could be fed continuously to the kilns. The introduction of the rotary kiln and grinding machinery instead of millstones was the next step. In 1895 powdered coal was first used as fuel, and soon all other fuels were abandoned in its favor. The size of the kiln has also undergone great changes until kilns up to 250 feet in length with capacities up to 1,000 barrels are now in use.

The Report on "Portland Cement Materials and Industry in the United States" by Edwin C. Eckel, *Bulletin* No. 522 of the United States Geological Survey (1913), gives a very comprehensive treatment of the development of the industry in this country, together with a number of analyses of materials and cements. Anyone interested in the industry will find this work especially helpful and instructive. The accompanying table of the growth of the industry is taken from *Mineral Resources* for the year 1912 (p. 512).

The total amount of cement of all kinds produced in this country during the year 1912 was 83,351,191 barrels valued at $67,461,513. The output for 1911 was 79,547,958 barrels valued at $66,705,136. This represents an increase of 4.78 per cent in quantity and 1.13 per cent in value over the previous year. Of this amount over 98.5 per cent was Portland cement. This quantity of cement which is given in barrels represents a total weight of 13,985,034 long tons and a value of about $4.79 per ton.

Indiana with five producing plants put out (in 1912) 9,924,124 barrels with a value of $7,453,017. The average price per barrel for cement in Indiana for the year was 75 cents. Of this amount 9,634,582 barrels was shipped.



PRODUCTION OF NATURAL AND PORTLAND CEMENTS FROM 1890 TO 1911

The five plants at present operating in Indiana are located at the following points:

Mitchell. This plant uses limestone and shale.
Speeds. This plant uses limestone and shale.
Buffington. This plant uses blast-furnace slag and crushed limestone.
Syracuse. This plant uses marl and clay.
Stroh. This plant uses marl and clay.

Indiana ranks second only to Pennsylvania as a producer of Portland cement altho only five plants are operated in the State.

The deposits of stone in Indiana with which this part of the study is concerned are included in the Mississippian rocks of the State and are described in the earlier chapters of the study

Composition and Nature of Portland Cement. The following analyses are taken from Eckel's work on "Portland Cement Materials and Industry in the United States" (p. 155) and are quoted by him from reports on the limestones of Indiana as shown (*Bulletin* No. 522 of the U. S. Geological Survey):

ANALYSES OF MISSISSIPPIAN LIMESTONES FROM INDIANA

	1	2	3	4	5	6	7	8	9
(SiO_2)	0.50	0.70	1.74	1.60	0.65	0.90	1.13	0.31	0.48
(Al_3O_2) and (Fe_2O_3)	.98	.91	.29	.18	1.00	3.00	1.06	.32	.15
($CaCO_3$)	96.60	96.79	95.62	95.55	95.54	95.00	96.04	98.09	98.91
($MgCO_3$)	.27	.23	.89	.93	.40	.22	.72	.....	.63

	10	11	12	13	14	15	16	17	18
(SiO_2)	0.84	0.86	0.64	0.76	1.26	1.69	0.63	0.15	0.50
(Al_2O_3) and (Fe_2O_3)	.13	.16	.15	.15	.18	.49	.39	.64	.71
($CaCO_3$)	97.39	98.11	98.27	98.16	97.90	97.26	98.20	93.80	93.07
($MgCO_3$)	.78	.92	.84	.97	.65	.77	.81	4.01	4.22

1. Chicago and Bedford Stone Company, Bedford, Lawrence county. Eighth, Ninth, and Tenth Ann. Repts. Indiana Geol. Survey, 1879, p. 95.

2. Simpson and Archer quarry, near Spencer, Idem, p. 94.

3, 4, 5. Dunn and Company, Bloomington. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.

6. Monroe Marble Company, Stinesville. Report of a geologic reconnaissance of Indiana, 1862, p. 137.

7. Salem, Idem, 1886, p. 144.

8. Stockslager quarry, Harrison county. Idem, 1878, p. 96.

9. Milltown. W. A. Noyes, analyst. Twenty-seventh Rept. Indiana Dept. Geology, 1902, p. 98.

10. Acme Bedford Stone Company, Clear Creek, Monroe county. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1899, p. 381.

11. Hunter Brothers quarry, Hunter Valley. W. A. Noyes, analyst. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.

12. Indiana Stone Company, Bedford, Lawrence county. W. A. Noyes, analyst, Idem.

13. Twin Creek Stone Company, Salem, Washington county. W. A. Noyes, analyst. Idem.

14. Romona Oölitic Stone Company, Romona, Owen county. W. A. Noyes, analyst. Idem.

15-16. Hoosier Stone Company, Bedford, Lawrence county. F. W. Clarke, analyst. Bull. U. S. Geol. Survey No. 42, 1887, p. 140.

17-18. Indiana Steam Stone Works, Big Creek. L. H. Streaker, analyst. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.

"Cement consists of certain anhydrous double silicates of calcium and aluminum, which are capable of combining chemically with water to form a hard mass." The above definition is given in most texts on industrial chemistry but from an industrial standpoint it is an intimate mixture of limestone and shale or marl and clay that has been calcined and ground until it will harden under water. Cements differ from lime mortars in that they do not require carbon dioxide from the air in hardening and are insoluble in water. The hardening of the cement takes place thruout the whole mass simultaneously and thus makes it very useful as a building material.

Cements are of three classes, as follows:

1. Those cements formed from volcanic tufas or materials resembling them such as Pozzuolana, blast-furnace slags, etc. These cements require the addition of lime before showing their hydraulic properties.

2. Those cements which contain large quantities of free lime such as Roman cement and "hydraulic" limes. These cements have been formed by burning a natural argillaceous limestone at a temperature that has driven off all the carbon dioxide present in the limestone, without being sufficiently high to fuse the product.

3. True Portland cements or those which have been prepared by burning at a high temperature an intimate mixture of clay or shale with a calcium carbonate rock.

The chemical composition of Portland cement has not been definitely determined, but the most exhaustive work on the subject has been done by a French chemist, Le Chatelier. After careful synthetic determinations he gave the following formula for its compostion:

$$x(3CaO, SiO_2)\ y(CaO, Al_2O_3)$$

In this formula x and y are variable quantities depending on the relative proportions of silica and alumnia in the clay used.

The essential ingredients of Portland cement may vary slightly in their chemical composition, but the limits of variation are reasonably well marked. The average composition of the raw materials is shown in the following table (Thorp, *Outlines of Industrial Chemistry*, p. 184):

	Clay	Marl	Limestone	Shale
SiO_2	42.20	0.50	3.00	15.00
Al_2O_3	12.30	0.20	1.50	7.00
Fe_2O_3	4.60	0.10		
$CaCO_3$	23.90	94.50	96.50	71.00
$MgCO_3$	16.05	2.25	3.00	4.00
Alkalies, moisture, etc.	0.95	2.45	....	....

It will be accurate enough to state that the mixture from which Portland cement is made must contain approximately 75 per cent of calcium carbonate, 20 per cent of silica, alumina, and iron taken together, while the remaining 5 per cent includes the magnesia, sulphur, and other substances that are present as impurities in the raw materials.

It is seldom possible in nature to find a rock deposit approaching the necessary composition for the making of Portland cement, so that the materials have to be derived from different deposits and mixed as used. The usual ingredients for the manufacture of Portland cement are obtained from deposits of limestone which supply the calcium carbonate, and deposits of shale which furnish the silica, alumina, and iron.

Factors Determining Development. The factors that determine the value of a deposit of limestone for the manufacture of Portland cement are as follows: (1) chemical composition of the material, (2) physical character of the material, (3) amount of the material available, (4) location of the deposit of limestone with respect to deposits of the other ingredients, (5) location of the deposits with regard to transportation routes, (6) location of the deposits with regard to location of fuel supply, (7) location of the markets to be supplied.

When considering the possibilities of turning the waste rock of the Southern Indiana quarry districts into Portland cement it would be well to look at the deposits in the light of the above requirements. In chemical composition the Mitchell and Oölitic stone are both very well fitted for the manufacture of cement. In fact, the Lehigh Portland Cement Company is operating a plant at Mitchell, Ind., in which the Mitchell limestone is used altogether. The United States Cement Company's plant at Bedford, Ind., operated for some time with Oölitic stone and pronounced it of first-class quality. Both deposits are very high in their percentage of calcium carbonate and contain very little other material which could be considered as impurity in the manufacture of cement. It is generally conceded that other things being equal no better stone deposits for the manufacture of Portland cement can be found.

In its physical characters the stone is well adapted to cement manufacture since it is easily crushed and carries a low percentage of moisture.

The discussion of the supply of material available for the manufacture of Portland cement from the waste limestone of the quarry district raises several questions that are rather difficult of solution. The amount of material necessary for a paying plant is quite large, and the process of getting the waste to a centrally located plant involves a problem in transportation which will be taken up later in this study. So far as the amount of stone necessary for the manufacture of cement is concerned, the supply is practically unlimited, but the problem of its delivery at a central plant is difficult of solution.

The relation of the deposits of limestone to deposits of shale is favorable for economical operation. The shale used by the Lehigh Cement Company is brought from the Knobstone formation (near Brownstown and Sparksville, Ind.). These shale deposits are available for any plant operating in the southern part of the district since several roads enter the stone belt from the east. The Knobstone formation outcrops east of Bloomington along the Illinois Central Railroad and would be available for a plant located at Bloomington. There are deposits of shale in the Chester formation which outcrops west of the city, but it is not known how plentiful the deposits are or whether they are adapted in composition to cement manufacture.

A cement plant located at either Bedford or Bloomington would be in a favorable position with regard to fuel supply, markets, and transportation routes generally. The belt is penetrated by at least five east and west roads and by the Monon running from north to south.

"Run of mine" and slack coal can be laid down in either town very cheaply since the coal fields are less than forty miles away.

Methods of Manufacture. There are two general methods of cement manufacture known as the wet and dry method respectively. The process adopted in any locality depends upon the deposits to be worked and the economic conditions under which the work is to be carried on.

In the wet process the clay and chalk or marl are ground in edge runners with heavy rolls till fine. This material is then mixed with about half its weight of water. This slime or "slurry", as it is called, is pumped into buhrstone or tube mills where it is given a thoro grinding. After this wet paste is dried, it is sent to the kilns where it is calcined. The burned clinker is then ground fine to produce the finished product. The Hoffman ring furnace which has already been described in the part of this study treating of lime, is often used in the calcining of cement. Another type of furnace much used is the Dietsch two-storied kiln. This is a continuous kiln, the material being fed in at the top and discharged at the bottom. Tests made on this type of furnace with regard to the fuel consumption give about 7 tons of clinker per ton of coal burned. The Hoffman furnace uses about the same amount of coal per ton of clinker.

In the dry process the materials, shale and limestone, are ground separately to a good degree of fineness; then they are carefully mixed in predetermined amounts by large mixing machines and this mixed material is charged into the upper end of a long rotating kiln. The fuel is driven into the lower end of the kiln by compressed air and burns as it enters. The hot gases and flame are driven up the kiln and meet the mixture as it rolls down as a result of the rotating of the kiln. The burned clinker drops from the lower end of the kiln where it is picked up by a conveyor, carried to the top of a high tower, and allowed to fall thru space to cool. The fuel charged into this kiln is powdered coal, which gives a very high temperature, on account of the powerful draft produced by the compressed air.

The cooled clinker is charged into a mill where it is finely ground, and the product is then ready for the storage bins. The shale and the limestone are first ground by large crushers for coarse crushing, and following these the material is fed to fine crushers and rolls in succession before mixing. The crushers most commonly used are crushers of the Gates gyratory type which reduce the material to about 2-inch size. Fine crushers follow these and are usually of the Gates and Gardiner types. The material usually needs drying before it is mixed, and this is accomplished by conducting it thru a smaller kiln into which the waste gases from the calcining kilns are conducted. The tube mills used consist of horizontal iron tubes about 16 feet long by 4 to 6 feet in diameter, which rotate on a shaft at the rate of about 25 times per minute. The tube is about half full of quartz pebbles about the size of hens' eggs and these produce a grinding action as the tube rotates. These pebbles are retained in the tube by the screens at the outlet end thru which the ground clinker passes. The clinker is fed to the mill by means of belt conveyors, and a new supply of pebbles is charged in the tube as fast as the old ones wear out. The rapidity of rotation and the rate of the feed determine the fineness of the product.

This fine grinding is often done by a Griffin mill. This consists of a heavy steel roll revolving on a vertical shaft with a gyratory motion, and pressing by centrifugal force against a steel-inclosing ring. These mills have a great capacity and will grind very fine, but the cost of upkeep is much greater than with the tube mill.

The power required in the manufacture of cement is given by Professor Bleininger, *Geological Survey of Illinois*, Bulletin No. 17 (p. 57), as 1.5 horse-power per barrel of output, that is, a 1,000-barrel plant would require 1,500 horse-power. This is rather high for larger plants where one horse-power per barrel of output has been realized. One 5,000-barrel plant is now operating on 4,500 horse-power.

The fact that the deposits of material for the manufacture of cement are located near coal mines does not insure a cheap supply of fuel under present conditions where powdered coal is to be used as a fuel. Many coals are not suited for the burning of cement since the ash from the coal mixes with the cement in the kiln, and with a coal of high sulphur content or high percentage of ash these impurities will spoil the cement made. Coals must have a high heating value since the temperature of the kiln should be kept up to about 2,500 degree Fahrenheit. To cause even heating thruout the entire length of the kiln the coal should contain a large amount of volatile matter. These considerations are so important that the location and supply of fuel becomes more important than the location of the deposits of cement material. As mentioned before, the cement deposits are located near the Indiana coal fields, but at the present time the plants of Indiana are using Pittsburgh coals. This difficulty could be remedied by the use of producer gas in the kilns. In fact, the use of gas is increasing even in the coal districts of West Virginia and Pennsylvania. The advantages of the use of producer gas as a fuel for the manufacture of lime or cement are many and the use of gas as a fuel in both industries is sure to grow rapidly. Producer gas is better than coal for the following reasons:

1. The absence of ash in the burned product. In the producer gas the ash remains behind and only the combustible gases are passed into the kilns to burn, thus insuring a purer product.
2. The presence of a great amount of water as the gas burns. A large percentage of the gas consists of hydrocarbons and hydrogen and the combustion of these gives water. This is of especial advantage in the manufacture of lime.
3. The high heating value of the gas.
4. The ready control of the point of burning and the tempera ture.
5. The fact that any coal can be utilized in the manufacture of gas.

Cost of Cement Manufacture. The cost of the raw materials varies greatly in the different districts. Estimates on the loss of weight due to burning the raw material to cement clinker are: for dry, hard limestone and shale about 33⅓ per cent, that is, 1,000 pounds of the mixture of limestone and shale will give about 665 pounds of cement clinker. A barrel of Portland cement weighs about 380 pounds and Eckel (*op. cit.*, p. 59) states that if the losses of manufacture are included, it is safe to say that 600 pounds of raw material will produce a barrel of cement. The cost of excavation and delivery is given as from 8 to 15 cents per barrel. That represents a cost of from 27 to 50 cents per ton of raw material at the mill. Since it takes from four to five carloads of limestone per carload of shale and the price of limestone delivered in the quarry district is very low, the shale could be brought quite a distance without exceeding this figure.

As has been already stated, the fuel cost is a more important consideration than the cost of raw materials. In the use of powdered coal the coal must be dried, then crushed. The average moisture content of coals is about 8 per cent, and under favorable conditions it takes about a pound of fuel to dry 100 pounds of coal. The best type of dryer now in use is the rotary dryer. At the above figures the cost of drying fuel will be about 3 to 4 cents per ton of dried product. Coal, to give the best results, when powdered for cement burning, must be very fine, and the usual practice is to reduce it to such a size that from 85 to 95 per cent will pass a 100-mesh sieve. The poorer the grade of coal used the finer it must be powdered. The coal is usually powdered by two operations. It is first reduced to about 30-mesh by means of ball mills and then fed thru a tube mill. This process may be varied to fit the conditions in any mill altho the cost will total about the same.

The total cost of crushing (provided fine slack is not obtainable), drying, and pulverizing the coal, together with the cost of elevating and conveying the coal to the kilns, will amount to as much as 30 cents per ton, which is equivalent to from 1 to 2 cents per barrel on the cost of the cement.

Power cost in a cement plant is also a large item since the power consumption is put as high as a horse-power per barrel of output per day, while the figure of 1 cent per horse-power hour is low except in the very large plants. Of course many plants are saving a part of the heat from the kilns and using it in the form of power, but it will be seen that the power cost will in any case be fairly heavy.

The cost of labor varies so in different localities that any figures given will be only approximations. Professor Grimsley gives the relative cost of production as follows: fuel 35 per cent of total cost, labor 45 per cent of total cost, and other expenses as 20 per cent of the total (*West Virgiana Geological Survey*, Vol. III, p. 440).

The following figures are given for the cost of production per barrel of cement in Bulletin 3 of the *Ohio Geological Survey* (p. 330):

LABOR

Quarrying	$0.050	
Crushing and drying	0.005	
Grinding	0.015	
Burning	0.015	
Power generation	0.011	
Coal grinding	0.010	
Yard work	0.015	
Machine shop	0.0225	
Miscellaneous	0.0025	
		$.15

RAW MATERIALS		
Coal	$0.225	
Gypsum	0.0125	
		.2375
ACCESSORY EXPENSES		
Repairs	0.04	
Oil	0.02	
Miscellaneous	0.03	
		0.09
Packing and loading	0.04	
Works and management	0.02	
		0.06
Interest on investment ($700,000)	0.07	
Sinking fund and deterioration	0.10	
Management and selling expenses	0.065	
		0.235
Total per barrel of output		$0.7725

The total cost of production in Michigan is figured as follows from data given in D. J. Hale's report on Portland cement, in Vol. VIII of the *Geological Survey* of that State (pp. 158-190):

Total cost of materials and labor of manufacture	$0.4785
Overhead and selling cost	00.2015
Total	$0.68

The figures given above are on a plant with an output of 1,200 barrels per day. The cost of production would fall below this figure in a larger plant since several of the items quoted above will not increase in the same ratio as the output.

No reliable figures as to the cost of production in Indiana are at hand but since these two States from which I have quoted prices are bordering States and operate under the same conditions, the figures will lie somewhere near those given.

The industry has reached a point where cost of production and selling price are so close together that cement can only be manufactured economically in large plants. In fact, with the selling price where it is there are very small profits with a plant with an output below 3,000 barrels.

Since it requires over 400 pounds of limestone to the barrel of cement, on account of the losses from ignition, a 3,000-barrel plant would require at least 600 tons of waste limestone a day. This would be equivalent to approximately 7,000 cubic feet of stone per day or over 2,000,000 cubic feet per year for a steady run. Figuring on the same basis, a 5,000-barrel plant would require nearly 3,500,000 cubic feet of limestone per year. The superintendent of the plant at Mitchell names a figure of 30 carloads per day, which will very closely approximate the estimates given above.

Altho the waste of the quarry district is probably considerably more than this during an active year, the collecting of this amount at a central plant with any degree of regularity would be impossible. It will thus be seen that a cement plant could not be constructed to use the waste of the quarry district economically, at least if a special quarry were not run to carry the plant over slack times. Another thing that would make it uneconomical is the fact that most of the waste is in large blocks which would need blasting and sledging before they would be in a form in which they could be fed to the crushing machines. This cost would be almost as much as the cost of blasting the material off the "solid" with high explosives, a process which would produce a large percentage of fines.

Transportation charges to a central plant would be at least 5 cents per ton (the price now paid for moving cars in the district if the product is to be hauled again).

If the cost of material and the charges for loading it on the cars be added to this, the resulting figure will exceed 20 cents per ton at the mill. Practically every estimate of engineers as to the cost of winning the raw materials and delivering it at the mill is as low or lower than the above figure, where the deposits can be worked by quarrying with high explosives. It will thus be seen that this method of waste utilization does not offer itself as a means of solving the problem in hand.

There are a number of old quarries or openings which have been worked out or have proved poor building stone, that could be optioned at a very low figure. Many of these contain almost unlimited supplies of limestone that, while it will not make good building stone, would make an excellent grade of cement. In many cases the railroad tracks are still in position, and where removed the grade remains. Feeling that these might be utilized, I asked several companies interested in stone quarrying with explosives to give estimates of the cost of blasting the material off the "solid" for a cement plant located near these quarries and delivering it to the crusher. Among the answers received, the data furnished by the E. I. DuPont de Nemours Company as to the cost of blasting with high explosives were very full and helpful.

The following letter received from Mr. H. S. Gunsolus, manager of the Technical Division of the DuPont Company, will be of interest in this connection to any company interested in blasting out limestone for cement:

Your letter of December 30th, in reference to the cost of explosives per cubic yard for blasting limestone to be used for fertilizing material is received.

We have not replied earlier, due to our wishing to get some information together which might be of assistance to you. We are going to list below a number of shots which have either been supervised or witnessed by some of our own technical men and we feel sure that the figures given are approximately correct. You understand, of course, that the variation in cost is due to local conditions, stratification, mud seams, etc., as well as the size of crusher to be used, which of course will regulate the size of the broken stone.

In limestone, used for railroad ballast, we had 8 holes, spaced 18 feet apart. Average face burden 19 feet; average depth 48 feet; approximately 4,900 cubic yards. There were used 3,300 pounds 40 per cent dynamite, making a cost per cubic yard of about .084 cents.

A blast in cement rock, 9 holes, spaced 22 feet apart. Average face burden 32 feet; average depth of hole 62 feet; approximately 13,000 cubic yards. For this there was used 2,500 pounds 60 per cent and 1,800 pounds 40 per cent dynamite, making a cost of about .046 cents per cubic yard.

Another blast in cement rock of 7 holes, spaced 15 feet apart. Average face burden 23 feet; depth 60 feet; about 5,400 cubic yards. For this there was used 500 pounds 60 per cent and 2,900 pounds 40 per cent dynamite, making a cost of about 8 cents per cubic yard.

Blast in hard, massive limestone, 8 holes. Average space between about 28 feet; average face burden 33 feet; depth of holes about 95 feet; approximately 26,000 cubic yards. For this there was used 2,200 pounds blasting gelatin, 3,350 pounds 60 per cent and 1,250 pounds 40 per cent dynamite, making a cost per cubic yard of about .046 cents.

Blast in limestone for lime manufacturing of 3 holes, spaced about 17 feet apart. Average face burden 24 feet; average depth of holes 100 feet; approximately 4,600 cubic yards. The dynamite used amounted to 1,200 pounds, 60 per cent and 1,600 pounds 40 per cent making an average cost of .082 cents.

Another blast in limestone for cement manufacture, 9 holes, spaced about 20 feet apart. Average face burden 36 feet, and about 53 feet in depth; approximately 12,700 cubic yards. For this there was used 1,720 pounds 60 per cent and 2,500 pounds 40 per cent, making a cost of .045 cents per cubic yard.

Another blast consisting of 4 holes 18 feet apart with about 25 feet face burden and 100 feet deep; approximately 6,700 cubic yards, for which there was used 1,200 pounds 60 per cent and 1,600 pounds 40 per cent, making an average cost of .056 cents per cubic yard.

Eight holes blast spaced 15 feet apart, with a face burden of approximately 25 feet, holes 115 feet deep; about 12,800 cubic yards, for which was used 3,950 pounds 40 per cent and 2,000 pounds 50 per cent, cost per cubic yard being about .038 cents.

Sixteen 70-foot holes, face burden of 25 feet, spaced about 15 feet apart; approximately 15,000 cubic yards, for which was used 3,750 pounds 60 per cent, 4,050 pounds 40 per cent making a cost per cubic yard of about .068 cents.

Another nine 50-foot hole blast, spaced 18 feet apart, with 25-foot face burden; approximately 7,500 cubic yards for which there was used 3,250 pounds 40 per cent, making cost of .055 cents per cubic yard.

Seven 60-foot holes spaced 15 feet apart with about 20 feet face burden, approximately 4,600 cubic yards. For this was used 500 pounds 60 per cent, 2,900 pounds 40 per cent making cost of .095 cents per cubic yard.

Eight holes which ran from 80 to 108 feet in depth spaced 27 feet apart, with 30-foot face. There was about 22,000 cubic yards in this shot, for which there was used 2,200 pounds blasting gelatin, 3,350 pounds 60 per cent and 1,200 pounds 40 per cent, making cost of about .055 cents per cubic yard.

Another eight 48-foot hole blast, spaced 18 feet apart, with 20-foot face burden, approximately 4,500 cubic yards, for which there was used 3,300 pounds of 50 per cent making average cost of about 10 cents per cubic yard.

A nine 62-foot hole blast, with a 32-foot face burden, spaced about 20 feet apart; approximately 13,300 cubic yards. Used 2,500 pounds 60 per cent and 1,800 pounds 40 per cent making average cost of about .045 cents per cubic yard.

A fourteen 86-foot hole blast, spaced 18 feet apart, with a 30-foot face burden, making approximately 24,000 cubic yards. Used 850 pounds 50 per cent, 3,250 pounds 40 per cent, and 4,000 pounds 60 per cent making cost of about .046 cents per cubic yard.

Another shot was five 85-foot holes, spaced 18 feet apart, with about 25-foot face burden. About 5,000 cubic yards, for which there was used 1,300 pounds 60 per cent and 1,000 pounds 35 per cent. This cost about .06 cents per cubic yard.

These figures are taken from various sections of the country, not being confined to any particular locality, and we have figured the explosives on basis of 12½ cents for the 40 per cent, 13.7 cents for the 50 per cent, and 14.9 cents for the 60 per cent, and 25 cents for the blasting gelatin. These are about the average figures, and of course vary according to the location.

Thinking perhaps you might be interested in the comparative cost between the steam or air drill and the well drill system:

One of our technical men made a close study of this and found that the cost of drilling with an ordinary tripod drill varies from 10 cents to 25 cents per foot, this wide variation depending on the nature of the rock, cost of labor, fuel, oil, the number of drills in operation, and the accessibility to source of power, water, etc. The fewer the drills in operation, if run from a central power plant, the higher the cost per foot.

In rock of medium hardness, such as limestone, a man working industriously should average about 50 or 60 feet of hole per 10-hour day. The cost of drilling such rock seldom falls below 15 cents per foot in a quarry operating several drills.

The cost of drilling a $5\frac{5}{8}$-inch hole with a well drill varies from 20 cents to 50 cents per foot, the general average being somewhere around 30 cents. A good operator and helper in ordinary limestone can make from 15 to 40 feet per day of 10 hours.

A 25-foot headway is a very good average. Room for comparison—180 feet of drilling with each type of drill. Relative cost 15 cents per foot for steam drilling, and 30 cents per foot for well drilling. Steam drill drilling 180 feet at 15 cents is $27. At a 7x7 spacing nine 20-foot holes will break about 325 cubic yards. About 140 pounds of 40 per cent dynamite would be required, which would amount to $17.50. This plus the cost of drilling makes $44.50. Breakage of 325 cubic yards would mean a cost of about 13.6 cents. Working this by well drill system, take three 60-foot holes, drilling 180 feet at 30 cents equals $54. At 20x20 spacing thirty 60-foot holes will break approximately 2,600 cubic yards. About 1,300 pounds of 40 per cent explosive would be needed, which would cost $168.75, making total of $222.75 to get out 2,600 cubic yards or about .085 cents per cubic yard.

We trust that this information will be of some interest and benefit to you, and that we have not delayed so long that you cannot use it in your paper, which we understand you are preparing for report of the State Geologist.

Yours very truly,

Manager Technical Division.

Practically all the data furnished by other companies, altho not given in detail, agreed with the above figures as to cost when the conditions under which the blasting was done were the same.

Much work has been done by the United States Bureau of Mines on the production of explosives especially fitted to different grades of work, and as a result much information is at hand as to the explosives best fitted to the work in hand and the uses to which it can be put. These bulletins are for free distribution by the Director of the Bureau of Mines, Washington, D.C., and can be had by asking for them.

It will be seen that the approximate cost of blasting out material in large amounts in localities such as this district would approximate 8 cents per cubic yard. The cost of transporting this material to the crushers in a form in which they can use it (that is, including the cost of extra blasting and sledging where necessary) would be about the same, while labor and capital charges on the machinery would be about 26 cents per cubic yard, giving a total of about 44 cents per cubic yard for the limestone, which is about 19 cents per ton. Calculating along the same lines, the cost of shale winning is about 11 cents per ton under favorable conditions. This makes the raw material cost on an average $17\frac{1}{2}$ cents per ton or about $5\frac{1}{4}$ cents per barrel of output. These figures are made on the basis of four parts of limestone to one part of shale and 600 pounds of raw material per barrel of cement burned. It will be seen that this figure is rather low as compared with the figures given by engineers who have written on the subject, but when it is taken into account that the deposits of limestone are in a very favorable location for quarrying in this district and that no calculations have been made on the cost of bringing the materials together at a central plant, the figure can be taken as a close approximation of the actual cost.

The demand for cement is growing rapidly in this country and as soon as cheaper methods of power production and cheaper fuels are utilized the industry is sure to be a good paying venture. The fact that the difference between cost of production and selling price is so small is an added incentive to the development of better methods and better machinery of production.

CHAPTER XI

CRUSHED LIMESTONE

Waste Limestone for Road Metal, Railroad Ballast, and Concrete. The value of the crushed limestone used for road-making, railroad ballast, and crushed rock concrete is greater than that of any other limestone product. In 1913 the output of this material in the United States was 35,169,528 short tons, or approximately 420,000,000 cubic feet of limestone with a value of $19,072,024. The output was divided as follows:

Road-making, 13,296,377 short tons; value $7,353,665.
Railroad ballast, 11,774,121 short tons; value $5,551,415.
Concrete, 10,099,030 short tons; value $6,167,144.

The average price of this material was 54 cents per ton. In road-making material Indiana ranked third, with an output valued at $956,234, being outranked only by Ohio and New York. In the production of railroad ballast Indiana was tenth, with an output valued at $203,431. In the use of limestone for concrete Indiana ranked sixteenth, with an output valued at $103,855.

The two properties of limestone which are of importance in road-making material are its wearing qualities and its cementing properties. The subject of good roads has attracted wide attention in a number of States, and while there is a great variety of rocks which can be used as a road material, none is better adapted to the work than a good, hard limestone.

The limestone of the Mitchell formation which must be removed as stripping in many of the quarries is admirably adapted to road construction because it is a very hard limestone with good wearing qualities. The stone, altho hard, is easily crushed because it is brittle, and works up easily.

The stone of the Oölitic formation is softer and will not wear long on roads that have to withstand heavy traffic. When a road receives a thick covering of this stone the surface of the stone coating tends to pack together and become firmly cemented. If the traffic is not too heavy during the time the material is setting, the road will harden down in good shape. But if the traffic is too heavy the stone is ground fine before it has a chance to become cemented together. The roads of Monroe and Lawrence counties are to a great extent built of limestone, most of the material having been taken from the Harrodsburg and Mitchell limestones which outcrop extensively in these counties. These roads are for the most part in good condition, altho some of them have been in use for a long time without any special care.

The waste limestone resulting from the removal of the overburden of Mitchell limestone in many of the quarries is an ideal road metal, and if transportation charges were reasonable its use thru the State would give Indiana far better roads than exist at the present time in many parts of the State.

The Office of Public Roads of the United States Department of Agriculture maintains a testing plant for the testing of road materials, and many specimens have been tested, including 8 samples of limestone from Lawrence county and 5 samples of limestone from Monroe county. All of these samples, altho showing a low value of toughness, were high in their cementing value and good in hardness and percentage of wear. The data of these tests can be found in *Bulletin* No. 44 of the Office of Public Roads. It is believed that Indiana has reached a new period of road improvement, and it would be a good thing for the quarrymen who are puzzling over methods of waste disposal to see that the limestones of Lawrence and Monroe counties are properly advertised and brought to the notice of officers in charge of road construction thruout the State.

The railroads that have tried to use the Oölitic limestone as railroad ballast have been inclined to give an unfavorable report of its usefulness. The roads which have used the Mitchell as ballast report that it is very successful, but that the softer Oölitic stone will not give a firm enough bed. The tests that have been made with this stone have usually been over harder ballast which had already been used. Under such conditions the softer stone is held by the harder particles and ground as tho in a ball mill by the jar of the passing trains. It seems probable that if the entire roadbed could be made of the soft stone, it would tend to cement in a solid mass and become in a sense monolithic. If the material were ground reasonably fine before being placed in position, then wet down and allowed to settle, the jarring action of the passing trains would not tend to grind it fine as in the experiments already mentioned. Much of the waste from some of the quarries has been removed for ballast, but in most cases it was given to the railroad for hauling it away. In most cases also the operator loaded the material free of charge.

Much crushed stone is used in concrete work. The strength of the concrete is measured by the strength of the cement and so concrete made from crushed limestone is practically as strong as that produced from any other stone. In the manufacture of concrete the crushed rock should be angular since the resulting aggregate is stronger than with worn particles.

For any of the above uses the material need only be crushed to about 2-inch size. Thus a single coarse crusher is all that is needed. The most common type used in this work is the Blake jaw crusher.

Extensive tables on the cost of coarse crushing are given in the chapter on Ground Limestone, and these cost figures will apply equally well to the work on road material because the same machinery is used for rough crushing in both cases.

The cost of crushing with a Blake type crusher ranges from 3 to 6½ cents per ton, depending on the output of the crusher. The power consumed per ton crushed to 2-inch size is about $\frac{1}{16}$ of a horse-power per hour.

Waste Limestone as a Flux for Blast Furnaces. In the treatment of iron ore in the production of pig iron it is necessary to add some fusible material of low specific gravity as a means of removing the impurities present in the ore. The present method of ore treatment in use in this country is to feed the ore together with coke and limestone into the blast furnace thru a pair of hoppers closed by means of bells. The object of the double valve is to avoid the escape of the furnace gases. Large quantities of air heated to 600 or 800 degrees Centigrade are forced into the lower part of the furnace at a pressure from 12 to 15 pounds per square inch. This air burns the coke and the heat thus generated melts the charge, and as the material settles to the bottom of the furnace the ore and the slag separate on account of their different specific gravities. The limestone is decomposed by the high temperature, giving up carbon dioxide, and changing to calcium oxide or common lime.

The large amount of silica and clay or alumina which is contained in the ore unites with the lime formed from the limestone to form what is called the slag. This slag is the waste product in the manufacture of iron and usually has the following general composition: 30 to 35 per cent SiO_2, 10 to 15 per cent Al_2O_3, and 50 to 55 per cent CaO. The amount of limestone to be used with any ore is determined by the amount necessary to produce an easily fusible slag.

If the slag is not made use of it is drawn off into large tilting ladle cars and dumped away. In most cases this slag has the proper composition to form a good grade of cement, if properly handled. When the slag is to be used as material for the manufacture of cement it is drawn off into water where it takes on a coarse granular texture which leaves it in an easily handled form. Great efforts are made to maintain the proper quality of the slag, and if a uniform grade of iron is to result the composition of the slag must be carefully watched.

Both limestone and dolomite are extensivley used for fluxes thruout the country. Both of these fluxes have their advantages, but as the manufacture of cement from blast f rnace slags becomes more widespread the demand for a high ca ium limestone will increase for the reason that the slags from dolomite flux are not suitable for the manufacture of cement.

The slags obtained from high calcium fluxes develop hydraulic properties when allowed to cool quickly. This is accomplished by running the molten slag into water. The resulting granular product is dried and ground very fine, and mixed with a certain percentage of slaked lime, and this mixture is again ground so as to pass a 200-mesh sieve. The resulting powder will have the properties of a good hydraulic cement. This form of cement works best in places where it is constantly wet, because drying tends to disintegrate it.

Dolomite flux is favored in the Birmingham iron district, as shown from the following quotation from the work of Burchard-Butts and Eckel on "Iron Ores, Fuels and Fluxes of the Birmingham District, Alabama" (*Bulletin* No. 400, U. S. Geological Survey, p. 197):

> The fluxing power of dolomite is greater than that of limestone; an equivalent of carbonate of magnesia weighs 84, while an equivalent of carbonate of lime weighs 100; in fluxing power these equivalents are equal because the power of a base to combine with an acid does not depend upon its atomic weight, but upon its chemical affinity. So the fluxing powers of the two carbonates are to each other as 84 to 100.
>
> The dolomite of this district is a great deal purer than the limestone. The foreign matter of the former does not exceed 2 per cent while of the latter an average is at least 4 per cent. To determine the value of a stone as a flux we must deduct the impurities it contains, plus as much of the base as is necessary to flux those impurities. Taking the limestone as a 96 per cent lime carbonate, and deducting 8 per cent to take care of its own impurities, we have left 88 per cent of lime carbonate as available flux. Taking the dolomite to contain 2 per cent of impurities and 43 per cent carbonate of magnesia, with 55 per cent of carbonate of lime, we have left, after deducting 4 per cent of the carbonate of lime to take care of the impurities, 43 per cent of magnesia carbonate and 51 per cent lime carbonate. The fluxing

powers of the two carbonates are to each other as 84 is to 100, so reducing the magnesia carbonate to its equivalent in fluxing power of lime carbonate, we have

$$\frac{43 \times 100}{84} + 51 = 102.19$$

Therefore the relative value of the two fluxing materials of this district are to each other as 88 is to 102.19.

In other words, the dolomite flux is preferred because of its greater purity, but this excuse will not apply to the waste limestone of Southern Indiana quarry districts since none of the dolomites used for flux is any freer from impurities than the Oölitic limestones which often carry as high as 98.5 per cent calcium carbonate. The overlying Mitchell limestone is, if anything, purer than the Oölitic stone.

Another argument in favor of dolomite fluxing stone is that it gives a more liquid slag than a limestone fluxing stone. On this point I would say that very liquid slags are only necessary where the ore used contains a large quantity of impurities; and that the only blast furnaces that could use our waste stone, on account of the high freight rates, are those located around Gary and Chicago, which use much higher grade ores than those demanding highly liquid slags.

Dolomite cannot be used as a slag when the ores run high in sulphur. In such cases the lime carbonate is better than magnesium carbonate because the calcium has a greater affinity for sulphur than has magnesium.

Since most of the ores now coming from the ore fields of Michigan and Minnesota are high-grade ores carrying some sulphur, the demand for limestone slag is sure to increase, even if the manufacture of blast furnace cement does not increase. This latter industry is, however, developing rapidly in many foreign countries, and seems almost sure to increase in this country because the cost of manufacture is very small and it offers an opportunity for the profitable disposal of a large amount of waste material.

Waste stone has been sent out of the Southern Indiana quarry district for use as flux in the steel mills of Gary and Chicago for a long time; but the amount has been small and the benefit to the quarryman from this source has been little more than that of getting their waste piles out of the way. This condition results from the excessive freight rates charged by the railroads, or, at least, the adverse conditions under which shipments must be made. As soon as the railroad officials realize the amount of this material that could be carried if more favorable rates were made there will be a tendency to make better rates and conditions.

One thing that has held back the development of this outlet for the waste stone of the district is the fact that in the past many quarry operators have adopted the practice of giving the waste stone to the railroads if the latter would remove it, even going so far as to load the material free of charge. Thus it will be seen that the entire profit of the transaction has gone to the railroad and it would therefore be to their interest to maintain high rates on shipments of this material by individuals to the blast furnaces.

The total amount of limestone used for flux in this country in 1913 represented a value of $11,103,989 of which Indiana produced $199,995 worth, ranking ninth in this industry. The above total represented a production of 22,620,961 long tons, at an average price of 49 cents per ton.

The production in 1912 was 20,190,554 long tons with a value of $9,937,772, an average price of nearly 50 cents per ton.

Limestone and Lime in the Manufacture of Glass. "Glass is an amorphous, transparent, or translucent mixture of silicates, one of which is always that of an alkali." The above definition of glass is taken from a standard work on industrial chemistry. This study is concerned only with the glass which contains calcium as the alkali metal. In technical discussions of glass two general classes are recognized: lead glass and lime glass. The lime glass is more widely used, harder, cheaper, less fusible, and has greater brilliancy than the lead glass. The essential materials for the manufacture of lime glass are silica, an alkali (soda or potash), and lime or limestone. In the manufacture of glass, materials free from iron or iron compounds must be used. The alkalis most commonly used are the carbonate or sulphate of sodium or potassium. The carbonates fuse more easily, but the sulphates are more commonly used because they are cheaper. With the sulphate, powdered carbon must be used as a reducing agent, the reaction being as follows:

$$2Na_2SO_4 + 6SiO_2 + C = 2(Na_2O, 3SiO_2) + 2SO_2 + CO_2$$

Or, $2Na_2SO_4 + 2SiO_2 + C = 2Na_2SiO_3 + 2SO_2 + CO_2$

Common salt as a source of sodium in the manufacture of glass has not yet reached any extended use, but some method whereby it can be used economically is sure to be perfected.

Lime, or more properly calcium, is obtained from limes or finely ground limestone. The lime has been used much longer than the limestone, but has always given more or less trouble on account of the fact that it changes in volume as it takes up carbon dioxide from the air. This makes it difficult to mix the constituents of the glass in the correct proportions. The fact that the only form in which the limestone can be used is as a finely ground powder makes this a very good way for the plants turning out ground limestone for fertilizing purposes to dispose of their product during the dull season. The one plant already turning out ground limestone in the quarry district disposes of a large amount of its surplus product in this way.

The ground limestone can be used at the same mesh for glass manufacture as for fertilizer, thus doing away with the necessity of installing extra screens. The manufacture of glass in this country has increased notably in the last year or so and is sure to grow into a large industry in the next few years.

The chemical composition of the limestones of the Southern Indiana quarry district makes them very well adapted to the manufacture of glass since they are very high in calcium carbonate and contain only traces of iron and aluminum. The demand for the ground limestone of this district is sure to grow when it becomes generally known that the chemical composition of the stone is so well adapted to this industry.

The final reactions in the manufacture of lime glass are as follows:

$$Na_2CO_3 + CaCO_3 + 2SiO_2 = Na_2Ca\ (SiO_3)_2 + 2CO_2$$
$$\text{Or, } Na_2SiO_3 + CaCO_3 + SiO_2 = Na_2Ca\ (SiO_3)_2 + CO_2$$

Data on the amount of stone used for the purpose of glass manufacture in this country are not at present available, since the U. S. government in its reports on the amount of stone used puts the stone used in glass factories, paper mills, carbonic acid plants, and for fertilizing purposes in one group, for the reason that it is as yet impossible to secure separate data on each of these.

Limestone in the LeBlanc Process of Soda Manufacture. As the result of chemical experiments encouraged by the offer of a large prize by the French Academy of Science in 1775, Nicholas LeBlanc patented the process of soda manufacture which remains in use to the present time. The only process at present that offers competition to it is the Solvay process which will be discussed later. The LeBlanc Process consists of treating common salt with sulphuric acid to produce hydrochloric acid and acid sodium sulphate, or at higher temperature the normal sodium sulphate. The first reaction is as follows:

$$2NaCl + H_2SO_4 = 2HCl + Na_2SO_4$$

This sodium sulphate is mixed with limestone and coal or charcoal and calcined in a reducing flame forming a mixture of calcium sulphide and carbonate of soda. This reaction takes place as follows:

$$Na_2SO_4 + 2C + CaCO_3 = Na_2CO_3 + CaS + 2CO_2$$

The sodium carbonate and calcium sulphide can be readily separated by leaching with moderately warm water because the sulphide is practically insoluble, while the carbonate is easily soluble. This industry has been able to hold its own with the newer processes because hydrochloric acid and bleaching powder are produced as by-products of the process. At least one-half of the world's supply of carbonate of soda is produced by the LeBlanc process at the present time.

The manufacture of chloride of lime, or muriate of lime, can be carried on along with the process of soda manufacture since the only chemicals needed are limestone and weak solutions of hydrochloric acid. When limestone is treated with a dilute solution of hydrochloric acid and the solution concentrated by evaporation and allowed to cool, crystals of lime chloride are deposited. These crystals have the composition ($CaCl_2$, 6 H_2O), but when they are heated they lose two-thirds of the water, leaving a porous lime chloride which has a wide use as a drying and dehydrating agent in chemical laboratories. At the present a large supply of this compound is produced as a by-product of the Solvay process of soda manufacture.

Limestone in the Solvay Process of Soda Manufacture. The reactions of the ammonia process, later known as the Solvay process, were discovered by Dyar and Hemming in 1838, but no use was made of them till Solvay, a Belgian, constructed an apparatus for their use in 1863. Its advantage over the LeBlanc process lies in the fact that there are no troublesome by-products such as "tank waste" formed. No hydrochloric acid or chlorine is formed in the process, since these all pass into the form of calcium chloride. The process depends upon the fact that sodium bicarbonate is but slightly soluble in cold ammoniacal solution of common salt. The most important part of the process depends upon a careful regulation of temperature. The chemical reactions involved in the process are as follows:

$$NaCl + NH_3 + H_2O + CO_2 = NaHCO_3 + NH_4Cl$$

This formula means that salt, plus ammonia gas, plus water, plus carbon dioxide, equals sodium bicarbonate plus ammonium chloride.

The carbon dioxide is obtained by burning limestone in a specially constructed kiln which is arranged for saving the carbon dioxide. This gas is forced upward thru a tower where a concentrated brine of common salt charged with ammonia is flowing down. The temperature of the whole is kept at 35 degrees Centigrade. The sodium bicarbonate, being less soluble than the other constituents, is separated from them on filters. The bicarbonate is readily changed to the carbonate by heating. The liquor which passes the filters is treated with the lime formed in the producing of the carbon dioxide gas used in the tower and the following reaction takes place:

$$2NH_4Cl + CaO = 2NH_3 + CaCl_2 + H_2O$$

The liquor will contain calcium chloride and some sodium chloride. After this reaction these are separated by crystallization, since the salt is more soluble and remains in solution. The ammonia and salt solution can be used again in the tower, so there is no waste. The limestone used in either this or the LeBlanc process must be very pure because the presence of iron, silica, or magnesia interferes with the reactions and the purity of the product.

Carbon Dioxide Recovery in the Manufacture of Lime. In the manufacture of lime there are large quantities of carbon dioxide driven off. This gas is now used extensively in charging mineral water and in the manufacture of paints. It is usually made for these industries by the action of weak acids on lime carbonate, using marble or limestone in the operation. Since this gas can be condensed to a colorless liquid under a pressure of 50 atmospheres and is easily handled, it seems like an unnecessary loss to allow it to escape in the manufacture of lime, and then produce it as it is needed in other industries.

This recovery process is already in operation in England and the more progressive lime plants of this country are sure to install it in the near future.

Limestone in Lead Smelting. The Savelsburg process of lead smelting consists of heating an intimate mixture of galena or lead sulphide with limestone and water, in a reverberatory furnace in a strongly oxidizing atmosphere. The resulting mass contains the lead in the form of an oxide, and calcium sulphate, from which the lead can be removed by any of the ordinary methods of shaft furnace purifying. This process is often carried on with lime, instead of limestone, mixed with the galena. These methods are giving way to direct-blast furnace oxidation which can be accomplished if the temperatures are carefully regulated.

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AN EXPERIMENT TO TEST THE NATURE OF THE VARIATIONS ON WHICH SELECTION ACTS. By FERNANDUS PAYNE, Ph.D., Associate Professor of Zoölogy, Indiana University.

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AN EXPERIMENT TO TEST THE NATURE OF THE VARIATIONS ON WHICH SELECTION ACTS. By Fernandus Payne, Ph.D., Associate Professor of Zoölogy, Indiana University.

This (the March) issue of the Indiana University Studies *was published in May.*

Contents

(Contribution from the Zoölogical Laboratory of Indiana University, No. 165.)

An Experiment to Test the Nature of the Variations on which Selection Acts

By Fernandus Payne, Ph.D., Associate Professor of Zoölogy, Indiana University

Introduction

In recent years there have developed two contrasted views concerning the action of natural selection, or rather concerning the nature of the variations on which selection acts. On the one hand, we have the work of Johannsen and his followers, who maintain that selection can do nothing more than isolate pure lines. They further maintain that the only method of change within the pure lines is by mutation. Since by selection so-called unit characters in bisexual forms can be modified, a further development of the pure line theory has been necessary. This is the multiple factor hypothesis, the basis of which was given by Nilsson-Ehle ('09) when he showed that in certain crosses of oats and wheat two or three factors may be involved. Selection acts in such cases by eliminating or accumulating such multiple factors, and acts for a few generations only, or until a homozygous strain is produced. The second view concerning the variations on which selection acts has been developed by Castle, who holds that the individual variations of a given character are expressions of the variations of the gene which stands for that character.

My own experiment was devised and carried out primarily to find the nature of the variations on which selection acts. The character chosen was bristle number on the scutellum of Drosophila ampelophila. By starting with a female with one extra bristle (four is the normal number) the number of bristles was gradually increased until a maximum of eleven extra bristles was produced. The mean bristle number was increased until it reached 9.123. Tests were made and are described in the text which show conclusively, I think, that extra bristle number in this experiment is due to two factors and possibly more. One of these factors is located in the X-chromosome and the other is probably in the third.

I wish to express my thanks to Professor Morgan and Drs. Sturtevant and Bridges for stocks of their different mutations. Without these it would have been impossible to analyze my results.

Material and Methods

Drosophila ampelophila Loew was chosen after a search thru the list of material which could be bred in the laboratory. It was chosen for two principal reasons: first, it is easily bred; and secondly, because of the four sets of linked genes described by Morgan and others, it is possible, if there are multiple factors present, to link them with other genes. In other words, it is possible to demonstrate the presence of multiple factors, if they are present. So far as I know such a clear-cut demonstration cannot be made in any other form. I might have increased the number of spots on the back of a beetle, and I might have hypothesized how the results were brought about, but I could not have given demonstrative evidence. I make this statement because a number of persons have asked me why I used Drosophila when so many others are working with it. My problem was that of artificial selection. The choice made, my next problem was the selection of material, and it was done regardless of the number of workers using this fly.

The character chosen for selection was bristle number on the scutellum. There are four large bristles on it, but no small hairs as on the thorax (see Figure 1, a). This character was chosen, in part, because it is a definite, clear-cut character. The bristles are easily counted with a low-power binocular. It was chosen also, in part, because the work of MacDowell ('15 and '17) did not seem to be an absolute demonstration in favor of multiple factors. In fact, MacDowell ('15) admits this when he says, "Taken then on their own merits, the results presented in this paper do not give critical evidence in support of either the hypothesis of modification or of accessory factors." It is a matter of interpretation then, which side of the question MacDowell's data favor. In this connection it is interesting to quote from Pearl ('17). He says, "Any theory which has to depend for its sole support upon its interpretative value is sure to receive scant attention." Yet Pearl in this same paper accepts MacDowell's conclusions. I agree with Pearl that what we need most of all is demonstrative evidence and more of it. MacDowell used bristle number on the thorax. Altho some of my conclusions may agree with MacDowell's, the work is in no way a repetition of his.

The usual method in selection experiments is to start with a single pair of parents and from the offspring isolate two or more strains which are carried on by mating brother and

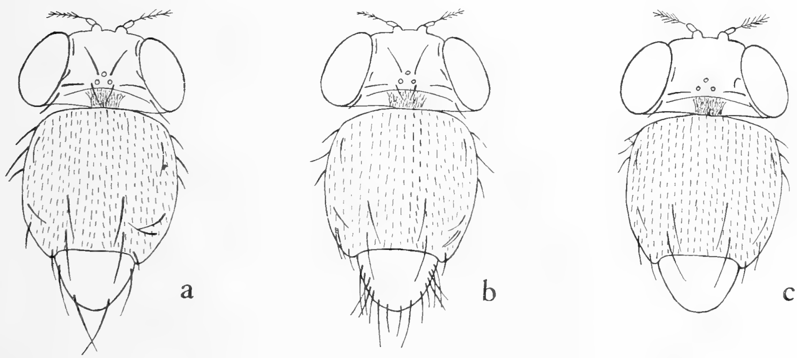

FIGURE 1

(a), an outline of the head and thorax with the scutellum of a normal wild type fly, showing the position of the bristles. Note the four on the scutellum. (b), a similar outline showing 15 bristles on the scutellum, the maximum number found in any one fly in the strain selected for extra bristles. (c), an outline similar to the preceding showing no bristles on the scutellum. This is taken from the minus selected strain of the mutant race "reduced". In this strain nearly all the flies have extra bristles (as high as 99.52 per cent in the seventeenth generation).

sister. In the present experiment, this method has not been strictly followed. A single pair of parents, female with one extra bristle and normal male, was the starting-point. From among their F_1 offspring, the two females with one extra bristle were mated to their normal brothers. In the second generation, several flies with one extra and a few with two extras were found. These extra bristled flies were used as parents for the next generation. In all the following generations, flies with the highest bristle number were used as parents regardless of whether they were brother and sister. Most matings, however, were brother and sister matings. In the later generations they were all of this type. In most cases single pair matings were made, but a few times when the vigor of the strain seemed low, two pairs were placed in the same bottle, or sometimes two or three males were placed with a single female. It was the male which showed lack of vigor. The females have been vigorous thruout the experiment (38 generations). I have asked a number of persons whether there were any objections to this method, but so far no one has suggested any. It was suggested, however, that if the strain were heterozygous for a particular character, it might take a little longer to produce a homozygous strain. This is, of course, perfectly obvious. On the other hand, it might produce a homozygous strain more quickly. Certainly, at any rate, there can be no serious objection to the method, especially if the experiment is carried on for a sufficient length of time. This method, I believe, has been followed by Castle in his experiments on hooded rats and has been criticized by MacDowell in his bold denunciation of Castle's interpretation. Castle's starting-point, however, was several individuals instead of a single pair.

The flies were bred in eight-ounce bottles. In all cases fresh banana was used as food. The bananas were bought when fairly green, before the skin was broken, and allowed to ripen in glass containers protected from flies. When they began to turn black and get soft, a small amount of alcohol was poured into the jars to prevent growth of molds. The bananas in this ripe condition were peeled and cut into pieces about three-fourths to an inch in length. One piece was put into each bottle along with such absorbent paper as was needed to take up the extra moisture. If this food became bad because of mold, bacteria, or too much acid, before eggs were laid, the parents were transferred to new bottles. In case the food became too dry or the supply insufficient for the developing larvæ, fresh food was added. Extreme care was used to prevent contamination.

Nothing has been done in the way of a biometrical treatment of the data. This has not been done because of any belief that such treatment is valueless in all cases, but because in this particular case the facts stand out clearly without such treatment. If anyone believes he could draw different conclusions by such a biometrical study, I am willing to turn the data over to him and to assist him in the attempt.

Thruout the paper I have adopted the terminology used by Morgan and his students. I have adopted it because it is the easiest way of expressing myself, and because I believe the theories, which have made necessary this new terminology, are the most acceptable working hypotheses we have. If some readers object to locating factors in the chromosomes, they have the privilege of translating my expressions into any terminology they like.

The Experiment

An examination of 613 flies from a mass culture which had been bred in the laboratory for about three months gave one female with one extra bristle and 612 normal. This female mated to a normal male from the same mass culture was the starting-point of the experiment. For comparison, counts were also made in two other lines. One line gave 710 flies with the normal bristle number (four), one fly with three bristles, and four flies with five bristles. The second line gave 2,514 with the normal number, 14 with three, and 15 with five bristles. All three lines, then, showed some variations in bristle number. The experiment was started from the line which showed the least variation.

The pair which was mated (female five with normal male) gave 228 offspring, 226 of which were normal and two females with one extra bristle each. Twelve pairs of the normal F_1 flies were mated. They gave 2,647 offspring, 2,588 of which were normal and 59 with extra bristles, a ratio of normals to extras of 1:43.8. Of the extras, 51 had one extra bristle and eight had two extras. The two F_1 females with one extra bristle were mated to normal brothers. They gave F_2 offspring as follows: 935 normal, 39 with one extra bristle, and four with two extra bristles, a ratio of 1:21.7. Neither of these F_2 ratios would be called Mendelian, at least, not without further analysis. I mention this because extra bristle number in MacDowell's experiment behaved as a recessive unit character, giving in F_2 a ratio of approximately three normals to one extra. The extra bristled F_2 flies from the F_1 females with one extra bristle were selected as parents for the next generation. From their offspring the flies with the highest number of extra bristles were again selected as parents. This method of selecting the highest grade flies as parents has been

TABLE I

Generation	Mean Bristle Number of Parents	Bristle Number of Offspring: Female Normal	Female 5	Female 6	Female 7	Female 8	Female 9	Female 10	Female 11	Female 12	Female 13	Female 14	Female 15	Male Normal	Male 5	Male 6	Male 7	Male 8	Male 9	Male 10	Male 11	Male 12	Male 13	Male 14	Totals
1	4.5	226	2																						228
2	4.5	935	29	3											10	1									978
3	5.187	1757	148	36	8	1									34	3									1987
4	5.850	1376	259	109	17	4									120	13	2								1900
5	5.642	2122	467	231	59	13									182	65	9	1							3149
6	6.428	1786	601	444	225	69	10								424	131	32	3							3725
7	7.000	690	258	220	190	81	11								240	129	43	13	1						1867
8	7.566	68	142	252	290	187	20	3						203	240	176	66	26	2						1675
9	7.794	98	161	319	371	316	44	7	1					293	304	293	167	85	4	1					2464
10	7.666	101	166	339	440	422	69	7						326	437	299	185	93	6						2890
11	8.230	11	62	142	181	246	66	18						89	169	139	99	47	6						1275
12	7.952	31	133	278	350	357	111	15	2	1				232	333	323	170	90	6						2432
13	7.470	22	52	125	172	178	60	21						117	135	137	92	31	3						1145
14	7.800	17	35	158	216	248	146	29	5		1			153	207	199	128	61	12	1					1616
15	8.650	13	23	114	269	584	305	95	4	2				100	240	372	316	252	29	7	1				2726
16	9.000	1	9	59	147	359	235	70	21	6				29	122	216	258	156	27	4	1				1720
17	9.944		1	18	66	181	140	51	11	1				1	25	61	106	148	36	3	1				850
18	10.136	1	10	53	208	146	70	16	3					1	18	81	125	150	42	9		1			934
19	9.673			17	65	215	146	58	13	5		1		1	12	82	167	179	53	9					1008
20	9.717		9	18	103	327	199	82	9	2				9	48	146	245	208	63	11	1				1480
21	9.576		2	19	86	199	181	67	14	5				3	28	83	176	169	57	8	1				1098
22	9.764		2	9	44	153	185	81	33	3	1				9	64	158	165	70	14					889
23	10.117			5	27	179	175	100	19	7					9	46	130	213	92	19	2	1			1024
24	10.400	2	8	64	230	214	79	14	4	1				3	18	95	190	227	81	6	1				1237
25	9.550			19	45	213	183	66	17	3				1	11	80	128	149	57	12	1				985
26	9.555		1	3	31	125	113	65	22	4	1			1	4	43	95	131	42	9	7	1			698
27	10.000			1	30	220	255	216	64	8	3				2	22	109	316	178	57	10		1		1492

28.	10.222	....	....	3	14	110	165	136	53	19	6	....	....	....	3	13	56	179	131	58	12	2	1	....	959
29.	10.454	....	....	....	16	64	153	142	75	23	3	....	....	....	....	11	39	171	134	59	11	....	....	....	901
30.	10.555	....	....	1	9	61	154	150	63	19	6	2	1	....	2	17	48	177	123	69	17	....	....	1	920
31.	11.000	....	....	2	3	20	64	41	16	7	....	1	....	....	....	8	17	64	36	23	1	....	1	....	304
32.	10.454	....	....	1	11	54	123	135	43	21	3	2	1	....	4	11	46	123	89	35	2	3	....	1	708
33.	9.750	....	....	....	10	91	159	103	35	8	3	....	....	....	1	21	79	145	124	41	2	....	....	....	822
34.	10.166	....	....	....	1	40	90	102	42	9	1	....	1	....	....	3	22	10	99	42	5	....	....	....	567
35.	10.300	....	....	....	2	31	42	52	20	2	....	....	....	....	....	3	19	53	45	16	2	....	....	....	287
36.	9.849	....	....	....	4	40	75	58	25	10	....	....	....	....	2	5	20	93	59	22	1	....	....	....	414
37.	9.666	....	....	....	4	65	115	137	61	14	2	....	....	....	1	3	36	142	136	35	5	....	....	....	756
38.	9.850	....	....	1	2	23	58	67	36	6	1	....	....	....	1	3	27	92	65	26	7	....	....	....	415
Total.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	50,425

Table I gives the mean bristle number of the parents generation by generation; also the number of flies in each generation with the normal bristle number (four), the number with 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. The data for the two sexes are kept separate with the exception of the normal males and females in the first seven generations. It also gives the total number of flies in each generation.

TABLE II

Generation	Mean of Parent	Mean of Offspring	Per cent of offspring in each generation with: 5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles	10 Bristles	11 Bristles	12 Bristles	13 Bristles	14 Bristles	15 Bristles	Pct. Norm'l
1	4.5	4.008	.88											99.12
2	4.5	4.048	3.98	.40										95.62
3	5.187	4.144	9.15	1.96	.40									88.43
4	5.85	4.368	19.95	6.37	1.00	.21								72.46
5	5.642	4.766	20.74	8.82	2.17	.44								67.82
6	6.482	4.881	27.51	15.43	6.89	1.93	.27							47.94
7	7.000	5.245	26.74	18.74	12.24	4.51	.64							37.06
8	7.566	5.961	17.90	27.23	22.60	13.46	1.39	.19						17.21
9	7.794	6.111	18.87	24.82	21.82	16.26	1.94	.32						15.87
10	7.666	6.156	20.71	21.91	22.15	17.68	2.57	.24						14.70
11	8.230	6.567	18.11	22.03	21.97	22.98	5.64	1.41						7.85
12	7.952	6.349	19.01	24.88	21.62	18.23	4.77	.61	.08					10.74
13	7.470	6.340	16.69	22.78	22.95	18.17	5.47	1.82						12.09
14	7.800	6.622	14.97	22.09	21.28	19.12	9.77	1.85	.30					10.52
15	8.650	7.168	9.64	17.82	21.46	30.66	12.25	3.74	.18	.07				4.75
16	9.000	7.436	7.62	15.99	23.56	29.95	15.18	4.30	1.22	.34				1.74
17	9.944	7.778	3.05	9.28	20.11	38.66	20.68	6.34	1.52	.23				.11
18	10.136	7.988	1.82	9.76	19.09	38.41	20.21	8.47	1.71	.42				.12
19	9.673	7.919	1.20	9.93	22.28	38.75	19.97	5.72	1.40	.50		.10		.10
20	9.717	7.731	3.98	11.06	23.48	36.09	17.67	6.27	.67	.13				.60
21	9.576	7.895	2.74	9.33	23.42	33.66	21.77	6.86	1.46	.45				.27
22	9.764	8.184	1.11	7.37	20.40	32.12	25.75	9.49	3.33	.30	.10			
23	10.117	8.306	.87	4.98	15.33	38.28	26.07	11.62	2.05	.78				
24	10.400	7.998	1.61	8.32	20.53	36.94	23.84	6.87	1.21	.32	.08			.32
25	9.550	8.054	1.10	10.98	17.14	36.49	24.19	7.86	1.81	.30				.10
26	9.555	8.255	.71	6.59	18.01	36.67	22.20	10.60	4.15	.71	.14			.14
27	10.000	8.711	.13	1.57	9.50	36.66	27.56	18.67	5.06	.54	.27			
28	10.222	8.929	.31	1.66	7.28	30.07	20.18	6.76	2.18	.72				
29	10.454	9.084		1.22	6.01	25.94	31.95	22.38	9.57	2.18	.72			

30	10.555	9.072	.21	1.95	6.19	30.10	25.86	23.80	8.69	2.06	.65	.32	.10	...
31	11.000	8.914	...	3.28	6.57	27.63	32.56	21.05	5.92	2.30	.32	.32	...	...
32	10.454	9.031	.56	1.69	8.05	25.00	29.94	24.01	6.37	3.38	.42	.42	.14	...
33	9.750	8.720	.12	2.55	10.82	28.71	34.42	17.51	4.50	.97	.36	...	...	...
34	10.166	9.123	...	.52	4.05	26.45	33.33	25.39	8.28	1.58	.17	...	.17	...
35	10.300	8.940	...	1.04	7.32	29.26	30.31	23.69	7.66	.69	...	...	...	...
36	9.849	8.898	.48	1.20	5.79	32.12	32.36	19.32	6.28	2.36	...	...	...	...
37	9.666	9.071	.13	.39	5.29	27.38	33.20	22.75	8.73	1 85	.26	...	...	...
38	9.850	9.028	.24	.96	6.98	27.71	29.63	22.40	10.36	1.44	.24	...	...	...

Table II gives the mean bristle number of the parents and the offspring generation by generation. It also gives the percentage of flies in each generation with the normal number of bristles (four), with five bristles, six bristles, and so on up to 15 bristles.

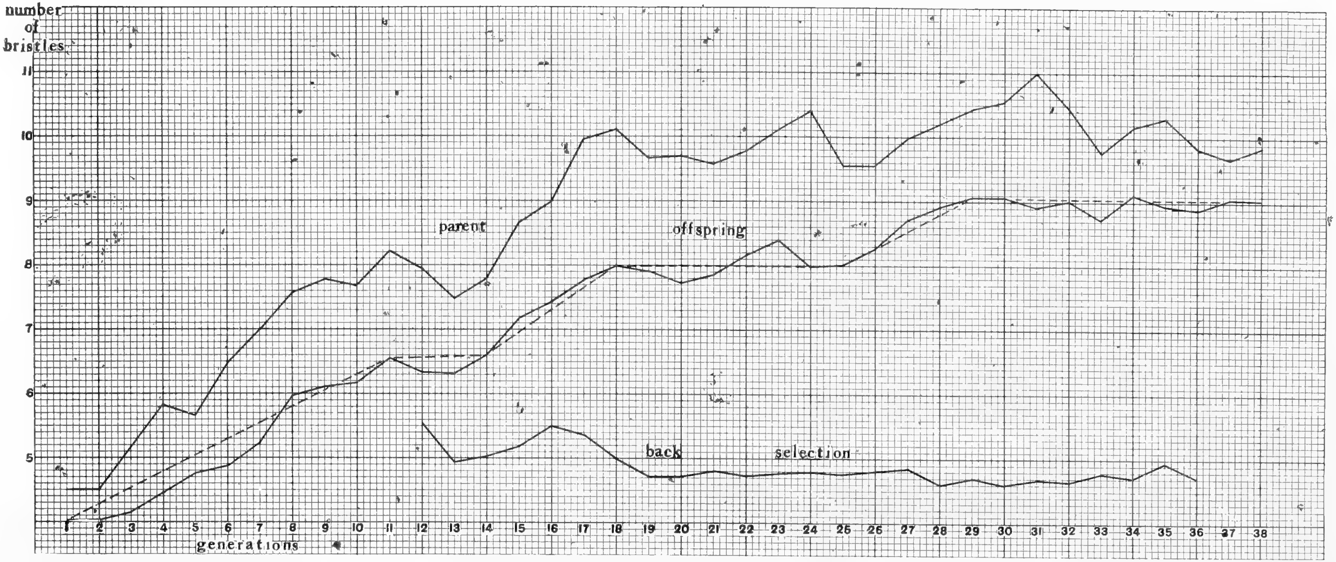

FIGURE 2

The upper two curves are plotted from the mean bristle number in each generation of the parents and offspring in the line selected for extra bristles. The broken line is drawn to bring out more clearly the three separate rises in the curve, the first from the first to the eleventh generations, the second from the fourteenth to the eighteenth, and the third from the twenty-fifth to the twenty-ninth. The lower curve is that of the back selection line started from the eleventh generation of the selected line.

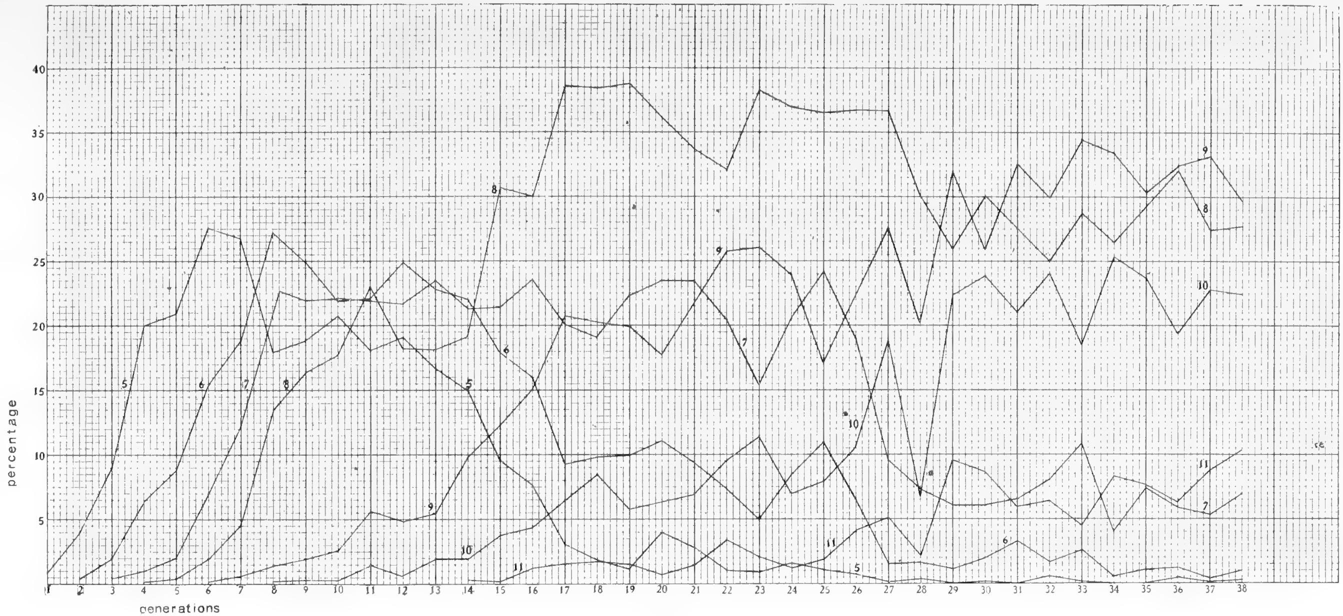

FIGURE 3

These curves are plotted from data given in Table II. The first curve shows the percentage of flies in each generaation with five bristles, the second the percentage with six bristles, and so on up to eleven bristles. The curves for 12, 13, 14, and 15 bristles were not plotted inasmuch as the percentages were small. Note that the curves for five, six, and seven bristles rose rapidly and then declined until at the end of selection there were but few flies with these numbers. The curve for eight rose rapidly and higher than any of the others and remained high. The curve for nine rose more slowly but at the end was highest of all. The curve for ten rose more slowly but was third in height at the end. The curve for eleven begins in the fourteenth generation and rises slowly and never gets beyond 10.36 per cent.

continued thruout the experiment. For some reasons it would be desirable to give the complete data, but it would take up so much space that, instead, a summary generation by generation is given (Table I). This table gives in each generation the total number of offspring, the number of offspring that are normal, i.e. those with four bristles, and the number with five bristles, six bristles, and so on as high as they go.

The data for the males and females are kept apart with the exception of the normal males and females in the first seven generations. A glance at this table shows clearly that the number of flies having extra bristles has been increased until in the last generations no normal flies are found. It also shows that the number of extra bristles has been increased until the maximum, 15, is reached. Only three females, however, show this extreme number. Fourteen is the highest number reached in the male. In this connection it should be mentioned that the bristle number of the female is always slightly higher than in the males. MacDowell observed this same fact in his experiment and believed it was a question of size, the larger flies having the higher bristle number. In my work this suggestion has no support. Often the smallest flies have the highest bristle number. As will be shown later, there is present a sex-linked factor which when homozygous produces a more marked effect than when heterozygous. Table 2 gives the mean bristle number of the parent and offspring in each generation, and also the percentage of flies having five bristles, six bristles and so on. The means of parent and offspring are plotted in Figure 2. The percentage of flies in each class is plotted in Figure 3. Table II and Figure 2 show the rather remarkable fact that selection has not only been effective, but that it has been effective for 29 generations. MacDowell reached his maximum results in six generations. In most experiments on artificial selection the effect is immediate and lasts for only a few generations. Castle's experiments on hooded rats is an exception, where he has produced results up to the seventeenth generation and believes the end has not yet been reached. An analysis of the curves in Figure 2 shows, however, that the increase for 29 generations has not been a gradual one, but that there are three separate and distinct rises. From the first to the eleventh generations there is a distinct rise, the mean reaching 6.567 in the eleventh generation. From the eleventh to the fourteenth generations there is practically no change, at least not in the direction of selection. From the fourteenth to the eighteenth generations a second upward trend is shown, the mean reaching 7.988 in the eighteenth generation. From the eighteenth to the twenty-fifth generations there is again a standstill. Most of the time the mean is below eight, but in the twenty-second and twenty-third generations it is slightly above. In the twenty-fourth and twenty-fifth it is approximately eight again. From the twenty-fifth to the twenty-ninth generations the third rise occurs until the mean reaches 9.084 in the twenty-ninth generation. From the twenty-ninth to the thirty-eighth generation, or to the end of the experiment, the curve is again practically a straight line, with the exception of the thirty-third generation when the mean drops considerably below nine. There has been, at least, no decided increase in this period. In other words, the curve forms a series of steps, a thing rather difficult to explain on the basis of selection acting on mere fluctuating variations. It looks more as tho a series of mutations had occurred during the course of the experiment. When a new mutation occurs the the curve goes steadily up until the race is homozygous for this factor. Then it remains on the same level until something else happens. As will be shown later, this is the conclusion I am forced to reach in this experiment.

A comparison of the curves for the parents and offspring shows a close parallel.

In order to see whether a return to the normal could be produced by mating low grade parents, a back selection line was started from the eleventh generation and carried for 25 generations. In all matings except the first, the parents used had the normal bristle number (four). Table III summarizes these data by generations. The curve plotted from the mean of each generation is shown in Figure 2. With the exception of the first generation no return was produced. From the eighth to the twenty-fifth generation the curve is practically a straight line. It shows clearly, I think, that what has been done by selection cannot be undone. A mass culture bred in the laboratory for more than a year has not returned to the normal.

The data given in Tables I and II and in Figures 2 and 3 show conclusively, I think, that selection has been effective, at least as far as the twenty-ninth generation. No one, it seems to me, can deny this statement. Immediately, however, the question arises: What has been the method of selection and what is the nature of the variations on which selection has acted? The analysis which follows answers this question for this particular case.

TABLE III

Back Selection Line

All parents with normal bristle number except in first generation

Generation	Number of Offspring	Mean of Offspring	Per Cent Normal	Per Cent With Extra Bristles
1	321	5.548	21.18	78.80
2	542	4.933	44.46	55.53
3	763	5.031	41.15	58.78
4	770	5.205	32.07	67.92
5	819	5.534	25.03	74.98
6	933	5.486	20.47	71.92
7	795	5.217	31.57	68.42
8	593	4.715	52.61	47.38
9	1583	4.728	52.87	47.12
10	1846	4.833	46.74	53.25
11	1418	4.748	53.10	46.89
12	491	4.782	50.71	49.28
13	253	4.830	45.45	54.54
14	871	4.754	48.56	51.43
15	1373	4.827	45.22	54.77
16	1177	4.863	46.04	53.95
17	1322	4.604	56.19	43.80
18	921	4.741	48.20	51.79
19	538	4.628	56.68	43.31
20	80	4.675	47.49	52.50
21	435	4.662	51.02	48.97
22	605	4.791	46.93	53.06
23	341	4.747	48.37	51.62
24	151	4.993	38.40	61.59
25	381	4.716	48.81	51.18

Table III summarizes the data for the back selection line generation by generation. It gives the number of offspring (total number is 19,322), the mean bristle number of the offspring, the percentage of flies with the normal number of bristles (four), and the percentage of flies with extra bristles.

The Effect of the Environment

Since considerable variation appears in the number of extra bristles present in the offspring of a single pair of parents, it seems probable that the environment plays some rôle in their development. No critical attempt has been made to analyze this effect or its cause. A few observations have been made, however, during the course of the experiment. MacDowell believed that the quantity of food influenced the number of bristles on the thorax. The first flies which hatched from any given bottle had more bristles than those which hatched later. He believed temperature to have but little effect. In my work food seems to play only a minor rôle. It is possible by starvation to produce small weak flies. Such flies have fewer extra bristles, but where the food is kept in good condition, the last flies to appear in a bottle have as many bristles as the first. My experiment has been conducted at room temperature, and this means considerable fluctuation. While I have not made definitely controlled experiments, my observations indicate that low temperature is more favorable for the production of extra bristles than a higher temperature. How it produces its effect, I do not know.

The Analysis of the Results of Selection

By a comparison of the males and females in Table I it is noticeable at a glance that the females have a higher number of extra bristles than the males. As previously stated MacDowell ('15 and '17) obtained similar results in his experiments on Drosophila, and thought this difference due to a difference in size. The females are larger than the males. In my own experiments this difference in bristle number in the two sexes is not due merely to a difference in size. During the course of my observations it was often noticed that the smaller flies had more bristles than the larger ones. This led me to doubt the applicability of MacDowell's conclusion to my own work. The mean bristle number of the males and females from the eighth to the thirty-eighth generations has been plotted in Figure 4. The two curves show a marked degree of parallelism and remain about one unit apart. Since the difference is a sexual one it seemed to me that it might be due to a sex-linked factor which when homozygous produced a more marked effect than when heterozygous. MacDowell tested this possibility in his experiment by crossing extra males and females to the wild. In both cases there was a dominance of the normal in F_1 and in F_2 the ratios of the normals to extras were the same and the distribution of the extras was similar. I have used a different method in making my test. In fact,

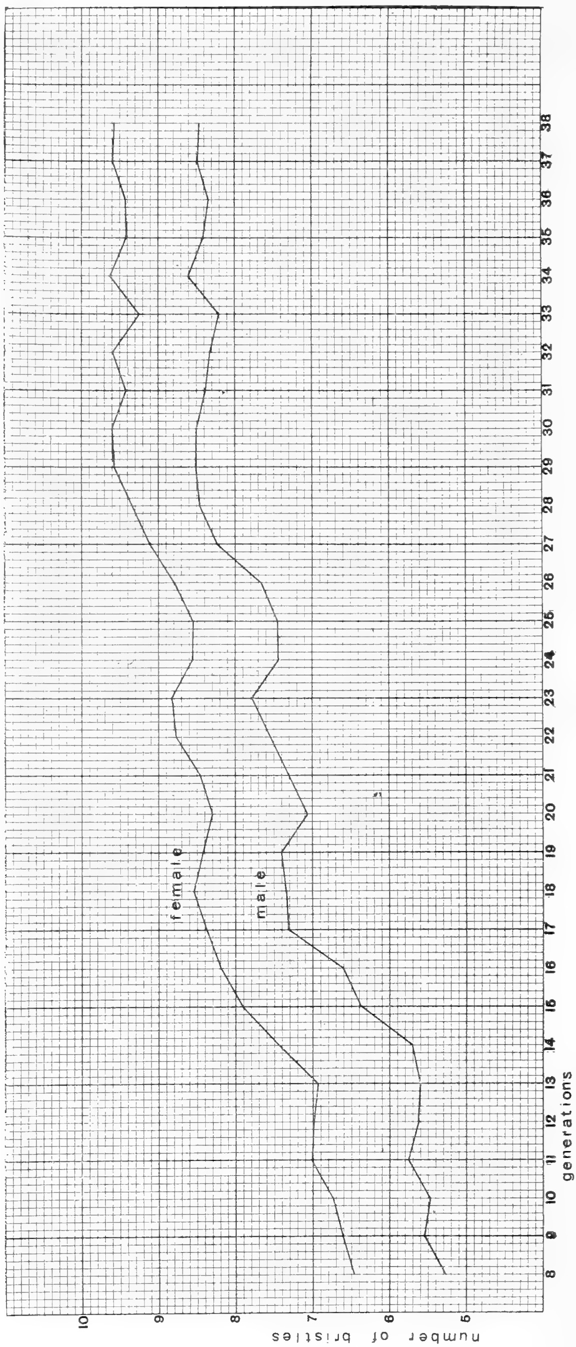

FIGURE 4

These two curves are plotted from the mean bristle number of the males and females separately, from the eighth to the thirty-eighth generation. They show the difference in the two sexes. Note the close parallelism of the two curves.

I have used two methods. The first was to get rid of the X-chromosome by outcrossing and inbreeding to produce a strain with both members of the second, third, and fourth chromosome pairs from the selection line and the X-chromosome from some other line. This was done by crossing the selection line male to a bar-eyed female. The F_1 males from this cross get their X-chromosome from the bar line and will get one member of each of the second, third, and fourth chromosome pairs from the selection line and the other member of each of these pairs from the bar line. These

TABLE IV

	Offspring			
	Normal	Extra Bristles	Total	Mean Bristles Number
Selection line male × bar female	168	70	238	4.436
F_1 male × bar female from stock	375	12	387	4.033
$F_2 \times F_2$	986	206	1192	4.233
$F_3 \times F_3$	454	252	706	4.573
$F_4 \times F_4$	196	267	463	5.066
$F_5 \times F_5$	163	237	400	5.260
$F_6 \times F_6$	417	680	1097	5.188

Table IV gives the data from the cross of the selection line male to a bar female. The F_1 bar male was mated to a bar female from stock. The flies with bristles were inbred and, in the next three generations, flies showing the highest number of extra bristles were used as parents. The table gives the number of flies in each generation which have the normal bristle number (four), the number of flies with extra bristles, the total number of flies, and the mean bristle number of all the flies.

F_1 bar males (bar is dominant) were mated out to bar females from stock. All the F_2 flies thus produced would have X-chromosomes from the bar line. They might get one member of each of the second, third, and fourth chromosome pairs from the selection line, or they might get only two or one or none at all from this line. If there are factors for extra bristle number in any of the chromosomes other than the first, and if they are dominant to the normal, some of the F_2 flies should have extra bristles. Twelve of the females did have extra bristles. These were mated to their normal F_2 brothers. Of the F_3 offspring, 986 were normal and 206 had extra bristles (for the number of extra bristles and the mean bristle number in each generation see Table IV). The extra bristled flies were mated and the line was thus continued for six generations to see whether the mean bristle number could be raised to what it was in the selection line. If so, there certainly could be no factor for extra bristles in the X-chromosome. If not, it would at least be indicative, if not conclusive

TABLE V

Selection line male × eosin miniature female

Normal Flies, Wild Type						Eosin Miniature Males	
Normal Bristles	5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles	Normal Bristles	5 Bristles
13	18	37	27	1	1	46	17

F_1 female × eosin miniature male from stock

	Normal	5 Br.	6 Br.	7 Br.	8 Br.	9 Br.	Total	Mean
Eosin miniature	249	60	18	3	1		331	4.329
Eosin	190	55	21	4	1		271	4.416
Miniature	120	83	51	9	7		270	4.888
Normal, wild type	139	113	75	44	16	4	391	5.222

In Table V the selection line was crossed to eosin miniature, and the F_1 females were back-crossed to eosin miniature males. The table gives the F_1 and the F_2 data. Four types of flies appear in F_2 as crossing-over occurs in the F_1 female. Eosin miniature and normal (wild type) are non-cross-overs, and eosin and miniature are cross-overs. Of the non-cross-overs, eosin miniature has a low mean bristle number (4.329), while the mean bristle number of the normal is 5.222. Of the cross-over type, eosin, the mean (4.416) approaches that of eosin miniature, while the mean of miniature (4.888) approaches that of the normal.

proof, that there was such a factor in the X-chromosome. As can be seen in Table IV, the mean in the fourth, fifth, and sixth generations was practically the same. The highest point was reached in the fifth generation when the mean was 5.26. This experiment then proves conclusively that there is one or more factors outside the X-chromosome and makes probable the presence of a factor in the X-chromosome which influences bristle number. A second test was made by crossing the selection line to eosin miniature, and to eosin ruby forked, and back crossing the F_1 females to eosin miniature and to eosin ruby forked males. These characters are all sex-linked and according to Morgan and Bridges ('17) are located in the chromosome as follows: eosin 1.1; ruby about 6; miniature 36.1; forked 56.5. This is the linkage test. The

TABLE VI

Selection line female × eosin ruby forked male

F_1

Normal Bristles	5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles
3	12	52	52	37	3

F_1 female × eosin ruby forked male

	Normal Br.	5 Br.	6 Br.	7 Br.	8 Br.	9 Br.	Mean	Total number
Normal, wild type	64	62	77	57	32	3	5.79	295
Eosin ruby forked	143	58	24	6	1	......	4.55	232
Eosin ruby	118	63	23	8	2	......	4.65	214
Forked	56	63	54	38	18	2	5.58	231
Ruby forked	9	8	8	1	2	......	5.25	28
Ruby	11	8	5	2	......	......	4.92	26
Eosin forked	7	3	2	......	......	......	4.58	12
Eosin	6	4	3	2	......	......	5.06	15

In Table VI the selection line was crossed to eosin ruby forked, and the F_1 females back-crossed to eosin ruby forked males. The table gives the results in both generations. It shows the distribution of the bristles and the mean bristle number of each class which appears in F_2. Here the mean of eosin ruby, 4.65, approaches that of the non-cross-over, eosin ruby forked, 4.55, while the mean of forked, 5.58, approaches that of the normal, 5.79.

results of the eosin miniature cross are given in Table V. If crossing-over occurs between eosin and miniature in the F_1 females, and if there is a factor for extra bristle number in the X-chromosome nearer one of these loci than the other, then one of the cross-over classes should show a higher bristle number than the other. Such is the case. The mean bristle number of the miniature flies is 4.888, approaching that of the normal (5.222) one of the non-cross-over classes, while the mean bristle number of the eosin flies is 4.416, very near to that of the other non-cross-over class, eosin miniature, which is 4.329. This demonstrates quite clearly, I think, that there is a factor for extra bristle number in the X-chromosome somewhere near the eosin end. The cross of the selection line to eosin ruby forked brings out the same fact. The cross was made in the same way as with eosin miniature. The results are given in Table VI. Since eosin and ruby are only about five units apart, there is very little crossing-over between them. Of the non-cross-over classes, normal and eosin ruby forked, the mean bristle number of the normal is much higher, being 5.79 while it is only 4.55 in the eosin ruby forked flies. Of the cross-over classes, eosin ruby and forked are of most interest. The number of flies in the other classes is too small to be of much significance. The mean bristle number of the eosin ruby flies is 4.65, which is very close to the mean of the non-cross-over type, eosin ruby forked. On the other hand, the mean of the forked flies is 5.58, approaching that of the normal. Here again, of the cross-overs, one has a much higher bristle number than the other. The evidence in this case corroborates that of the former in demonstrating the presence of a factor for bristle number in the X-chromosome near the eosin end. All the facts then point to the presence of a factor for extra bristle number in the X-chromosome, and my conclusion can be none other than that there is such a factor present.

The experiment in which the X-chromosome was eliminated by crossing the selection line to bar demonstrated the presence of a factor or factors outside the X-chromosome. The next problem was to locate them if possible. In an attempt to do this, the selection line was first crossed to black, pink, bent stock. The gene for black is in the second chromosome, that for pink in the third chromosome, and that for bent in the fourth. The easiest method would be to mate the F_1 females from this cross back to black, pink, bent males. I have mated F_1 to F_1. It is a little more laborious this way, but the results show the same thing. The data are given in Table VII, a study of which shows that the pink flies when compared to the normal, to black, and to bent have fewer extra bristles. Further, 85 per cent of them have the normal bristle number, while in the case of the black it is only 37 per cent, in the normal 33 per cent, and in the bent 26 per cent. The highest number of extra bristles which any of the pink flies have is two, while among the normal flies there may be as many as six extra bristles, among the black, five, and among the

TABLE VII

Summary of data from the cross. High selection line × black, pink, bent

F_1

Normal Bristles	5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles
197	241	182	72	17	2

F_2

	Normal Bristles	5 Bristles	6 Bristles	7 Bristles	8 Bristles
Normal, wild type	585	460	337	244	110
Black	201	154	112	44	18
Pink	515	76	8	....	....
Bent	122	106	114	70	19
Black, pink	123	30	7	....	....
Black, bent	37	29	9	4	3
Pink, bent	39	6	1	1	....
Black, pink, bent	5	1	1	....	....

	9 Bristles	10 Bristles	11 Bristles	Mean Bristle Number	Per Cent of flies Wild Type
Normal, wild type	23	3	....	5.327	33.20
Black	3	....	....	5.122	37.78
Pink	....	....	....	4.153	85.97
Bent	19	2	1	5.642	26.93
Black, pink	....	....	....	4.275	76.87
Black, bent	1	....	....	4.915	44.57
Pink, bent	....	....	....	4.234	82.97
Black, pink, bent	....	....	....	4.428	71.42

Table VII gives a summary of the data from the cross of the selection line with black, pink, bent, both in F_1 and in F_2. It shows the distribution of the extra bristles and the mean bristle number in the different types in F_2. It also shows that pink flies and flies with pink in combination with any other character have few extra bristles.

bent, seven. The same results are shown when pink is in combination with any of the other characters. Since pink is in the third chromosome and is recessive, all F_2 pink flies must get both third chromosomes from the pink line. This

TABLE VIII

Selection line × sepia spineless kidney sooty rough

Female					Male				
Normal Br.	5 Br.	6 Br.	7 Br.	8 Br.	Normal	5 Br.	6 Br.	7 Br.	8 Br.
230	128	55	33	5	175	103	65	19	4

$F_1 \times F_1$

Normal, wild type

Female						
Normal Br.	5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles	10 Bristles
900	272	138	94	28	10	2

Male						
Normal Br.	5 Bristles	6 Bristles	7 Bristles	8 Bristles	9 Bristles	10 Bristles
1042	126	51	22	8	6	2

$F_1 \times F_1$ (Continued)

Sepia spineless kidney sooty rough					Spineless kidney sooty rough	
Female		Male			Female	Male
Normal Bristles	5 Bristles	Normal Bristles	5 Bristles	6 Bristles	Normal Bristles	Normal Bristles
343	12	250	2	2	4	4

$F_1 \times F_1$ (Continued)

Sepia			Spineless
Female	Male		Female
Normal Bristles	Normal Bristles	5 Bristles	Normal Bristles
2	3	2	2

In Table VIII the selection line was crossed to sepia spineless kidney sooty rough and the F_1's inbred. The table shows a summary of the data. Practically no crossing-over occurred.

means, of course, that neither of the third chromosomes from the selection line is present in a pink-eyed fly. As the pink flies have few extra bristles, and as they get both third chromosomes from the pink line, the probability is that there is a factor for extra bristles in the third chromosome.

An attempt was made to test this by means of linkage. The selection line was crossed to the combination, sepia spineless kidney sooty rough. The genes for these five characters are located in the third chromosome. The F_1's were inbred. If crossing-over occurs, and if there is a gene for extra bristle number in the third chromosome, it would be possible to link it with one of these five. To my surprise, however, practically no crossing-over occurred (see Table VIII). I have not as yet tested out the possibilities for this unexpected result, but presumably it is due to the presence of some factor which modifies crossing-over. Factors of this type have been listed by Morgan, Sturtevant, Muller, and Bridges in their textbook as "little-cross-over" and "low-cross-over". So far as I know, a description of their behavior has not appeared in print. This cross again brought out the fact that all flies which get both third chromosomes from a line other than the selection line, in this case, sepia spineless kidney sooty rough, have fewer extra bristles. The analysis of the cross between these two lines made a little differently is suggestive. A female from the selection line was mated to a sepia spineless kidney sooty rough male. The F_1 males were back-crossed to sepia spineless kidney sooty rough females. The offspring of this mating are normal (wild type) males and females and sepia spineless kidney sooty rough males and females. Some of the normal males and females have extra bristles. Also some of the sepia spineless kidney sooty rough females have extra bristles, but none of the sepia spineless kidney sooty rough males have extra bristles (see Table IX). When the origin of the chromosomes of these four groups of flies is studied, the following facts come to light. The F_1 male gets his X-chromosome and one member of each of the second, third, and fourth pairs from the selection line. The other member of the second, third, and fourth pairs comes from the sepia spineless kidney sooty rough line. In the formation of the germ cells of this male there will be two classes of spermatozoa so far as the X-chromosome is concerned. One class will get it, the other will be without

TABLE IX

Selection line female × sepia spineless kidney sooty rough male

Bottle Number	Bristle Number of Female Parent	Bristle Number of Offspring. Female: Normal	5 Bristles	6 Bristles	7 Bristles	8 Bristles
2370	12	63	28	11	2	....
2560	9	31	11	2	....	....
2676	11	20	23	3	9	2
2693	10	1	....	2	2	....

Bottle Number	Bristle Number of Female Parent	Bristle Number of Offspring. Male: Normal	5 Bristles	6 Bristles	7 Bristles	8 Bristles
2370	12	30	33	17	5	....
2560	9	19	15	5	1	....
2676	11	11	9	11	2	....
2693	10	....	2	2	2	2

F_1 male (from the cross, selection line female × sepia spineless kidney sooty rough male) × sepia spineless kidney sooty rough female.

Wild Type, Normal

Female					Male	
Normal	5 Bristles	6 Bristles	7 Bristles	8 Bristles	Normal	5 Bristles
38	15	6	....	....	54	....
11	7	....	....	....	28	....
36	17	11	3	1	55	3
32	10	2	1	....	38	1
19	11	6	2	1	27	....
35	22	6	2	1	83	....
26	15	6	....	....	48	....

Sepia spineless kidney sooty rough

Female			Male
Normal	5 Bristles	6 Bristles	Normal
54	6	....	54
20	7	2	21
17	7	3	24
20	1	1	20
12	5	....	15
41	2	1	36
28	6	....	28

In Table IX the selection line female was crossed to a sepia spineless kidney sooty rough male, and the F_1 male back-crossed to a sepia spineless kidney sooty rough female. Four types of flies appear in F_2. The distribution of the bristles in these four types is given.

it. The distribution of the other three chromosomes from the selection line is a random one. It is possible for all of them, or any two of them, or any one of them, or even none of them to pass into the same cell with the X-chromosome. All the eggs of the sepia spineless kidney sooty rough females will be alike. Taking up each class of flies which appears in F_2 and analyzing it separately, we find the normal females get one X-chromosome from the selection line and one from the other. They may get one member of each of the second, third, and fourth pairs from the selection line. Of course, they may get none of them or any two or any one. The sepia spineless kidney sooty rough females also get one X-chromosome from the selection line and one from the sepia spineless kidney sooty rough line. They must get both third chromosomes from the sepia spineless kidney sooty rough line, but may get one member of each of the second and fourth pairs from the selection line. The normal males will get their X-chromosome from the sepia spineless kidney sooty rough line, but may get one member of each of the second, third, and fourth pairs from the selection line. The sepia spineless kidney sooty rough males get their X-chromosome and both third chromosomes from the sepia spineless kidney sooty rough line. They may get one member of each of the second and fourth chromosome pairs from the selection line. The interesting fact is that the normal males and females and the sepia spineless kidney sooty rough females have extra bristles, while all of the sepia spineless kidney sooty rough males have the normal bristle number. In these males the X-chromosome and both third chromosomes come from the sepia spineless kidney sooty rough line. In the other three classes either one of the X-chromosomes or one member of the third pair from the selection line may be present. Since extra bristle number is partially dominant to the normal, extra bristles would be expected in these classes if the genes for extra bristles are in the first and third chromosomes. On the other hand, if these genes are present in the X-and third chromosomes, no extra bristles would be expected in the sepia spineless kidney sooty rough males. I do not mean to say that this test is an absolute demonstration of the presence of a factor for bristle number in the third chromosome, since extra bristle number is only partially dominant to the normal. I think it is indicative, however, and when taken in conjunction with the fact that the F_2 pink-eyed flies in the cross of the selection line to black, pink, bent, have very few extra bristles, it becomes even probable that there is a factor for extra bristles in the third chromosome. Crosses of the selection line were made to sooty by itself and also to spineless. The F_2 sooty and spineless flies were similar to the F_2 pink-eyed flies in bristle number.

The selection line was also crossed to black purple curve plexus speck, the genes of which are in the second chromosome. The F_1's were mated *inter se* and also the F_1 females were mated back to black purple curve plexus speck males. Crossing-over occurred in this case, but no significant difference in the bristle number of the various types of cross-overs was observed. The selection line was also crossed to another mutant provisionally called "star", a lethal which affects the arrangement of the ommatidia of the eye. The gene for this character, according to Sturtevant, is near the zero end of the second chromosome. The F_1's were inbred. The distribution of the bristles was practically the same for the two types which appeared in F_2.

A further test for the fourth chromosome was made with eyeless. The F_2 eyeless and normal flies, however, were similar when compared with respect to bristle number.

In all of the crosses of the mutant races to the selection line, with one exception, the normal or wild type flies in F_2 had a slightly higher bristle number than those of the mutant race. In the case of bent, as shown in the cross of the selection line with black, pink, bent, the mean bristle number of the bent flies is slightly greater than the mean of any of the other types. Also the percentage of normal flies is less. It is possible, of course, that the gene for bent influences bristle number.

While my main conclusion that multiple factors are operative in the production of extra bristles agrees with the conclusion of MacDowell, yet some of the other conclusions do not agree. In the development of his interpretation, MacDowell assumes the presence of a primary inhibitor which keeps the number down to normal. In order to account for the fact that "extra bristles" at the beginning of his experiment behaved as a Mendelian recessive, he assumed that this primary inhibitor had been eliminated. By continued selection he increased the number of extra bristles. In order to account for this increase, he further assumed the presence of a series of secondary inhibitors which keep the extra bristle number reduced, and that when in the course of selection these secondary inhibitors are eliminated the number of extra bristles increases. The difficulty in this explanation, it seems to me, is in getting rid of the inhibitors. This MacDowell does not discuss. In fact, I see no way of getting rid of them except by mutation, if the strain is homozygous for them. If the strain is heterozygous for such inhibitors, then we ought to find many more flies in the wild and in our mass cultures with extra bristles. In this connection it is interesting to speculate whether there are also primary and secondary inhibitors which keep the number of bristles from going below normal. Such an assumption would be as logical as the one MacDowell makes. It would give, however, a complicated mechanism for keeping a character constant and seems awkward and cumbersome.

Occasionally flies are found with only two or three bristles. I have made an attempt at a minus selection from a male with three bristles on the thorax. This male was mated to a wild female. In F_1 there were 194 normal flies, four with three bristles, and two with two bristles, or three per cent with a reduced number. The flies with the reduced bristle number were mated and gave in F_2 690 flies, 16 or 2.31 per cent of which had three bristles. The others were normal. Again the flies with the reduced bristle number were used as parents. In F_3 there were 2,688 normal flies, 93 with three bristles, and three with two. This was 3.44 per cent showing the reduced number. This strain was carried on for six generations without any further increase in the reduction. The per cent of reduced flies in F_4 was 2.21, in F_5 it was 2.69, and in F_6, 2.10. Unfortunately, at this time the strain died out, all attempts to keep it going proving useless. Six generations may not be long enough to produce results in this case, but I am of the impression that even if the strain could have been continued, no marked results would have been produced.

It is interesting tho that the number of flies with the reduced bristle number is greater than in stock cultures. I hope to be able to repeat such a test.

In the sixth generation of the line selected for extra bristles (parent number 113) appeared a male with only one bristle on the scutellum. Males with two and three bristles on the scutellum had appeared before in other strains, and when paired with normal females the minus condition showed no indication of being inherited. However, the male with only one bristle was mated to a normal female. In F_1 all flies (328) were normal. Five pairs of the F_1's were mated and gave in F_2 1,634 males and 1,594 females. All the females were normal. Of the males, 834 were normal, but 804 or approximately one-half of them showed a reduced bristle number. There was no definite number of bristles among these "reduced" flies. Two hundred fifty-five of them had no bristles, 296 one bristle, 219 two bristles, and 34 three bristles. From this and further tests it was evident that this reduced condition was a mutation and behaved as a sex-linked Mendelian character. The character was transferred to the female line by mating "reduced" males to F_2 females. The line was then made pure by inbreeding reduced males and females. In this reduced stock, selection has been practiced in two directions, one to produce a strain with no bristles and the other to raise the strain to normal again. These two lines have been subjected to selection for more than 21 generations and the experiment is still in progress. In the minus line the number of bristles has been gradually reduced until in the seventeenth generation 99.52 per cent of the flies had no bristles, and the flies which did have bristles seldom had more than one. In the plus line the number of bristles has been gradually increased until in the twenty-first generation 47.77 per cent of the flies had the normal number, four. Most of the other flies had two or three bristles and in the later generations of selection a fly with no bristles rarely occurred. The normal flies, however, are not normal genetically, for when mated to wild stock they throw the characteristic sex-linked ratio. Occasionally a fly with five bristles appears in this line. The two lines have thus been gradually pulled apart until they are no longer the same, and sufficient tests have been made to show that they are not the same genetically, but just what this difference is I am not prepared as yet to say. The necessary tests will be made and the results published later. It was thought best not to delay the publica-

TABLE X

Summary of data of a series of outcrosses of the selection line to the wild

	Number With Normal Bristle Number	Number With Extra Bristles	Per Cent of Flies With Normal Bristle Number	Mean Bristle Number of all	Mean Bristle Number of Extras
FIRST OUTCROSS					
Female, selection line × wild male	227	329	40.82	4.89	5.51
$F_1 \times F_1$	346	381	47.59	5.08	6.07
SECOND OUTCROSS					
F_2 female from first outcross	56	32	63.63	4.48	5.34
$F_1 \times F_1$	431	428	50.17	5.05	6.11
THIRD OUTCROSS					
F_2 female from second outcross	440	77	85.10	4.18	5.23
$F_1 \times F_1$	484	254	65.58	4.53	5.55
FOURTH OUTCROSS					
F_2 female from third outcross	570	269	66.67	4.51	5.56
$F_1 \times F_1$	407	508	44.48	5.13	6.04
FIFTH OUTCROSS					
F_2 female from fourth outcross	602	372	61.80	4.60	5.59
$F_1 \times F_1$	341	379	47.36	5.00	5.91

Table X gives a summary of the data of five outcrosses to the wild. Females from the selection line were outcrossed to wild males. The F_1's were inbred. F_2 females with extra bristles were crossed to the wild again. The F_1's were inbred and the F_2 females with extra bristles were again crossed to the wild. This was continued for a fourth and a fifth outcross. The table gives the number of flies with the normal bristle number (four), the number with extra bristles, the percentage of flies with the normal bristle number, the mean bristle number of all flies, and the mean bristle number of the extras.

tion of the results obtained in the line selected for extra bristles.

One point of interest concerning Castle's work may be briefly discussed inasmuch as I have made an experiment which bears directly upon the same question. Castle found that when he crossed either of his selection lines to the wild, the extracted hooded animals obtained in F_2 showed a regression toward the mean of the hooded race before selection was begun. As this fact suggested the presence of multiple modifying factors, he outcrossed the extracted F_2's again to the wild, and obtained twice extracted hooded rats in the second F_2 generation. Castle believed he should obtain a further regression if modifying factors are the cause of the regression in the first extracted rats. However, he did not find a further regression, but found that the movement of the mean, mode, and range of variation was in the reverse direction. From these results Castle concludes, "So the hypothesis of modifying factors to account for the regression and for the progressive changes observed under selection becomes untenable."

I have repeated this same experiment with my flies, where I have demonstrated the presence of multiple factors. Instead of stopping with twice extracted flies, the outcross has been made five times. The results are given in Table X. This table shows the number of flies in each generation with the normal bristle number (four), the number of flies with extra bristles, the percentage of flies with the normal bristle number, the mean bristle number of all flies, and the mean bristle number of the extra bristled flies. These data are given for the F_1's as well as the F_2's. In each case it was the female which was outcrossed to the wild, and in each case this female had extra bristles. In the first outcross females with nine, ten, and eleven bristles were used. In the others the females had either seven, eight, or nine bristles. The parents used in the first outcross were taken from the twenty-second, twenty-third, and twenty-seventh generation of the selection line. The mean bristle number of these three generations is 8.41. The mean of the first F_2's is 6.07. This is a marked regression toward the normal. In the second F_2's as in Castle's rats, there is a slight swing in the opposite direction, the mean reaching 6.11. This difference, however, is hardly enough to be of any marked significance, especially when the percentage of normal flies increased from 47.59 in the first F_2 to 50.17 in the second. In the third F_2's there is a further regression toward the normal, the percentage of normal flies going to 65.58 and the mean of the F_2 extra bristled flies to 5.55. In the fourth and fifth outcrosses, the percentage of normal flies and also the mean of the extras come back to approximately what they were in the first and second outcrosses. The percentage of normal flies in F_2 of the fourth outcross is 44.48 and in the fifth outcross 47.36; the mean of the extras in these two generations is 6.04 and 5.91 respectively. The question might be asked whether the second regression is of any significance or whether it is due to the effect of the environment. It is certain that the environment does affect bristle number, but to what extent and in what way is problematical. I admit that the second regression in the third F_2's might be interpreted as an effect of the environment, altho conditions at all times were as nearly alike as they could be made under room conditions. If this be granted, we would have a regression in the first outcross, and then no further change. But this would not satisfy Castle's demands if multiple factors are present, as he holds that there should be a further regression. On the other hand, the second regression could as well be interpreted differently. It will be noticed that the F_1 flies in this outcross showed a high percentage of normals (85.10) and the mean dropped to 4.183. This is a marked change from the preceding and also from the following F_1's. It seems to me very probable that in selecting the female parents for this outcross, individuals were chosen which were not homozygous for the same factor or factors which were present in the preceding and following outcrosses. If such were the case a regression would be expected in F_1 and F_2. Some homozygous flies would appear in F_2 and in selecting the parents for the next outcross these homozygous flies were chosen. Hence the percentage of normal flies and the mean bristle number of the fourth F_2's come back to what they were in the first and second F_2's. It is a matter of interpretation then whether we accept the actuality of the second regression. If we do not accept it, then there is no further change after the first outcross. As stated, this does not satisfy Castle's demands of multiple factors. If we do accept the second regression as an actuality, then we have results similar to Castle's, except we have two regressions and a swing back in the direction of selection. I can see no significant difference, however, in the two cases.

Castle says his results show the multiple factor hypothesis to be untenable, yet in our work we know there are multiple factors present.

Discussion

The theory of natural selection is rightly attributed to Darwin, as he was the first to develop it to a point where it was a recognizable and acceptable theory. Darwin supported his theory by a large mass of facts drawn largely from the production of domestic plants and animals, and in the collection of his data relied mainly on the statements of breeders. His theory was very generally accepted inasmuch as no one questioned his data and the theoretical discussion seemed very plausible. It was really the first sound piece of logical reasoning backed by an accumulation of facts presented in favor of evolution and the method of evolution. The evidence seemed overwhelming and the explanation so simple that many wondered why they had not thought of it themselves. At any rate, the people accepted the theory, partly perhaps, because the time was ripe for the acceptance of an evolution theory, but primarily, because of the forcible manner in which Darwin presented his argument.

No one seriously attacked the evidence and offered something to take its place until Galton ('89) compared fluctuating variations to the oscillations of a polyhedron on one face, and discontinuous variations to the overturn of the polyhedron on to a new face, and suggested that species may arise from such discontinuous variations. Bateson ('94) in his "Materials for the Study of Variations", argues for the fixity of species. While he is cautious as to his generalizations, yet, I think, he means to imply that the evidence for evolution by means of fluctuating variations is far from satisfactory, and that discontinuous variations may give a more plausible and acceptable explanation.

Following the work of Galton and Bateson a number of things happened in rapid succession. Mendelism was rediscovered in 1900. DeVries developed his "Mutationstheorie" in 1901, and Johannsen the pure line theory in 1903. Korschinsky ('01), in a review of the horticultural literature, showed that where the origin of a variety is known and recorded, the origin, in most cases, was sudden. The work of Nilsson and Burbank demonstrated that, from their own experience, cultivated plants are not improved by selection but by hybridization and mutation. These discoveries and discussions have caused biologists in general to take an invoice of their stock in trade. It has caused them to question whether the small fluctuating variations of Darwin are of sufficient advantage to the individuals possessing them to cause such individuals to be preserved while neighboring individuals not possessing such minute imperceptible variations are destroyed. The more detailed study of heredity has also caused most biologists to believe that these fluctuating variations are in the main merely somatic variations and hence not inherited. In fact, Pearl ('17) goes so far as to say that "The differences upon which natural selection directly operates are somatic differences by hypothesis and in fact." Whether this is the exact meaning which Darwin meant to convey is difficult to say from his writings. He realized clearly that all fluctuating variations are not inherited, as in the *Origin of Species* he says, "These individual differences are of the highest importance for us, for they are often inherited." Again, however, he makes it very emphatic that "Under the term of 'variations' it must not be forgotten that mere individual differences are included." He does not discuss why some individual differences are inherited and others not, nor did he seem to realize clearly that the moment such a difference is introduced, the two things would no longer be the same.

Since these doubtful points concerning the action of natural selection have arisen, several experiments on the effect of artificial selection have been designed and carried out. It is not necessary to review these papers in detail, but a brief summary is desirable to lead up to a discussion of the two main interpretations of the effect of selection. The experiments have been made on two different types of material. Some have been patterned after Johannsen's, i.e. to test the effect of selection in pure lines. Others have worked on bisexual forms. The conclusions reached from these recent investigations depend in no way upon the material used. It has been said by some and may be said by others that selection in bisexual forms is beset with difficulties and is not comparable to selection within a pure line. This is in part true. Castle maintains, I believe, that a bisexual strain which is homozygous for any particular character is a pure line with respect to that character. This is my own belief, but the difficulty arises in knowing when the strain is homozygous, particularly when there may be so many modifying factors which influence it.

Since the formulation of the genotype concept by Johannsen ('03), a number of papers have given corroborative evidence. Jennings ('08) isolated a number of pure lines from a culture of paramecium and was unable by selection within these lines to produce anything new. He later concluded that the only method of change within the genotype is by mutation. Calkins and Gregory ('13), however, have found differences within the four lines descended from the first four cells resulting from the first two divisions following conjugation. They hold this to be direct evidence in favor of variation within pure lines. Jennings ('16) does not accept it as such, primarily because the two divisions following conjugation are different from the others. They are the ones in which the eight nuclei formed by the division of the micronucleus after conjugation are redistributed. Jennings himself, earlier in the same year, had shown that, following conjugation, inherited variations may occur within a single stock. While the work of Hanel ('08) and Lashley ('15) on Hydra might be more convincing, their conclusions support the pure line theory. It is further supported by the work of Woltereck ('09) upon Daphnia, of East ('10) upon the potato, of Love ('10) upon peas, of Shull ('11) and East ('11) upon maize, of Agar ('14) upon Simocephalus, of Ewing ('14 and '16) upon Aphis, of Surface and Pearl ('15) upon oats, and of others.

In biparental forms we have the work of Pearl ('15, '16, and '17) upon egg production in the domestic fowl, of MacDowell ('15 and '17) upon bristle inheritance in Drosophila, of Zeleny and Mattoon ('15) and May ('17) upon bar eye in Drosophila, and a brief abstract by Sturtevant ('16) on the effect of selection in a mutant race, "Dichaete", of Drosophila, and also a brief abstract by Morgan ('16) upon selection in another mutant, "Notch", of Drosophila. All these experiments give positive evidence of selection. They were interpreted, however, in favor of the pure line hypothesis by assuming the presence of two or more factors which influence the character subjected to selection. The effect of selection was for a few generations only and then the race became stabile. What selection did according to these experiments was to isolate a homozygous strain.

Opposed to the multiple factor interpretation is the work of Castle and Phillips ('14) and Castle ('15, '16, and '17). In the hooded rat they have selected plus and minus strains for 16 and 17 generations respectively, and have produced marked differences in the two lines. Instead of assuming the presence of several modifying factors, Castle believes that the single gene or factor which stands for the hooded pattern varies. MacDowell, Morgan, and Pearl, in particular, have attacked this interpretation of Castle's and have attempted to show that Castle's data can be interpreted in favor of the multiple factor hypothesis. These criticisms are well known and need not be repeated here.

Goldschmidt ('18) extends his ideas of the heredity of sex to all characters. Fluctuating variations, as with Castle, are expressions of the genes which stand for those characters. In addition, however, he maintains this variation to be a quantitative variation. The modifying factor, according to Goldschmidt, is superfluous and hence put into the scrap heap. I am willing to admit that a gene may vary, possibly quantitatively and certainly qualitatively, but I also wish to make it emphatic that the modifying factor cannot be so easily buried, as we have demonstrated its action in the case of extra bristle production.

Three interesting experiments have recently been made which show that selection, even in pure lines, may produce results. One of these is by Middleton ('15) on Stylonychia, in which he is able to isolate lines differing in division rate; another by Stocking ('15) on Paramecium, where she separated strains differing in hereditary abnormalties; the third by Jennings ('16) on Difflugia in which he finds a marked effect of selection on the number of spines on the shell, the depth of the shell, the number of the teeth surrounding the mouth, and the diameter of the mouth. Jennings does not state in plain terms that he rejects his former conclusions based on Paramecium and accepts those obtained from his study of Difflugia. He gives one the impression that he does, however, when he says: "As set forth in our introduction, the present work was designated as a test for the adequacy of the results hitherto reached in a study of uniparental inheritance, a test that would meet the criticisms hitherto made, by employing an organism not open to these criticisms. In this favorable organism, as we have seen, the results are opposite to those commonly reached; gradual hereditary differentiation occurs. The direct, simple, and natural conclusion is that the experiments have supplied precisely the test they were designed to supply and have given clear results. By working with clearly marked characters, and by excluding growth stages and environmental modifications; by basing selection entirely on congenital characters, and continuing it through a great number of generations, we have found that in these organisms the genotype is not constant, but changes by slow gradations, such as would not be revealed by imperfect selection for a few generations."

The facts in these cases seem clear, but the interpretation of Jennings' results have been questioned by Morgan ('16) and Pearl ('17). Morgan says: "If through sexual union the germ plasm of these wild types has in times past been recombined, then selection would be expected to separate certain types again, if, at division, irregular sampling of the germ plasm takes place. Until these points are settled the bearing of the general problem on heredity is uncertain." Pearl suggests that when Jennings changed his method of selection at the end of the sixth generation in family No. 326 and based it to a considerable extent on past performance, he changed his basis of selection from the soma to the germ. In the first six generations, selection produced no results, but after the basis of selection was changed, selection was effective.

And so the question still remains an open one with the balance of evidence, I think, in favor of the multiple factor hypothesis.

Perhaps some of the differences of opinion are due to misunderstandings as to terminology and meaning, and if some of these differences were cleared away we might be a little nearer to a common viewpoint. Jennings ('17b) has attempted to clarify the atmosphere and I think has done it remarkably well, except that he leaves one with the general impression that there still exist two enemy camps, Castle and himself on one side and the mutationists on the other.

These two hypotheses as I see them may be briefly stated as follows: The mutationists hold that natural selection can do nothing more than preserve favorable heritable variations. They believe, in addition, that all heritable variations are mutations. They further believe that selection can modify a given character only by bringing in or getting rid of factors which influence it, or by another mutation occurring in the same direction in which selection is operative. This is the multiple factor hypothesis.

Castle's view, backed by his own experimental evidence as he interprets it, is that fluctuating variations are expressions of germinal changes and that these germinal changes are variations of a single gene.

Jennings has tried to bring these two different views nearer together. First he uses the series of multiple allelomorphs of eosin eye color in Drosophila ampelophila. Here are six variations or mutations of a single gene. Jennings holds such variations comparable to Castle's hypothetical fluctuating variations of the gene. Secondly he discusses the seven modifiers of eosin eye color as described by Bridges ('16), and which are located in chromosomes other than the first. According to Jennings this set of modifiers of a single character, in this case eosin eye color, could be used by the adherents of the multiple factor hypothesis as an explanation of the effect of selection. They might be brought together or separated in the course of selection. On the other hand, Castle could use the six allelomorphs of eosin eye color as an illustration of the variation of a single gene. Jennings believes such differences are mere differences of expression and that it matters not so far as selection is concerned whether the variations which do occur are variations of a single gene or of several genes. The essential fact is, according to Jennings, that we have here two series of almost imperceptible gradations in eye color, and he can see nothing more for the selectionist to ask. The two viewpoints are essentially one, except that Castle thinks of the changes as continuous while the mutationists think of them as discontinuous. However, this is again a question of detail according to Jennings.

Jennings meets one serious difficulty which, it seems to me, he fails to meet squarely. This is the fact suggested by

Morgan that these graded series of mutations in eye color have not occurred in the order in which they are graded. White eye color occurred at a single change from the red and not thru the series of intergrades from red to white. Of course as Jennings says, "There is nothing to prevent a passage from one extreme to the other by minute changes, just as is held to occur by the paleontologists and selectionists, although change by large steps occurs also." Certainly this statement is true, but the chances that the changes will occur in this way are rather small. The only way Jennings attempts to meet this objection of Morgan is by saying that the mutations which have been described in Drosophila are retrogressive, and that it is doubtful whether they are the kind of variations by which the complex structures were built up in phylogeny. If we are to believe this and throw away this much of the data from Drosophila, why not throw all of it away and not use part of it to support the theory of natural selection?

I have presented my own evidence and my own conclusions. The evidence was beyond a doubt in favor of the multiple factor hypothesis. Yet I do not wish to generalize and say that the results of selection are always accomplished in this way. It seems to me it is possible that there may be some truth in both of these interpretations and that there may be evolution by more than one method. In fact, it has been suggested by several writers recently that we are farther from a constructive process of evolution than we were fifty years ago. The reason is that we are not so easily satisfied now as then. Bateson, in his Silliman lectures ('13), says, "When we contemplate the problem of evolution at large the hope at the present time of constructing even a mental picture of that process grows weak almost to the point of vanishing." Pearl ('17) approaches this viewpoint when he says, "The great outstanding need in research on the problem of evolution in general, and of selection in particular, is more and more searching investigations as to the cause of genetic (factorial) variation."

Summary

1. Selection was effective in increasing the number of bristles up to a maximum of 15 in the female and 14 in the male and until the mean bristle number was 9.123.

2. The increase in bristle number was not continuous, but there were three distinct rises, the first from the first to the eleventh generations, the second from the fourteenth to the eighteenth generations, and the third from the twenty-fifth to the twenty-ninth generations.

3. A back selection line started from the eleventh generation of the selection line and carried for twenty-five generations did not return to the normal.

4. The females have a higher bristle number than do the males. This difference in bristle number is not due to a difference in size but to the presence of a sex-linked factor for extra bristles.

5. The linkage tests demonstrate a factor for extra bristles in the X-chromosome, somewhere near the zero end.

6. When the X-chromosome is eliminated by crossing to "bar" and the line inbred, extra bristles are still present, demonstrating the presence of one or more factors for extra bristles outside the X-chromosome. Since the bristle number cannot be raised to what it was in the selection line, this experiment also indicates the presence of a factor in the X-chromosome.

7. In F_2 of the cross of the selection line with black, pink, bent, the pink flies have very few extra bristles. This indicates the presence of a factor for bristle number in the third chromosome. The same result is obtained by crossing to any other third chromosome mutant.

8. When the F_1 males of the cross of the selection line female with a sepia spineless kidney sooty rough male, are mated back to sepia spineless kidney sooty rough females, the F_2 sepia spineless kidney sooty rough males have no extra bristles. These males get their X-chromosomes and both third chromosomes from the sepia spineless kidney sooty rough line, indicating further that there is a factor for extra bristles in the third chromosome.

9. There are at least two factors for extra bristles on the scutellum. There may be more if the three rises in the

curve are significant. One of them is in the first chromosome and the other is probably in the third.

10. While the evidence from my own experiments supports the multiple factor interpretation, I do not wish to say that a gene is a fixed thing incapable of variation. In fact, the numerous multiple allelomorph systems already described show that genes do vary, but they further show that these variations are mutations.

11. One of the factors for extra bristles was no doubt present at the beginning of the experiment. The others probably occurred as mutations during the progress of selection.

12. "Extra bristles" is partially dominant to the normal.

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Vol. V June, 1918

INDIANA UNIVERSITY STUDIES

Study No. 37

A COÖPERATIVE STUDY OF READING IN SIXTEEN CITIES OF INDIANA. By Bureau of Coöperative Research, Indiana University School of Education.

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Vol. V

STUDY No. 37

A COÖPERATIVE STUDY OF READING IN SIXTEEN CITIES OF INDIANA. By Bureau of Coöperative Research, Indiana University School of Education.

Foreword

SINCE the departure of Professor Melvin E. Haggerty no permanent director of the Bureau of Coöperative Research has been appointed, but the Dean of the School of Education has in the meantime had general supervision of the work of the Bureau. W. S. Gray, Dean of the College of Education in Chicago University, and author of the Gray Oral and Silent Reading Tests, prepared the interpretation of the data and the conclusions and recommendations contained in this publication. Mrs. Cecile White Fleming and Mr. W. E. Uphaus assisted in the organization and tabulation of the data.

H. L. SMITH,
Dean of the School of Education.

A Coöperative Study of Reading in Sixteen Cities of Indiana

Introductory Statement

During the winter of 1916-17 the Bureau of Coöperative Research of Indiana University conducted an investigation of the results secured thru reading instruction in sixteen school systems of Indiana. Reading was chosen for investigation because teachers and supervisors alike recognize that it is a subject of first importance in the elementary school curriculum. In the lower grades, ability to read is frequently accepted as the most important factor in determining promotion. In the upper grades, ability to read content subjects independently and intelligently is prerequisite to rapid progress. At the same time that increasing recognition has been given to the importance of reading, numerous questions have been asked by progressive supervisors and teachers of Indiana concerning the specific outcomes of reading instruction. The following questions are typical: Do the pupils develop as rapidly as they should in the acquisition of reading ability? Which phases of reading are well taught and which are poorly taught as judged by the results secured? Which phases of reading instruction receive most emphasis? What changes should be made in present methods of instruction to improve the character of the results? The investigation which is reported in this study was undertaken to determine partial answers at least to some of the questions which progressive teachers are asking in regard to the results of their own teaching.

The distinction between oral and silent reading which has been emphasized in numerous recent investigations of reading was observed in this study. It is sufficient to state here that this distinction is one of first importance. In the primary grades of the elementary school special emphasis has usually been given to oral reading. This type of reading is appropriate and economical during that period in which the pupil is mastering the fundamental steps in reading. In the intermediate and upper grades pupils are frequently called upon to read orally in connection with many class exercises. On the other hand, the pupil soon learns to use reading as a means of securing ideas for himself, and he substitutes silent study for oral reproduction. During the larger part of his school life the progress which a pupil makes depends primarily on his ability to read independently, rapidly, and intelligently during periods of silent study. Furthermore, in most ordinary situations of life one reads silently for the purpose of gathering ideas and not for the purpose of oral exhibition. With this recognition of the large importance of silent reading in mind, it is clear that a thorogoing investigation of reading must be based on the results of instruction both in oral reading and in silent reading.

The facts upon which this report is based were secured thru reading tests which were given to 4,780 pupils in sixteen school systems of Indiana. In nearly all cases the tests were given during February, 1917. In one or two cities, however, the tests were not completed until the first week in March. A list of the cities which engaged in the study, together with the name of the superintendent in each case, is given below. The cities are classified in three groups on the basis of population. Group I includes small towns ranging in population from 200 to 2,000; Group II, small cities from 2,000 to 10,000; and Group III, larger cities from 10,000 to 70,000.

In the discussions that follow the cities will be referred to by number. Below is given the list of cities and the name of the superintendent thru whom the work was carried on:

Anderson	W. A. Denny
Brookville	A. J. Reifel
Cayuga	H. E. Stahl
Connersville	E. L. Rickert
East Chicago	E. N. Canine
Fort Wayne (Normal)	Flora Wilbur
Greenwood	H. W. Marshall
Metamora	A. Lawrence Clark
Noblesville	A. C. Payne
Richmond	J. T. Giles
Seymour	T. A. Mott
South Whitley	H. L. Humke
Valley Mills	Everett Davis
Wabash	O. J. Neighbors
Waveland	N. J. Lasher
Westport	O. W. Holmes

The total number of pupils tested is 4,780. The number in each grade above the first is as follows:

Second grade	500
Third grade	913
Fourth grade	990
Fifth grade	974
Sixth grade	881
Seventh grade	269
Eighth grade	253

Description of the Tests

The materials used in this study of reading were the standardized oral reading paragraphs and the silent reading tests which were used in connection with the surveys in Cleveland, Grand Rapids, St. Louis, and in a large number of investigations carried on in other cities. The derivation and validity of these tests have been discussed in detail in a number of articles and reports. Those who are interested in such problems are referred to the *Supplementary Educational Monograph* Vol. I, No. 1, entitled "Studies of Elementary-School Reading through Standardized Tests" (University of Chicago Press). A double advantage arose thru the use of material which had been carefully rated and used in previous investigations. In the first place, the reading selections were standardized, that is, their relative difficulty was known. In the second place, the earlier studies yielded results which could be used in making productive comparisons.

The oral reading test consisted of a series of twelve short paragraphs arranged in the order of increasing difficulty. These passages had been carefully selected from readers, text-books, and current literature. The arrangement of the passages and the steps of difference of difficulty had been determined after several thousand pupils had been tested. The passages of the test are reproduced below, except that in the original test sheets the type of the first three paragraphs was larger than in the others:

1

A boy had a dog.
The dog ran into the woods.
The boy ran after the dog.
He wanted the dog to go home.
But the dog would not go home.
The little boy said, "I cannot go home without my dog."
Then the boy began to cry.

2

Once there was a little pig.
He lived with his mother in a pen.
One day he saw his four feet.
"Mother," he said, "what can I do with my feet?"
His mother said, "You can run with them."
So the little pig ran round and round the pen.

3

Once there were a cat and a mouse. They lived in the same house. The cat bit off the mouse's tail. "Pray, puss," said the mouse, "give me my long tail again."

"No," said the cat, "I will not give you your tail till you bring me some milk."

4

Once there lived a king and queen in a large palace. But the king and queen were not happy. There were no little children in the house or garden. One day they found a poor little boy and girl at their door. They took them into the beautiful palace and made them their own. The king and queen were then happy.

5

One of the most interesting birds which ever lived in my bird-room was a blue-jay named Jackie. He was full of business from morning till night, scarcely ever still. He had been stolen from a nest long before he could fly, and he had been reared in a house long before he had been given to me as a pet.

6

The part of farming enjoyed most by a boy is the making of maple sugar. It is better than blackberrying and almost as good as fishing. One reason why a boy likes this work is that someone else does most of it. It is a sort of work in which he can appear to be very industrious and yet do but little.

7

It was one of those wonderful evenings such as are found only in this magnificent region. The sun had sunk behind the mountains, but it was still light. The pretty twilight glow embraced a third of the sky, and against its brilliancy stood the dull white masses of the mountains in evident contrast.

8

The crown and glory of a useful life is character. It is the noblest possession of man. It forms a rank in itself, an estate in the general good will, dignifying every station and exalting every position in society. It exercises a greater power than wealth, and is a valuable means of securing honor.

9

He was approximately six feet tall and his body was well proportioned. His complexion inclined to the florid; his eyes were blue and remarkably far apart. A profusion of hair covered the forehead. He was scrupulously neat in his appearance; and, although he habitually left his tent early, he was well dressed.

10

Responding to the impulse of habit, Josephus spoke as of old. The others listened attentively but in grim and contemptuous silence. He spoke at length, continuously, persistently, and ingratiatingly. Finally exhausted through loss of strength he hesitated. As always happens in such exigencies he was lost.

11

The attractions of the American prairies as well as of the alluvial deposits of Egypt have been overcome by the azure skies of Italy and the antiquities of Roman architecture. My delight in the antique and my fondness for architectural and archaeological studies verges onto a fanaticism.

12

The hypotheses concerning physical phenomena formulated by the early philosophers proved to be inconsistent and in general not universally applicable. Before relatively accurate principles could be established, physicists, mathematicians, and statisticians had to combine forces and work arduously.

The directions for giving the tests and for scoring the results are given in detail in the following paragraphs. In most schools the tests were given by the principal or superintendent after a period of preliminary training. In a few cases, however, the tests were given by classroom teachers after they had been carefully trained by the principal or superintendent.

DIRECTIONS FOR GIVING THE ORAL READING TESTS

1. The pupils should be tested individually in a quiet place where they will be free from distraction and where the remainder of the pupils to be tested will not hear the reading.

2. When everything is in readiness to begin, hand the pupil a copy of the standardized paragraphs and give the following directions: "I should like for you to read some of these paragraphs for me. Begin with the first paragraph when I say 'Begin.' Stop at the end of each paragraph until I say 'Next.' If you should find some hard words, read them as best you can without help and continue reading." Pupils above the fourth grade should begin with paragraph 4. If two or more errors are made in this paragraph, ask the pupil to read the preceding para-

graphs also. In case pupils in the first two grades hesitate several seconds on a difficult word, pronounce it for the pupil and mark it as mispronounced.

3. While the pupil is reading, record two sets of facts in regard to the reading: the time required to read each paragraph and the errors made.

(*a*) The time record is secured by noting the exact second at which the pupil begins reading a paragraph and the time when he completes it. The number of seconds required to read the paragraph should be recorded in the margin to the right of the paragraph.

(*b*) In order to illustrate clearly the character of errors and the method of recording them, the following paragraph is inserted:

The sun pierced into my large windows. It was the opening of October and the sky was of a dazzling blue. I looked out of my window and down the street. The white houses of the long, straight street were almost painful to the eyes. The clear atmosphere allowed full play to the sun's brightness.

If a word is wholly mispronounced, underline it as in the case of "atmosphere." If a portion of a word is mispronounced, mark appropriately as indicated above: "pierced" pronounced in two syllables, sounding long *a* in "dazzling," omitting the *s* in "houses" or the *al* from "almost," or the *r* in "straight." Omitted words are marked as in the case of "of" and "and"; substitutions as in the case of "many" for "my"; insertions as in the case of "clear"; and repetitions as in the case of "to the sun's." Two or more words should be repeated to count as a repetition.

It is very difficult to record the exact nature of each error. Do this as nearly as you can. In all cases where you are unable to define clearly the specific character of the error, underline the word or portion of the word mispronounced. Be sure you put down a mark for each error. In case you are not sure that an error was made, give the pupil the benefit of the doubt. If the pupil has a slight foreign accent, distinguish carefully between this difficulty and real errors.

4. Each pupil should be allowed to continue reading until he makes seven errors in each of two paragraphs.

DIRECTIONS FOR SCORING THE RESULTS

1. Score the results for each paragraph through the use of the following table. The numbers in the left-hand column refer to the number of seconds required to read a paragraph. The numbers in the horizontal line at the top of the table refer to the number of errors made in reading. The numbers in the horizontal line to the right of 40 mean that if a paragraph is read in 40 or more seconds with no errors a credit of 4 is given; with 1 error, a credit of 4; with 2 errors, a credit of 3; with 3 errors, a credit of 2, etc.

Seconds	Errors							
	0	1	2	3	4	5	6	7 or More
40 or more	4	4	3	2	1	0	0	0
30–39	4	4	3	2	1	1	1	0
25–29	4	4	3	2	2	1	1	0
20–24	4	4	3	3	2	1	1	0
19 or less	4	4	4	3	2	1	1	0

To find the score for a given paragraph, note the time required to read it and the number of errors made. For illustration, paragraph 1 may be read by pupil A in 34 seconds with 3 errors.

In the left-hand column of the table find the time unit which corresponds to 34 seconds. Evidently it is the time unit 30-39.

Follow the horizontal line of numbers to the right of 30-39 to the column which represents 3 errors. The score indicated there is 2.

Enter this score on the score sheet in the column for paragraph 1, opposite the reader's name.

The score for each paragraph should be determined and entered in the same way. Make no entry on the score sheet if the score is 0.

2. Proceed as follows to find the average class score:

(*a*) Find the sum of the scores for each paragraph separately and enter each total score at the foot of the appropriate column on the score sheet.

(*b*) Enter the total score for each paragraph in the column under "Score," in the following table:

Paragraph	Score × Value	Product
1	....	
2	 5	
3	 5	
4	 5	
5	 5	
6	 5	
7	 5	
8	 5	
9	 5	
10	 5	
11	 10	
12	 5	
Total product		
Average class score		

VALUE FOR PARAGRAPH I

Grade I	55
II	35
III	30
IV	25
V	20
VI	15
VII	10
VIII	5

(*c*) The value or credit given for the successful reading of paragraph 1 varies with the grade. These values are given in the column to the right of the table. Enter the appropriate value for paragraph 1 in the blank space in the column under "Value." Thus, the appropriate value for paragraph 1, for the third grade, is 30. The values for all other paragraphs remain the same for all grades.

(*d*) Multiply the score for each paragraph by its value and enter the result in the column under "Product."

(*e*) Find the sum of the products and divide by 4 times the number of pupils in the class. The result is the average class score.

3. Individual scores may be found as follows:

(*a*) Do as directed in (*b*), (*c*), and (*d*) in the directions for finding the average class score.

(*b*) Divide the sum of the products by 4. The result is the individual score.

(*c*) The average class score may be found by finding the average of the individual scores.

No estimate of the quality of oral reading was made in this investigation for two reasons. In the first place, previous investigations have shown that it is very difficult to define the various elements which make up quality of oral reading on a basis which is acceptable to a large number of teachers; in the second place, it has been found that the scores given to pupils by the methods employed in this study correspond very closely to the teacher's estimate of the relative quality of the reading of the various pupils. For illustration, the principals who gave the oral reading tests in connection with the Grand Rapids survey were asked to make a record of the quality of the reading in terms of A, B, or C. If the reading was very well done, this fact was indicated by placing an A before the paragraph. If, on the other hand, the reading was very poorly done from the standpoint of expression, the fact was indicated by placing a C before the paragraph. These records of quality showed that the time records and records of errors can be relied on as satisfactory measures of the pupil's reading ability. In nearly every case a pupil received a quality mark of A if the paragraph was read at a normal rate with not more than one or two errors. On the other hand, as the number of errors increased and as the rate of reading decreased the quality mark recorded was B or C. These results suggest that when pupils read very poorly the reason may usually be sought in the fact that they have been assigned material which presents too many difficulties for them.

The Silent Reading Tests

At the time that the pupils were tested in oral reading, other tests were given to determine how rapidly they read silently and to what extent they understood what was read. The materials used in the silent reading tests consisted of three short selections, each less than three hundred words in length. These selections formed a series of increasing difficulty. The first was appropriate for second and third grade pupils; the second for fourth, fifth, and sixth grade pupils; and the third for seventh and eighth grade pupils.

The selections used for the tests were printed on cards so that they could be easily handled. Each selection was printed in three sections. The middle section contained one hundred words in the case of the easiest selection and two hundred words in the case of each of the two more difficult selections. The section at the left of the middle section serves a double purpose: first, it gives the pupil something to read by way of preparation for the test part of the passage; secondly, the tester can readily determine the moment at which the reader moves his eyes from the bottom of the card to the top of the card where the words upon which the time record is based begin. In the following passages the ends of sections are indicated by the short horizontal lines. The passages used are as follows:

Tiny Tad

(FOR SECOND AND THIRD GRADES)

Tiny Tad was a queer little fellow with only two legs and a short tail. He was nearly black, too, and much smaller than most tadpoles in the big pond. He could hardly wait for his front legs to grow.

"When I have them all," he said, "I'll leave this dirty water and go up into the orchard. What fun it will be to hop and hop and hop. If only I had a little brother to hop with me, I should be so happy."

It wasn't long before his legs began to grow. He moved about and kicked around until his legs were quite strong. "I am going out on the bank to see if I can hop," he said one night when he was just six weeks old.

The sun was hardly up the next morning when a

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little toad jumped out of the water and hopped up on the bank. He was very small, but none too small for the little legs that wabbled under him. It was Tiny, the young toad.

The Grasshoppers

(FOR FOURTH, FIFTH, AND SIXTH GRADES)

The grasshoppers were among the worst enemies of the early settlers of Nebraska. Their homes were on the high plains and among the hills at the foot of the great mountains in the West. Here they lived and raised their families.

In dry seasons there were more children and less food at home. Then they assembled and flew away in great swarms to the east and to the south. They traveled hundreds of miles. Sometimes on clear, warm, moonlight nights they traveled all night. More often they settled down late in the afternoon and fed, and then continued their way the next day.

The great grasshopper raid took place in September, 1874. Suddenly along the frontier states the air to the west was filled with grasshoppers. There were billions of them in the great clouds which darkened the sun. The noise of their wings filled the air with a roaring sound like a rushing storm, followed by a deep hush as they dropped to the earth and began to devour the crop.

All the corn was eaten in a single day. Where cornfields stood at sunrise nothing remained at night but stumps of stalks swarming with hungry hoppers struggling for the last bite. They stripped the garden patches bare. They gnawed great holes in the rugs and carpets put out to save favorite plants. The buds and fruit of trees were consumed. They followed the potatoes and onions into the ground.

When they finished the garden and green crops, they attacked the wheat and oats in the shock and the wild grass in the unplowed fields. Only two green crops escaped them, broom corn and sorghum cane. They did not seem to have a sweet tooth.

Ancient Ships

(FOR SEVENTH AND EIGHTH GRADES)

There is no more interesting study to marine architects than that of the growth of modern ships from their earliest form. Ancient ships of war and of commerce equally interest them; but as they study the sculptures and writings of the ancients, they find records of warships far outnumbering ships of commerce.

Among ancient nations the Greeks and Romans were the best shipbuilders. Judging from the description of their works their crafts must have been elegant, swift, and seaworthy. This is more than can be said of many of the more showy productions of the shipyards of Britain, France, and Spain even so late as the Middle Ages.

There is no question now that the ships of the ancients made extended voyages urged by oars alone. A thousand oarsmen were sometimes required to man the sweeps, besides a crew of five hundred soldiers and sailors. Written descriptions give us splendid pictures of fleets of these ancient ships moving swiftly along the white villa-dotted shores of Greece, or majestically sweeping into some mirror-like harbor and with sounding trumpets saluting the setting of the low, western sun.

We are able to make from old records very fair models of these ancient warships. One writer describes the great galley of Philopator as propelled by forty banks of oars. His description is questioned, for however plain the description of these warships may be, no one has yet shown the precise manner in which forty banks could be arranged. A bank of oars means a

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row on one deck, and while there are many pictures of galleys they show nothing more than a trireme, which is a ship of three banks. A ship of forty banks puzzles our imagination.

After the pupil had read the selection appropriate for his grade he was given a sheet of printed directions. On one side of the sheet the directions state that the pupil should write thereon all he could remember of the story which he had read. As soon as he completed his reproduction he turned the sheet and answered the ten questions which were printed there. The questions for each of the selections are as follows:

Tiny Tad

1. How many legs did Tiny Tad have at the first of this story?
2. How did Tiny compare in size with most of the other tadpoles in the pond?
3. Which legs did Tiny wish would grow?
4. Where did Tiny say he would go when he got all his legs?
5. What did Tiny wish he had to hop with him?
6. What did Tiny do to make his legs grow strong?
7. How old was Tiny when he decided to leave the pond?
8. What part of the morning did Tiny choose for leaving the pond?
9. How did Tiny get upon the bank?
10. What size was Tiny at the end of the story?

The Grasshoppers

1. In what western state were the grasshoppers enemies to the settlers?
2. What effect did dry seasons have on the number of grasshoppers?
3. On what kind of nights did the grasshoppers sometimes travel all night long?
4. When the grasshoppers were making their long journeys, what would they often do late in the afternoon?
5. In what year did the great grasshopper raid take place?
6. Like what did the great groups of grasshoppers look as they traveled through the air?

7. What sort of noise did they make when flying through the air?
8. What change was brought about in the appearance of the cornfields by the grasshoppers between morning and night?
9. What did the settlers do to protect their favorite plants?
10. Why didn't the grasshoppers eat the broom corn and sorghum?

Ancient Ships

1. To whom is the study of the growth of modern ships interesting?
2. How do the records of warships compare in number with the records of the ships of commerce?
3. What peoples were the best shipbuilders among the ancient nations?
4. How did the ancient vessels compare in elegance and swiftness with the more showy productions of the Middle Ages?
5. What kind of voyages were sometimes made by ancient ships when propelled by oars only?
6. What was the total number of men required on some of the ships?
7. Explain clearly what a "white villa-dotted shore" means to you.
8. From what source do we secure the ideas which enable us to make models of the ancient warships?
9. What does a "bank of oars" mean?
10. Why do we question the statement that the great galley of Philopator had forty banks of oars?

The directions for giving the tests as individual tests and for scoring the results are reproduced below:

DIRECTIONS FOR GIVING THE SILENT READING TEST

1. Grades II and III are tested on "Tiny Tad"; Grades IV, V, and VI on "The Grasshoppers"; Grades VII and VIII on "Ancient Ships."

2. The teacher then hands the pupil a card with the selection appropriate for his grade printed on it, with these directions: "Read the story on this card silently. Read the story from beginning to end without stopping or repeating any of it. Read the story rapidly but carefully. Do not stop reading to ask about difficult words; read such as best you can. Be prepared to tell the story or to answer any question about it when you are through. Do you understand?" Make the directions clear to the pupil before beginning the reading.

3. Secure the time record as follows: When the pupil shifts from the bottom of the first column to the top of the middle column, note the position of the second-hand. When he shifts from the bottom of the middle column to the top of the third column, note the second-hand again. Record the number of seconds required to read the middle column. Be sure that your record indicates the time for reading the middle column only. If possible, use a stop watch.

4. If the pupil has been reading "Tiny Tad," ask him to tell you the story of Tiny Tad as well as he can. In the meantime write as rapidly as you can just what the pupil says. Ask the pupil to tell it

sentence at a time if he talks too rapidly. When he discontinues speaking ask him if he remembers anything else. Following this, ask him the questions and record his answers.

5. If the pupil has been reading "The Grasshoppers" or "Ancient Ships," hand him the report blank to fill out. Ask him to write the story which he has read as well as he can. Impress upon him the fact that he should not look at the questions on the opposite side of the sheet until he has finished writing his story.

DIRECTIONS FOR SCORING THE RESULTS

Rate of silent reading—

1. Enter the number of seconds required by each pupil to read 100 words in the column under "Rate" on the record sheet. The time record for pupils who read "The Grasshoppers" and "Ancient Ships" was based on 200 words. Divide the time record for these pupils by two before entering the rate on the record sheet. Drop fractions.

2. Find the average number of seconds required by the pupils of a class to read 100 words.

3. Express this average in terms of the number of words read per second. To do this divide 100 by the average number of seconds required by the class to read 100 words.

Quality of silent reading—

1. Score the reproductions as follows: Check from the pupil's reproduction all wrong statements, all irrelevant statements, and all repetitions. Count the remaining words. Find the percentage that these words are of the total number of words in the selection. Enter the result in the column under "Reproduction" on the record sheet.

2. Give a credit of 10 points to each question answered correctly. Enter the total grade for each pupil for questions answered correctly in the column under "Questions."

3. Average the reproduction grade and the grade received for correct answers to questions for the quality score. Drop fractions. Enter the quality score in the appropriate column on the record sheet.

4. Find the average quality score for the class by finding the sum of the individual quality scores and dividing by the number of pupils in the class.

In order to economize time in giving the silent reading tests, the following supplementary suggestions were offered at the time the tests were sent to the schools:

The silent reading tests can be given as follows in the grades above the third: The grade teacher assigns a study period to the pupils of her room. She then gives the test by having a pupil come forward to her desk and read silently the selection which is appropriate for him. As soon as the reading has been completed, the pupil takes the sheet to his seat where he writes his reproduction and answers to questions. In the meantime the teacher tests other pupils. The teacher should instruct each pupil carefully concerning what he is to do before sending him to his seat.

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TABLE I

AVERAGE SCORES IN ORAL READING IN EACH GRADE ABOVE THE FIRST IN FIFTEEN INDIANA CITIES

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score
Group I (200–2,000)														
1	10	30	10	41	10	41	10	45	10	47	10	38	.....	.....
2	.....	.....	10	37	21	39	17	43	35	39	22	39	43	41
3	20	33	22	43	14	42	25	43	29	46	22	45	19	43
4	10	46	.....	.....	.....	.....	.....	.....	10	47	.....	.....	.....	.....
5	19	21	22	42	17	50	22	43	18	46	20	47	17	34
6	14	32	17	28	17	38	21	43	18	55	19	40	16	44
7	.....	.....	.....	.....	10	42	17	40	.....	.....	9	36	10	37
Group II (2,000–10,000)														
8	10	37	10	45	10	44	10	48	10	51	10	50	10	54
9	20	41	20	49	20	46	20	50	20	54	20	51	8	48
10	36	37	36	34	24	41	24	43	24	41	12	40	12	36
11	.....	.....	45	45	30	48	51	47	79	42	76	44	60	42
12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Group III (10,000–70,000)														
13	.....	.....	288	39	313	46	324	47	235	46	.....	.....	.....	.....
14	30	39	40	47	30	47	30	48	30	49	20	55	20	49
15	.....	.....	.....	.....	.....	.....	22	40	16	47	.....	.....	.....	.....
16	325	27	149	37	342	41	125	43	279	40	.....	.....	.....	.....
Total	494		669		858		718		813		240		215	
Average		34		40.5		43.4		44.5		46		44		42.8

RESULTS OF THE ORAL READING TESTS

The oral reading tests were scored under the immediate direction of the Bureau of Coöperative Research. The scores which are used in this report were calculated on the basis of the time required to read a paragraph and the numbers of errors made. The reduction of each child's record to a simple numerical statement is based on a system of scoring which turns into quantitative terms the fact that a paragraph should be read in a certain amount of time with a limited number of errors. If the pupil exceeds the amount of time which has been found in earlier investigations to be common and if the number of errors increases, the amount of credit which he gets for reading a paragraph should be proportionately reduced. The final score for an individual is found by calculating the total amount of credit due the pupil on all paragraphs which he reads. The average class score is found by calculating the arithmetical average of all individual scores in the class.

The scores for fifteen cities are presented by grades in Table I. The arabic numerals from 1 to 16 which appear at the left of the table refer to the various cities which coöperated in the study. The cities are arranged in groups on the basis of population. In connection with the report for each grade the number of pupils which were tested is indicated. In many cases a minimum of ten pupils was tested. In a majority of the cases, however, a much larger number of pupils were tested. The average score for Indiana appears at the foot of the table. The entries in the table reveal the fact that the results varied widely in different schools. In the second grade, for illustration, the scores varied from 21 to 46. These scores indicate that the class which made the highest score had progressed more than twice as rapidly as the class which received the lowest score. The schools which rank low in each grade, particularly in the lower grades, may legitimately question the adequacy of their instruction in oral reading. The average scores show that the schools of Indiana make steady progress thru the second, third, fourth, and fifth grades, and that there is an apparent decrease in the rate of progress beyond that point.

The average oral reading scores for Indiana are compared with the average scores which were secured in a number of other investigations in Table II. The investigations have

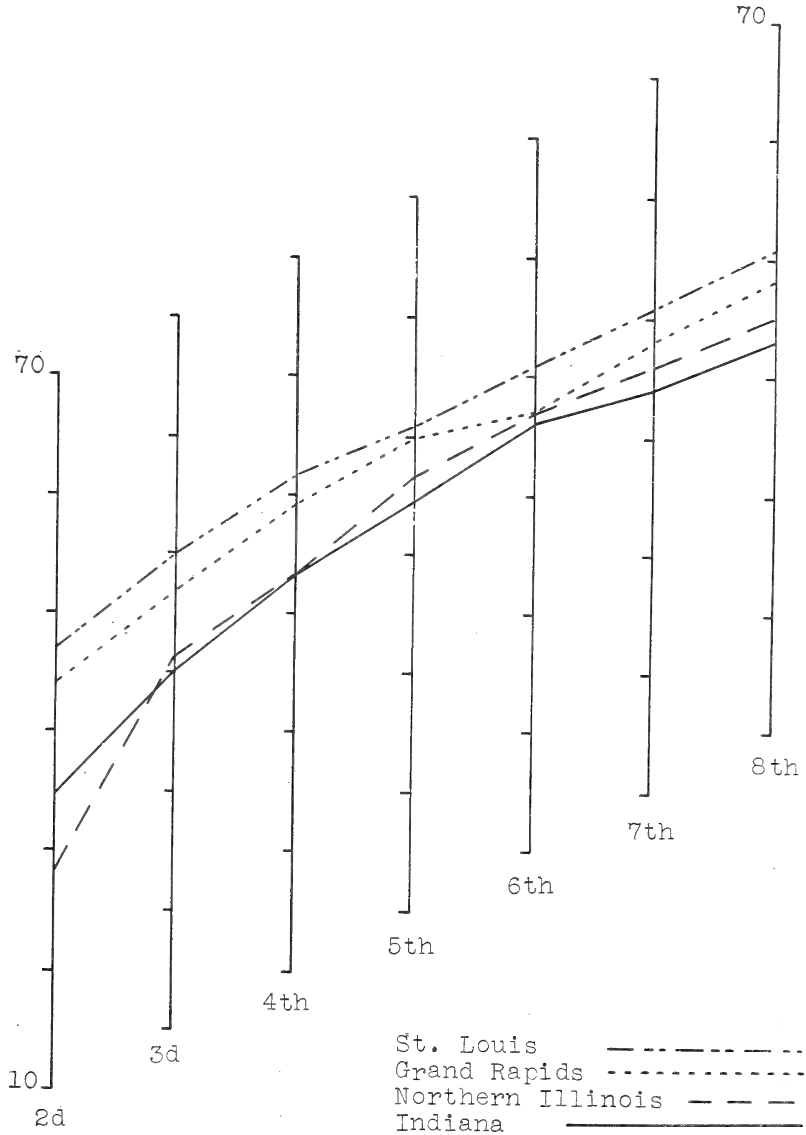

DIAGRAM 1. AVERAGE ORAL READING SCORES FOR INDIANA, NORTHERN ILLINOIS, GRAND RAPIDS, AND ST. LOUIS

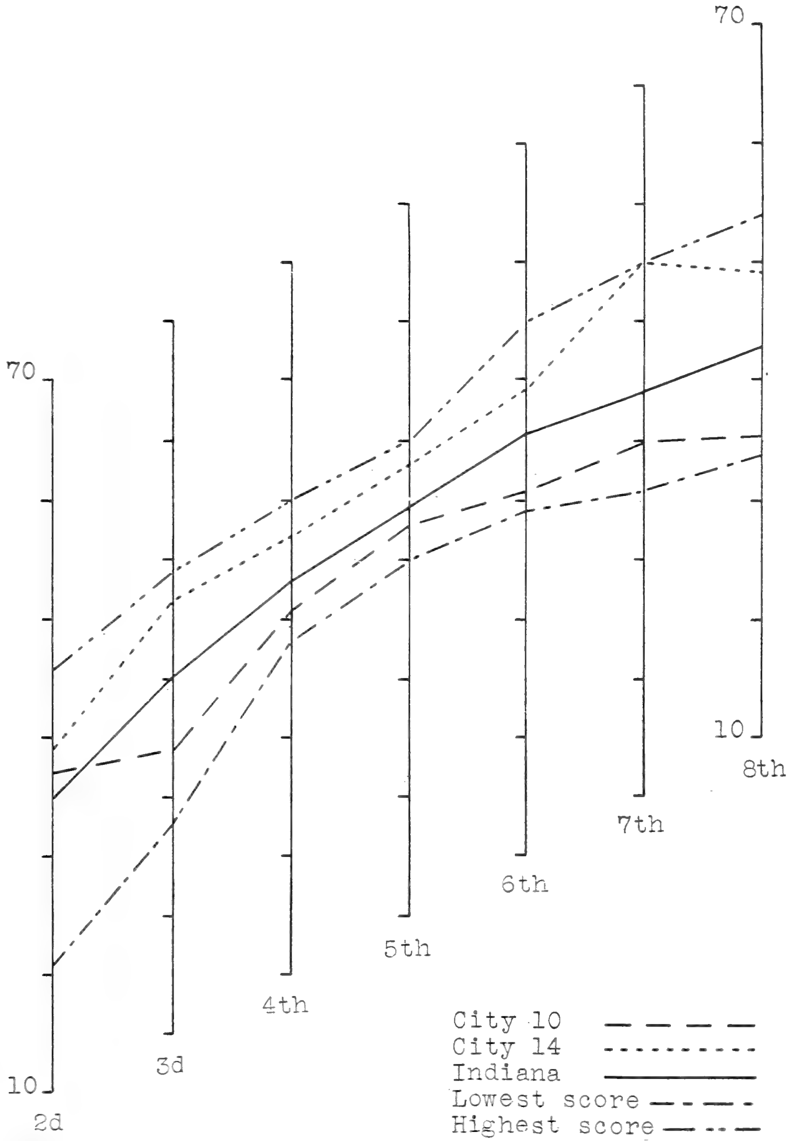

DIAGRAM 2. AVERAGE ORAL READING SCORES FOR INDIANA AND FOR TWO SELECTED CITIES; ALSO HIGHEST AND LOWEST SCORES FOR EACH GRADE

been listed in the order in which they were given during the school year. The tests were given in Indiana at about the same time in the school year that the tests were given in Grand Rapids. If all the other factors involved were comparable we should naturally expect to find the scores in Indiana and Grand Rapids approximately equal. The entries in the table indicate that Grand Rapids secured distinctly superior results.

TABLE II

Average Oral Reading Scores

Cities	Date	Gr. 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 7	Gr. 8
Twenty-three Illinois schools	Sept., 1914	20	28	39	43	45	46	....
Northern Illinois	October, 1916	28	42	43	47	47	46	45
Indiana	February, 1917	34	40.5	43.4	44.5	46	44	42.8
Grand Rapids	March, 1916	44	47	49	50	47	48	48
Cleveland	June, 1915	42	46	47	48	49	47	48
St. Louis	June, 1916	47	50	52	51	51	51	51

Many of the facts of Table II are represented graphically in Diagram 1. A word of explanation is necessary in order that the diagram in which the results are presented may be readily understood. Ability to read a certain paragraph without errors means less on the part of a pupil in the upper grades than on the part of a pupil in the lower grades. Grades must be compared with each other, therefore, by recognizing different levels of achievement. These different levels, as determined from previous tests, can be expressed graphically by the vertical lines in Diagram 1. Each vertical line represents the scale for a grade and begins below at the point where a score of 10 should be recorded. Higher scores can be represented by appropriate distances along the vertical line above 10. Each vertical line ends above where a score of 70 belongs. The oblique lines in Diagram 1 represent the average scores for Indiana, St. Louis, Grand Rapids, and Northern Illinois.

The diagram shows clearly that the scores for Indiana were distinctly inferior to those for St. Louis and Grand Rapids, and were slightly inferior to those for Northern Illinois, excepting in the second grade. Inasmuch as the tests were given in Indiana and in Grand Rapids at about the same time

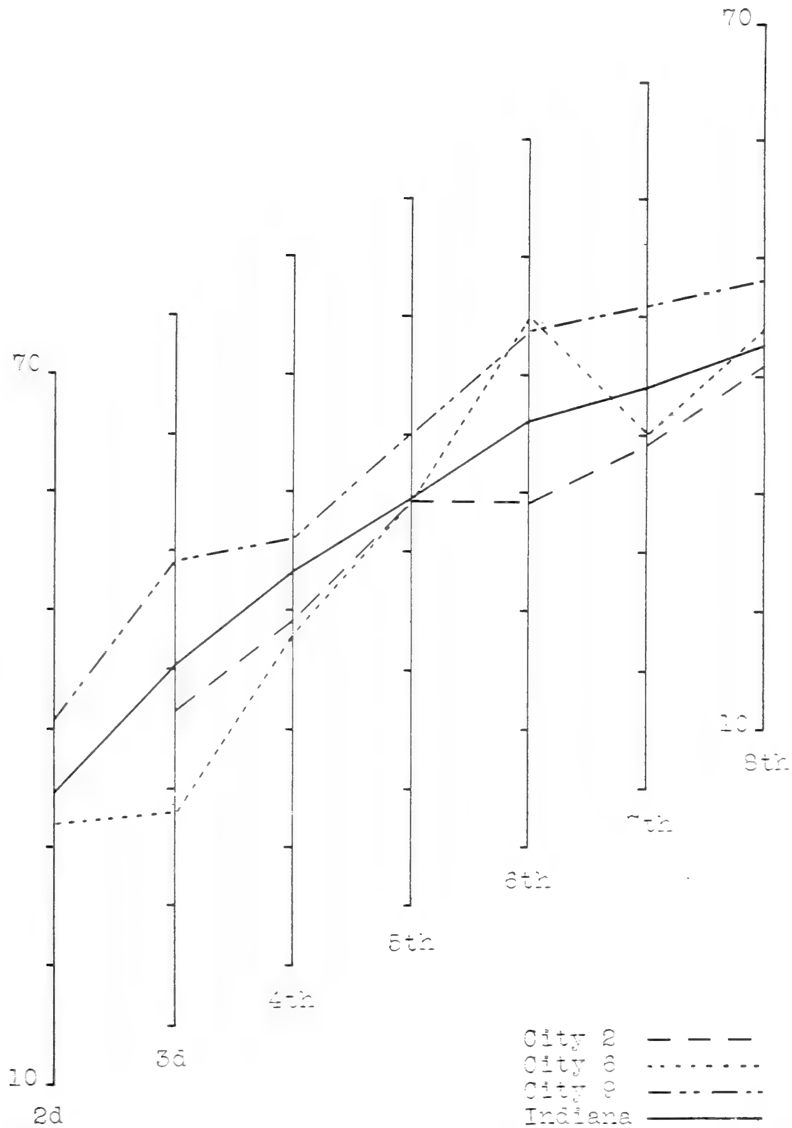

DIAGRAM 3. AVERAGE ORAL READING SCORES FOR INDIANA AND FOR THREE SELECTED CITIES

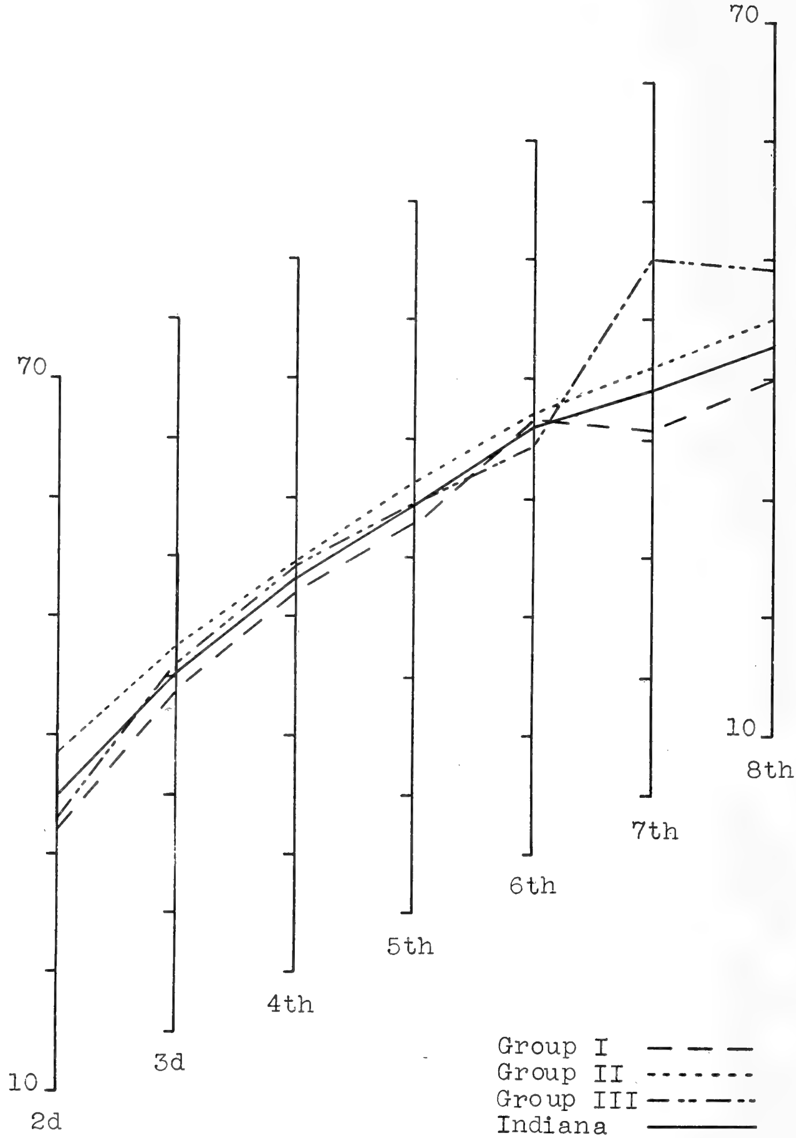

DIAGRAM 4. AVERAGE ORAL READING SCORES FOR INDIANA AND FOR GROUPS I, II, AND III

during the school year, we should naturally expect that the scores would be approximately the same. The diagram shows that Indiana is more than one-half year behind Grand Rapids in oral reading achievement. This situation should challenge the attention of every teacher and supervisor of Indiana. If the teachers of Indiana are devoting as much time and energy to instruction in reading as are the teachers in Grand Rapids and St. Louis, or even in Northern Illinois, it is evident that the results secured per unit of time are distinctly inferior. Expert supervisors and teachers should make careful and continued studies of the reading problem in order to determine the real cause of the slow progress in Indiana.

Diagram 2, on the other hand, shows clearly that excellent results are possible. The diagram presents the average oral reading scores for Indiana and for two selected cities; also the highest and lowest scores for each grade. The scores for City 14 are uniformly high. They approximate, and in some places even excel, the scores for Grand Rapids. The scores for City 10 are uniformly low. The wide difference in the results secured by these two cities is evidence that there are fundamental differences within these cities which should be investigated. Investigations of this type enable the teachers in a given state or section to locate the cities in which superior results are secured. Special studies should be made of the reading material and methods of teaching in such cities in order that the less successful cities may profit thru the use of more effective methods. In a number of recent investigations of reading it has been found that an abundance of interesting and appropriate reading material is a factor of greatest importance in securing superior results. Each city which ranks below Grand Rapids should study its own needs carefully and should take steps immediately to improve its instruction. A limited number of constructive suggestions will be found in the recommendations which are given at the end of the report.

The average oral reading scores for Indiana and for three selected cities are presented in Diagram 3. The interesting fact in connection with this diagram is revealed by the curve of progress for City 6. In contrast to the uniformly high scores which are made by City 9, City 6 starts at a very low level in the second grade and makes but little progress dur-

TABLE III

AVERAGE SCORES IN ORAL READING IN EACH GRADE ABOVE THE FIRST FOR GROUPS I, II, AND III

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score
Group I	73	32.4	81	38.2	89	42.0	112	42.8	120	46.7	102	40.8	105	39.8
Group II	66	38.3	111	43.3	84	44.8	105	47.0	133	47.0	118	46.3	90	45.0
Group III	355	33.0	477	41.0	685	44.5	501	44.5	560	45.5	20	55.0	20	49.0
Total	494		669		858		718		813		240		215	
Average		34.0		40.5		43.4		44.5		46.0		44.0		42.8

ing the third grade. From the third to the sixth grade, however, progress is unusually rapid. Beyond the sixth grade progress is distinctly irregular. Results of this type suggest the need of frequent tests in reading. Undoubtedly the second and third grades do not assume their full share of the responsibility in securing rapid progress in reading. Altho the results secured by the intermediate grades are commendable from several points of view, it is probable that these results were secured at the expense of time and energy which might have been devoted to other phases of school work. Frequent measurements of progress in reading will reveal whether or not the various grades are directing the appropriate amount of time and energy to reading instruction.

The data which were secured make it possible to study one possible cause of the differences in the achievement of schools. The cities which coöperated in this investigation were grouped together on the basis of population to determine whether the size of school system was an important factor in progress. All cities were included in Group I which had a population between 200 and 2,000, in Group II between 2,000 and 10,000, and in Group III between 10,000 and 70,000. Inasmuch as the number of cities included in each group is small, no final conclusions can be drawn in regard to the questions under consideration. The results may indicate a general tendency. Table III presents the average oral reading scores in each grade above the first for Groups I, II, and III. The same facts are presented in graphical form in Diagram 4. The diagram shows that the average scores made by each of these groups are similar to the average scores for Indiana. The one noteworthy exception to this general similarity is found in the seventh and eighth grades in Group III. This variation is explained by the fact that results were secured from only one school in these grades. In general it may be said that the scores for the cities of Group II average highest, that the scores for the cities of Group I average lowest, and that the scores for the cities of Group III are intermediate.

The facts revealed by the results of the oral reading tests may be summarized as follows: (1) The average oral reading scores for sixteen cities of Indiana are lower than the scores in many other cities in which the tests have been given. (2) The wide variation in the results secured in different schools suggests the need of a careful study of the methods and materials which are used in successful cities by representatives of the cities which secured inferior results in order that the latter cities may profit thru the use of more effective methods. (3) The irregular progress made by some schools reveals the need of frequent objective studies of progress in reading in order to avoid misspent time and energy in reading instruction. (4) A study of the relation between population of city and progress in reading showed that small cities made most rapid progress, that villages and towns made slowest progress, and that large cities were intermediate in rate of progress.

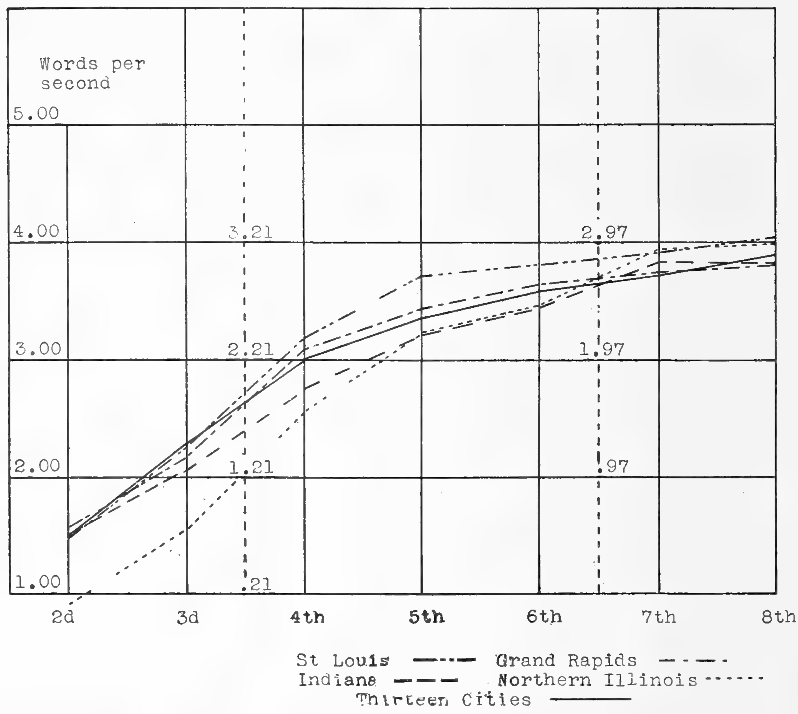

DIAGRAM 5. AVERAGE SILENT READING RATES FOR INDIANA, NORTHERN ILLINOIS, GRAND RAPIDS, ST. LOUIS, AND THIRTEEN CITIES

RESULTS OF THE SILENT READING TESTS

At the same time that the pupils were tested in oral reading, other tests were given to determine how rapidly they read silently and to what extent they understand what is read. The material used in the silent reading tests consisted of three short selections, each less than three hundred words in length. These selections formed a series of increasing difficulty. The first was appropriate for second and third grade pupils; the second was appropriate for fourth, fifth, and

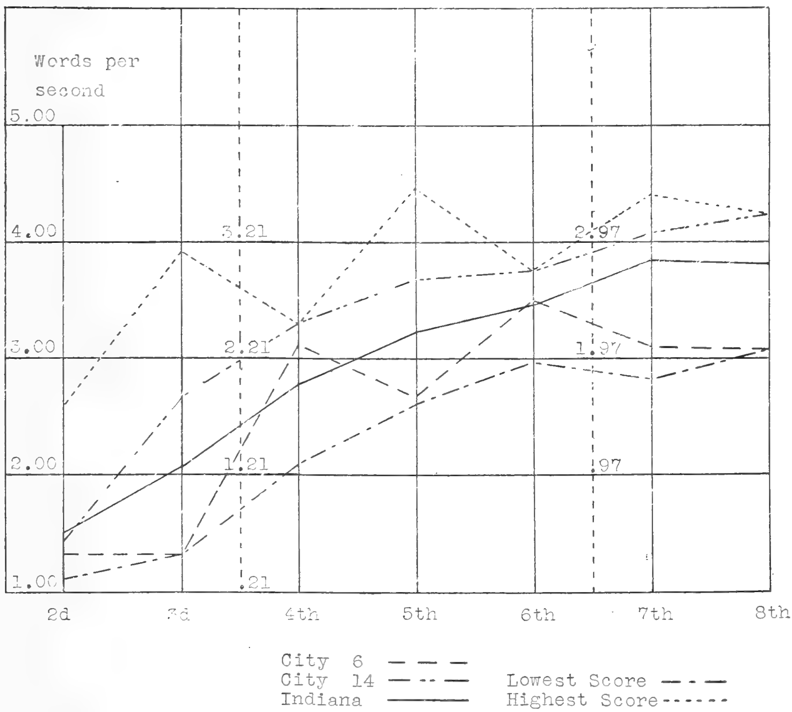

DIAGRAM 6. AVERAGE SILENT READING RATES FOR INDIANA AND TWO SELECTED CITIES; ALSO HIGHEST AND LOWEST SCORES FOR EACH GRADE

sixth grade pupils; and the third was appropriate for seventh and eighth grade pupils. The tests were given as individual tests according to the directions which were included in earlier paragraphs of this report. While the pupil read, the teacher who gave the test noted the number of seconds required to read the middle column of the selection. When the pupil had finished reading, he was given a sheet of paper upon which to write all he could remember of what he had read. After completing the written reproduction, he wrote the answers

TABLE IV

Average Rates in Silent Reading in Each Grade Above the First for Fifteen Indiana Cities

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate
Group I (*200–2,000*)														
1	10	1.49	10	2.40	10	1.80	10	3.15	10	2.80	10	3.11	...	...
2	...	...	13	2.40	21	2.00	17	2.10	37	2.80	21	3.00	43	2.90
3	...	...	22	1.38	14	1.31	25	1.90	29	2.28	22	2.68	19	2.20
4	10	1.53	...	...	...	...	...	...	10	2.86	...	...	...	...
5	25	1.20	20	2.03	23	1.60	22	1.80	18	2.94	20	3.24	17	2.99
6	14	1.33	17	1.33	17	2.32	21	1.87	18	2.70	19	2.08	16	2.04
7	...	...	...	...	10	1.70	16	2.14	...	...	8	1.78	10	2.36
Group II (*2,000–10,000*)														
8	10	2.59	10	3.91	10	1.74	10	1.93	10	2.59	10	2.45	10	2.73
9	...	...	...	...	...	...	...	...	...	...	...	...	...	...
10	36	1.42	36	1.86	24	2.01	24	2.64	24	2.17	12	3.38	12	2.99
11	...	...	115	1.97	100	2.19	117	2.36	81	2.64	77	2.55	56	2.70
12	20	1.37	50	1.56	50	2.02	50	2.43	50	2.75	50	2.66	50	2.61
Group III (*10,000–70,000*)														
13	...	...	287	1.93	300	2.00	316	2.33	238	2.85	...	...	...	...
14	30	1.44	40	2.68	30	2.50	30	2.88	30	2.96	20	3.05	20	3.20
15	...	...	...	...	...	...	22	3.67	16	2.69	...	...	...	...
16	345	1.09	293	1.94	381	1.93	294	2.47	310	2.66	...	...	...	...
Total	590		913		990		974		881		269		253	
Average		1.59		2.07		1.98		2.44		2.67		2.81		2.79

to ten specific questions in regard to the content of the selection.

The average rate at which a class read was determined by finding the average number of seconds required by the class to read one hundred words. This result was then expressed in terms of the number of words read per second. The average rates of reading for each of fifteen cities are presented in Table IV. The average rates for Indiana appear at the foot of the table. The cities vary widely in rate of silent reading. For illustration, in the third grade the pupils of City 6 read at the rate of 1.33 words per second, and the pupils of City 8 read at the rate of 3.91 words per second. Granted that the pupils of City 8 comprehend what is read as well as do the pupils of City 6, it is evident that the pupils of City 8 are capable of advancing three times as rapidly during periods of silent study as are pupils of City 6. This is an advantage which every class should strive to gain.

Diagram 5 represents the average silent reading rates for Indiana, Grand Rapids, St. Louis, Northern Illinois, and Thirteen Cities. A word of explanation is necessary in order that the diagram may be readily understood. Since three selections were used in the test, two readjustments have been necessary in the diagram. The points of these readjustments are between the third and fourth grades and between the sixth and seventh grades. In Diagram 5 dotted vertical lines are drawn at each of these points. The numbers at the left of the diagram indicate the numbers of words read per second in the easy selection. The numbers on the line between the third and fourth grades indicate the equivalent rates when the second selection was read. The numbers on the line between the sixth and seventh grades indicate the equivalent rates when the most difficult selection was read.

Diagram 5 shows that the average silent reading rates for Indiana are below those for Thirteen Cities and for Grand Rapids, particularly in the intermediate grades. The rates for St. Louis are distinctly superior thruout the grades and the rates for Northern Illinois are noticeably low in the primary and intermediate grades but reach a high level in the upper grades. It is evident that the cities of Indiana make a good start in rate of silent reading in the second grade but that they fail to progress as rapidly during the intermediate grades as

TABLE V

Average Rates in Silent Reading in Each Grade Above the First for Groups I, II, and III

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate	Number of Pupils	Rate
Group I	59	1.39	82	1.90	95	1.79	111	2.16	122	2.73	100	2.64	105	2.41
Group II	66	1.79	211	2.33	184	1.99	201	2.34	165	2.53	149	2.76	128	2.76
Group III	375	1.26	620	2.18	711	2.14	662	2.84	594	2.76	20	3.05	20	3.20
Total	500		913		990		974		881		269		253	
Average		1.50		2.07		1.98		2.11		2.67		2.81		2.79

do several cities with which they are compared. Hence there is need for more emphasis on rate of silent reading beginning with the third grade if the cities of Indiana are to approximate the achievement of other progressive cities.

Diagram 5 reveals other significant facts. It should be noted that progress in rate of reading is rapid in the lower and intermediate grades and approaches a high level in the

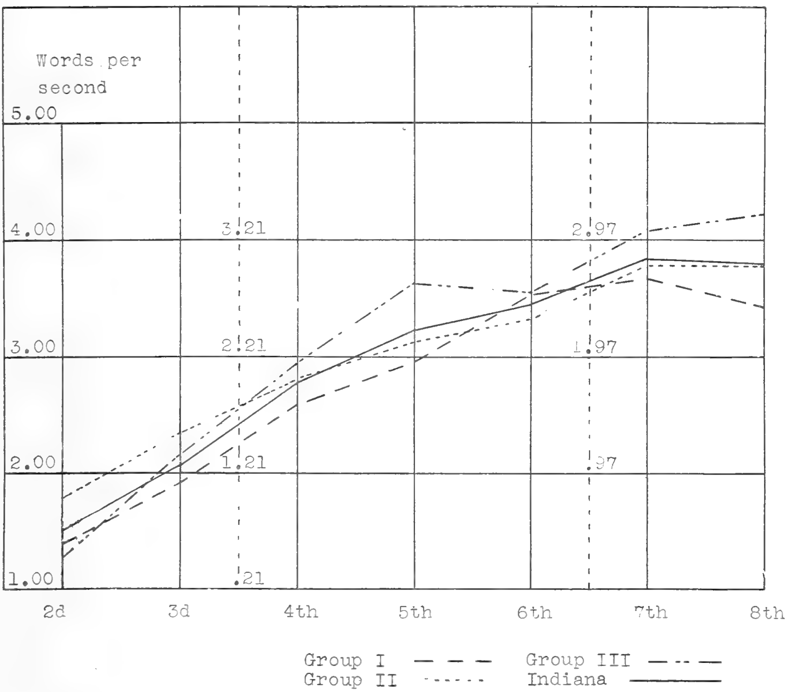

DIAGRAM 7. AVERAGE SILENT READING RATES FOR INDIANA AND FOR GROUPS I, II, AND III

seventh and eighth grades. Altho the different cities vary widely in rate of reading during the lower grades, they approach the same level of achievement in the upper grades. Since much of the information which the pupil secures in the intermediate grades is gained during periods of silent study, it is evident that the pupil who learns to read rapidly and intelligently during the third and fourth grades will be able to progress much more rapidly than the pupil who does not develop this ability until he reaches the upper grades. In view of these facts, it is evident that the cities of Indiana should consider seriously the advisability of emphasizing rate of silent reading in the intermediate grades.

Diagram 6 presents in graphical form the average silent reading rates for Indiana and for two selected cities, also the highest and lowest scores in each grade. The diagram empha-

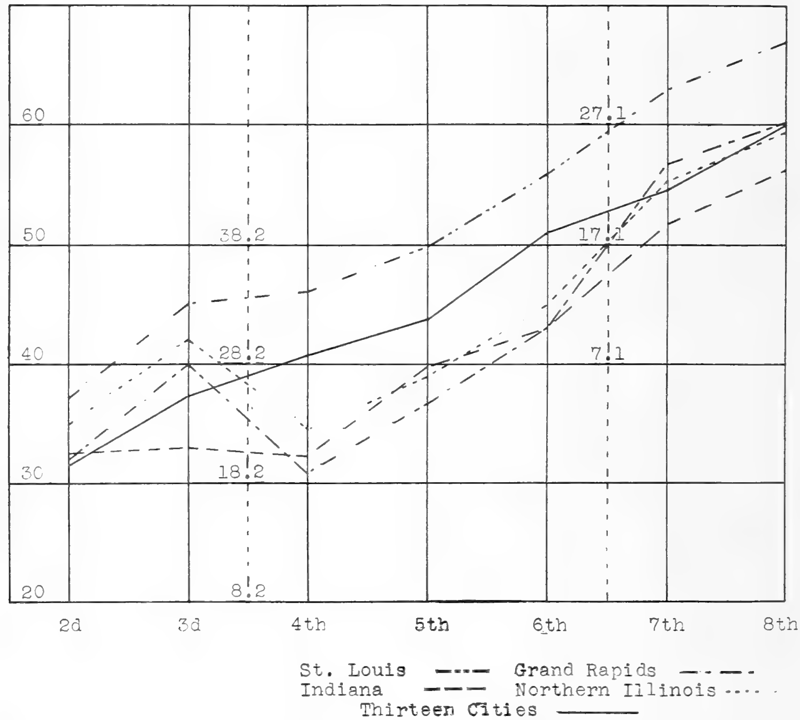

DIAGRAM 8. AVERAGE QUALITY SCORES IN SILENT READING FOR INDIANA, NORTHERN ILLINOIS, ST. LOUIS, GRAND RAPIDS, AND THIRTEEN CITIES

sizes the fact that schools vary widely in rate of reading. The average rates of reading in some classrooms are three times as high as the average rates in other classrooms. In numerous recent investigations it has been found that emphasis on silent reading instruction, together with abundant opportunity to read simple selections silently, is prerequisite to rapid progress in rate of reading. The diagram shows clearly the need of a careful scrutiny of the methods and materials employed in reading instruction in many cities of Indiana.

Table V presents the average rates in silent reading in each grade above the first for Groups I, II, and III. The facts of the table are presented in graphical form in Diagram 7. The diagram shows that Group I ranks lowest in rate of silent reading, Group II ranks second, and Group III ranks highest. It is generally recognized that the schools of larger cities are more amply provided with appropriate reading material than are the smaller cities and towns. Hence it is in harmony with natural expectation for the larger cities to rank highest. Furthermore, the fact that the larger cities rank only second in oral reading achievement indicates that relatively less time is given to oral reading and relatively more time to silent reading than is given in smaller cities and towns. The results of the study of rate of silent reading should suggest to each city the need of studying carefully the emphasis which it gives to this phase of reading and the opportunity which it provides for quantitative reading of appropriate selections.

In order to determine the quality of a pupil's reading the reproductions and the answers to questions were scored as follows: All wrong statements, all irrelevant statements, and all repetitions were checked from the pupil's reproduction and the remaining words counted. The percentage of the entire selection that these words formed was adopted as the reproduction score. For each question answered correctly a grade of ten points was given. The average of the reproduction grade and the grade received for correct answers was then found. This average grade was adopted as the quality score for silent reading. The average quality scores for fifteen cities of Indiana are presented in Table VI.

Diagram 8 presents in graphical form the average quality scores for Indiana, Grand Rapids, St. Louis, Northern Illinois, and Thirteen Cities. The diagram shows that the cities of Indiana rank low in the comprehension of what is read. In this connection it should be stated that the scores for the intermediate grades are no lower than those for Grand Rapids. In order to compare favorably with the average for Thirteen Cities and with St. Louis it will be necessary for the cities of Indiana to give more effective emphasis to the content of what is read.

Diagrams 9 and 10 present the records for a number of

TABLE VI

Average Quality Scores in Silent Reading in Each Grade Above the First for Fifteen Indiana Cities

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score
Group I (200–2,000)														
1	10	51	10	41	10	13	10	28	10	23	10	14	......	......
2	......	......	13	36	21	16	17	27	37	27	21	19	43	26
3	......	......	22	28	14	24	25	34	29	42	22	21	19	27
4	10	40	......	......	......	......	......	......	10	34	......	......	......	......
5	25	21	20	28	23	21	22	30	18	24	20	17	17	22
6	14	46	17	41	17	12	21	25	18	29	19	16	16	24
7	......	......	......	......	10	20	16	27	......	......	8	15	10	19
Group II (2,000–10,000)														
8	10	35	10	32	10	32	10	35	10	41	10	25	10	27
9	......	......	......	......	......	......	......	......	......	......	......	......	......	......
10	36	27	36	29	24	23	24	24	24	30	12	16	12	12
11	......	......	115	35	100	24	117	24	81	27	77	20	56	27
12	20	23	50	31	50	17	50	29	50	33	50	23	50	30
Group III (10,000–70,000)														
13	......	......	287	32	300	19	316	27	238	30	......	......	......	......
14	30	25	40	31	30	26	30	31	30	32	20	20	20	20
15	......	......	......	......	......	......	22	25	16	33	......	......	......	......
16	345	25	293	33	381	20	294	24	310	32	......	......	......	......
Total	500		913		990		974		881		269		253	
Average		32.5		33.1		20.5		27.8		31.1		18.7		23.4

TABLE VII

Average Quality Scores in Silent Reading in Each Grade Above the First for Groups I, II, and III

Cities	Grade 2		Grade 3		Grade 4		Grade 5		Grade 6		Grade 7		Grade 8	
	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score	Number of Pupils	Score
Group I	59	39.5	82	34.8	95	17.6	111	28.5	122	29.8	100	17.0	105	23.6
Group II	66	28.3	211	31.7	184	24.0	201	28.0	165	32.5	149	21.0	128	24.0
Group III	375	25.0	620	32.0	711	21.6	662	26.5	594	31.7	20	20.0	20	20.0
Total	500		913		990		974		881		269		253	
Average		32.5		33.1		20.5		27.8		31.1		18.7		23.4

selected cities. The general impression which one secures from these diagrams is that results of a widely different character are secured. City 8 makes an unusually good record and City 10 is uniformly low. The irregular progress which is made by some cities such as City 5 and City 6 leads one to question the consistency of reading instruction in some

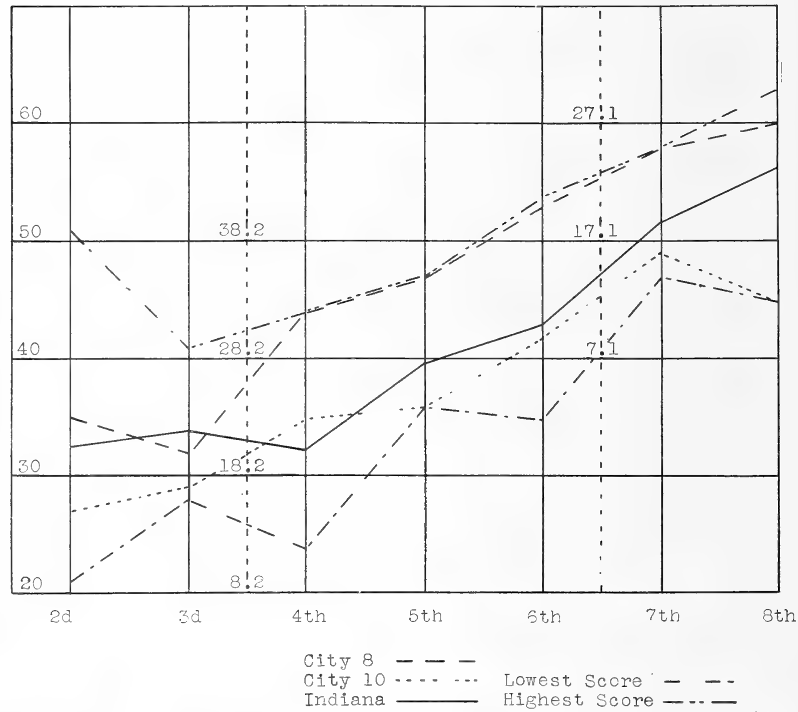

DIAGRAM 9. AVERAGE QUALITY SCORES IN SILENT READING FOR INDIANA AND TWO SELECTED CITIES; ALSO HIGHEST AND LOWEST SCORES FOR EACH GRADE

schools. It has only been in recent years that questions have been raised in regard to the achievement of pupils in silent reading. The investigations which have been made recently are raising a large number of questions in regard to present methods of instruction and in regard to the changes which should be introduced in public schools in order to improve the quality of the results. Diagrams 9 and 10 reveal the presence of similar problems in the cities of Indiana. A limited number of constructive suggestions concerning silent reading instruction will be given in the final section of this report.

Table VII presents the average quality scores for Indiana and for Groups I, II, and III. The same facts are presented in graphical form in Diagram 11. The results are not so uniform as they were in the two earlier comparisons of the scores for these groups. In general, however, it may be said that

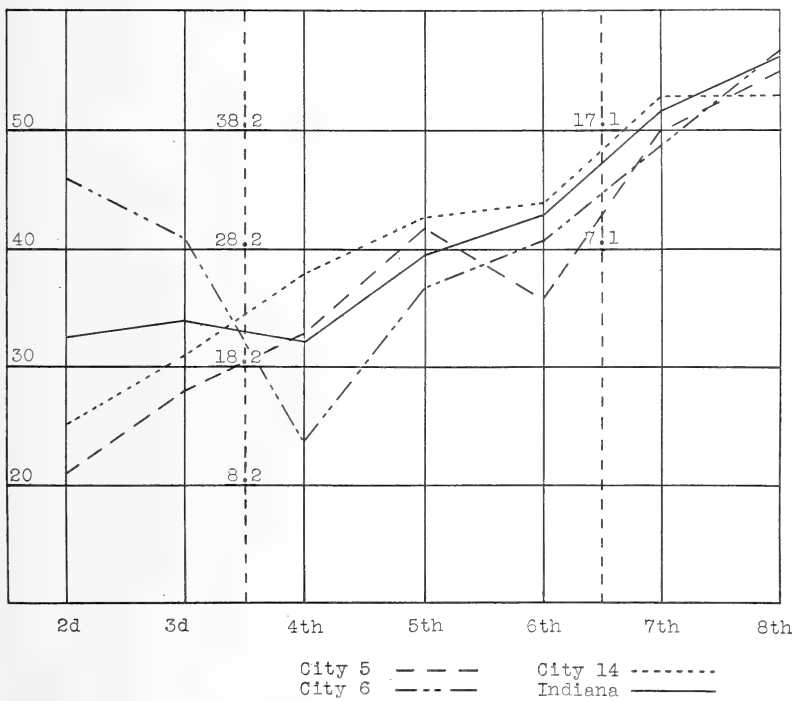

Diagram 10. Average Quality Scores in Silent Reading for Indiana and Three Selected Cities

Group I ranks lowest, Group II ranks highest, and Group III is intermediate in quality of silent reading. The relative positions which these groups hold in quality of silent reading correspond with the results which were secured in the study of oral reading achievement.

The objective study of reading in Indiana may be summarized as follows:

1. The cities of Indiana rank relatively low in achievement in the three phases of reading which were measured.

There is need of a general reorganization of instruction in reading in order to improve the quality of the results which are secured. Oral reading should be emphasized more effectively in the lower grades in order to give more time for silent reading instruction in the intermediate and grammar grades.

2. The wide variation in the results secured in different cities justifies the recommendation that a careful study be

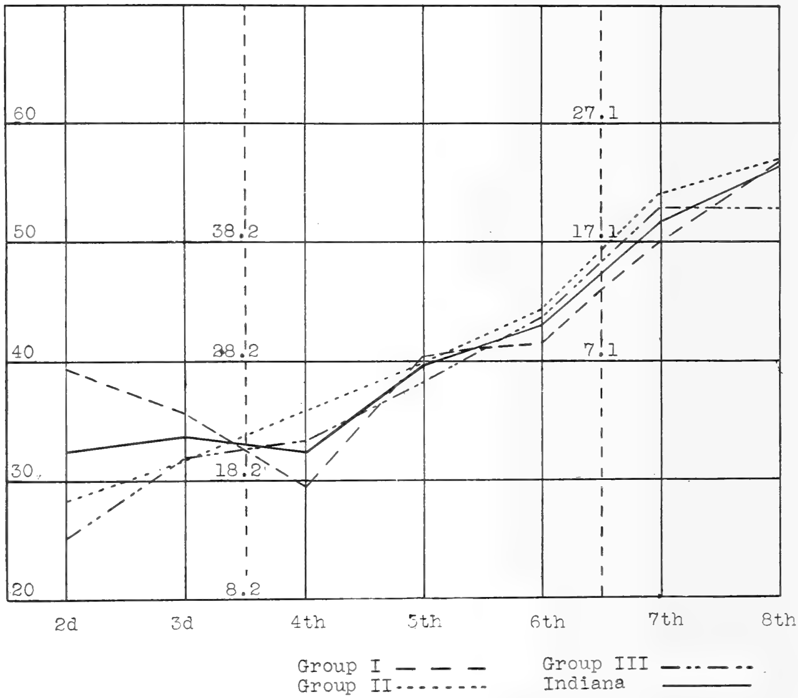

DIAGRAM 11. AVERAGE QUALITY SCORES IN SILENT READING FOR INDIANA AND GROUPS I, II, AND III

made of the methods and materials employed in the successful schools in order that effective changes might be introduced into the less successful classrooms.

3. The irregular progress made in some cities suggests the need of frequent objective studies of achievement in reading in order that the character of the progress which is made may be determined, and in order that additional emphasis may be given to those phases of instruction where emphasis is most needed.

4. The study of the records for Groups 1, II, and III showed that small towns rank lowest in oral reading and in rate and quality of silent reading, that small cities rank highest in oral reading and in quality of silent reading and rank second in rate of silent reading, and that large cities rank second in oral reading and quality of silent reading and highest in rate of silent reading.

Recommendations

It is the purpose of this section of the report to outline a limited number of definite suggestions in regard to reading instruction in the various grades. In order to direct attention to the important stages in the acquisition of reading ability and in order to center attention on specific problems in reading instruction, the discussions which follow have been organized about the problems of the following periods: (1) the initial periods in attaching meanings to printed words (first grade); (2) the development of fundamental habits and associations involved in fluent oral reading (second and third grades); (3) the broadening of experience thru extensive silent reading (fourth, fifth, and sixth grades); (4) the independent application of reading ability to all phases of school work (seventh and eighth grades). The discussions of the problems of these periods will be very brief, but they will point out some of the major issues in reading instruction in the elementary school.

The first grade is unquestionably an initial period in the acquisition of reading ability. Since reading is primarily a process of securing information or experience, attention should be directed from the outset to the content of what is read. Like every other highly developed art, reading has its technique or skill side which must be developed effectively, if the pupil is to utilize his reading time economically, intelligently, and efficiently. The foregoing statements make it clear that the problem of reading in the first grade is a unique one inasmuch as the pupil must be introduced to reading exercises before he has developed skill in the art of reading. First grade teachers are confronted with the problem of presenting interesting reading exercises which will stimulate pupils to put forth effort to find out what is contained in the passages. Only exercises which stimulate this type of activity are reading exercises in the real sense of the word. In addition, it is necessary, particularly during the second half of the first year, to conduct special drill exercises in order to develop independence in the recognition of words. Drill exercises should not be substituted for reading exercises, otherwise the pupil may interpret reading as word pronunciation rather than thought getting.

The tests which were given in Indiana showed that the pupils of the second and third grades had developed considerable ability in oral reading. The tests showed clearly that further progress in oral reading depended on the permanent establishment of the simpler habits and associations which had been only partly formed and on the development of ability to read and interpret selections of increasing difficulty. Recent investigations of reading reveal the fact that progressive school systems carry on two types of reading exercises in the second and third grades in order to provide for the establishment of those habits on which effective reading depends. In one exercise each day pupils are asked to read at sight simple, interesting selections. In such exercises attention is directed primarily to the content of what is read. If difficulties are encountered the teacher quickly renders the necessary help and the reading proceeds. Thru quantitative reading of the type just described those habits and associations are established which are prerequisite to fluent reading. In the second reading exercises each day pupils are assigned selections which are more difficult. During periods of silent and supervised study the pupils are introduced to problems of increasing difficulty and more or less responsibility is imposed on them for the solution of the problems encountered. Under the guidance of a skilful teacher the pupils develop rapidly in ability to read intelligently and independently selections of ordinary difficulty. It is recommended that the cities of Indiana organize their instruction in reading during the second and third grade to secure corresponding results. Quantitative reading of interesting selections and skilful instruction are prerequisite to rapid progress.

By the time the pupil of average ability enters the fourth grade he is able to read simple, untechnical selections with a high degree of comprehension and at a rate equal to or greater than his rate of vocalization. When the pupil has reached this stage in his development his interest in what he is reading leads him to proceed as rapidly as he can and hence he substitutes silent reading for oral expression. It has been shown in recent investigations that many pupils in the fourth grade have developed more power in the pronunciation of words than in ability to interpret what has been read. Further progress in the acquisition of reading ability requires that the pupil extend his field of experience in order to gain a broader background for more comprehensive and critical interpretations. Hence the intermediate grades should be devoted largely to quantitative reading of an informational character. Inasmuch as silent reading is a more rapid process than oral reading, most of this material should be read silently by the pupils during periods of independent study. In order to secure the results which are desired the schools must provide an adequate number of interesting books for pupils to read. One of the first steps which should be taken by the teachers and supervisors of Indiana is the reorganization of the work of the intermediate grade to provide abundant opportunity for silent reading. In this connection provision should be made for an adequate supply of appropriate books.

In order to illustrate at least one method of conducting silent reading exercises the following quotation is inserted. It is presented at this point because it describes a type of silent reading lesson which secures a large amount of information and which trains in effective methods of silent study.

> The teacher was conducting a series of information lessons concerning Holland. She had secured a large number of books which contained relevant chapters. The pupils were given two reading periods in which to read as much as they could silently and to make notes in regard to the interesting points which they discovered. At the end of this period the teacher and the class made a list of the most important problems relating to Holland. Each pupil chose a problem from the list and made it the basis for further study. He read carefully but rapidly all of the references which he could find relating to his problem. Pictures were secured, illustrative materials of various types were collected, and the facts which were secured through reading were organized in good form. After two days of intensive study of this type each pupil reported to his classmates the results of his reading and study. Whenever necessary, references were read to the class to illustrate an important point or to give support to a judgment expressed by the pupil in regard to some phase of life in Holland.

It is recommended that the teachers of Indiana substitute productive silent reading exercises similar to the one described above in place of some of the stereotyped oral reading exercises which prevail in many schools.

In connection with the discussion of the results of the silent reading tests two facts were pointed out which are significant at this point. In the first place, Indiana ranks relatively low in rate of silent reading in the intermediate grades, and in the second place the investigations which have been made in various other states show clearly that progress in rate of reading is particularly appropriate for these grades. It is fair to conclude that the teachers of Indiana should give added emphasis to rate of reading. Scientific studies have shown that the reader of average ability uses only a part of the possibilities of recognition which are supplied by his field of clear vision. An enlargement of the units of recognition demand broad experience which makes possible the comprehension in a single act of meaningful phrases, freedom from the difficulties which new and unfamiliar words present, and freedom from the limitations of vocalization. It is evident therefore that pupils of the intermediate grades must be given frequent opportunity to read silently material which is relatively easy for them, if the eye is trained to perceive and comprehend wide units of the line at each fixation. Occasional exercises may be assigned to advantage in which the pupil will be required to complete a given selection within a relatively short time. It is recommended at this point that the teachers of Indiana consider the advisability of frequently introducing silent reading exercises in which relatively easy material is read in order to enlarge the units of recognition and to increase the rate of reading.

By the time the pupil reaches the seventh grade he should be able to read independently with ease and intelligence. He has reached that stage in his development when he can apply the ability which he has developed in reading to the wider fields of interest which develop at this time. As a rule, reading in the upper grades is restricted to the intensive study of a limited number of literary selections. No objection is offered here to the study of classical literature in reading classes. The point of importance is that reading should not be limited to selections of this type. A pupil should be given opportunity thru wide reading to interpret the broader significance of the content subjects which he studies. He should be trained to discover and appreciate the valuable contributions which reading makes to his vocational interests. He should develop a permanent interest in current events and he should establish the habit of reading newspapers and periodicals regularly. On the technique side two problems are appropriate for this period. The first is the development of effective and appropriate habits of study, and the second is the development of more comprehensive and critical interpretations. The latter should be developed by building up an extensive background of experience rather than by the intensive study of a limited number of selections.

In conclusion it should be said that the teachers of Indiana are confronted with the following reading problems: (1) the development of fluent oral reading ability in the first three grades so that pupils can read independently and intelligently selections of ordinary difficulty; (2) the development of a wide background of experience thru extensive silent reading and the enlargement of units of recognition in the fourth, fifth, and sixth grades; (3) the independent application of reading ability to various fields of experience in the seventh and eighth grades. This includes an increase in a pupil's ability to make comprehensive and critical interpretations.

VOL. V SEPTEMBER, 1918

INDIANA UNIVERSITY STUDIES

Study No. 38

STUDIES IN ARITHMETIC, 1916-17. Edited by WALTER S. MONROE, Director of Bureau of Coöperative Research, Indiana University School of Education.

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Contents

Prefatory Note

THIS study, the third of its kind to be made by the Bureau of Coöperative Research of Indiana University, is devoted to a general investigation of the arithmetical abilities of the school children in 27 Indiana cities. As in the 1914 and 1915 investigations, the Courtis Standard Research Tests, Series B, were used to measure the abilities of the children in the fundamentals of arithmetic. The first part of the study is concerned with a general review of the 1917 achievements. Following that, comparison is made of the 1917 achievements with former Indiana standards as well as with standards determined for Iowa and Kansas. In addition, the following questions are briefly discussed: (*a*) How do the abilities of children in schools of different size compare? (*b*) Since achievement in the state as a whole seems to be somewhat inferior in quality, what can children in the best five systems out of 27 do? (*c*) Do the scores of the only city that has coöperated in all three investigations show any growth? (*d*) How do the medians found by a general distribution of all the pupils of the state differ from those determined by taking the average of the medians of the individual towns and cities as units? (*e*) How do the classes in the different systems range in ability, and to what degree is their work dependable?

Acknowledgment is due to the numerous school superintendents, principals, and teachers for their services in giving tests and doing the initial work in scoring the test papers. Credit is also due to a number of students and assistants who helped in the final work of arranging the comparative tables and planning the figures. Among these are Mrs. Cecile White Fleming, instructor in philosophy, who supervised the correction of the class and city score sheets, and Mr. Willard E. Uphaus, assistant in education, who supervised the making of the distribution tables, and the construction of the various graphs and figures. Mr. Clyde Henks, a student in the University, did the mechanical drawing.

The present Director of the Bureau of Coöperative Research is entitled to no credit for this report. The manuscript, except for a final editing, was "inherited" at the time of his appointment, September 1, 1918. Dean H. L. Smith, who was Acting Director prior to that date, originally edited the study and deserves the credit for it.

WALTER S. MONROE, *Director,*
Bureau of Coöperative Research.

October 24, 1918.

Third Report on the Measurement of Arithmetic in Indiana Town and City Schools

The Cities which Coöperated. The third report on the measurement of certain arithmetical abilities is based on the Courtis Standard Research Tests, Series B, which were given in January and February, 1917. Twenty-seven town and city school systems sent in returns for all or a part of their pupils. The following are the names of the towns and cities with the superintendents and principals who coöperated with the Bureau:

Bluffton	Supt. P. A. Allen
Boonville	Supt. C. E. Clarke
Brookville	Supt. A. J. Reifel
Carlisle	Supt. O. H. Greist
Cayuga	Supt. H. E. Stahl
Churubusco	Supt. L. J. Gates
Coesse	Supt. W. C. Wilson
Cowan	Prin. C. T. Fewell
Cumberland	Prin. G. R. Smith
Edinburg	Supt. A. D. Montgomery
Etna	Prin. R. E. McLucas
Francesville	Prin. W. E. Lennel
Freedom	Prin. W. J. Wakefield
Huntingburg	Supt. N. F. Hutchison
Judyville	County Supt. Harry Evans
Kokomo	Supt. C. V. Haworth
Larwill	Prin. E. P. Smith
Mishawaka	Supt. D. W. Horton
Monticello	Supt. J. M. Leffel
Montmorenci	Prin. Mortimer Lewis
Pine Village	County Supt. Harry Evans
Royal Center	Supt. F. G. Neel
Selvin	Prin. Elen Trimble
Seymour	Supt. T. A. Mott
Spencer	Supt. W. O. Holman
West Lebanon	County Supt. H. Evans
Williamsport	County Supt. H. Evans

In the tables, figures, and discussions that follow, these cities are indicated by number, each city retaining the same number thruout the study. But the order is not alphabetical as in the above arrangement. All 27 systems reported in the seventh and eighth grades in the four tests, the total number of the children being 1,017 and 919 respectively; 26 systems reported the fifth and sixth grades in all four tests with a total of 1,326 and 1,194 children respectively, whereas only 18 systems reported the fourth grade in addition, subtraction, and multiplication, and only 14 in division, all having a total of 1,016. Thus the grand total of children reported in the investigation is 5,472. The scarcity and irregularity of the data for the fourth grade has caused the omission of this grade from some parts of the study.

Checking the Class Record Sheets. As in the two earlier studies, 1914[1] and 1915[2], the tests were given and scored by the local school officers, the results tabulated on the Class Record Sheet No. 1, and sent to the Bureau of Coöperative Research.

When this material was examined considerable corrective work was found necessary.

Student assistants who were assigned to this work were given the following instructions:

1. Count the individual test sheets for each class, e.g. 7B, Central School, Bluffton.
2. Check number of pupils indicated for each class on the Class Record Sheets. See if this number tallies with number of individual test sheets. If it does, O.K. with your initials and date; if not, go thru the individual sheets comparing scores with those recorded on the Class Record Sheet and correct all errors. Then O.K. with initials and date.
3. Total the number of pupils and throw together the records for all classes within a given grade, for each city; e.g. Bluffton may have three 7B's and four 7A's. Throw together all these records to get the record in speed and accuracy for the seventh grade in Bluffton.

Calculation of City Scores. Following the correction of the class tabulations, median scores for both rate and accuracy were calculated for each city. Class Record Sheet No. 1 for use with Series B yields distributions of the scores for rate or number of examples attempted and for accuracy or per cent of examples done correctly. For cities having only one class for a grade the city medians for attempts and accuracy were calculated directly from the class record sheets. In the case of cities having two or more classes to a grade, the corres-

[1] M. E. Haggerty: "Arithmetic: A Coöperative Study in Educational Measurements" (Indiana University *Studies*, No. 27).

[2] M. E. Haggerty: "Studies in Arithmetic" (Indiana University *Studies*, No. 32).

ponding frequencies of the several distributions were added together for a total distribution for that grade and the city medians were calculated from this distribution. The city distributions for seventh grade division are given in Table I. The median number of examples right was obtained by multiplying the median number of attempts (rate) by the median accuracy.

It will be remembered that Class Record Sheet No. 1, which is with Series B, does not provide a distribution for the per cent of accuracy when it falls below 50. In all cases where the median accuracy of a class fell below 50 per cent the original test sheets were distributed according to rights only to obtain the median for rights. This latter median was divided by the class median in attempts to get the per cent of accuracy or dependability. In some cases it was not possible to compute the median rights and accuracy because a few schools did not send in the individual test sheets. For example, in Tables II to VI, this is the reason why no scores are given for City 4 in the sixth grade addition, fifth grade addition and division, and the fourth grade in all the fundamental operations.

Calculation of State Scores. The calculation of state scores was similar to that of the city scores. The frequencies of the several city distributions were added to form a state distribution. The median of this distribution is the state score. The method is illustrated in Table I.

Importance of This Method of Calculating City and State Medians. Sometimes the median of two or more distributions is found by averaging the medians of the several distributions. The validity of this method is based upon the assumption that each of the distributions contain the same number of pupils. When this is not the case, the "average" median is not the true median. The difference in the results obtained may be illustrated by the addition medians for number of examples attempted. Carried to two decimal places they are 4.97, 6.33, 7.01, 7.67, and 8.60 (see Tables II to VI), whereas the "average" medians are 5.05, 6.27, 7.16, 8.03, and 8.65. In four cases the "average" medians are larger.

The reason for these differences is that when city medians are averaged, each city contributes equally to the "average" median. When the distributions are combined, each city con-

TABLE I—CITY DISTRIBUTIONS: SEVENTH GRADE DIVISION ATTEMPTS

City Number	Number of Examples Attempted																									Total	Median
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Group I																											
1			1	1	7	6	8	2	1	1								1								28	5.8
2				1	6	2	3	1	4	1	1			1												20	6.3
3					2	1	2	3		2	1		2	1	1		1									16	9.0
4				1		1	5	2	2																	11	6.8
5					2	3	6	1	3	1	1		1	2												20	6.8
6					1		2	4	2	1	1	1														12	7.8
7				1		2	1	1	1	1																7	7.0
8					2	1			3	2	1	1	1													11	9.0
9						2	3	2	5	1	1															14	8.0
10			1		3	3	1	2		1																11	5.7
11				1	3	1	1	1	2	3		1		3	1											17	9.0
12				1		2	1		2	1	2		3	1			1									14	10.0
13						2		2	1		1		1													7	8.0
14			1	1	3	1	2	2	3						1											14	6.5
15						1	1	1						1												4	7.0
16					2	1	4		1		2	1	1													12	6.8
Total			3	7	31	29	40	24	30	15	11	4	9	9	3		2	1								218	7.0
Group II																											
17				1	1	1	2	5	6		1															17	7.8
18				5	9	6	7	7	5	3			1	2	1											46	6.4
19					2	2		2	4	4	3	2	4	2												25	9.8
20							3	3	2	3	3	3	2	3	2			1								25	10.6
21				2	6	6	5	9	11	4	1		2	1												47	7.5
22				1	1	2	2	2	1	1		3			1		1									15	8.0
Total				9	19	17	19	28	29	15	8	8	9	8	4		1	1								175	7.9

Group III																										
23	...	...	4	21	11	12	5	8	5	3	2	...	2	...	...	1	...	...	...	...	...	...	...	...	74	5.1
24	...	...	...	1	6	11	9	6	7	8	4	2	2	1	...	...	...	...	...	...	...	...	...	...	57	7.3
25	...	...	...	1	4	2	9	12	13	13	6	4	5	4	1	...	1	2	1	...	...	...	...	...	78	8.9
Total	...	...	4	23	21	25	23	26	25	24	12	6	9	5	1	1	1	2	1	...	...	...	...	...	209	7.4
Group IV																										
26	2	4	20	53	58	66	32	20	22	17	4	3	2	...	...	1	...	...	...	...	...	...	...	...	304	5.2
27	...	...	2	12	8	21	27	11	15	3	6	...	3	...	...	...	1	...	...	...	...	...	...	...	109	6.4
Total	2	4	22	65	66	87	59	31	37	20	10	3	5	...	...	1	1	...	...	...	...	...	...	...	413	5.6
Grand Total	2	4	29	104	137	158	141	109	121	74	41	21	32	22	8	2	5	4	1	...	...	...	...	...	1015	6.5

TABLE II—SHOWING MEDIAN SCORES: ATTEMPTS, RIGHTS, AND ACCURACY IN GRADE IV

CITY NUMBER	ADDITION			SUBTRACTION			MULTIPLICATION			DIVISION		
	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	
Group I												
1	....	....	....	....	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....	....	....	....	....
3	4.6	2.3	50	6.7	3.9	58	6.0	4.3	72	4.5	1.0	22
4	4.6	....	....	3.8	....	....	4.2	....	....	....	....	....
5	5.5	....	....	5.8	....	....	3.8	....	....	3.7	....	....
6	....	....	....	....	....	....	....	....	....	....	....	....
7	5.0	4.3	85	6.5	5.5	85	6.3	3.8	60	3.0	1.8	60
8	4.8	....	....	4.7	2.3	50	3.3	....	....	2.0	....	....
9	4.3	2.3	53	3.0	1.6	53	1.8	0.8	43	....	....	....
10	....	....	....	....	....	....	....	....	....	....	....	....
11	4.9	2.5	50	6.0	3.6	60	4.3	1.3	30	3.0	0.6	19
12	6.3	2.7	43	6.7	4.7	70	8.0	5.6	70	5.3	1.3	25
13	....	....	....	....	....	....	....	....	....	....	....	....
14	....	....	....	....	....	....	....	....	....	....	....	....
15	5.0	....	....	6.1	3.1	50	4.5	2.7	60	....	....	....
16	....	....	....	....	....	....	....	....	....	....	....	....
Total	4.8	....	....	5.6	3.0	53	4.1	....	....	3.2	....	....
Group II												
17	4.9	2.5	52	5.5	4.0	73	4.5	2.6	58	2.6	0.6	22
18	4.5	1.0	22	5.5	1.3	24	3.9	0.7	17	4.0	0.6	14
19	5.5	....	....	6.4	3.7	59	5.9	3.4	57	3.1	....	....
20	6.2	4.7	75	6.6	4.6	70	4.6	3.0	63	3.4	1.7	53
21	4.3	2.2	50	4.8	1.8	36	3.9	1.5	38	2.6	1.0	39
22	....	....	....	....	....	....	....	....	....	....	....	....
Total	4.9	....	....	5.7	3.0	53	4.6	....	....	3.0	....	....
Group III												
23	5.1	3.9	76	6.1	5.0	82	4.5	3.2	72	3.2	2.0	62
24	....	....	....	....	....	....	....	....	....	....	....	....
25	5.6	3.9	70	5.6	4.2	74	4.6	2.8	62	....	....	....
Total	5.4	3.9	72	5.9	4.6	78	4.6	3.0	66	3.2	2.0	62
Group IV												
26	4.8	2.2	47	5.3	2.8	50	3.4	0.9	27	2.1	0.6	29
27	5.1	2.6	51	5.7	3.8	66	4.5	2.2	51	3.7	0.7	19
Total	4.9	....	....	5.5	3.2	57	3.7	....	....	2.8	....	....
State Total	5.0	2.6	52	5.6	3.4	60	4.1	....	....	3.0	....	....
Iowa	6.2	3.5	56	6.8	5.0	74	5.8	3.5	61	4.2	2.5	59
Kansas	5 8	3.0	51	6.4	4.1	64	5.2	3.0	58	3.8	2.1	56
Indiana '15	....	....	....	....	....	....	....	....	....	....	....	....
Indiana '14	....	....	....	....	....	....	....	....	....	....	....	....
Courtis	5.0	5.0	100	6.0	6.0	100	5.0	5.0	100	4.0	4.0	100

TABLE III—SHOWING MEDIAN SCORES: ATTEMPTS, RIGHTS, AND ACCURACY IN GRADE V

City Number	Addition			Subtraction			Multiplication			Division		
	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy
Group I												
1	4.8	3.1	65	6.0	4.2	70	5.3	3.3	63	3.3	1.3	39
2	6.8	3.4	50	7.3	4.0	56	6.7	3.0	45	5.8	2.9	50
3	6.0	3.0	50	7.5	5.3	70	6.5	4.2	65	4.5	3.5	70
4	6.7	.....	....	6.5	3.6	55	6.3	4.1	65	3.9	.....	....
5	8.0	.....	....	6.9	4.0	58	6.4	4.3	67	4.6	2.6	58
6	....	.....	....	....	.....	....	....	.....	....	....	.....	....
7	6.0	3.0	50	8.0	6.0	75	6.5	3.9	60	3.5	2.3	65
8	6.0	3.0	50	6.8	4.8	70	5.0	3.1	63	4.0	2.0	50
9	5.7	3.4	60	6.0	3.2	53	4.2	.9	21	3.2	.7	23
10	5.0	3.0	60	5.3	3.7	70	6.3	4.4	70	3.0	1.5	50
11	6.0	3.4	57	6.8	5.4	80	6.5	3.8	59	4.0	2.2	55
12	7.3	4.8	67	9.5	5.5	63	7.3	5.5	75	6.0	4.2	70
13	6.0	3.2	54	6.2	3.7	60	4.6	3.0	70	4.8	1.3	27
14	7.1	3.7	53	6.7	4.4	65	5.8	2.5	43	4.5	1.0	22
15	7.0	4.9	70	7.3	4.0	55	6.3	5.7	90	5.0	3.3	65
16	6.5	4.6	70	6.8	5.7	85	5.5	4.9	90	3.7	2.4	64
Total	6.1	3.4	55	6.7	4.3	65	5.7	3.3	58	4.1	2.1	53
Group II												
17	5.6	3.6	64	7.0	5.8	83	6.2	4.2	68	3.5	1.4	41
18	6.3	2.9	45	7.5	4.3	58	5.3	2.3	42	4.0	1.1	28
19	5.9	3.2	54	7.0	5.6	80	6.4	3.4	53	3.8	.....	....
20	5.3	2.3	44	5.7	3.9	68	5.6	3.6	64	4.0	1.0	24
21	5.5	2.8	51	6.1	3.3	54	4.4	1.7	39	2.6	.8	32
22	6.0	3.0	50	5.8	3.1	53	5.7	4.0	70	4.3	2.5	58
Total	6.0	2.9	52	6.5	4.1	63	5.6	3.2	56	3.7	.....	....
Group III												
23	6.4	5.1	81	7.5	6.5	86	6.1	5.1	84	4.4	4.1	93
24	7.6	2.9	38	8.1	4.9	60	6.6	3.0	45	4.9	1.8	37
25	7.4	5.2	71	8.2	7.1	87	6.5	4.9	75	5.8	4.8	82
Total	7.2	4.7	65	8.0	6.5	82	6.5	4.7	72	4.9	3.7	74
Group IV												
26	6.3	3.2	51	6.5	4.1	63	4.6	1.8	39	3.2	.9	29
27	6.1	3.6	58	6.3	5.0	79	5.8	3.8	66	4.2	2.3	55
Total	6.2	3.3	53	6.4	4.4	68	5.0	2.6	53	3.5	.....	....
State Total	6.3	3.5	56	6.8	4.7	70	5.6	3.3	59	4.0	2.2	55
Iowa	7.4	4.6	62	8.2	6.6	80	7.0	4.9	70	5.5	4.1	74
Kansas	7.0	4.3	61	7.9	5.9	75	7.0	4.8	69	4.9	3.3	68
Indiana '15	7.2	4.2	59	7.5	7.3	71	6.0	3.7	61	5.0	3.3	65
Indiana '14	6.6	3.6	55	7.3	5.0	68	6.3	3.9	62	4.5	2.6	57
Courtis	7.0	7.0	100	8.0	8.0	100	7.0	7.0	100	6.0	6.0	100

TABLE IV—SHOWING MEDIAN SCORES: ATTEMPTS, RIGHTS, AND ACCURACY IN GRADE VI

CITY NUMBER	ADDITION			SUBTRACTION			MULTIPLICATION			DIVISION		
	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy
Group I												
1..........	5.9	4.1	70	6.9	6.9	100	6.2	5.2	83	4.2	2.8	67
2..........	7.3	3.8	52	8.8	4.8	55	8.7	5.9	68	8.0	6.5	82
3..........	6.8	4.0	58	9.3	7.1	77	8.0	5.2	65	6.0	4.4	74
4..........	7.3	....	....	7.5	5.0	67	7.0	4.0	57	4.0	2.0	50
5..........	9.7	5.6	58	10.0	6.5	65	9.0	6.6	73	6.4	5.8	90
6..........	....	....	....	....	....	....	....	....	....	....	....	....
7..........	7.0	4.2	60	7.6	6.1	80	8.5	6.8	80	5.0	5.0	100
8..........	6.7	4.0	60	7.0	4.9	70	6.5	4.6	70	4.8	3.4	70
9..........	6.6	3.0	45	7.5	6.0	80	5.5	3.7	67	3.5	1.8	50
10..........	5.3	3.7	70	8.0	6.7	83	6.5	4.6	70	5.0	4.0	80
11..........	7.0	4.0	57	8.3	5.6	68	7.6	4.9	65	5.0	3.4	68
12..........	9.0	5.2	58	9.0	5.4	60	7.3	5.1	70	8.0	5.3	67
13..........	8.0	6.4	80	9.6	7.9	83	7.3	6.4	88	7.0	5.3	75
14..........	6.8	3.4	50	7.4	5.8	78	6.3	3.5	55	4.3	2.3	55
15..........	7.5	....	....	7.5	4.5	60	7.5	5.6	75	5.5	....	....
16..........	6.3	4.4	70	7.0	7.0	100	6.3	5.4	85	4.5	3.2	70
Total....	7.0	4.0	57	8.0	5.8	73	7.0	4.9	70	5.2	3.5	67
Group II												
17..........	6.0	3.3	56	7.9	6.3	81	6.4	4.1	66	4.6	3.6	81
18..........	7.4	4.3	58	8.9	6.5	74	7.3	4.4	60	5.1	2.8	55
19..........	7.9	4.3	55	8.7	6.7	77	8.3	5.9	72	7.2	6.2	86
20..........	7.0	3.9	56	7.4	5.5	74	6.7	4.1	61	4.2	2.3	54
21..........	7.0	2.3	32	7.3	3.7	50	5.8	3.5	61	5.2	3.1	60
22..........	6.5	4.2	65	7.6	5.9	78	7.2	5.1	73	5.5	4.5	78
Total....	7.0	3.8	55	8.0	5.9	74	6.8	4.4	64	5.3	3.6	68
Group III												
23..........	7.0	4.8	69	8.1	6.7	83	5.5	4.4	80	4.1	2.8	69
24..........	8 0	4.3	53	8.5	6.0	71	8.3	5.1	62	6.5	4.2	65
25..........	8.8	7.3	83	9.6	8.4	87	8.7	7.0	80	7.3	6.5	89
Total....	8.2	5.6	68	8.6	6.9	81	7.9	5.7	73	6.3	4.9	78
Group IV												
26..........	6.6	3.9	60	7.5	5.4	72	5.9	3.4	57	3.9	2.2	56
27..........	7.0	4.5	65	6.8	5.2	76	6.3	4.7	75	5.2	3.9	75
Total....	6.7	4.1	61	7.3	5.4	73	6.0	3.8	63	4.2	2.7	63
State Total .	7.0	4.2	60	7.8	5.8	75	6.6	4.4	66	4.8	3.2	67
Iowa.......	8.5	5.7	67	9.7	8.0	83	8.6	6.5	76	7.0	5.8	83
Kansas.....	8.1	5.3	65	9.1	7.4	81	8.1	6.2	77	6.5	5.5	84
Indiana '15.	8.3	5.3	64	8.7	6.7	77	7.5	5.1	68	6.1	4.8	79
Indiana '14 .	7.4	4.4	59	8.9	6.5	73	7.6	5.1	67	5.7	4.8	84
Courtis......	9.0	9.0	100	10.0	10.0	100	9.0	9.0	100	8.0	8 0	100

TABLE V—Showing Median Scores: Attempts, Rights, and Accuracy in Grade VII

City Number	Addition			Subtraction			Multiplication			Division		
	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy
Group I												
1...........	8.5	5.6	67	8.7	7.5	86	9.0	7.3	81	5.8	3.8	66
2...........	7.5	3.3	44	8.0	5.2	65	8.0	4.5	57	6.3	4.0	63
3...........	8.8	3.8	44	11.0	8.5	78	10.0	6.8	68	9.0	7.4	82
4...........	8.0	4.8	60	9.3	6 9	74	8.2	6.6	80	6.8	4.6	68
5...........	8.9	6.2	70	10.2	8.2	80	9.3	8.1	87	6.8	5.6	81
6...........	8.0	5.2	65	10.5	8.8	84	8.0	6.8	85	7.8	7.0	90
7...........	7.0	3.5	50	8.5	6.8	80	8.0	5.6	70	7.0	5.3	75
8...........	8.3	5.4	65	9.7	8.7	90	9.0	7.2	80	9.0	9.0	100
9...........	7.0	3.0	43	9.5	5.5	57	8.7	4.8	55	8.0	5.4	67
10...........	6.7	4.7	70	9.3	7.8	84	6.5	5.4	83	5.7	4.0	70
11...........	8.0	4.2	53	11.0	9.6	88	9.0	5.1	57	9.0	7.5	83
12...........	10.0	6.3	63	11.0	7.3	67	10.8	8.3	77	10.0	9.3	93
13...........	8.5	7.2	85	10.0	9 0	90	10.0	8.0	80	8.0	8.0	100
14...........	6.6	3.7	57	8.3	6.6	80	8.0	4.8	60	6.5	4.9	76
15...........	9.0	4.5	50	10.3	8.2	80	9.5	4.8	50	7.0	3.5	50
16...........	7.0	5.8	83	9.3	9.3	100	7.5	6.8	90	6.8	6.1	90
Total....	8.0	4.8	60	9.5	7.6	80	8.6	6.4	75	7.0	5.5	79
Group II												
17...........	9.7	7.2	75	9.8	7.9	80	8.3	6.6	80	7.8	6.8	87
18...........	7.9	4.0	50	8.4	5.9	70	8.1	5.0	62	6.4	4.6	72
19...........	7.6	4.1	54	12.0	9.9	83	10.0	7.3	73	9.8	7.9	81
20...........	8.8	5.7	65	11.8	9.8	83	11.3	9.8	87	10.6	10.6	100
21...........	7.7	4.1	54	9.4	6.8	72	7.3	5.1	70	7.5	5.5	74
22	8.6	6.2	73	10.0	8 4	84	9.0	7.8	87	8.0	7.6	95
Total....	8.1	4.5	56	9.8	7.4	76	8.6	6.3	73	7.9	6 4	81
Group III												
23...........	6.7	5.4	81	8.0	6.8	84	6.5	4.5	69	5.1	4.5	89
24	8.5	4.6	54	9.0	7.0	78	9.0	6.0	67	7.3	5.8	80
25...........	9.4	7.1	75	10.8	9.3	86	9.6	7.7	81	8.9	7.4	84
Total....	8.2	5.8	71	9.1	7.6	84	8.2	5.9	72	7.4	6.2	84
Group IV												
26	7.0	4.6	66	8.4	6.8	81	6.9	4.6	67	5.2	3.6	69
27...........	7.2	4.6	65	7.8	6.4	82	7.3	5.7	78	6.4	5.5	86
Total....	7.1	4.6	66	8.2	6.7	81	7.0	4.9	70	5.6	4.2	75
State Total..	7.7	4.9	63	8.9	7.2	81	7.9	5.7	72	6.5	5.2	80
Iowa........	9.1	6.2	68	10.7	9.0	84	9.9	7.7	78	8.5	7.5	88
Kansas......	8.7	5.8	67	10.0	8.3	83	9.0	7.0	78	9.3	8.1	87
Indiana '15..	8.9	5.7	64	9.9	7.9	80	8.5	6.0	71	7.8	6.5	84
Indiana '14..	8.0	5.0	62	10.1	7.8	77	8.6	5.9	68	8.5	6.7	78
Courtis......	11.0	11.0	100	11.0	11.0	100	10.0	10.0	100	10.0	10.0	100

TABLE VI—Showing Median Scores: Attempts, Rights, and Accuracy in Grade VIII

City Number	Addition			Subtraction			Multiplication			Division		
	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy	Attempts	Rights	Accuracy
Group I												
1	8.7	6.6	76	10.2	9.5	93	8.8	7.2	82	6.8	5.6	87
2	8.5	4.7	55	10.0	7.2	72	10.5	8.4	80	10.3	7.9	78
3	8.6	6.2	72	12.0	9.0	75	10.3	8.2	80	10.5	8.4	80
4	8.8	4.4	50	11.0	7.3	67	10.0	7.2	72	7.5	5.3	70
5	10.0	8.0	80	11.5	10.1	88	10.8	9.5	88	9.5	7.8	83
6	8.0	5.6	70	12.0	10.4	87	10.5	8.4	80	11.0	11.0	100
7	6.5	3.6	55	8.7	8.7	100	7.0	5.6	80	8.3	7.5	90
8	8.0	6.4	80	10.0	8.5	85	10.0	8.5	85	10.5	9.5	90
9	7.3	3.7	50	10.3	7.4	72	9.5	7.0	73	8.3	7.5	90
10	8.0	4.8	60	11.0	9.4	85	8.0	5.6	70	8.3	7.4	90
11	7.3	4.7	65	10.6	9.0	85	8.5	6.0	70	8.5	7.2	84
12	9.0	5.2	58	11.5	9.5	83	8.3	6.9	83	9.5	6.8	73
13	8.7	7.0	80	11.3	9.4	83	9.7	7.8	80	11.0	10.6	97
14	8.4	4.6	55	9.5	7.0	73	8.8	6.3	73	8.0	6.3	79
15	9.0	6.3	70	11.3	10.7	95	9.3	8.1	88	11.0	9.9	90
16	8.3	4.4	53	11.2	9.0	80	9.0	7.8	87	8.0	8.0	100
Total	8.4	5.5	66	10.5	8.5	82	9.3	7.4	80	8.6	7.3	85
Group II												
17	9.3	7.4	80	11.5	9.6	80	12.0	9.6	80	9.5	9.5	100
18	11.0	7.9	72	11.2	8.4	75	10.8	7.4	69	9.6	7.4	78
19	9.0	4.9	54	12.4	9.9	80	10.7	8.0	74	10.8	9.8	91
20	9.0	6.8	76	15.0	13.3	89	10.8	9.4	87	8.8	8.8	100
21	8.3	4.8	58	9.7	6.5	68	8.4	4.6	54	8.5	6.4	75
22	8.4	5.6	67	8.7	7.4	85	8.5	7.0	83	9.3	9.3	100
Total	9.0	6.0	67	11.5	9.2	80	10.0	7.3	75	9.4	8.0	85
Group III												
23	8.8	6.9	79	9.8	8.5	87	8.5	7.1	83	7.7	7.7	100
24	10.9	6.5	60	11.6	7.7	67	10.8	7.1	66	9.8	7.4	76
25	8.9	6.1	69	10.9	9.0	83	10.1	8.0	80	9.6	8.2	85
Total	9.3	6.7	72	10.6	8.5	80	9.7	7.5	78	8.9	7.6	86
Group IV												
26	8.1	4.7	58	9.7	7.1	74	8.5	5.5	63	7.0	5.0	72
27	8.8	6.4	74	9.6	7.8	82	8.5	6.4	75	8.4	8.1	96
Total	8.3	5.3	63	9.7	7.5	77	8.5	5.7	68	7.3	5.8	78
State Total	8.6	5.7	67	10.4	8.2	80	9.2	6.8	75	8.4	7.0	83
Iowa	10.0	7.2	72	12.0	10.6	88	11.5	9.3	81	10.8	9.8	91
Kansas	9.8	6.9	71	11.5	9.9	86	10.9	8.9	82	10.1	9.3	92
Indiana '15	9.5	6.3	67	10.9	8.9	82	9.9	7.3	74	9.7	8.4	87
Indiana '14	9.0	5.8	64	11.2	8.9	79	10.2	7.3	71	10.6	9.0	84
Courtis	12.0	12.0	100	12.0	12.0	100	11.0	11.0	100	11.0	11.0	100

tributes according to its size. For example, in the seventh grade division test, Cities 10 and 26 have approximately the same medians (see Table I). Taken as units they affect the average about equally. Taken as parts of the distribution for all the seventh grade pupils in the state, this is far from the case. City 10 has 11 pupils against 304 in City 26. These 304 pupils pull the median downward, for the heavy frequencies are the ones that have the low scores in the attempts, and produce a difference of .98 between the results of the two methods.

A General Review of the 1917 Achievements for Twenty-Seven Cities. The results of this part of the study are presented in Tables II to VI. The median scores for attempts, rights, and accuracy for Grades 4 to 8 in all the 27 systems are given in these tables. For the purposes of comparison, the medians for Indiana, in 1914 and 1915 studies[3], those for 52 towns and cities in Iowa (1916)[4], those for 24 towns and cities in Kansas (1915)[5], and the Courtis Standards[6] are also given.

Table II is read as follows: The median scores for City 3 are 4.6 examples attempted, 2.3 right, and 50 per cent of accuracy for addition; 6.7 examples, 3.9 right, and 58 per cent of accuracy for subtraction and similarly for multiplication and division. The blank spaces in this and other tables indicate either that the tests were not given in those grades or that reports were not made in such a way that the median could be calculated.

The cities are grouped according to population. Group I includes cities and towns having a population of less than 1,000; Group II, those having a population from 1,000 to 3,000; Group III, those having a population from 3,000 to 10,000; Group IV, those having a population of 10,000 and over. The median scores for each of these groups are also given.

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[3] See notes 1 and 2 on page 6.

[4] Ashbaugh, E. J.: "The Arithmetical Skill of Iowa School Children" (*Bulletin* No. 24, Extension Division, University of Iowa).

[5] Monroe, W. S.: "Report of the Use of the Courtis Standard Research Tests in Arithmetic in Twenty-Four Cities." Kansas State Normal School, Emporia, Kan. (*Bulletin*, New Series, Vol. 4, No. 8).

[6] Folder D, Courtis Standard Tests. (Courtis has issued more recent standards. See "Third, Fourth, and Fifth Annual Accountings.")

A Superintendent's Use of These Tables. The superintendent of a city which is included in this report may use these tables as a means of comparing the achievements of the pupils in his system with the achievements of the pupils in other cities of the same population group. Better still, he may compare his median scores with the standards proposed by Mr. Courtis, the author of the tests, and with the state medians and the median scores for other states. In making these comparisons two cautions must be kept in mind. First, the medians scores of other cities and even state medians are not necessarily satisfactory standards. This is probably true even of the standards set by Courtis[7]. However, they do show what results are being obtained in the other states and what results Courtis thinks should be obtained. As such, these median scores are valuable for comparative purposes and if a superintendent finds that the median scores of his city differ greatly from them he has a situation which needs investigating. Secondly, small differences in median scores should not be treated seriously. The performance of pupils is variable, i.e. if a pupil repeats his performance, for example, takes the addition test a second time, his results are frequently not identical. Also there may have been slight differences in the method or manner of giving the tests in the different cities which affected the scores. Thus small differences in median scores, particularly in the case of small groups of pupils, are not significant.

Large Differences in Achievement of Cities are Shown. An examination of the scores in Tables II to VI reveals the same wide variation in achievement in the different systems as has been found in former studies. City 18 ranks first in eighth grade addition with 11 examples attempted, whereas City 7 ranks last with 6.5 examples attempted. Cities 20 and 7, the best and poorest in subtraction, differ in attempts by 6.3 examples. The same thing is seen in the case of rights and accuracy. A difference of 50 per cent in accuracy is not uncommon, and an extreme case is found in the fifth grade division where the best and poorest cities, 23 and 14, differ by 71 per cent. In the same grade we find the striking example of City 9 getting a median score of only .7 of an example right on a meager effort of 3.2 attempts, whereas City 23 realizes 4.1

[7] See his "Third, Fourth, and Fifth Annual Accounting."

examples right from 4.4 attempts. Nine cities in the fifth grade subtraction are inferior to City 12 in number of examples attempted in the fourth grade which has a median of 6.7. Fourteen of the 18 cities reporting fourth grade subtraction attempts are superior to City 10 in the fifth grade subtraction attempts. Fifteen cities fail in the sixth grade multiplication to reach the median score for attempts of City 12 in the fifth grade. The median accuracy for all cities in the fifth grade is only 56 per cent, yet there are 6 cities in the sixth, 10 in the seventh, and 7 in the eighth grade that fall below this per cent of accuracy. In the eighth grade the range of the median scores in addition attempts and in accuracy is from 6.5 to 11.0 and 50 to 80 respectively; in subtraction it is from 8.7 to 15.0 and 67 to 100; in multiplication, from 7.0 to 12.0 and 54 to 88.5; and in division from 6.8 to 11.0 and 70 to 100.

The Significance of These Differences. These differences are significant. They mean that different cities are obtaining widely different products from the instruction in arithmetic which is provided in their schools. If those cities whose median scores are low are securing a product which is satisfactory, then we may ask if the cities which have the high medians are not placing too much emphasis upon the operations of arithmetic. On the other hand, if the higher median scores represent a satisfactory product, then those cities which have the lower median scores are allowing a majority of their children to advance from grade to grade and even to leave school without a satisfactory equipment in the fundamental operations of arithmetic.

Whenever the median score of a class or a city differs more than one example from the standard, the cause should be studied. It may be that there is some satisfactory explanation. If not, an adjustment in the instruction should be made which will bring the median scores within the "zone of safety". It should be noted that we are referring to the scores which are above standard as well as those which are below. Altho the situation probably is not as serious, it should be recognized that median scores which are distinctly above standard are unsatisfactory as well as those which are below.

Since 24 of the 27 cities gave these tests for the first time in 1917, we have here an illustration of the need for measuring the results of teaching with standardized tests. Without doing this, a superintendent or teacher cannot know whether they are securing results above or below standard, and when a group of cities are given the same test for the first time there has always been found a diversity of practice.

The Achievements of Some Cities Not Uniform. The tables reveal striking differences in achievement among not only the various cities, but also within any one system. The eighth grade in City 6 ranks first in speed in division but seventeenth in speed in addition. The seventh grade in City 8 ranks first in accuracy in division, but only sixteenth in addition. In the sixth grade City 2 ranks first in number of division examples correctly solved, and nineteenth in addition examples correctly solved. Two other cities afford striking examples of irregularity. City 24, that ranks fourth when speed alone is considered, ranks fifteenth in all points and twenty-first in accuracy. This is a clear case of sacrificing accuracy for speed.

Again, a system may be strong in certain grades and weak in others. In City 20 the averages of the rankings in all points in the fifth and sixth grades are 15 and 16, whereas the average for the seventh and eighth grades is 4. There are many conditions which contribute to this state of affairs, some of which might be differences in the amount of time devoted to the subject, in the quality of the teaching, or in the extent and quality of the supervision.

This non-uniformity of achievement is evidence that the product of instruction in arithmetic is not a single ability which functions for all types of examples, but a group of specific abilities. There may be and probably are certain abilities which function in the doing of examples of different types, but a pupil is not satisfactorily equipped until each of the necessary specific abilities have been engendered in the required degree. This makes it imperative for each teacher to be conscious of the different specific abilities and definitely train pupils in each of them.

Individual Differences. The wide range of achievement in both speed and accuracy is clearly seen by referring to the distributions given in Tables VII *A* to X *B*. These distributions are the result of reducing to per cents the frequencies found in the total distributions for each grade. Table VII *A*, for

TABLE VII*A*—ADDITION: RATE DISTRIBUTION—PER CENT OF PUPILS SCORING EACH NUMBER OF ATTEMPTS

GRADE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
IV	.2	2.2	8.5	14.4	**25.5**	20.4	14.9	6.2	4.1	1.5	1.7	.1	.1	.1	....	....	....	....	....	....	....	....	....	....	....
V	....	.5	3.2	7.2	14.8	17.5	**20.6**	15.1	11.2	4.5	2.3	1.1	.6	.15	.3	.15	....	.2	.1	....	....	.1	....	....	....
VI	.2	.3	1.2	3.4	8.7	15.2	**20.7**	17.4	14.8	8.7	4.3	2.0	1.2	.5	.25	.5	.1	.18	....	....	....	....	....	....	....
VII	.1	....	.8	2.1	6.9	12.7	14.7	**17.5**	17.0	10.4	7.7	3.9	2.1	1.4	1.1	.29	.1	....	.1	....	....	....	....	....	....
VIII	.2	....	.1	.9	2.9	5.7	13.1	14.7	**20.8**	15.4	9.2	5.9	4.3	2.7	1.1	1.4	.5	.1	.2	.2	.1	.1	....	.1	.1

TABLE VII*B*—ACCURACY DISTRIBUTION—PER CENT OF PUPILS SCORING EACH PER CENT OF ACCURACY

GRADE	0–49	50	60	70	80	90	100	TOTAL NUMBER OF PUPILS
IV	**48.3**	10.3	11.5	8.2	9.7	.3	12.4	1011
V	**41.5**	14.3	12.3	8.8	12.3	.6	10.2	1326
VI	**34.7**	15.7	15.2	10.1	12.6	1.3	9.7	1191
VII	**30.4**	15.4	13.2	12.1	16.9	2.8	9.2	1016
VIII	**26.1**	14.9	13.6	15.5	18.1	3.8	7.9	919

TABLE VIII*A*—SUBTRACTION: RATE DISTRIBUTION—PER CENT OF PUPILS SCORING EACH NUMBER OF ATTEMPTS

GRADE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
IV	.6	1.7	6.0	10.1	13.1	**21.2**	19.0	9.4	7.2	3.1	1.6	.6	.6	....	.1	....	....	....	.1	....	....	....	....	....	....
V	.8	1.8	1.9	4.8	9.2	16.6	21.7	16.1	13.9	6.2	1.6	2.5	.7	.1	.1	.1	.3	.2	.1	....	.1	....	....	....	....
VI	.2	.2	.8	2.2	5.5	10.2	16.3	11.3	**19.2**	11.6	8.0	4.1	1.1	1.1	.8	.8	.3	.3	....	.1	....	....	....	....	....
VII	.2	.2	.2	.7	2.2	5.1	11.8	13.1	**18.8**	13.0	13.0	7.9	1.3	3.1	1.9	1.2	.8	.7	.5	.1	.1	.1	....	....	....
VIII	.3	....	....	.2	.8	2.1	4.4	8.5	**15.0**	13.7	**15.0**	12.7	10.1	5.1	1.2	1.6	2.3	1.2	.33	.3	.1	.2	.3	.3	.2

TABLE VIII*B*—ACCURACY DISTRIBUTION—PER CENT OF PUPILS SCORING EACH PER CENT OF ACCURACY

GRADE	0–49	50	60	70	80	90	100	TOTAL NUMBER OF PUPILS
IV	**38.7**	11.5	10.5	8.2	12.2	.6	18.3	1016
V	**24.9**	12.6	13.0	9.9	17.7	1.9	20.0	1323
VI	**21.8**	9.3	11.9	15.4	19.3	3.4	18.8	1194
VII	11.9	9.6	11.8	14.4	**25.5**	6.5	20.3	1017
VIII	8.2	10.4	14.4	17.9	**21.3**	13.7	13.9	919

TABLE IXA—MULTIPLICATION: RATE DISTRIBUTION—PER CENT OF PUPILS SCORING EACH NUMBER OF ATTEMPTS

GRADE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
IV	1.6	6.6	17.7	**21.7**	19.5	15.2	9.3	3.7	2.2	1.0	.6	.3	....	.2	....	.1	....	.1	....	....	....	....	....	....	....
V	.5	2.7	8.5	11.3	16.4	18.4	**20.2**	10.4	5.2	4.4	.8	.5	.4	.1	.4	.2	....	.1	....	....	....	....	....	....	....
VI	.3	.8	2.2	5.5	13.1	16.4	**19.0**	13.7	11.3	7.6	5.2	3.0	1.4	.3	.1	.3	.2	....	....	....	....	....	....	....	....
VII	....	....	1.4	1.7	5.5	10.7	**17.4**	15.3	16.1	10.7	8.1	5.7	2.4	2.2	1.4	.8	.2	.1	.1	.1	....	....	....	....	....
VIII	....	....	.3	.8	3.2	4.6	8.3	12.4	**18.2**	14.5	14.3	8.8	6.2	2.3	1.8	1.7	1.4	.4	.2	....	.1	.1	....	....	.1

TABLE IXB—ACCURACY DISTRIBUTION—PER CENT OF PUPILS SCORING EACH PER CENT OF ACCURACY

GRADE	0–49	50	60	70	80	90	100	TOTAL NUMBER OF PUPILS
IV	**48.3**	12.3	10.4	6.3	7.8	.2	14.2	984
V	**38.4**	12.5	13.4	7.0	13.0	.5	15.1	1322
VI	**27.3**	13.5	14.6	13.2	16.1	2.4	12.9	1194
VII	**20.3**	11.7	15.4	14.7	19.3	3.9	14.7	1015
VIII	15.5	11.5	14.4	18.0	**21.1**	7.3	12.2	916

TABLE X*A*—Division: Rate Distribution—Per Cent of Pupils Scoring Each Number of Attempts

Grade	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
IV	12.2	18.9	**19.6**	17.7	16.8	7.0	2.7	1.4	1.8	1.2	....	.1	.2	....	....	....	....	....	....	....	....	....	....	....	....
V	2.3	10.5	15.1	**22.3**	20.0	12.1	6.5	3.5	2.5	1.6	1.3	.45	.37	.3	.2	.2	....	.1	....	....	.1	....	.1	....	....
VI	1.1	4.0	8.9	19.9	**20.1**	15.1	10.9	6.0	6.0	2.9	1.8	1.0	1.2	.4	.3	.1	.2	....	....	....	....	....	....	....	....
VII	.2	.4	2.9	10.2	13.5	**15.6**	13.9	10.7	11.9	7.3	4.0	2.0	3.1	2.2	.8	.2	.5	.4	.1	....	....	....	....	....	....
VIII	....	.7	1.4	2.2	8.1	9.7	10.2	11.5	**15.0**	10.2	8.8	6.1	6.1	4.7	1.4	1.4	.6	.8	.3	.7	....	....	....	.1	....

TABLE X*B*—Accuracy Distribution—Per Cent of Pupils Scoring Each Per Cent of Accuracy

Grade	0–49	50	60	70	80	90	100	Total Number of Pupils
IV	**73.2**	6.9	4.8	1.3	1.4	....	12.3	829
V	**51.3**	10.7	8.9	4.8	5.2	1.4	16.8	1323
VI	**32.0**	9.3	12.9	9.5	13.0	.8	22.3	1193
VII	16.9	8.5	13.0	12.0	20.5	3.9	**25.0**	1015
VIII	8.8	9.3	10.6	14.7	19.9	6.9	**29.5**	916

example, gives the per cent of pupils in each of the grades scoring each number of attempts. It gives the rate distribution in addition and should be read as follows: .2 per cent of the 1,011 fourth grade pupils finished 0 examples in the allotted time; 2.2 per cent finished 1 example; 8.5 per cent finished 2 examples, etc. The mode, that is, the largest single group, is given in bold-faced type. The speed distributions for all grades are read in the same manner. Table VII *B* gives the accuracy distribution for addition and should be read thus: 48.3 per cent of the 1,011 fourth grade pupils made an accuracy score of 0-49 per cent; 10.3 per cent made score of 50-59 per cent; 11.5 per cent made score of 60-69 per cent, etc.; 12.4 per cent made a perfect score in examples attempted. Here again the mode is given in bold type.

Tables VIII *A* to X *B* give the speed and accuracy distributions in subtraction, multiplication, and division, and are read in the same manner as Tables VII *A* and VII *B* for addition.

Further examination of Table VII *A* shows a wide range in adding ability. In all five grades there are some pupils who attempted as few as 0 or 1 example. In the fourth grade one pupil attempted 13 examples, in the fifth one pupil attempted 21 examples, in the sixth two attempted 17, in the seventh one attempted 18, and in the eighth there were pupils who attempted from 20 to 24 examples. In the eighth grade .2 per cent finished 0 examples and .1 per cent attempted 24 examples, and 22 different rates of speed were shown.

The data in Table VII *A* are not subject to adverse criticism only. They reveal the fact that there is a gradual growth in rate of work from the fourth to the eighth grade. Refer, for example, to the third column. They decrease gradually from 8.5 per cent to .15; i.e. there is a gradual decrease from the fourth to the eighth in the number of pupils who attempted so few as 2 examples. The same thing may be said of all the columns up to the modes. Now note the column to the right of the modes. The same growth is revealed. Here, however, the per cents naturally increase from the fourth to the eighth grade. Thus, in the column headed 9, we find that 1.5 per cent in the fifth attempted 9 examples and so on until in the eighth we have 15.4 per cent attempting the same number. This evidence of growth characterizes the columns to the right of the one in question.

The figures in Table VII *B* also show an improvement from grade to grade in accuracy, altho it is not so marked as in the rate. The modal score in all grades is below 50 per cent, but the per cent decreases from 48.3 in the fourth to 26.1 in the eighth. There is a slight irregular improvement in the columns 50 to 90, but a decrease in the percentage of pupils making perfect scores.

The Significance of Individual Differences. Individual differences are characteristic of nature. They are always shown by the measures of a group unless that group does not represent a random sample. Thus we must expect individual differences. The pupils in a school are "graded" and pupils are failed or permitted to skip a grade in order to reduce the individual differences of classes to a minimum. In spite of these provisions it is significant to note that the individual differences in general increase in Tables VII to X from the lower to the higher grades. This condition suggests that our present methods of teaching and our plan of school organization are yielding unsatisfactory results in this respect. A reclassification of these pupils is suggested. A large per cent of the pupils could be promoted one or more grades and yet their achievements would be above standard. However, reclassification involves many difficulties, and it might not be possible for a large number of pupils.

The facts of these tables also suggest that many pupils (those whose scores are below standard) are not satisfactorily responding to the instruction which is now being provided. The instruction may be excellent for some pupils and not reach others. Thus there is a group of pupils, the lowest third, whose instructional needs should be studied carefully by the teacher. Then the teacher will be in a position to plan wisely in attempting to adapt the instruction to the needs of his pupils. In doing this the scores which the pupils make on a standardized test, such as Series B, are very valuable.

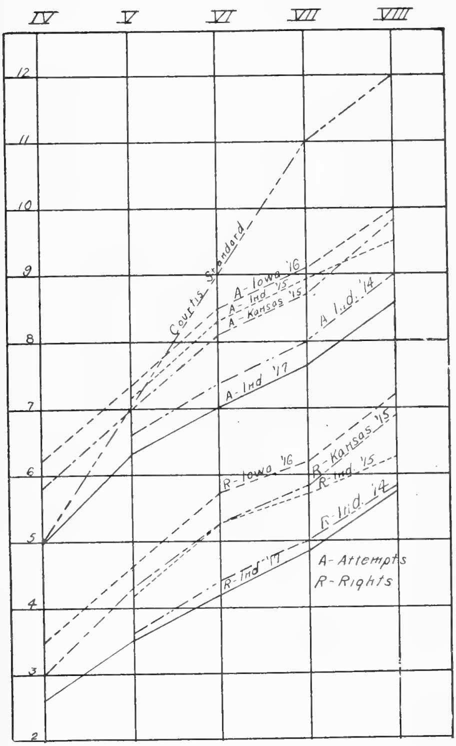
Accuracy or Dependability. Few cities reach the high requirement of 100 per cent set by Mr. Courtis. Cities 1 and 18 in the sixth grade subtraction get 100 per cent. There are 10 other cities that reach this perfect standard of accuracy, 6 of them being in eighth grade division. These perfect median scores do not mean that every pupil worked all the examples without error. This is not necessary for a median accuracy of 100 per cent. It is only necessary that half or more of the pupils do all the examples that they attempt correctly. The standard of 100 per cent set by Courtis is a theoretical one. In using it for comparative purposes one should keep in mind the significance which he attaches to it. For this reason we quote the following:[8]

> The question of proper standards is not so simple as that for speed. In the first place, children of all ages attain perfect accuracy, so that 100 per cent would seem to be the only standard possible. Certainly no inaccurate work is of value. On the other hand, "to err is human" and the most precise mortal will make mistakes at times. Should the standard be 90 per cent on straight ahead work, with the teaching of habits of constant checking, or should one aim for perfect accuracy, with checking as an activity to be used only in cases of doubt?
>
> It seems to the writer that such questions should be settled, not on the basis of opinion but by experimentation. It is possible to determine by actual measurement how many children, under the present conditions, attain standard speed and 100 per cent accuracy; also how many can be brought to this level. Certainly 100 per cent accuracy is better than 90 per cent accuracy, unless the time cost of the training should prove to be too great. Accordingly, for his own work he has adopted 100 per cent accuracy as a working standard, but he wishes to emphasize the fact that this is done with an open mind and a full realization of the possible necessity for change. A better statement would be that he has adopted no standard for accuracy, but is now trying to collect data that would enable a standard to be set intelligently, and that he is particularly interested in finding out the number of children who can work at standard speed and with perfect accuracy.

There appears to be as much fluctuation from city to city in accuracy as in the rate of work. An extreme case of this variation is seen in fifth grade division where there is a range from 22 per cent to 93 per cent. A range of 40 per cent is not uncommon. Compared with Kansas and Iowa, the Indiana accuracy median scores without exception are lower. Compared with the Indiana 1914 and 1915 scores, the 1917 scores are higher than the former in fifth grade subtraction, in sixth grade addition and subtraction, in all the operations in the eighth grade, whereas they are lower than the latter in all instances except in seventh grade addition and multiplication, in eighth grade multiplication, and in eighth grade addition, in which they tied.

[8] Courtis, S. A.: "Third, Fourth, and Fifth Annual Accountings" (Department of Coöperative Research, Detroit, Mich.) pp. 29-30.

The Indiana 1917 Achievement Compared with 1914 and 1915 Achievements. In Tables II to VI the Indiana achievements for 1914 and 1915 are given for comparative purposes. These scores together with the Iowa and Kansas scores are represented in Figures 1 to 4.



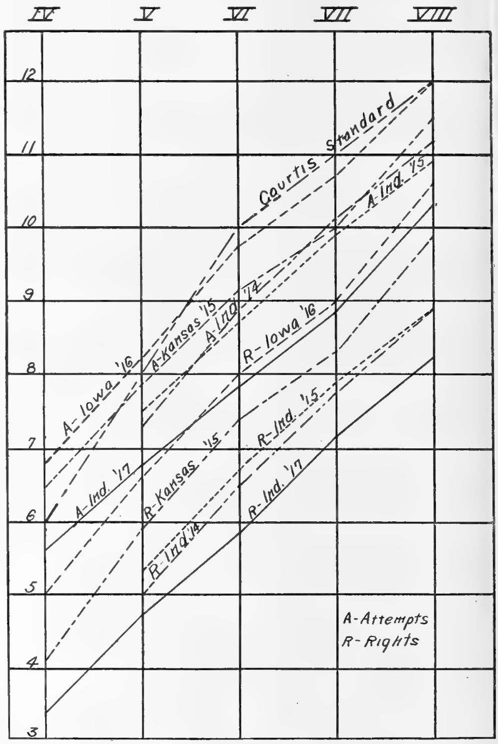
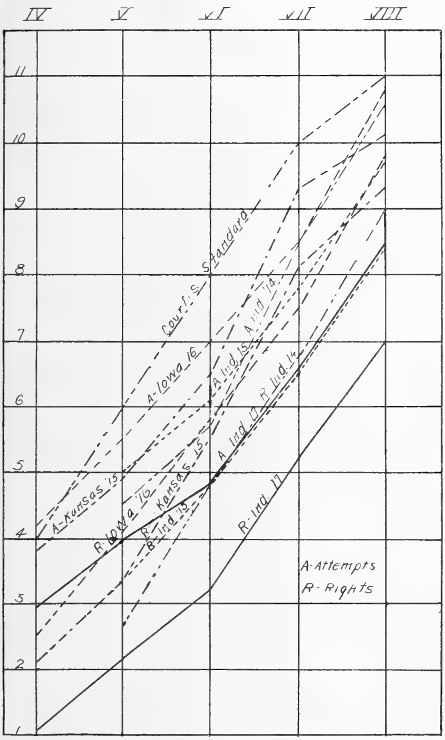


FIG. 1. Showing Indiana 1914, 1915, 1917 Median Scores in Comparison with other State Medians. Addition.

FIG. 2. Showing Indiana 1914, 1915, 1917 Median Scores, in Comparison with other State Medians. Subtraction.

In practically every grade in every fundamental operation the 1917 records of achievement are distinctly lower than those of the years 1914 and 1915, especially those of 1915, which compare more favorably with the Courtis standards and the standards of other states. The explanation of these differences, of course, will be one of the significant problems to be worked out in the future. As suggested in another part of the study, it may be that the 1915 increase over 1914 may be partially accounted for by the fact that 9 of the cities included in the 1915 test were also included in the 1914 test, and doubtless had attempted during the interval to bring up the work in arithmetic. The 1917 returns are from a wholly



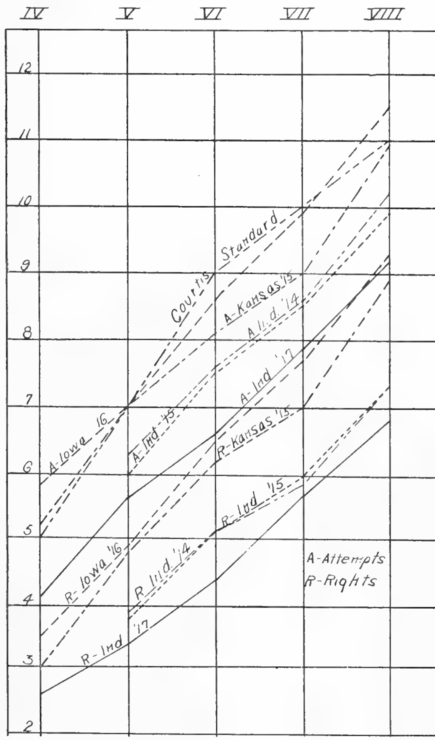


FIG. 3. Showing Indiana 1914, 1915, 1917 Median Scores in Comparison with other State Medians. Multiplication.

FIG. 4. Showing Indiana 1914, 1915, 1917 Median Scores in Comparison with other State Medians. Division.

different and smaller group of towns and cities. Only Bluffton is included in all three studies. Two other cities, Mishawaka and Seymour, gave the tests in 1915. A future analysis of the conditions in these cities compared with conditions in the cities furnishing returns for 1914 and 1915 may reveal some probable specific causes for the low results this present year. This very fact, however, is a clear instance of the possibility of error in estimating the achievements in arithmetic for a state as a whole on a basis of the returns from a comparatively few cities that furnish the tests upon request. It is not at all clear that the Iowa and Kansas Standards are truly representative of the achievements in those states or that the Indiana returns for either of the three years are representative of Indiana.

The Indiana Scores for 1917 Compared with the Courtis Standard and with the Scores for Iowa (1916) and Kansas (1915). In addition the Indiana achievement, as far as number of examples attempted is concerned, is distinctly lower than the Courtis standard in all grades and noticeably lower than the Iowa and Kansas standards in all grades. As far as the number of examples worked correctly is concerned, the Indiana 1917 achievements are lower than the Courtis standards or other state standards.

In subtraction the Indiana 1917 achievement is distinctly lower than the Courtis or other standards in all grades in number of examples attempted, and in number of examples correctly solved.

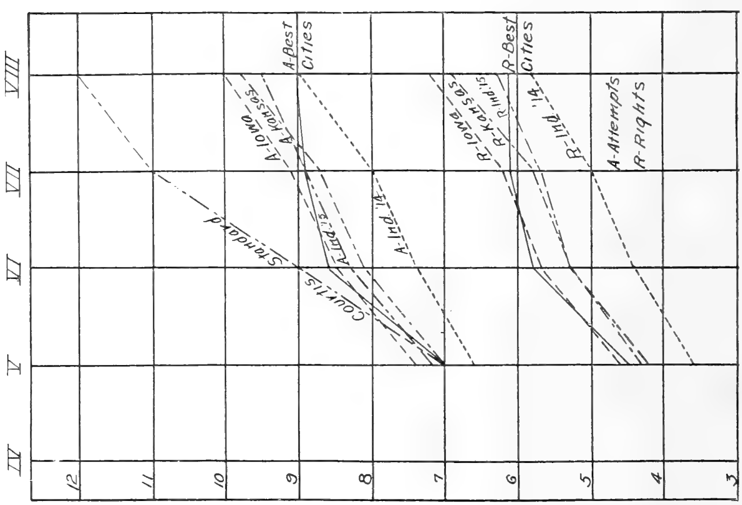
In multiplication the Indiana 1917 achievement in number of examples attempted is lower in all grades than the Courtis standard and other state standards, and in number of examples correctly solved the same thing is true.

In division the Indiana 1917 achievement in number of examples attempted is lower in all the grades. In examples correctly solved it is lower in all grades.

It may be argued that the data obtained are not representative of the state, because only 27 cities are included in the study. Consider the scores for 1914 and 1915. Only one of the 20 cities in 1914 gave the tests in 1917, and whereas 80 per cent of the cities and towns reporting in 1917 were under 3,000 in population, all but one of the 20 reporting in 1914 were over 3,000. Despite the fact that there was a distinctly different type of school represented in 1914, the 1914 medians fall far below those of Iowa and Kansas. By actual count from Tables II to VI, where all the medians are collected, it is found that out of twenty-two chances in attempts and rights together, one Indiana 1914 median exceeds a Kansas median by .1 and another just equals an Iowa median. In all other cases Indiana in 1914 falls distinctly below Kansas and Iowa. The Indiana medians (1915) are generally above those of 1914. Nine of the 20 cities that gave the tests in 1914 continued their use in 1915 and presumably in the meantime attempted to bring up the work in arithmetic. Considering the effect that these 9 cities might have had on the results, the Indiana 1915 medians are still below the other state standards. In this connection it will be interesting to examine Figures 1 to 4, pp. 26, 27, which set forth these comparisons graphically. It will be seen in Figures 1 to 4 how the solid lines for Indiana 1917 scores in both attempts and rights fall distinctly below the other lines. No one should fail to see that in subtraction and division the Iowa line for rights runs above the Indiana line for attempts. Such a graph should challenge the attention of every teacher in the state.

A Study of the Best Five Cities. Since the results for the state as a whole show that Indiana achievements are inferior to those of Iowa and Kansas, the question arises whether there are any cities in the state whose achievements equal or excel outside standards. To answer that question a brief study has been made of the 5 cities that rank highest. These cities are 5, 12, 13, 19, and 25. Of these five cities, City 25 is first with 5, 13, 12, and 19 following in descending order of achievement. City 6 really ranks fifth, but since it has only the seventh and eighth grades represented, City 19, ranking sixth, was selected instead. The medians for each of the Best Five Cities, the medians for the group, for the Indiana 1914 and 1915 studies, and for other states have been collected in Table XI. A graphic representation of the results is given in Figures 5 to 8. An examination of these figures reveals a characteristic common to all four fundamental operations. The solid lines representing the number of attempts and rights for the Best Five Cities assume the same general shape. This is particularly noticeable in the case of the eighth grade. It invariably fails to show the growth that should be expected, considering the advanced positions that the sixth and seventh grades hold. This same thing is true of the seventh grade in addition.

At this point compare the Indiana lines in Figures 1 to 4 and 5 to 8. This tendency to move downward characteristic



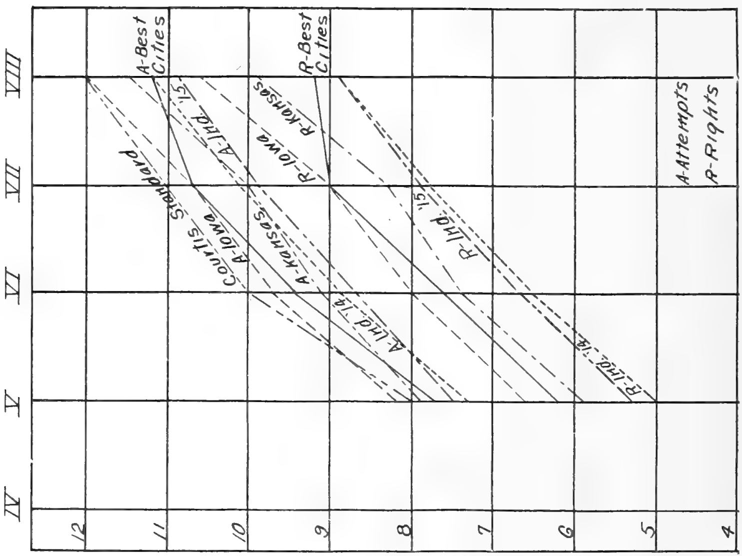
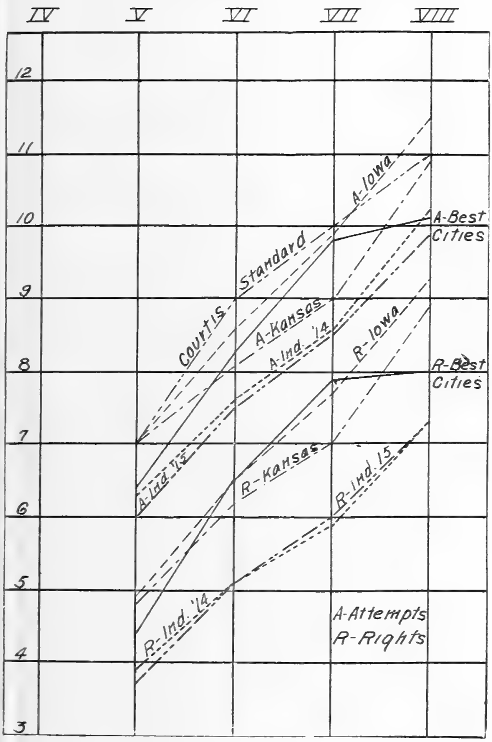


FIG. 5. SHOWING MEDIAN SCORES OF BEST FIVE CITIES IN COMPARISON WITH INDIANA, IOWA, AND KANSAS MEDIAN SCORES. ADDITION.

FIG. 6. SHOWING SCORES OF BEST FIVE TOWNS IN COMPARISON WITH INDIANA, IOWA, AND KANSAS MEDIAN SCORES. SUBTRACTION.

of the lines for the Best Five Cities is not so evident in the lines for the entire state. At seven of the possible eight points where the lines of achievement for speed in Figures 5 to 8 cross the vertical grades lines, these lines of achievement



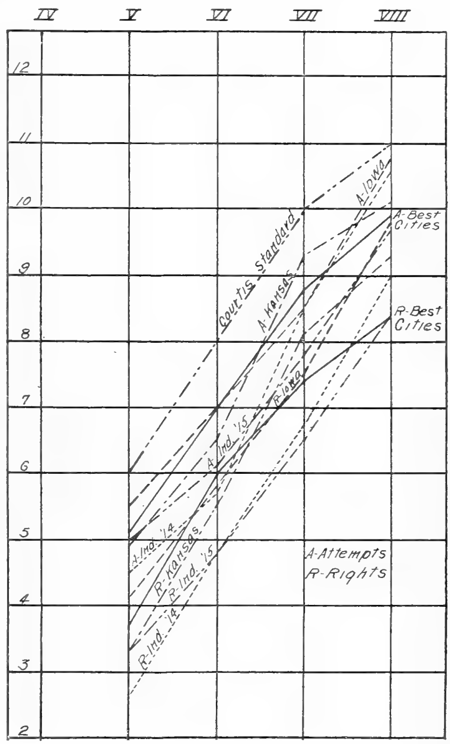


FIG. 7. Showing Median Scores of Best Five Cities in Comparison with Indiana, Iowa, and Kansas Median Scores. Multiplication.

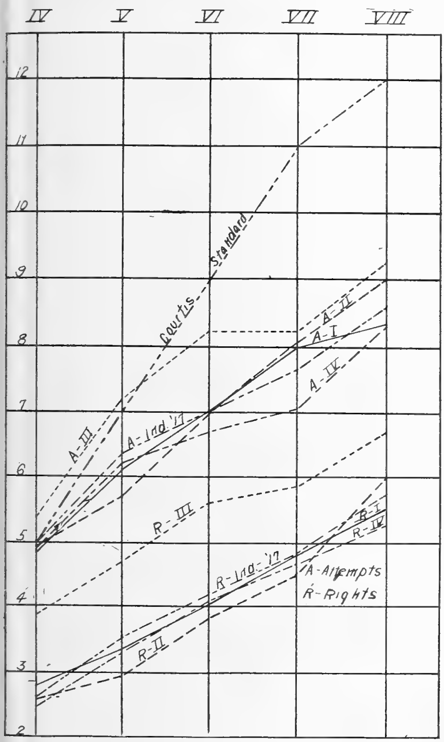
FIG. 8. Showing Median Scores of Best Five Cities in Comparison with Indiana, Iowa, and Kansas Median Scores. Division.

refract downward, whereas the same lines in Figures 1 to 4 refract downward at only six of the twelve possible points, and at three of these the lines are practically straight. In the lines for rights the same distinction holds. Do these facts mean that growth from grade to grade in the systems that rank highest is the least consistent and the most irregular?

TABLE XI—MEDIANS OF FIVE CITIES MAKING HIGHEST SCORES, MEDIAN OF GROUP, AND OTHER STATE STANDARDS

City	Grade 8												Grade 7											
	Addition			Subtraction			Multiplication			Division			Addition			Subtraction			Multiplication			Division		
	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability	Attempts	Rights	Dependability
19	9.0	4.9	54	12.4	9.9	80	10.7	8.0	74	10.8	9.8	91	7.6	4.1	54	12.0	9.9	83	10.0	7.3	73	9.8	7.9	81
12	9.0	5.2	58	11.5	9.5	83	8.3	6.9	83	9.5	6.8	73	10.0	6.3	63	10.0	7.3	67	10.8	8.3	77	10.0	9.3	93
13	8.7	7.0	80	11.3	9.4	83	9.7	7.8	80	11.0	10.6	97	8.5	7.2	85	10.0	9.0	90	10.0	8.0	80	8.0	8.0	100
5	10.8	8.0	80	11.5	10.1	88	10.9	9.5	88	9.5	7.8	83	8.9	6.2	70	10.2	8.2	80	9.3	8.1	87	6.8	5.6	81
25	8.9	6.1	69	10.9	9.0	83	10.5	8.0	80	9.6	8.2	85	9.4	7.1	75	10.8	9.3	86	9.6	7.7	81	8.9	7.4	84
Grand Total	9.0	6.1	68	11.2	9.2	82	10.1	8.0	79	9.9	8.4	85	8.9	6.1	69	10.7	9.0	84	9.8	7.9	81	8.8	7.4	84
Iowa	10.0	7.2	72	12.0	10.6	86	11.5	9.3	81	10.8	9.8	91	9.1	6.2	68	10.7	9.0	84	9.9	7.7	78	8.5	7.5	88
Kansas	9.8	6.9	71	11.5	9.9	86	10.9	8.9	82	10.1	9.3	92	8.7	5.8	67	10.0	8.3	83	9.0	7.0	78	9.3	8.1	87
Indiana '15	9.5	6.3	67	10.9	8.9	82	9.9	7.3	74	9.7	8.4	87	8.9	5.7	64	9.9	7.9	80	8.5	6.0	71	7.8	6.5	84
Indiana '14	9.0	5.8	64	11.2	8.9	79	10.2	7.3	71	10.6	9.0	84	8.0	5.0	62	10.1	7.8	77	8.6	5.9	68	8.5	6.7	78
Courtis	12.0	12.0	100	12.0	12.0	100	11.0	11.0	100	11.0	11.0	100	11.0	11.0	100	11.0	11.0	100	10.0	10.0	100	10.0	10.0	100
	Grade 6												Grade 5											
19	7.9	4.3	55	8.7	6.7	77	8.3	5.9	72	7.2	6.2	86	5.9	3.2	54	7.0	5.6	80	6.4	3.4	53	3.8	....	....
12	9.0	5.2	58	9.0	5.4	60	7.3	5.1	70	8.0	5.3	67	7.3	4.8	67	9.5	5.5	63	7.3	5.5	75	6.0	4.2	70
13	8.0	6.4	80	9.6	7.9	83	7.3	6.4	88	7.0	5.3	75	6.0	3.2	54	6.2	3.7	60	4.6	3.0	70	4.8	1.3	27
5	9.7	5.6	58	10.0	6.5	65	9.0	6.6	73	6.4	5.8	90	8.0	....	....	6.9	4.0	58	6.4	4.3	67	4.6	2.6	58
25	8.8	7.3	83	9.6	8.4	87	8.7	7.0	80	7.3	6.5	89	7.4	5.2	71	8.2	7.1	87	6.5	4.9	75	5.8	4.8	82
Grand Total	8.6	5.8	67	9.4	7.6	81	8.3	6.5	78	7.0	6.0	85	7.0	4.5	64	7.7	6.2	81	6.4	4.4	69	5.1	3.7	72
Iowa	8.5	5.7	67	9.7	8.0	83	8.6	6.5	76	7.0	5.8	83	7.4	4.6	62	8.2	6.6	80	7.0	4.9	70	5.5	4.1	74
Kansas	8.1	5.3	65	9.1	7.4	81	8.1	6.2	77	6.5	5.5	84	7.0	4.3	61	7.9	5.9	75	7.0	4.8	69	4.9	3.3	68
Indiana '15	8.3	5.3	64	8.7	6.7	77	7.5	5.1	68	6.1	4.8	79	7.2	4.2	59	7.5	5.3	71	6.0	3.7	61	5.0	3.3	65
Indiana '14	7.4	4.4	59	8.9	6.5	73	7.6	5.1	67	5.7	4.8	84	6.6	3.6	55	7.3	5.0	68	6.3	3.9	62	4.5	2.6	57
Courtis	9.0	9.0	100	10.0	10.0	100	9.0	9.0	100	8.0	8.0	100	7.0	7.0	100	8.0	8.0	100	7.0	7.0	100	6.0	6.0	100

A little closer examination of the achievement in each grade might be helpful. Figure 5 may be interpreted as follows: In fifth grade attempts in addition the Best Five Cities start with the Courtis and Kansas standards, excel the Indiana 1914 achievement, but fall below those of Indiana 1915



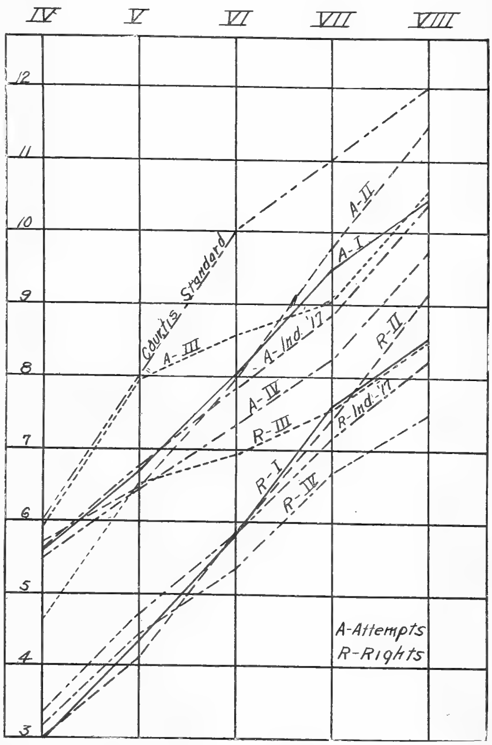
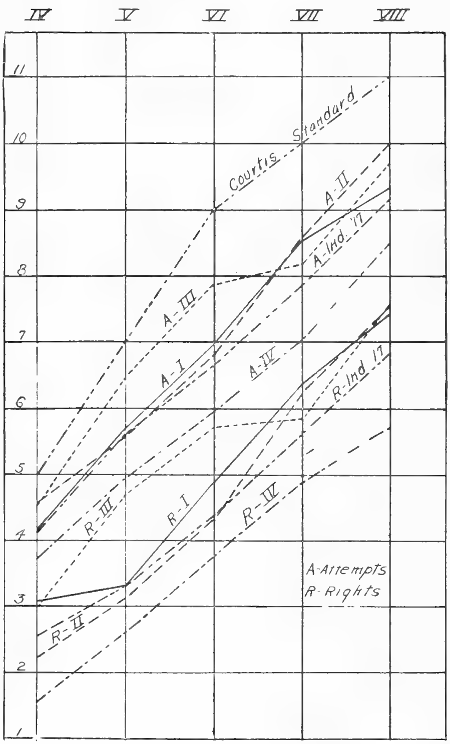


FIG. 9. Showing Group Medians in Comparison with State Medians and Courtis Standard. Addition.

FIG. 10. Showing Group Medians in Comparison with State Medians and Courtis Standard. Subtraction.

and Iowa 1916. In rights they are superior to all except Iowa, which is slightly above; in the sixth grade the Best Five Cities are superior to all other standards (except the Courtis) in both attempts and rights; in the seventh grade in attempts they excel the Indiana 1914 and Kansas scores, equal those for Indiana 1915, but fall slightly below those for Iowa, while in rights they are only slightly excelled by Iowa. The achievement of the eighth grade in all the operations has already been emphasized. In Figure 5 we find the Best Five Cities strikingly inferior in both attempts and rights in this grade. The remaining three figures may be interpreted in similar fashion.



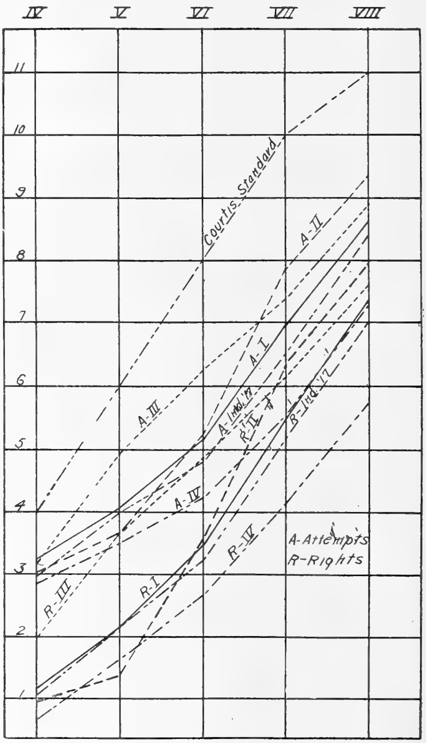


FIG. 11. Showing Group Medians in Comparison with State Medians and Courtis Standards. Multiplication.

FIG. 12. Showing Group Medians in Comparison with State Medians and Courtis Standards. Division.

Another question arises. Do the Best Five Cities that rank highest in all points rank equally well in speed, variability, and accuracy? Table XII has been arranged to present the facts in this connection. These cities are given to the left with their order numbers. Then reading to the right you will note the order number of each city in the three factors mentioned above. Obviously the answer is in the affirmative, particularly in the ranking for speed. City 5 ranks only one point lower, and City 13 five points lower, while the other three rank as high or higher. The relation is fairly good in variability and accuracy except for Cities 12 and 19 in accuracy.

TABLE XII—Comparison of Rankings of Best Five Cities in All Points, with Their Rankings in Speed, Variability, and Accuracy

City	Rank	Rank in Speed	Rank in Variability	Rank in Accuracy
25.....	1	1	6	3
5.....	2	3	2	6
13.....	3	8	8	5
12.....	4	2	8	16
19.....	5	5	3	15

Another general condition is noticeable in Figure 5. A mere glance is sufficient to show how Indiana achievement keeps falling farther below the Courtis Standard and other state standards as the lines move from left to right. Compare Figure 5 with 6, 7, and 8, and it will be seen at once that accuracy is much lower in addition than in subtraction, multiplication, and division. The same condition is presented in Figures 1 to 4 for the state as a whole.

Comparison of the Achievements of Population Groups. The cities and towns that gave the arithmetic test in 1917 have been divided into four groups: (1) those cities and towns with a population of less than 1,000, of which group there were 16 school systems; (2) from 1,000 to 3,000, of which there were 6; (3) 3,000 to 10,000, of which there were 3; (4) 10,000 and above, of which there were 2 (see Tables II to VI). In connection with these four groups comparison has been made in regard to the number of examples done correctly. The median scores for each of the four groups are represented in Figures 9 to 12.

In the addition test, results show that in number of examples attempted in Group III (3,000 to 10,000) the achievement is above the Indiana median in all points. Group I (less than 1,000) is below in all grades except sixth and seventh; Group II (1,000 to 3,000) is above in seventh and eighth grades, equal to in the sixth, and below in the other two grades; whereas Group IV (10,000 and above) is below in all grades. In number of examples done correctly, Group III (3,000 to 10,000) is distinctly above the state median in all grades; whereas all other groups are below, except Group II (1,000 to 3,000) in eighth grade and Group I in fourth grade.

In subtraction tests, results show that in number of examples attempted, Group I (1,000 or less) is above the Indiana standard in all grades except the fourth and fifth. Group II (1,000 to 3,000) is above in all grades except the fifth. Group III (3,000 to 10,000) is above in all grades, particularly in the fifth grade. Group IV (10,000 and above) is below in all grades. In examples done correctly, Group I (1,000 or less) is below in the fourth and fifth grades, equal in the sixth, and above in the seventh and eighth grades. Group II (1,000 to 3,000) is below in the fourth and fifth grades, and above in the sixth, seventh, and eighth. Group III (3,000 to 10,000) makes the best showing and is above from one to two points in the fourth, fifth, and sixth grades. Group IV (10,000 and above) is below in all grades.

In the multiplication test, results show that in number of examples attempted, Groups I (less than 1,000) and III (3,000 to 10,000) are above the 1917 state median, and Group II (1,000 to 3,000) is above in every grade except the fifth, whereas Group IV (10,000 or above) is below in all grades. In number of examples done correctly, Group III (3,000 to 10,000) in all grades is above the 1917 Indiana median; Group I (less than 1,000) in all grades except the fifth, which equals the state median; Group II (1,000 to 3,000) is below in the fourth and fifth, equal to in the sixth, and above in the seventh and eighth, whereas Group IV (10,000 and above) is below in all grades.

In the division test, results show that in number of examples attempted, Group I (less than 1,000) is above the Indiana 1917 standard in every grade, and Group III (3,000 to 10,000) in every grade. Group II (1,000 to 3,000) is equal to or above in all grades except the fifth. Group IV (10,000 and above) is above in all grades. In number of examples done correctly Group I (less than 1,000) is above the standard in all grades, except the fifth, which is below. Group III (1,000 to 3,000) is above in all grades except the fourth and fifth, which is below. Group IV is below in all grades.

Figures 9 to 12 depict the situation more clearly than by means of words. In each figure the line for Group III (3,000 to 10,000) stands out distinctly above those for the other groups. In subtraction the fifth grade in cities of Group III gets more examples right than those in Groups II and IV attempt. In this same figure, however, Group II stands above all others in the eighth grade in both attempts and rights. The lines for Group I (less than 1,000) hold about an average position in all figures, while those for Class IV (10,000 and above) as a rule fall distinctly below.

These results are in general agreement with the results found in Iowa and Kansas, particularly Kansas. It appears that the type of supervisory and instructional organization which a city of 3,000 to 10,000 permits secures results superior to those now secured both in cities smaller and in cities larger. If this inference is correct, it would be profitable to study the supervisory organization in the schools in cities of 3,000 to 10,000.

Variability. Two types of variability are of particular interest. One is a variability in achievements in the different schools systems, a kind of variability that has been emphasized in other parts of this study. We have noticed not only widely different scores in different cities, but we also found widely different results within some of the individual systems. This marked variability cannot be justified satisfactorily on the grounds of difference in mental endowment, for population of the state and of any city is too homogeneous for that. It must be due rather to environmental conditions, to differences in amount of time devoted to the subject, or to differences in the quality of teaching or supervision.

The second type of variability is that within a single class itself. This is computed by the directions given in Folder D. This rule is, "Multiply the median deviation (M.D.) by 100 and divide by the median." A low per cent of variability is the result of having the most of the cases clustering around the median of the distribution, whereas a high per cent is due to a wide range represented by scores scattered at a great distance in either direction from the median.

The teacher and supervisor of a class should strive then to accomplish two things: to increase the median achievement of the class, and to reduce the per cent of variability. Several methods have been suggested to accomplish the latter aim. The brightest pupils might be promoted to a class that equals them in ability, while those at the other end of the scale might be demoted or given special attention until they approach median ability. All should receive the benefit of supervised study. There is quite as much waste from inattention to the superior pupil as from the retarded state of the inferior one in ability.

The variabilities for the 27 cities are given in Table XIII. For attempts in the column for fifth grade addition the per cent of variability ranges from 12 in Cities 5 and 14 to 36

TABLE XIII—VARIABILITIES: TWENTY-SEVEN TOWNS AND CITIES; FOUR GRADES, FOUR TESTS. ALSO CITY AND INDIVIDUAL VARIABILITIES

City	Grade 5								Grade 6							
	Addition		Subtraction		Multiplication		Division		Addition		Subtraction		Multiplication		Division	
	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy
1	17	27	25	36	26	31	32	...	15	29	13	...	16	23	18	27
2	17	23	19	17	12	...	16	23	21	17	14	20	17	22	27	...
3	33	19	20	21	27	25	30	18	15	15	12	33	21	27	21	19
4	29	...	18	18	21	28	19	...	14	...	27	20	27	19	30	21
5	12	...	13	16	16	28	25	19	19	14	15	20	18	20	23	16
6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7	19	25	19	13	18	25	29	23	26	31	20	22	29	25	30	...
8	17	21	13	37	22	24	21	20	22	29	18	36	28	25	24	36
9	23	33	23	22	44	...	31	...	17	...	15	19	21	31	33	24
10	23	36	...	36	...	40	50	23	16	41	37	30	23	39	40	31
11	37	15	24	24	19	17	37	18	21	22	13	25	17	26	26	23
12	31	19	18	22	28	33	34	37	10	14	19	28	17	19	19	15
13	30	14	16	28	18	19	21	...	19	27	12	27	23	17	15	27
14	12	18	20	28	20	...	23	...	18	26	19	22	27	24	29	22
15	19	21	...	...	...	17	30	23	13	...	15	21	27	17	27	...
16	23	19	17	22	27	17	...	16	19	37	14	...	21	20	20	39
17	17	25	18	23	18	15	23	...	18	20	15	21	17	29	30	25
18	16	...	26	19	30	...	37	...	16	19	16	24	18	29	23	21
19	22	21	19	23	19	21	31	...	16	19	17	18	23	19	27	19
20	26	...	23	28	21	28	30	...	24	16	20	17	19	23	36	21
21	18	20	21	21	37	...	44	...	19	...	16	23	18	26	41	35
22	36	23	20	20	21	40	27	19	21	23	25	24	25	23	30	32
23	25	24	19	19	26	21	28	14	23	22	20	20	25	28	32	25
24	14	...	19	26	17	...	21	...	16	21	14	18	17	22	27	26
25	17	25	21	19	19	19	36	23	17	23	25	16	23	17	31	21
26	23	22	20	31	29	...	35	...	20	20	18	28	23	21	28	22
27	19	21	19	23	25	25	32	21	16	24	19	22	21	19	25	31
Individual	22	21	20	26	24	21	32	...	20	20	18	24	25	26	28	29
City	22	22	14	23	22	25	29	21	18	23	18	21	22	23	27	23

TABLE XIII—Continued

City	Grade 7								Grade 8							
	Addition		Subtraction		Multiplication		Division		Addition		Subtraction		Multiplication		Division	
	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy	Attempts	Accuracy
1	15	24	16	20	20	25	17	29	15	18	12	11	15	19	29	22
2	14	...	27	26	21	16	30	22	24	25	15	17	21	15	19	22
3	14	...	18	17	17	16	33	22	13	17	12	16	12	22	22	22
4	12	25	17	16	9	15	10	22	17	24	19	19	15	21	33	21
5	17	14	15	26	16	13	21	15	15	19	12	11	12	14	32	23
6	19	17	24	12	31	18	13	13	15	21	27	17	11	9	20	...
7	14	20	29	19	25	17	26	20	23	14	6	...	21	22	30	17
8	24	27	13	13	13	15	17	15	25	23	20	13	15	...	22	13
9	16	...	14	23	11	24	15	19	21	24	16	17	14	14	22	14
10	...	21	27	18	17	24	22	40	19	33	14	15	19	29	14	16
11	19	21	16	20	26	22	42	20	17	23	18	19	20	27	29	15
12	35	20	15	20	14	17	23	13	14	17	22	18	30	15	18	15
13	...	14	15	17	22	16	31	18	21	22	18	16	23	16	23	9
14	32	19	10	19	19	31	28	11	15	20	15	19	19	19	31	15
15	...	20	...	...	...	17	21	20	17	36	18	14	12	14	23	13
16	27	14	12	...	20	13	26	11	19	19	11	16	15	15	31	...
17	16	33	15	24	18	14	13	18	20	22	16	19	12	18	16	...
18	18	23	16	21	17	24	26	18	15	19	11	17	11	20	16	14
19	15	13	16	12	15	17	21	17	17	22	17	14	19	15	23	12
20	14	20	16	19	16	17	23	...	18	18	13	14	19	11	22	...
21	17	19	13	24	18	21	19	19	18	18	15	25	15	21	24	23
22	21	21	30	20	23	15	36	12	9	25	11	20	18	18	23	17
23	24	22	21	21	21	22	35	23	18	15	15	15	16	13	21	...
24	18	20	18	18	26	24	25	24	19	27	18	19	15	24	26	19
25	18	20	20	13	16	20	18	13	13	21	12	14	13	15	19	15
26	20	21	19	21	20	25	27	26	17	19	17	18	17	25	31	21
27	21	27	17	20	15	19	21	20	19	18	16	13	19	19	26	12
Individual	19	27	19	20	20	21	29	23	17	25	18	18	18	19	27	21
City	17	21	17	18	18	19	24	19	18	21	15	16	17	17	24	14

in City 22 and 37 in City 11. In the same table, in the column for accuracy in eighth grade addition, it ranges from 17 in Cities 3 and 12 to 33 in City 10, and 36 in City 15.

According to Mr. Courtis' standard, Indiana still has much to accomplish. He believes variabilities of 12 per cent to 15 per cent represent good work under present conditions. Out of the 816 possible per cents of variability there are 124 that range from 12 to 15, 11 are 11 per cent, 3 are 9 per cent, and 1 is 6 per cent. In several cases the per cent is zero, but the distributions for these cases are so small that they are not generally reliable. Haggerty in his 1914 study places the maximum variability from 20 per cent to 25 per cent. This lower standard would include many more of the total number of per cents of variability in the present study. There are, however, many cases left where there is room for improvement in class organization. Some way must be found to administer more successfully both to the individual child that is behind the standard for his grade, and to the brightest child who should be placed in a different class or given useful things to do along lines in which he is not so proficient.

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VOL. V DECEMBER, 1918

INDIANA UNIVERSITY STUDIES

Study No. 39

PROGRESS AND PROMOTION OF PUPILS IN CERTAIN INDIANA CITY AND RURAL SCHOOLS. By WALTER S. MONROE, Director of the Bureau of Coöperative Research, Indiana University School of Education.

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Foreword

THE data upon which this study is based were collected under the direction of Dean H. L. Smith during the year 1917-18. The details of gathering the data were planned by Mr. W. E. Uphaus and some preliminary tabulations were made by him. The present Director of the Bureau is responsible only for the final form in which the data were arranged and the interpretations which are given. It was originally planned to make the study much more complete by including a larger number of cities, but several superintendents who expected to coöperate were prevented from doing so. It is hoped, however, that the results of these partial studies of certain phases of school organization will prove suggestive and helpful.

WALTER S. MONROE,
Director, Bureau of Coöperative Research.

Progress and Promotion of Pupils in Certain Indiana City and Rural Schools

How the Data were Secured. The portion of this study which deals with the relation between the age of pupils and their progress in school is based upon data from twenty-eight (28) city and town school systems and one county school system.[1] The total number of children included is 29,932.

For the purpose of reporting these data, the usual age-grade blank form was used. It provided for listing the numbers of pupils separately by sex for each half-year age and for each half-school grade. The data called for were based upon the number of pupils "belonging on December 18, 19, 20, 21, 1917" (depending upon the day the study was made). The following directions were printed upon the blank:

2. In securing the number belonging, the following should be construed to terminate membership in school: 1. Death. 2. Withdrawal on notice. 3. Suspension or expulsion. 4. Transfers to other schools, or departments in the same system. 5. Six consecutive half-days' absence.

   In order to obtain fair and impartial information about conditions in the state, it is imperative that pupils in special classes for retarded and defective pupils be included in the age-grade report. Whenever pupils in such classes can be classified with reasonable accuracy on the basis of entrance of one or other of the several regular grades, they should be included in the general report. Whenever they cannot, they should be reported on a separate form arranged by the school.

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[1] The Bureau of Coöperative Research is glad to acknowledge its indebtedness to the following superintendents for furnishing the data upon which this study is based:

School systems having semiannual promotions—Supt. Harry Nixon, Dunkirk; Supt. E. N. Canine, East Chicago; Supt. N. F. Hutchison, Huntingburg; Supt. F. H. Kinney, Ligonier; Supt. C. H. Douglass, Logansport; Supt. L. E. Kelley, Montpelier; Supt. Homer Long, Madison; Supt. J. F. Nuner, South Bend; Supt. O. J. Neighbours, Wabash.

School systems having annual promotions—Supt. Chas. A. Boss, Avilla; Supt. L. B. Job, Boswell; Supt. A. W. Hines, Cambridge City; Supt. H. E. Stahl, Cayuga; Prin. E. L. Lindsall, Ellettsville; Supt. H. C. Clausen, Grovertown; Supt. J. M. Haigerty, Loogootee; Supt. J. H. Thomas, Medora; Prin. Mortimer Lewis, Montmorenci; Supt. I. S. Hahn, Middletown; County Supt. A. B. Oswalt, North Manchester; Supt. J. A. Yager, Owenville; Prin. C. W. Odell, Oxford; County Supt. Harry Evans, Pine Village; County Superintendent Floyd M. Annis, Plymouth, for Marshall County; County Supt. Lee L. Driver, Ridgeville; Supt. O. H. Greist, Union City; Supt. J. M. Leffel, Warsaw; Supt. F. G. Neel, Winamac; Supt. E. B. Rizer, Worthington.

3. **How to record ages.** First find the date of the birth of the pupil from the school records. Then refer to the table given below. The age of the pupil will be found opposite the dates **on which** or **between which** the date of birth falls.

March 2, 1912, to any later date	Under 5½ years
Sept. 2, 1911, to March 1, 1912	5½ years
March 2, 1911, to Sept. 1, 1911	6 years
Sept. 2, 1910, to March 1, 1911	6½ years
March 2, 1910, to Sept. 1, 1910	7 years
Sept. 2, 1909, to March 1, 1910	7½ years
March 2, 1909, to Sept. 1, 1909	8 years
Sept. 2, 1908, to March 1, 1909	8½ years
March 2, 1908, to Sept. 1, 1908	9 years
Sept. 2, 1907, to March 1, 1908	9½ years
March 2, 1907, to Sept. 1, 1907	10 years
Sept. 2, 1906, to March 1, 1907	10½ years
March 2, 1906, to Sept. 1, 1906	11 years
Sept. 2, 1905, to March 1, 1906	11½ years
March 2, 1905, to Sept. 1, 1905	12 years
Sept. 2, 1904, to March 1, 1905	12½ years
March 2, 1904, to Sept. 1, 1904	13 years
Sept. 2, 1903, to March 1, 1904	13½ years
March 2, 1903, to Sept. 1, 1903	14 years
Sept. 2, 1902, to March 1, 1903	14½ years
March 2, 1902, to Sept. 1, 1902	15 years
Sept. 2, 1901, to March 1, 1902	15½ years
March 2, 1901, to Sept. 1, 1901	16 years
Sept. 2, 1900, to March 1, 1901	16½ years
March 2, 1900, to Sept. 1, 1900	17 years
Sept. 2, 1899, to March 1, 1900	17½ years
March 2, 1899, to Sept. 1, 1899	18 years
Sept. 2, 1898, to March 1, 1899	18½ years
March 2, 1898, to Sept. 1, 1898	19 years
Sept. 2, 1897, to March 1, 1898	19½ years
March 2, 1897, to Sept. 1, 1897	20 years
Sept. 2, 1896, to March 1, 1897	20½ years
March 2, 1896, to Sept. 1, 1896	21 years
Sept. 2, 1895, to March 1, 1896	21½ years
Sept. 1, 1895, to any earlier date	Over 21½ years

4. Those schools that do not promote semiannually will use only the 1B, 2B, etc., spaces on the table, leaving 1A, 2A, etc., vacant.

5. **How to assign pupils:**

   a. **In the First Six Elementary Grades and in Grammar Grades where promotion is by grade.** Here pupils will simply be assigned according to the ages and grades in which they are found. Schools that promote by subject below 7B should use the standard for junior high school and grammar grades in (*b*).

b. **In Junior High Schools and Grammar Grades where promotion is by subject.**

7B all pupils having 2 or more subjects of grade 7B and who are not carrying more than one subject in work of a grade below 7B.

7A all pupils having 2 or more subjects of grade 7A and who are not carrying more than one subject in work of a grade below 7A.

8B all pupils having 2 or more subjects of grade 8B and who are not carrying more than one subject in work of a grade below 8B.

8A all pupils having 2 or more subjects of grade 8A and who are not carrying more than one subject in work of a grade below 8A.

c. **In High Schools.** Assign pupils to the grades indicated below if they have completed the number of credits indicated before the beginning of the present school year.

9B all pupils who have completed 0 to 2 semester credits of ordinary high school work, inclusive.

9A all pupils who have completed 3 to 6 semester credits of ordinary high school work, inclusive.

10B all pupils who have completed 7 to 10 semester credits of ordinary high school work, inclusive.

10A all pupils who have completed 11 to 14 semester credits of ordinary high school work, inclusive.

11B all pupils who have completed 15 to 18 semester credits of ordinary high school work, inclusive.

11A all pupils who have completed 19 to 22 semester credits of ordinary high school work, inclusive.

12B all pupils who have completed 23 to 26 semester credits of ordinary high school work, inclusive.

12A all pupils who have completed 27 to 31 semester credits of ordinary high school work, inclusive.

d. Those schools, having yearly promotions only, should consider a semester credit complete if the pupil has satisfactorily passed the half year's work in a subject. The pupil should then be classified as indicated above.

6. Since 6 years to 6½ years is considered the normal age for entering the 1B grade, all pupils recorded in the heavy rectangular figures of the age-grade table are considered normal in age and progress. Those of any grade recorded above this rectangle are accelerated; those below the rectangle are retarded. The degree of acceleration or retardation may be determined by noting the number of half-years any individual or group is from the rectangle. Spaces have also been allowed for tabulating the total number of normal, accelerated, and retarded pupils for each grade.

7. **Record sexes separately.**

2—16697

TABLE I

Distribution of Boys According to Age in Each Grade. Systems Having Annual Promotion

Grade	Age 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
I	78	303	87	29	6	3	2	.....	3	.....	.....	.....	.....	.....	.....	.....	.....	511
II	1	74	243	101	30	14	9	2	1	1	.....	1	.....	.....	.....	.....	.....	477
III	.....	4	74	222	134	47	16	13	2	2	.....	1	.....	.....	.....	.....	.....	515
IV	.....	.....	1	74	223	121	63	27	12	2	1	.....	.....	.....	.....	.....	.....	524
V	.....	.....	.....	3	62	215	88	58	18	5	6	.....	.....	.....	.....	.....	.....	455
VI	.....	.....	.....	.....	1	51	168	112	72	42	14	1	.....	.....	.....	.....	.....	461
VII	.....	.....	.....	.....	.....	21	60	154	106	76	22	7	3	1	.....	.....	.....	450
VIII	.....	.....	.....	.....	.....	.....	5	71	187	91	50	8	2	.....	.....	.....	.....	414
IX	.....	.....	.....	.....	.....	.....	.....	7	68	106	57	34	21	12	7	.....	.....	312
X	.....	.....	.....	.....	.....	.....	.....	.....	5	38	82	39	18	1	.....	.....	.....	183
XI	.....	.....	.....	.....	.....	.....	.....	.....	1	5	35	66	34	12	8	1	.....	162
XII	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	30	43	34	8	6	1	123
Total	79	381	405	429	456	472	411	444	475	368	268	187	121	60	23	7	1	4,587

TABLE II

DISTRIBUTION OF GIRLS ACCORDING TO AGE IN EACH GRADE. SYSTEMS HAVING ANNUAL PROMOTION

GRADE	AGE																	TOTAL
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
I	88	298	57	14	4	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	462
II	1	96	243	75	12	5	2	1	1	.....	.....	1	.....	.....	.....	.....	.....	437
III	.....	2	100	239	82	28	7	11	3	1	1	.....	.....	.....	.....	.....	.....	474
IV	.....	.....	4	79	217	91	37	31	11	4	3	.....	.....	.....	.....	.....	.....	477
V	.....	.....	1	9	76	216	103	51	19	3	2	.....	.....	.....	.....	.....	.....	480
VI	.....	.....	.....	.....	.....	23	141	121	58	36	13	4	1	.....	.....	.....	.....	397
VII	.....	.....	.....	.....	.....	29	61	152	106	44	10	3	.....	.....	.....	.....	.....	405
VIII	.....	.....	.....	.....	.....	.....	9	78	164	93	43	12	2	.....	.....	.....	.....	401
IX	.....	.....	.....	.....	.....	.....	.....	6	67	136	73	15	3	2	.....	.....	.....	302
X	.....	.....	.....	.....	.....	.....	.....	.....	5	42	93	47	15	2	2	.....	.....	206
XI	.....	.....	.....	.....	.....	.....	.....	.....	.....	4	65	75	46	6	1	1	.....	198
XII	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7	38	81	47	12	3	2	190
Total	89	396	405	416	391	392	360	452	434	363	310	195	148	57	15	4	2	4,429

TABLE III

DISTRIBUTION OF BOYS AND GIRLS ACCORDING TO AGE IN EACH GRADE. SYSTEMS HAVING ANNUAL PROMOTION

Grade	Age																	Total
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
I	166	601	144	43	10	3	2	1	3									973
II	2	170	486	176	42	19	11	3	2	1		2						914
III		6	174	461	216	75	23	24	5	3	1	1						989
IV			5	153	440	212	100	58	23	6	4							1,001
V			1	12	138	431	191	109	37	8	8							935
VI					1	74	309	233	130	78	27	5	1					858
VII						50	121	306	212	120	32	10	3	1				855
VIII							14	149	351	184	93	20	4					815
IX								13	135	242	130	49	24	14	7			614
X									10	80	175	86	33	3	2			389
XI									1	9	100	141	80	18	9	2		360
XII											8	68	124	81	20	9	3	313
Total	168	777	810	845	847	864	771	896	909	731	578	382	269	117	38	11	3	9,016

TABLE IV

DISTRIBUTION OF BOYS ACCORDING TO AGE IN EACH HALF-GRADE. SYSTEMS HAVING SEMIANNUAL PROMOTION

Grade		Age																	Total
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
I	B	201	684	188	43	8	1	....	1	....	....	....	....	....	....	....	....	....	1,126
I	A	8	210	250	74	15	9	3	1	1	....	....	....	....	....	....	....	....	571
II	B	2	104	452	175	52	25	9	3	....	1	....	....	....	....	....	....	....	823
II	A	1	14	177	216	109	32	10	4	2	1	....	....	....	....	....	....	....	566
III	B	....	4	79	355	191	83	33	16	7	1	....	....	....	....	....	....	....	769
III	A	....	....	28	159	203	98	57	24	7	2	3	....	....	....	....	....	....	581
IV	B	....	....	2	80	321	185	81	42	22	8	5	....	....	....	....	....	....	746
IV	A	....	....	3	23	142	177	93	59	34	16	3	....	....	....	....	....	....	550
V	B	....	....	....	4	93	261	180	96	45	19	8	....	....	....	....	....	....	706
V	A	....	....	....	....	16	103	163	93	56	21	11	1	....	....	....	....	....	464
VI	B	....	....	....	1	8	83	185	160	121	25	14	....	....	....	....	....	....	597
VI	A	....	....	....	....	4	17	79	113	81	22	13	2	....	....	....	....	....	331
VII	B	....	....	....	....	....	14	58	183	147	77	20	5	....	....	....	....	....	504
VII	A	....	....	....	....	....	2	30	88	104	57	10	5	....	....	....	....	....	296
VIII	B	....	....	....	....	....	....	6	62	136	76	30	5	2	....	....	....	....	317
VIII	A	....	....	....	....	....	....	4	17	64	62	36	6	2	....	....	....	....	191
IX	B	....	....	....	....	....	....	....	8	44	164	97	51	15	....	....	....	....	379
IX	A	....	....	....	....	....	....	....	....	9	48	46	32	10	4	....	....	....	149
X	B	....	....	....	....	....	....	....	....	4	30	103	43	16	7	1	....	....	204
X	A	....	....	....	....	....	....	....	....	1	8	34	38	30	13	6	....	....	130
XI	B	....	....	....	....	....	....	....	....	....	10	30	47	32	11	8	1	....	139
XI	A	....	....	....	....	....	....	....	....	....	2	2	22	25	14	3	....	....	68
XII	B	....	....	....	....	....	....	....	....	....	1	4	33	53	38	8	4	1	142
XII	A	....	....	....	....	....	....	....	....	....	....	....	4	11	7	7	....	....	29
Total		212	1,016	1,179	1,130	1,162	1,090	991	970	885	1,651	469	294	196	94	33	5	1	10,378

TABLE V

Distribution of Girls According to Age in Each Half-Grade. Systems Having Semiannual Promotion

Grade		Age 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
I	B	204	732	163	34	7	1												1,141
I	A	12	160	197	62	20	8	1	1										461
II	B	1	103	509	137	38	8	4	3	1									804
II	A		16	185	207	66	23	11	1	2									511
III	B		3	104	397	176	66	17	12	1	1								777
III	A		1	23	166	181	97	37	15	1	1	3							525
IV	B			8	90	344	163	68	26	8	4								711
IV	A			3	54	171	120	74	54	22	5	1							504
V	B				3	104	307	167	87	36	15	3		1					723
V	A					30	121	132	85	48	14	2	1						433
VI	B					7	79	254	125	88	21	2	1						577
VI	A					1	24	134	132	77	28	6							402
VII	B						5	75	227	150	52	11	2						522
VII	A						1	26	110	112	48	9	3						309
VIII	B						1	9	95	199	107	27	12						450
VIII	A							3	16	82	58	43	8	2					212
IX	B								5	77	199	87	35	5	2	1			411
IX	A								1	10	41	68	21	14					155
X	B									3	47	117	62	13	3				245
X	A										7	39	30	14	5	1	1		97
XI	B										7	50	89	57	8	1	1		213
XI	A										3	15	35	16	9	2			80
XII	B									2	1	24	88	81	20	5			221
XII	A											3	16	21	9	5			54
Total		217	1,015	1,192	1,150	1,145	1,024	1,012	995	919	659	510	403	224	56	15	2	....	10,538

TABLE VI

Distribution of Boys and Girls According to Age in Each Half-Grade. Systems Having Semiannual Promotion

Grade		Age																	Total
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
I	B	405	1,416	351	77	15	2		1										2,267
I	A	20	370	447	136	35	17	4	2	1									1,032
II	B	3	207	961	312	90	33	13	6	1	1								1,627
II	A	1	30	362	423	175	55	21	5	4	1								1,077
III	B		7	183	752	367	149	50	28	8	2								1,546
III	A		1	51	325	384	195	94	39	8	3	6							1,106
IV	B			10	170	665	348	149	68	30	12	5							1,457
IV	A			6	77	313	297	167	113	56	21	4							1,054
V	B				7	197	568	347	183	81	34	11							1,429
V	A					46	224	295	178	104	35	13	2						897
VI	B				1	15	162	439	285	209	46	16	1						1,174
VI	A					5	41	213	245	158	50	19	2						733
VII	B						19	133	410	297	129	31	7						1,026
VII	A						3	56	198	216	105	19	8						605
VIII	B						1	15	157	335	183	57	17	2					767
VIII	A							7	33	146	120	79	14	4					403
IX	B								13	121	363	184	86	20	2	1			790
IX	A								1	19	89	114	53	24	4				304
X	B									7	77	220	105	29	10	1			449
X	A									1	15	73	68	44	18	7	1		227
XI	B										17	80	136	89	19	9	2		352
XI	A									2	5	17	57	41	23	5			148
XII	B										2	28	121	134	58	13	4	1	363
XII	A											3	20	32	16	12			83
Total		429	2,031	2,371	2,280	2,307	2,114	2,003	1,965	1,804	1,310	979	697	420	150	48	7	1	20,916

General Summary—Age-Grade Tables. Of the school systems reporting, nine have semiannual promotion and twenty have annual promotion. The returns from these two groups of school systems were compiled separately so that in the tables and figures which follow it is possible to make comparisons between these two types of school organization.

In the group of twenty school systems having annual promotion there is included one county system with the excep-

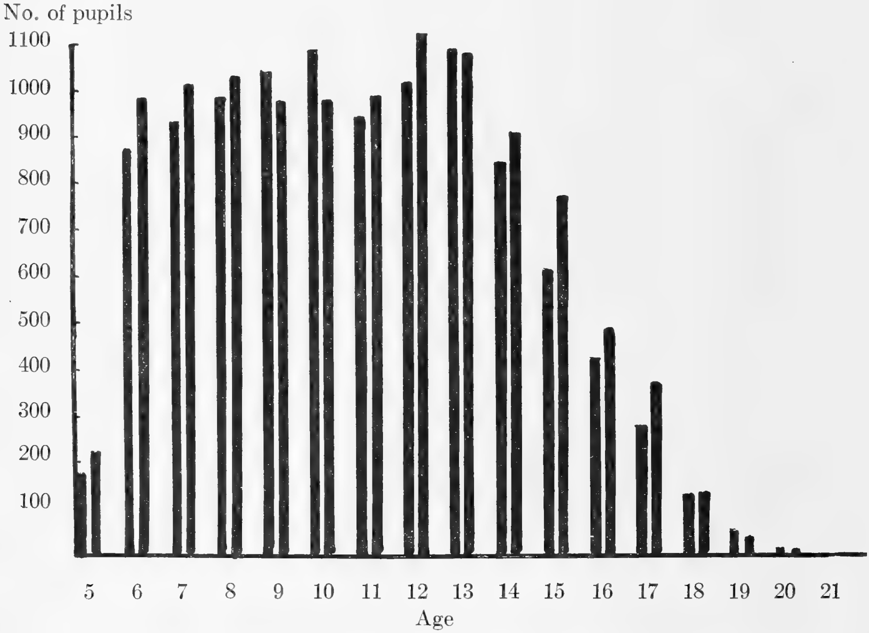

FIG. 1. Showing the distribution of the number of boys and girls in each age-group on the basis of 1,000 in the average of the age-groups 7 to 12. The first line for each age-group represents boys and the second line girls. Systems having annual promotion.

tion of one city and three towns. The number of children reported is approximately 3,000, or one-third of the total number in this group. Of this total about 2,000 are from rural schools. However, to avoid awkward statements, we shall not specify this fact each time this group of school systems is mentioned in the following papers.

Tables I to VI inclusive give a general summary for these two groups of school systems of the age of the pupils "belonging" on December 18 to 21, 1917, recorded as of September 1, in relation to their progress in school. In the original tabulations the ages were given by half-year intervals but, since this finer grouping did not appear significant, an interval of one year is used in this report.

Table I should be read as follows: In Grade I, there were 78 five-year-old boys, 303 six-year-old boys, 87 seven-year-old boys, etc. The total number was 511. The facts for the other grades are read in the same way. The "total" column

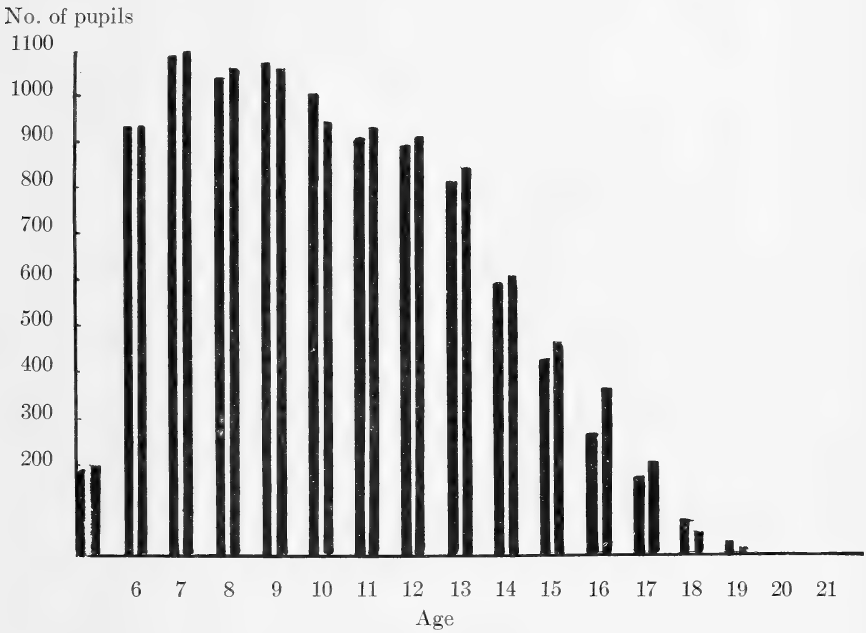

FIG. 2. Showing the distribution of the number of boys and girls in each age-group on the basis of 1,000 in the average of the age-groups 7 to 12. The first line for each age-group represents boys and the second line girls. Systems having semiannual promotion.

at the right gives the number of pupils in the successive grades and will be referred to as the "grade distribution". The "total" line at the bottom gives the number of pupils in the different age groups. It will be referred to as the "age distribution". Tables II to VI are read in the same way.

Problems Studied. The facts presented in Tables I to VI make possible the study of two fundamental educational problems.

I. *Elimination.* To what extent do the schools hold children after they pass beyond the age of compulsory attendance? This is important because if a child starts to school when six and makes regular progress he has only finished the eighth grade at the age of fourteen. If he leaves school at this age he has failed to take advantage of the high school opportunities which the community offers. This, however, is the most favorable case. At fourteen, only 44 per cent of

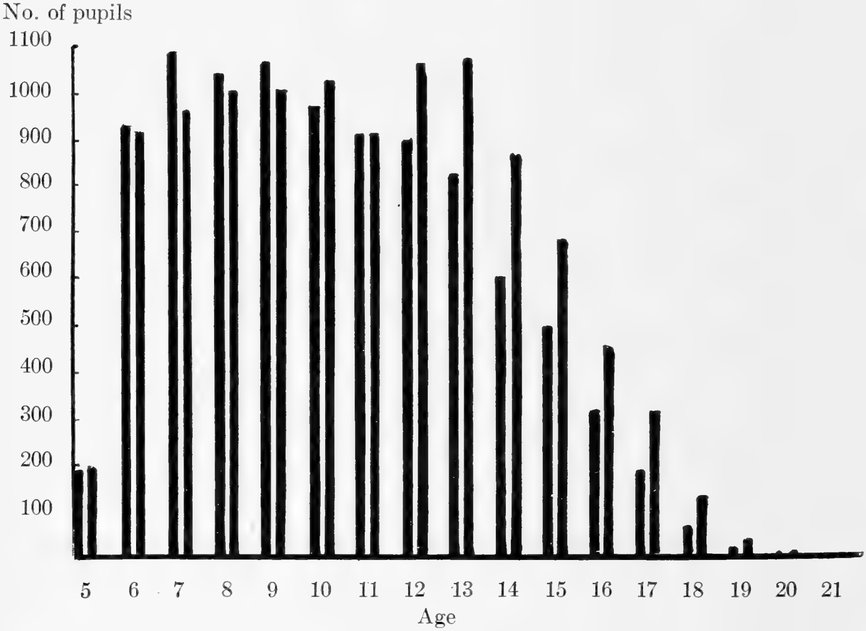

FIG. 3. Showing the total number "belonging" in systems having semiannual promotion and in systems having annual promotion in each age-group on basis of 1,000 in the average of the age-group 7 to 12. For each age-group the left line represents systems having semiannual promotion and the right line represents systems having annual promotion.

the children in the schools studied had completed the eighth grade and for the remaining 54 per cent, their leaving school at fourteen means that they have not obtained even a "common school" education.

II. *Progress.* The other problem concerns the progress of those pupils who are in school. It is important that children be in school, but it is even more important how they respond to the instruction which the school offers. In case they fail to respond satisfactorily and the school asks them to repeat the work of the year, the expense of the instruction for that year has been largely wasted, and, more important, pupils' time and efforts have also been largely wasted. The extent to which children respond in a manner which the school considers satisfactory is indicated by the progress of the children thru the several grades.

I. THE ELIMINATION OF PUPILS

Legal Provisions for Compulsory Attendance. The school laws of the state of Indiana provide for compulsory attendance as follows:

1. It shall be the duty of every parent, guardian, or other person, in the state of Indiana, having the control or charge of any child, to cause such child to attend regularly a public, private, or parochial day-school, or two or more of such schools, during each school year for a term or period not shorter than that of the common schools of the school corporation in this state where the child resides. This section shall apply to every child not physically or mentally disqualified as hereinafter provided, who shall be of the age of *seven* years and of not more than the age of *fourteen* years, and shall apply to every child of fourteen years or more and not more than sixteen years of age, who is not actually and regularly employed, during the hours of the common school of such school corporation, in a useful employment or service, or is not lawfully employed in a gainful service agreeably to the provisions of this act concerning the employment of children in gainful *occupations.*

2. No child under sixteen years of age who under the provisions of this act would otherwise be required to attend school, shall be employed in any occupation during hours wherein the common schools at the residence of the child are in session, unless the child shall have attained the age of fourteen years and shall have procured a certificate from the executive officer of the common school corporation of which the child is a resident, or some person designated by him, showing the age, date and place of birth, if known, or ascertainable, of such child and showing that the child has passed the *fifth* grade in the common schools, or its equivalent.[2]

Upon the basis of these provisions we may expect that from the age of seven up to the age of fourteen all children who are physically and mentally fit will be in some school. From fourteen to sixteen a certain per cent will be excused, and after a child becomes sixteen his attendance is entirely voluntary.

[2] "Laws of Indiana relating to the Public School System," 1917, pages 263 and 264.

The extent to which children remain in school after they become sixteen becomes an index of the holding power of the school. From the point of view of its social function it is a measure of the efficiency of the school. Other things being equal, that school is serving its community best which is holding the largest per cent of the children until they complete the work of the high school.

Two Methods of Studying Elimination. The elimination of children from the schools may be studied in two ways: (1) on the basis of the number of children in each *age group;* (2) on the basis of the number of children in each *grade group.* The first method will enable us to say at *what age* children leave school. The second leads to a statement of the *grades which the children reach* before leaving school. Both methods will be used in studying the facts of Tables I to VI.

(1) Age Distributions of Children. The age totals in Tables I to VI show that some children, about twenty per cent, start to the public schools at the age of five, and about seventy per cent enter at six. From seven up to fourteen the number of pupils in the different age groups is reasonably constant, but beginning with the age of fourteen there is a marked decrease in the numbers. In those systems having a semiannual promotion, the age of fourteen appears to be anticipated because there is a noticeable decrease in the number of the thirteen-year-old pupils.

A Common Basis of Comparison. Before we can compare the several age distributions, they must be reduced to a common basis. The most satisfactory method would be to ascertain the *total* number of children of each age and calculate the per cent "belonging" in school. Unfortunately, this information is not at hand.

We may, however, assume that the age groups, seven to twelve inclusive, represent approximately the actual number of children of the respective ages. Four factors, (1) temporary termination of school membership, (2) physical or mental unfitness, (3) attendance at private or parochial school, and (4) non-enforcement of the compulsory attendance law, tend to reduce the number of pupils slightly. We have no data to show the effect of these factors.

The effect of the first two is probably constant for all ages and consequently negligible for this purpose. Attendance at private and parochial schools is variable between cities and in some cases affects certain ages more than others. Violations of the compulsory attendance law probably affects the older group more than the younger. On the other hand, the attendance of children from outside of the school district tends to increase the number of older children.

The population factors of death and normal increase in population affect the relative size of the successive age groups. The normal increase in population makes each age group slightly larger than the preceding. Thus in general there are more eight-year-old children than are children nine years old, more seven-year-old children than are children eight years old, etc. The factor of death adds to this condition. Hence, we should expect to find a slight decrease in the number of children from the younger to the older grade groups.

In order to have a basis of comparison we have used in this study the average of the six age groups, seven to twelve, as the most probable number of children of each age. While this may be considered the most probable number, it is necessary to bear in mind that it is only approximate and that many factors affect the age distributions.

Table VII gives the number of children in each age group on the basis of 1,000 in this average age group. It should be read as follows: Out of 1,000 five-year-old boys, 195 were in school in the systems having semiannual promotion. On the same basis there were 199 five-year-old girls and counting both boys and girls, the number was 197. In certain of the groups there are more than 1,000. Theoretically this is not possible, but it results from the slight lack of uniformity of the age groups of which the average was taken. Most of these variations are probably due to chance. The eleven-year-old group presents an interesting variation, which appears to be due to a cause which this investigation does not reveal.

The facts of Table VII are represented graphically in Figures 1, 2, and 3. Figure 1 shows the distribution of the boys and girls according to age in the systems having annual promotion. For each age group there are two vertical lines. The left one represents the number of boys and the right one the number of girls. Figure 2 represents the same facts for the other group of school systems. In Figure 3 the "totals" for the two groups are shown. The left line is for the systems having semiannual promotion. The right line is for the other group of school systems.

Sex Differences. The sex differences for the systems having semiannual promotion (Figure 2) are slight. There is an indication that the girls stay in school a little better than the boys. In Figure 1, which is for the other group of school systems, this condition is more pronounced.

TABLE VII

Distribution of Pupils According to Age Reduced to Basis of 1,000 in Average of 7 to 12 Age Groups

	Systems Having Semiannual Promotion			Systems Having Annual Promotion		
Age	Boys	Girls	Total	Boys	Girls	Total
5......	195	199	197	181	221	203
6......	935	934	934	873	985	937
7......	1,085	1,097	1,091	928	1,007	977
8......	1,040	1,058	1,049	983	1,034	1,019
9......	1,069	1,050	1,061	1,045	972	1,021
10......	1,003	943	972	1,082	975	1,042
11......	913	931	921	942	895	930
12......	892	916	904	1,018	1,124	1,081
13......	814	846	830	1,089	1,079	1,096
14......	598	606	602	844	902	882
15......	431	469	450	614	771	697
16......	270	371	320	428	485	461
17......	180	206	193	277	368	324
18......	86	51	690	137	142	141
19......	30	13	22	52	37	46
20......	4	1	3	16	9	13
21......	1	0	0.4	2	4	3.5

Group Differences. Figure 3 is the most significant. It it clear that above the age of eleven the school systems having annual promotion have relatively more children in school. This probably means that they are holding the children better, altho we cannot be certain because of the influencing factors mentioned above, particularly that of nonresident attendance.

One should not conclude that this difference is due to the difference in the organization of the two groups of school systems, since a number of other factors enter into the situation, such as the social and economic conditions, the per cent of foreign children, the size of the school systems, etc. This study shows only the condition which exists. It does not reveal the cause. The determination of the cause is a problem for future study. Its solution should be of special interest to superintendents in cities having semiannual promotion.

(2) Grade Distributions of Children. The same question (the elimination of children from the public schools) can also be studied by considering the distribution of the children in the several grades which are given in the column marked "total" in Tables I to VI. It is more important that a child reach a certain grade in school than that he remain in school until a specified age. Our public school course is twelve years in length. If a pupil enters at the age of six, which is the most frequent age, and progresses regularly, he will be eighteen when he completes the course. If he drops out before this age, he has failed to take advantage of the educational opportunities which the community offers him, unless he either started to school before he was six or has made rapid progress. Relatively few cases come under these two heads. On the other hand, a large per cent of children fail and take more than twelve years to finish the course. Hence, the age of a child is not a reliable index of the progress he has made. This is very obvious in Tables I to VI. Children of every age except the youngest are to be found in several different grades.

Table VIII gives the number of children in each grade for both groups of school systems reduced to the basis of 1,000 in the first grade. The most noticeable thing is the very rapid decrease of the number of children in those systems having semiannual promotions and that the decrease is much greater than that for those systems having annual promotions. In the systems having semiannual promotions the table suggests that out of 1,000 pupils who enter the first grade, 819 reach the second grade, 803 reach the third grade, 354 reach the last year of the elementary school, and 135 reach the twelfth grade. This table, however, is not subject to such simple interpretation. The number of pupils in the first grade consists of those who started to school in September, 1917, plus those who were not promoted from the first grade in May, 1917, and those who have been dropped to enter the first grade, less those who were dropped before December 19 to 23. The number of pupils in the fourth grade consists of (1) those of the 1,000 who started to school in September, 1914, and who have made regular progress; (2) those who were in the fourth grade in May, 1917, and were not promoted; and (3) those who started to school after September, 1914, and who have made rapid progress, i.e. have skipped a grade without being retarded at any time. Thus, the fourth grade includes several pupils who started to school before September, 1914, and some who entered at a later date. On the other hand, not all of the 1,000 remain in the

TABLE VIII

Number of Children Belonging in Each Grade for Both Groups of Systems, Reduced to Basis of 1,000 in First Grade

Grade	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Systems having annual promotion											
Number of Children	1,000	939	1,016	1,028	960	881	878	837	631	399	369	321
	Systems having semiannual promotion											
Number of Children	1,000	819	803	761	705	578	494	354	331	204	151	135

fourth grade. Some have become retarded and are now counted in grades below the fourth, while others who have been permitted to skip a grade are found in grades above the fourth. A small number have died or did not "belong" on the date the census was taken.

Still another factor must be taken into consideration. Because of the increase in population, the number entering school in these cities in 1914 was larger than the number which entered in any preceding year. If all other factors affecting the grade distribution were eliminated this one would cause a slight decrease in the number of pupils from grade to grade.

Thus there are four factors affecting the distribution of pupils in the several grades: (1) termination of membership in the school, (2) increase in population, (3) retardation, and (4) acceleration. The termination of membership in the school occurs in several ways: (*a*) by death, which is a relatively small factor; (*b*) by temporary absence of more than "six consecutive half-days' absence"; (*c*) by suspension or expulsion; and (*d*) permanent withdrawals. This last cause becomes the most dominating one after the age of thirteen is reached. Theoretically, it should not occur until after fourteen is reached, but as Tables I to VI show some children anticipate the age of fourteen by leaving school when only thirteen.

An additional factor should be included when data from public schools only are considered. Some children attend parochial schools during a portion or all of their school career below college. If they attend during all of the period, the grade distribution will not be affected, but when at certain grades a transfer is made to or from parochial schools, the grade distribution is affected.

TABLE IX

Grade Distribution as Influenced by Death and Increase of Population

GRADE	PUPILS
First Grade	1,000
Second Grade	985
Third Grade	964
Fourth Grade	938
Fifth Grade	920
Sixth Grade	904
Seventh Grade	889
Eight Grade	871

The effect of the termination of membership on account of death and the increase of population has been calculated by Ayres for the first eight grades. Table IX shows the number of pupils which we would find in each grade if only these two factors affected the grade distribution. This would be the case if all pupils were promoted, none accelerated, and none left school.

Number of Pupils Entering School. Before it will be possible to interpret the facts of grade distributions it will be necessary to know the number of pupils who enter school each year. This information was not collected. Incidentally, it may be remarked that it is seldom available in superintendents' reports. Therefore, it is necessary to compute the probable number entering. Three methods of calculating this number from the age-grade data have been proposed. Thorndike[3] proposed that the average of the enrollment in the first three grades, less certain corrections, be taken as the number of pupils entering the first grade. Ayres[4] proposed that the average of the age groups from seven to twelve be taken. It will be noted that these are the years during which attendance is required by law in most states. Strayer[5] took the largest age group. In this study Ayres's method has been used.

Grade Distributions Reduced to Basis of 1,000 entering the First Grade. Table X shows the number of pupils in each grade for 1,000 entering for both groups of Indiana school systems and for certain cities and other groups. This shows that in the systems having annual promotion there are 1,161 children in the first grade. We have assumed that 1,000 entered. Hence, 161 are repeating the year's work. If there were no eliminations and all children were promoted regularly, there would be 1,000 in each grade. Up to the eighth there are more than this number in each grade. In the eighth there are 972, and in the twelfth there are 373. Disregarding the factors mentioned on page 21, we may say that in the systems having annual promotion out of 1,000 pupils who enter school, 972 reach the last year of the elementary school and 373 reach the last year of the high school. The facts for the other systems are to be read in the same way.

Figure 4 represents graphically for the systems having annual promotion the number of children belonging in each grade (1) upon the basis of 1,000 in the first grade (Table VIII), (2) upon the basis of 1,000 entering, and (3) considering only the populations factor. Figure 5 shows the same facts for the other group of systems. It shows in an effective way the rapid decrease in the number of pupils from grade to grade. This is very much more rapid than in Figure 4.

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[3] Thorndike, E. L. "The Elimination of Children from School," U.S. Bureau of Education *Bulletin* No. 4, 1907.

[4] Ayres, L. P. *Laggards in Our Schools: a Study of Retardation and Elimination in City School Systems.* New York Charities Publication Committee, 1909.

[5] Strayer, G. D. "Age and Grade Census of Schools and Colleges." U.S. Bureau of Education *Bulletin* No. 5, 1911.

According to Table X the population factors reduce the number of children in the eighth grade to 871. In the systems having annual promotion there are 972 in the eighth

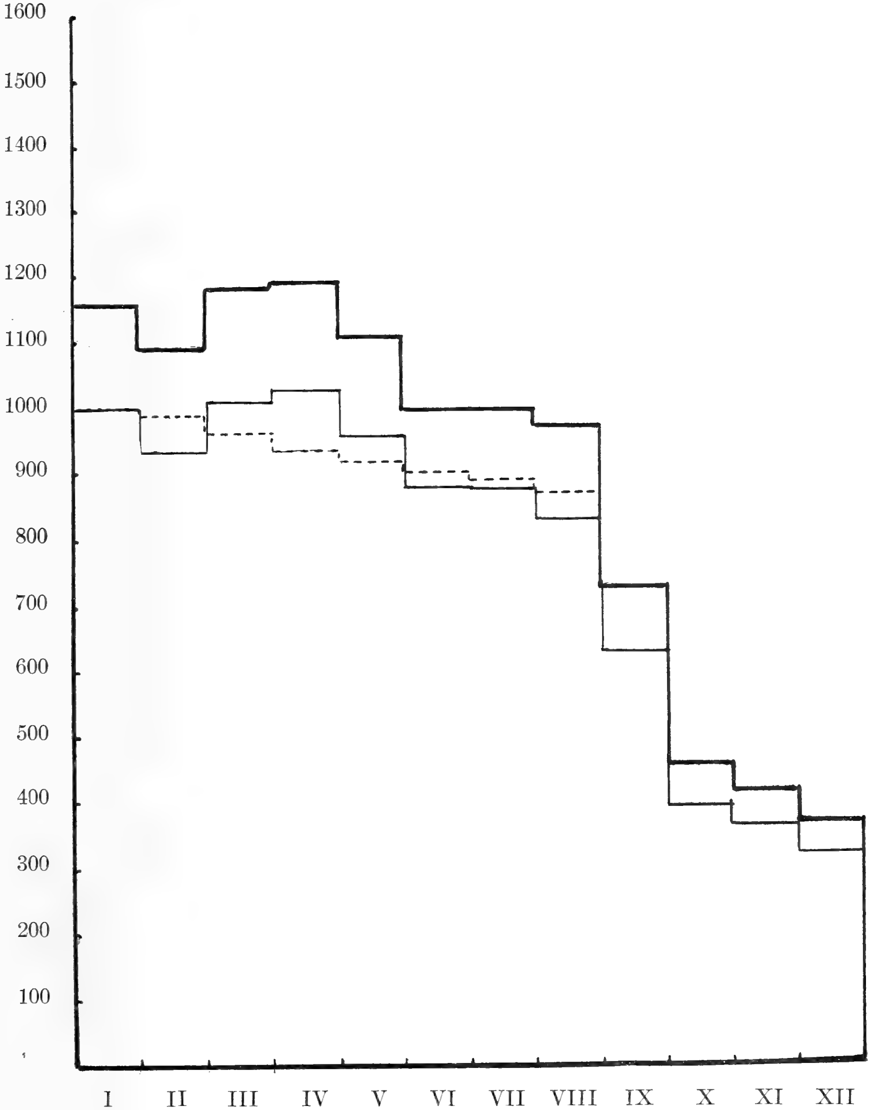

FIG. 4. Showing the number belonging in each grade on the basis of 1,000 entering school (upper line), on basis of 1,000 in the first grade (lower line) and the distribution as it would be if affected only by population factors (dotted line). Systems having annual promotion.

grade. This unexpected situation may be due to the population's not having increased in the estimated way, but it is more probable that it is caused by nonresident attendance. How-

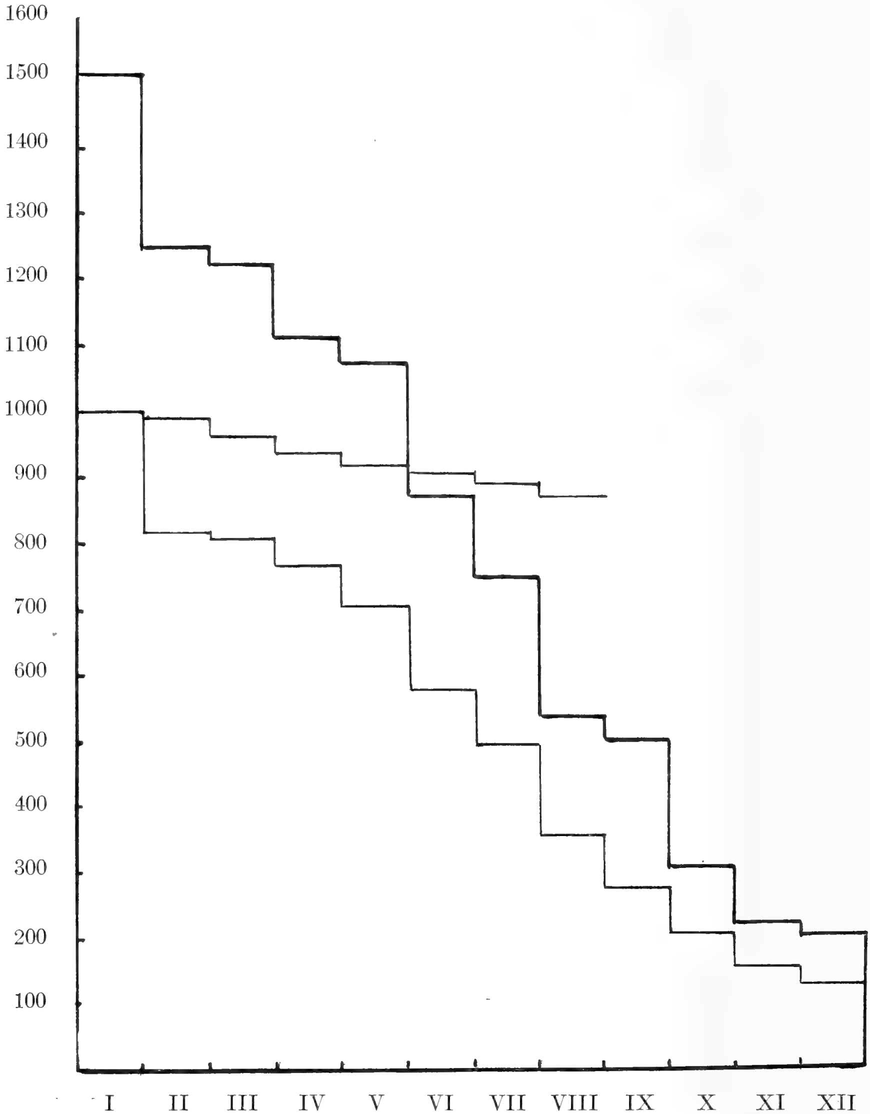

FIG. 5. Showing the number belonging in each grade on the basis of 1,000 entering school (upper line), on basis of 1,000 in the first grade (lower line), and the distribution as it would be if affected by only population factors. Systems having semiannual promotion.

ever, it is probable that the schools of this group hold most of their pupils as far as the eighth grade. It is significant that nearly two out of three fail to reach the fourth year of the high school. In the other group of systems only a little more than half of the children reach the eighth grade, and only one in five reach the fourth year of the high school.

Comparison with Other Systems. When we compare these data with similar data from other systems, it appears that the elimination in Indiana systems having annual promotion is less than in other systems. In the other group it is slightly greater. Comparisons, however, must be made with reservations because the facts for the other cities are for different years and were not collected at the same time of the school year. In the case of the "fourteen Kansas cities" the number entering was taken as the average of the four age groups, eight to eleven. In this case, also, the figures represent the number of children "actually in attendance some time during the last month of the school year" instead of the "number belonging" on a certain day in December. However, it is safe to say that the elimination in these Indiana cities is distinctly less than Ayres found it to be in fifty-nine (59) cities in 1907. It is also less than Thorndike's determination (80 out of 1,000 reaching the fourth year of the high school) and Strayer's determination (150 out of 1,000 reaching the fourth year of the high school).

Comparison of Systems. Grade Distributions. In Table XI the grade distributions for the systems having semiannual promotion are given. It is significant that with the exception of two systems (the extremes) there is a high degree of uniformity in the number of children in the first grade. In fact, uniformity is more significant than the differences. There are, of course, certain conspicuous variations from the general tendency. These are doubtless due for the most part to certain peculiar local conditions in the cities in which they occur. For this reason no interpretation is attempted in the report. Because the number of children in each grade is so small, the corresponding table for the other groups of school systems is not given.

TABLE X

SHOWING NUMBER BELONGING IN EACH GRADE ON THE BASIS OF 1,000 ENTERING SCHOOL EACH YEAR. NUMBER ENTERING DETERMINED BY AYRES'S METHOD

GRADE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Systems having annual promotion Dec., 1917	1,161	1,090	1,180	1,194	1,115	1,023	1,020	972	732	464	429	373
Systems having semi-annual promotion, Dec., 1917	1,513	1,245	1,220	1,155	1,075	877	750	538	503	311	230	205
Theoretical distribution produced by death and increase of population (Ayres)[1]	1,000	985	964	938	920	904	889	871	....	....	....	....
Median of 59 cities (1907, Ayres)	1,730	1,290	1,280	1,200	1,060	900	710	510	400	190	140	100
386 cities (1907, Ayres)	1,809	1,309	1,254	1,158	1,000	837	667	477	....	....	....	....
366 villages (1907, Ayres)	1,748	1,262	1,208	1,137	1,000	851	720	553	....	....	....	....
Rochester, N. Y.[2] Sept., 1916	1,410	1,334	1,255	1,108	1,091	1,012	562	484	....	....	....	....
Salt Lake City[3] May, 1915	1,596	1,101	1,266	1,178	1,096	982	865	727	427	257	178	114
Fourteen Kansas[4] cities, 1915-16	1,450	1,192	1,185	1,163	1,082	988	860	678	586	488	323	250

[1]The items marked (Ayres) are taken from "Laggards in Our Schools," by L. P. Ayres.
[2]The data for Rochester, N. Y., are from an unpublished report by Assistant Superintendent, J. P. O'Hern.
[3]The data for Salt Lake City are taken from the "Report of the Salt Lake City School Survey".
[4]The data for "Fourteen Kansas Cities" are taken from an unpublished study by Dean F. J. Kelly. In this the average of the age groups 8 to 11 were taken as the number entering. In all other cases the averages of groups 7 to 12 were taken.

TABLE XI

Showing Number Belonging in Each Grade on the Basis of 1,000 Entering School Each Year. Systems Having Semiannual Promotion

System	Number Entering	Grade											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
B	302	1,632	1,198	1,099	1,152	1,201	917	1,006	685	635	390	423	215
H	372	1,553	1,279	1,290	1,056	1,048	784	626	473	252	123	75	72
A	51	1,509	784	1,019	1,137	960	980	1,098	470	764	411	509	313
I	861	1,494	1,296	1,290	1,161	1,078	832	674	495	450	285	193	176
J	96	1,479	1,400	1,458	1,156	1,000	906	614	406	562	406	270	281
G	193	1,445	1,217	1,170	1,238	1,041	834	678	461	637	269	196	196
D	167	1,401	1,155	1,107	1,215	850	1,209	808	754	538	389	347	317
E	48	1,375	1,208	1,104	1,229	958	1,145	625	625	687	395	395	375
F	51	1,352	1,431	1,000	1,000	1,137	1,000	1,137	647	941	509	176	352
C	27	962	1,185	814	1,481	1,037	592	1,666	1,074	1,000	777	667	1,185

II. PROGRESS

Evidence of Progress other than Normal. Evidence that some pupils have not made normal progress, i.e. have not been promoted each year or have skipped grades, is contained in Tables I to VI. Consider, for example, Table III which is typical. In view of the fact that the provision of the compulsory attendance law requires that children attend school between the ages of seven and fourteen, the age distribution of the first grade children is evidence that some must be retarded. It is safe to assume that with very few exceptions all children in this grade who are eight years of age or over have failed of promotion at least once. Probably a number of the seven-year-old children are retarded.

In the first grade the largest age group (601) is the six-year-old which is what is to be expected, since most children start to school at this age. In the second grade the largest age group is the seven-year-old but has decreased to 486. If this "normal" group is traced thru the successive grades we find that in the eighth grade the largest age group is the thirteen-year-old which has 351 children. The population factors would tend to reduce this "normal" group slightly, but not to this extent. Thus we have here additional evidence that some pupils do not make normal progress.

Methods of Computing the Amount of Retardation and Acceleration. For computing the amount of retardation (overage) and of acceleration (underage) from age-grade tables such as Tables I to VI, two methods have been used. The *first* method is to consider that six years is the normal age for the first grade, seven years is the normal age for the second grade, etc. According to this method, the normal age for IB is from six to six and a half, IA from six and a half to seven, IIB from seven to seven and a half, etc. Children who are older than the "normal" age for the grade are counted as overage or retarded. Those who are younger than the "normal" age are counted as underage or accelerated. According to the *second* method, six or seven years is the "normal" age for the second grade, etc. When the progress of pupils is expressed in half-grades, a modification of allowing a year for each half-grade is sometimes used.

Criticism and Limitations of These Methods. In 1909 L. P. Ayres stated with reference to the second method "These ages have been accepted by common consent as the 'normal ages' for these grades by nearly all school men who have interested themselves in the problem."[6] Some school men have pointed out that this popularity of the second method was due to the fact that it gave a much lower amount of retardation than the first method. The difference in the amount of retardation for the two groups of Indiana school systems is shown in Table XII. The magnitude of this difference is striking.

TABLE XII

PER CENT OF RETARDATION BY METHODS I AND II

GRADE	SYSTEMS HAVING ANNUAL PROMOTION		SYSTEMS HAVING SEMIANNUAL PROMOTION	
	I	II	I	II
I	21	6	33	9
II	28	9	42	15
III	35	13	50	22
IV	40	19	51	25
V	38	17	55	28
VI	55	28	54	25
VII	44	17	50	18
VIII	37	14	41	15
IX	36	15	45	17
X	32	10	42	16
XI	30	8	38	12
XII	36	10	23	7

The true per cent of retardation is probably between the amounts obtained by the two methods. The superintendent of one city reported that a study of the pupils who have actually failed to be promoted at least once showed that 39.2 per cent were retarded. The first method gave for this city a retardation of 59.5 per cent and according to the second method it was 14.8 per cent. This is probably representative, but, in the absence of additional data, no method is available for the accurate calculation of the amount of retardation. When dealing with age-grade tables it is, therefore, necessary to employ one of the above methods or a slight modification of them. In this study the second method has been used pri-

[6] Ayres, L. P. *Laggards in Our Schools*, p. 38.

marily because it appears to be more generally used and hence more data are available for comparative purposes. The reader should bear in mind that the amounts of retardation and acceleration given in the following are computed by this method and not actual.

The Computed Quantities Represent Overage and Underage rather than Retardation and Acceleration. Strictly speaking, these quantities do not represent retardation and acceleration but overage and underage. They are, however, generally spoken of as representing the former. Thus, a significant distinction is lost sight of. If an age-grade table is studied with respect to the grouping of children for instructional purposes, one is primarily concerned with the homogeneity of the grade groups, for it is assumed that the more nearly alike the members of the group are the more favorable the conditions are for teaching. One characteristic of children is their chronological ages. When a grade group is made up of children of widely different chronological ages as is the case in Tables I to VI, the groups lack homogeneity in that respect and thus the most favorable conditions for instruction do not exist. Some have gone so far as to state that the age of a child is more important from this point of view than the number of years he has spent in school.[7] That from the instructional point of view there is some truth in this assertion one cannot deny. However, the mental age of a child frequently does not agree with his chronological age and it is the former factor rather than the latter which produces the non-homogeneity of the groups in ability to learn. Thus, from the instructional point of view the overage and underage of pupils have a certain significance. Their computation from age-grade tables is definite when we have defined the age or ages for the several grades.

From the point of view of the economical organization of the school, one is primarily interested in the progress of the pupils, i.e. the per cent who are promoted regularly, the per cent who fail, and the per cent who are permitted to skip a grade. Repeating the work of a grade or a half-grade represents a financial loss to the school and a time loss to the child. Thus, the per cent of retardation has been called a measure of the efficiency of a school system.

[7] Ayres, L. P. *Laggards in Our Schools*, pp. 39-42.

Limitations of Retardation and Acceleration as the Measure of School Efficiency. The per cent of retardation and acceleration is only a very crude measure of the efficiency of the school system. The efficiency of a school system is the ratio of the achievements of the pupils to the expenditures of time, effort, and money. That school system is most efficient which is obtaining the largest relative returns upon its investment. The giving of standardized tests has made very evident that some school systems are securing very much greater outcomes than others. Thus, it might happen that a school system which showed a very small per cent of retardation and a large per cent of acceleration, indicating an efficient system, was actually less efficient than another system which showed a higher per cent of retardation and a lower per cent of acceleration, because of the difference in the achievement of the pupils in the two systems. For this reason if one wishes to secure an absolutely trustworthy index of the efficiency of the school system, he must take into consideration the achievements of the pupils as well as their rate of progress.

Relation between Overage and Retardation. As was pointed out above, the amount of retardation is not the same as the amount of overageness, no matter what method is used. We can only assume that the per cent of overage pupils approximates the per cent of retarded pupils. Data are not at hand for showing the closeness of the approximation by either of the above methods for the Indiana school systems studied. They are available for three cities when a modification of the method of computing the amount of overageness and underageness was used. The normal age of IB was six or six and a half, the normal age of IA was six and a half or seven, etc. Using this method we have the following facts:

	Retarded	Overage	Difference
Dubuque, Iowa[1]	26	32	—6
Rochester, N. Y.[2]	33	42	—9
Cleveland, Ohio[3]	32	29	+3

[1] Harris, J. H., and Anderson, H. W. "An Investigation of the Progress of Children Through the Elementary Schools of Dubuque, Iowa."

[2] From an unpublished report by Assistant Supt. J. P. O'Hern.

[3] Ayres, L. P. "Child Accounting in the Public Schools" *(Cleveland Survey Report).*

The approximation is closest for Cleveland, but even in this case the difference is large enough to make close comparisons misleading.

The Progress of Children in the Systems Studied. The per cent of retardation (overage) and acceleration (under-

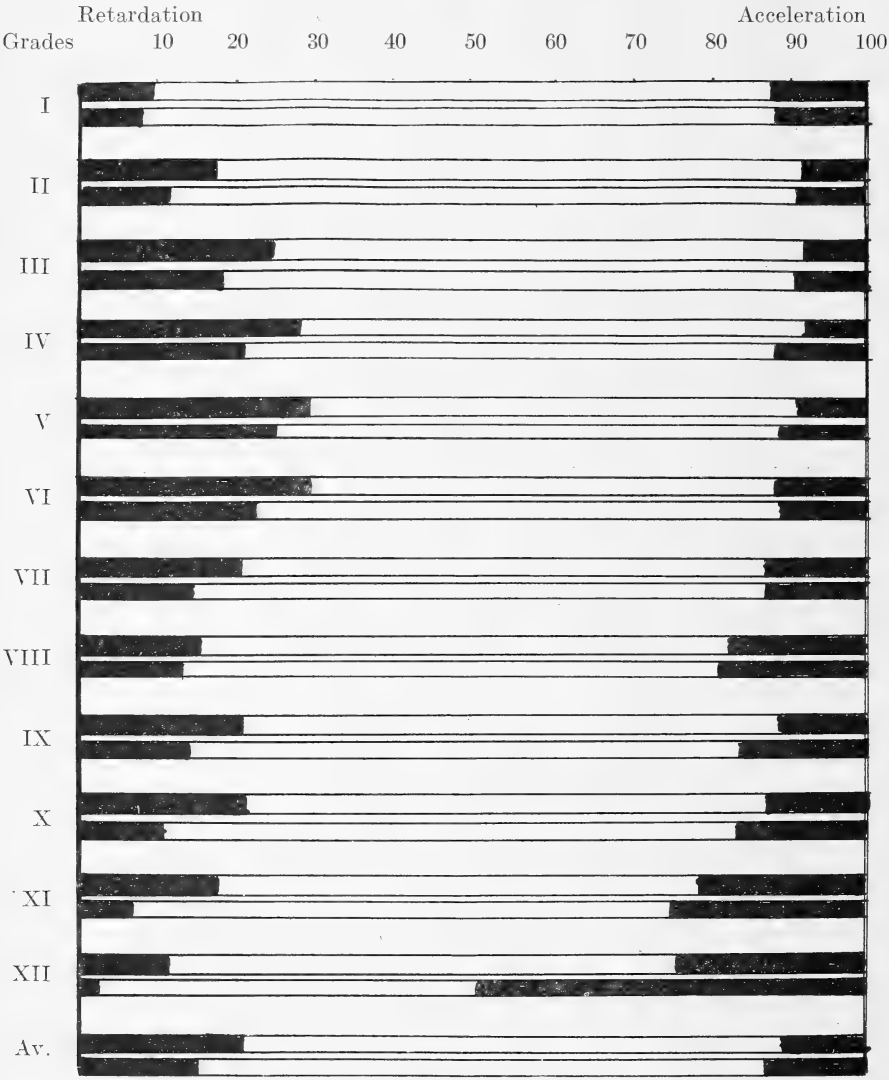

FIG. 6. Showing retardation and acceleration of boys (upper) and girls (lower) in systems having semiannual promotion.

age) have been computed from Tables I to VI by the "second method". The former is shown in Table XIII and the latter in Table XIV. Figure 6 shows the per cent of retardation and acceleration for both boys and girls in systems having semiannual promotion. In the first grade there is practically

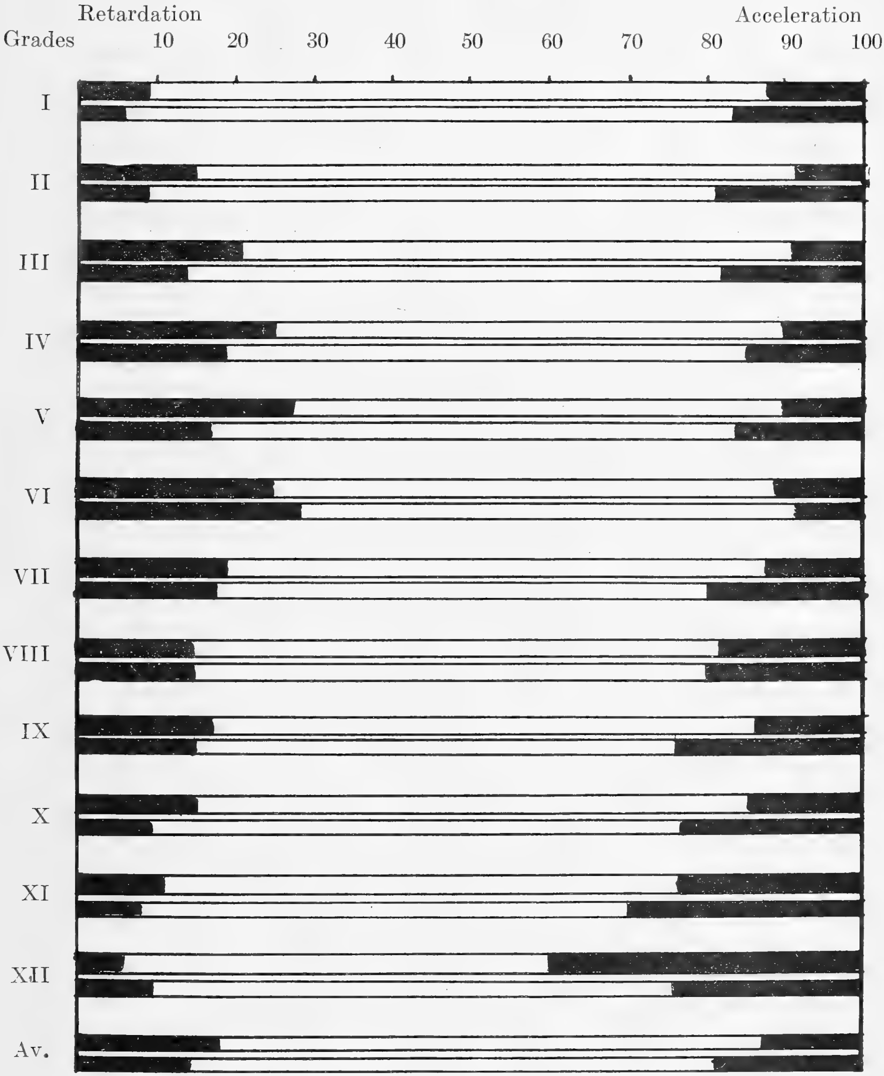

FIG. 7. Showing per cent of retardation and acceleration in systems having semiannual promotion (upper) and in cities having annual promotion (lower).

TABLE XIII

PER CENT OF PUPILS IN EACH GRADE WHO ARE RETARDED OR OVERAGE. 6 OR 7 YEARS NORMAL AGE FOR GRADE I, 7 OR 8 YEARS NORMAL FOR GRADE II

SYSTEMS HAVING SEMIANNUAL PROMOTION

	Grade												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Boys......	9.1	17.8	24.5	28.0	29.9	30.0	21.7	15.9	21.2	21.8	17.7	11.6	21.4
Girls......	7.9	11.9	18.0	21.5	25.2	22.8	15.0	13.7	13.8	10.8	7.1	3.6	15.9
Total...	8.8	14.9	21.9	24.8	27.5	24.6	18.3	14.7	17.2	16.3	11.6	6.7	18.5

SYSTEMS HAVING ANNUAL PROMOTION

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Boys......	8.4	12.1	15.7	20.0	19.1	27.9	24.2	14.4	23.7	10.3	12.9	12.1	17.2
Girls......	4.1	4.8	10.7	18.0	15.6	28.2	14.0	14.2	6.6	9.2	4.0	8.9	12.2
Total...	6.3	8.8	13.4	19.0	17.3	28.0	17.4	14.4	15.3	9.7	8.0	10.2	14.9

TABLE XIV

PER CENT OF PUPILS IN EACH GRADE WHO ARE ACCELERATED OR UNDERAGE. GRADE I, 6 OR 7 YEARS; GRADE II, 7 OR 8 YEARS, ETC.

SYSTEMS HAVING SEMIANNUAL PROMOTION

	Grade												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Boys......	12.3	8.7	8.2	8.3	9.6	12.1	13.0	17.5	11.5	12.8	21.2	24.5	11.1
Girls......	12.1	9.1	9.4	12.7	11.8	11.3	12.9	18.7	16.4	16.6	25.5	48.7	13.8
Total...	12.8	8.9	9.1	10.4	10.7	11.6	12.9	18.2	14.0	14.8	23.8	39.2	12.5

SYSTEMS HAVING ANNUAL PROMOTION

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Boys......	14.6	15.7	15.1	14.3	14.2	11.2	18.0	18.3	24.0	23.4	25.3	25.2	16.7
Girls......	19.0	22.1	21.5	17.4	17.9	5.7	22.2	21.6	24.1	22.8	34.8	23.6	20.0
Total...	17.1	18.8	18.2	15.7	16.2	8.7	20.0	20.0	24.1	23.1	30.5	24.2	18.4

no difference in the amount of retardation, but after this grade the girls are noticeably less retarded than the boys. However, there are only slight differences in the amount of acceleration until the ninth grade is reached. In the twelfth grade we find the largest amount of acceleration. The increase in the per cent of acceleration from the ninth to the twelfth grade is produced by two causes: (1) actual acceleration in the high school by carrying five subjects; (2) relatively more overage and normal age children than underage children leaving school. The increase of retardation up to the fifth grade and its decrease after the sixth is evidence of the tendency of overage children to leave school in larger numbers than the normal or accelerated children. The slight increase from the eighth to the ninth grade may indicate the presence of nonresident children or children from parochial schools. It may, however, be due to an actual increase in retardation produced by the large number of failures in the first and second year of the high school.

Figure 7 represents the acceleration and retardation for the two groups of school systems. In general there is more retardation in the systems having semiannual promotion than in those having annual promotion. This difference is especially noticeable in the first five grades. As has been pointed out in other places in this report where the two groups of school systems are compared, this does not necessarily mean that the plan of annual promotion is superior to semiannual promotion. Other factors, such as the economic and social conditions, nationality, public opinion, etc., make the situation a complicated one. However, those superintendents who are using the plan of semiannual promotion should study carefully the effect of its operation upon the progress of pupils. There is a possibility that when failure means the repetition of only a half-year that is given more frequently than when it means the repetition of the work of a whole year.

Comparison of Systems. Figure 8 represents the retardation and acceleration in each of the ten cities in the group having semiannual promotion. The average for twelve Kansas cities[8] and Cubberley's standard[9] are given for comparative purposes. These Indiana cities show a more satisfactory

[8] From an unpublished study by Dean F. J. Kelly.

[9] From Cubberley's *Public School Administration.*

condition than the group of Kansas cities and compare favorably with Cubberley's standard. The extremes are City A with 10.3 per cent of retardation and City J with 23.6 per cent. The extremes for the twelve Kansas cities are 12.8 and 48.2. Ayres's study and others have shown even greater variability among cities. Hence we may say that this group of Indiana cities shows a low amount of variability.

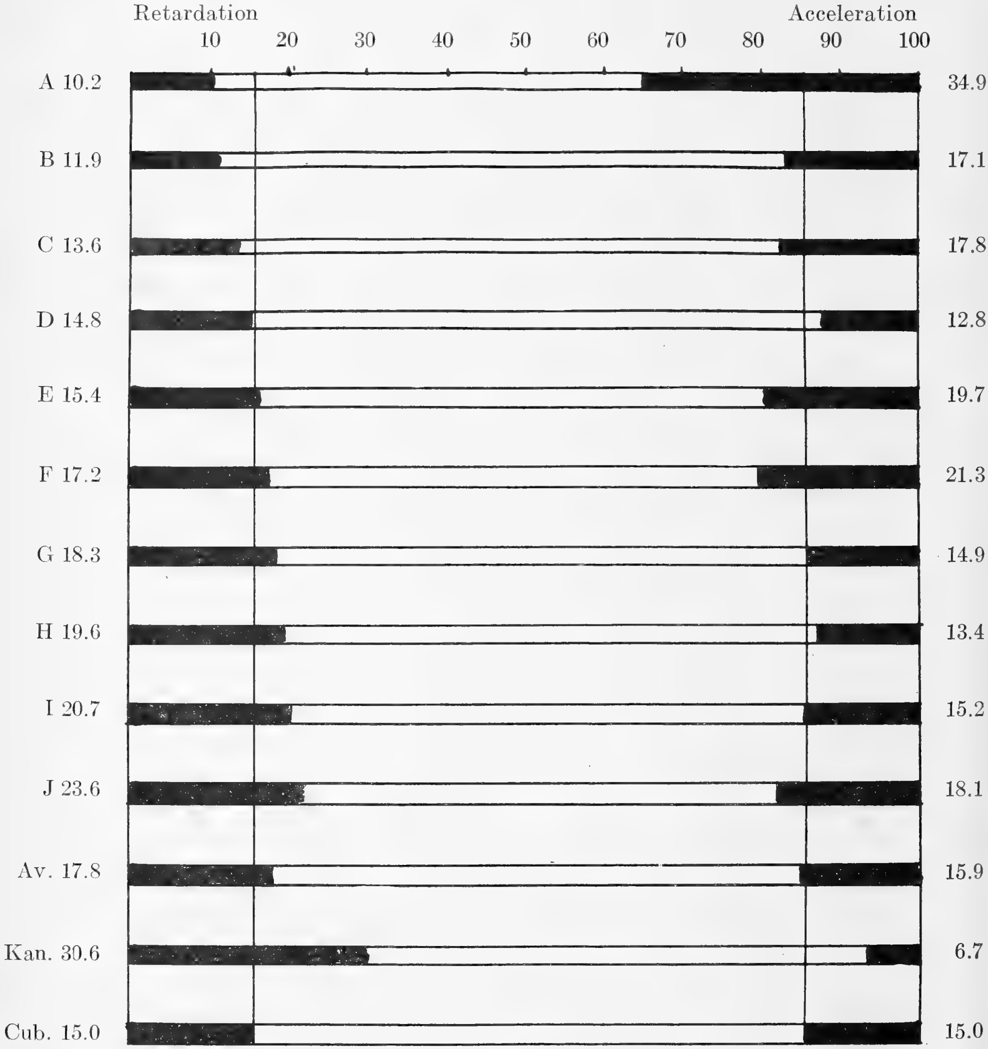

Fig. 8. Showing average retardation and acceleration in cities having semiannual promotion.

In Table XV there is given the average retardation and acceleration for the school systems having annual promotion. Here the variability is somewhat greater but probably less than we should expect. The average retardation for this group is 14.9 per cent, almost identical with Cubberley's standard.

TABLE XV

AVERAGE RETARDATION (OVERAGE) AND ACCELERATION (UNDERAGE) IN SCHOOL SYSTEMS HAVING ANNUAL PROMOTION

SYSTEM	RETARDATION	ACCELERATION
A	6.6	25.6
B	6.7	20.9
C	7.7	30.3
D	10.1	15.0
E	10.1	22.6
F	10.4	35.5
G	11.3	23.1
H	11.3	18.2
I	11.6	22.6
J	11.8	26.3
K	12.5	14.9
L	12.7	16.2
M	14.2	17.2
N	14.9	24.0
O (Marshall County)	17.4	15.0
P	17.6	21.7
Q (Township School System)	17.9	15.1
R	18.6	16.4
S	19.0	22.2
T	19.7	16.4
Average	14.9	18.4

Comparison with Similar Data from Other States. A comprehensive study for the elementary school of 227 cities in Michigan[10] according to the same method of computing the retardation showed 24.0 per cent of retardation and 6.5 per cent of acceleration. This study was based on data collected in December, 1915, but the age was taken on the day the report was made instead of September 1, as in the present study. This would tend to increase slightly the amount of retardation, but certainly not enough to account for this difference. Thus, we are justified in saying that altho Tables I to VI show that conditions are not satisfactory, this group of In-

[10] Berry, C. S. "A Study of Retardation, Acceleration, Elimination, and Repetition in the Public Elementary Schools of Two Hundred Twenty-five Towns and Cities of Michigan, 1915."

diana cities show a better condition than similar cities in Kansas and Michigan.

In Table XV-A the retardation and acceleration data from Marshall county are compared with similar data from 54 per cent of the one-teacher rural schools of eleven counties in Kansas.[11] These two sets of data are not entirely comparable. In the first place, the data from Marshall county includes not only one-teacher schools but all schools in the county with the exception of certain cities and towns. Also for the eleven Kansas counties we do not have any data with reference to acceleration. However, it appears that there is much less retardation in Marshall county than in the eleven Kansas counties. The differences are so large that it is not probable that it is due to the reasons suggested above. On the average Marshall county approximates Cubberley's ideal standards. In certain of the grades, notably the fourth and sixth, the amount of retardation is too large to be satisfactory.

Promotion Rate in the Elementary School. In May, 1918, four cities (South Bend, Michigan City, Kokomo, and Mount Vernon)[12] reported for the second semester of 1917-18 the following facts for the pupils enrolled in each grade of the elementary school: (1) number enrolled during the semester, (2) number dropped to leave city, (3) number dropped to enter lower grade, (4) number dropped to enter higher grade, (5) number dropped to leave school, (6) number remaining at end of term, (7) number of remaining failed, (8) number remaining promoted on trial. From a summary of these facts for the four cities Table XVI was derived by computing the per cents for all items except the first and sixth. The first was used as the base for items from two to five and the sixth was used as a base for the last two.

Pupils who are promoted on trial seldom fail to make good because a small fraction of 1 per cent are dropped to enter a lower grade. (Grade VIA is an exception to this statement.) We may, therefore, disregard the conditional promotions in considering the promotion rate. The per cent of failures varies from 16.6 in IB to 1.5 in VIIIB. The average

[11] The data for the eleven Kansas counties are taken from an unpublished report by Dean F. J. Kelly, of the University of Kansas, Lawrence, Kan.

[12] One other city, Oxford, having annual promotion instead of semiannual promotion also reported. It is omitted from this tabulation for this reason. The Director of the Bureau of Coöperative Research is glad to acknowledge his indebtedness to the superintendents who furnished these data.

is 9.2. About 1 per cent of the pupils enrolled were dropped to enter a higher grade during the term. Altho the blank did not specifically call for the information, the assumption is that no double promotions were made at the end of the year. This being the case, the average promotion rate is 9.2 per cent of failure or retardation and about 1 per cent of double promotion or acceleration.

TABLE XV-A

Showing Retardation and Acceleration in the Rural Schools (2,000 Children) and Small Towns (1,000 Children) of Marshall County, Indiana, in Comparison With Similar Data from 54 Per Cent of the One-Teacher Rural Schools in Eleven Counties of Kansas Enrolling 10,298 Children

	Grade												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Av.
Marshall County													
Retardation..	5	12	17	27	16	32	23	16	13	10	11	7	17
Acceleration..	11	18	19	12	18	7	16	16	24	19	34	30	15
Eleven Kansas Counties													
Retardation —Boys.....	26	32	39	46	51	55	49	54	41	....	....	....	42
Retardation —Girls.....	19	26	30	34	40	37	40	42	40	....	....	....	33
Total....	....	....	....	....	....	....	....	....	....	....	....	....	39
Acceleration Total......	....	....	....	....	....	....	....	....	....	....	....	....	4

For a promotion rate of 9.2 Ayres[13] has computed that the per cent of retardation is 24.0 and that the average number of years required to complete the elementary school is 8.69, provided there is no elimination.

Variations in Promotion Rate. The relatively high per cent of failures (16.6) in IB indicates that there is a tendency to hold pupils in this grade. This condition was found to exist in those school systems having semiannual promotion. (See Table X.) The per cent of failures varies only slightly from grade to grade until the sixth grade. The decrease in the number of failures in the "A" divisions of the sixth, seventh, and eighth grades is only partially balanced by the increase in the per cent of pupils promoted on trial. Prob-

[13] Ayres, L. P. "The Effect of Promotion Rates on School Efficiency," *Bulletin* E130, Russell Sage Foundation. Also in *American School Board Journal,* May, 1913.

TABLE XVI

SHOWING ENROLLMENT, WITHDRAWALS, AND PROMOTIONS IN FOUR INDIANA CITIES

Grade	Number Enrolled in Grade During Year	Per Cent Dropped to Leave City	Per Cent Dropped to Enter Lower Grade	Per Cent Dropped to Enter Higher Grade	Per Cent Dropped to Quit School	Number Remaining at End of Term	Per Cent of Failures of Those Remaining	Per Cent of Promotion on Trial of Those Remaining	Per Cent of Failures of Number Enrolled During Year (Eleven Kansas Cities)
I B	1,183	9.5	.3	1.2	4.3	992	16.6	.7	......
I A	1,362	10.6	.4	1.1	1.8	1,168	10.0	.8	17.1
II B	924	9.9	.1	1.6	1.6	801	8.7	1.0	......
II A	1,268	9.5	.2	1.1	.9	1,118	7.1	1.8	11.3
III B	880	8.8	.2	1.6	1.4	773	9.4	2.3	......
III A	1,159	8.7	.3	.8	1.1	1,029	8.0	1.1	11.8
IV B	960	10.6	.1	1.6	2.2	820	10.6	3.0	......
IV A	1,093	9.8	.3	.5	2.7	951	8.8	2.7	16.6
V B	846	9.8	.2	1.4	2.1	730	12.6	5.5	......
V A	991	9.3	.1	.2	2.3	873	8.8	5.1	12.9
VI B	776	6.7	......	1.3	9.9	637	10.3	7.7	......
VI A	795	6.5	1.0	.7	8.6	662	6.2	7.8	9.9
VII B	497	8.5	.2	.2	9.1	410	8.8	9.0	......
VII A	521	4.4	......	......	10.1	445	4.7	9.4	16.1
VIII B	407	1.4	......	......	13.5	346	7.0	9.4	......
VIII A	379	2.3	......	......	10.0	332	1.5	11.1	10.6
Totals	14,036	......	......	......	......	12,086	9.2	3.7	13.5

ably the decrease in the per cent of failures is primarily due to those pupils leaving school, who would fail. It is significant that the per cent of promotion on trial increases with considerable regularity from grade to grade. This suggests that in the upper grades there is a tendency on the part of the teacher to give pupils a chance to make good in the work of the next grade. The fact that a negligible per cent are dropped to enter a lower grade shows that pupils promoted on trial make good. The increase in the per cent dropped to quit school is, of course, what we should expect. In the sixth, seventh, and eighth grades there are a number of pupils who have passed beyond the age of compulsory attendance and many of these leave school. The decrease in the per cent dropped to leave the city in the upper grades may be due to to two or three causes. It may be that accurate information was not obtained in every case and that a number were classified as "dropped to quit school", who were leaving the city. Another factor may be that as children become older, families move less frequently. In general the parents of the children in the upper grades are older than the parents of the children in the lower grades.

South Bend is the only city which furnished data for both studies and thus we have no basis for comparing this per cent of retardation calculated from the age-grade tables. Considerable elimination is known to exist and in general retarded children leave school to greater extent than others.

Sex Differences in Promotion Rate. In Table XVII the per cent of failures of those remaining are given for the boys and the girls separately. This table is significant in that it shows that in almost every grade more boys than girls fail. In some grades the difference is relatively large. The determination of the cause of this condition would be an interesting problem. There are a number of possible explanations which occur to one at once. Some of these are rather improbable. Perhaps the most reasonable one is that our courses of study are better suited to girls than to boys. This same condition is revealed in the high school in Table XVIII.

Four Indiana Cities Compared with Eleven Kansas Cities. In the last column of Table XVI there is the per cent of failures of the number enrolled during the year for eleven Kansas cities. Since these per cents are computed on the basis of the total number enrolled, they are less than they would be if they were computed on the basis of the number remaining at the end of the term. Thus, the difference between these per cents and the ones of the four Indiana cities is really greater than it appears. In the cities considered, fewer children in Indiana fail in the elementary school than do in Kansas.

Promotion Rate in the High School. Table XVII shows the enrollment, withdrawals, and promotions by subject and grade in the high school in four Indiana cities for both boys and girls. This table is interesting from several points of

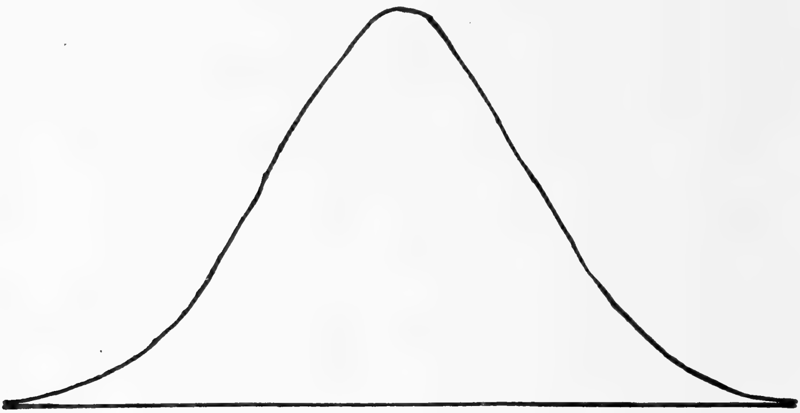

FIG. 9. Showing the shape of a normal distribution.

view. First, a comparison of the per cent of failures and conditions in the successive grades of a subject; second, a comparison of boys and girls; third, a comparison of different subjects.

In general we find that the per cent of failures and conditions decrease as we pass from a lower to a higher grade. This probably is due in part to the elimination of the less able pupils. In case there is a definite sequence in the several divisions of a subject, such as is the case in English or Latin, the reason for the fewer failures and conditions in the upper grades might be because the pupils have become acquainted with the subject. In the case of mathematics, there is an increase in the per cent of failures from algebra to geometry altho usually geometry is taken after algebra. There is little logical sequence between algebra and geometry and the increase in the per cent of failures is probably due to the newness of the field.

When we compare the boys with the girls we find that the boys are much less successful than the girls. The difference in the per cent of failures varies for the different subjects, but in practically all instances the per cent of failures and also the per cent of conditions is noticeably higher for the boys than for the girls. In many cases it is more than double. Even in mathematics the girls show a slight superiority.

TABLE XVII

SHOWING THE PER CENT OF FAILURES OF THOSE REMAINING FOR BOYS AND GIRLS

GRADE	BOYS	GIRLS
IB	.18	.14
IA	.11	.09
IIB	.09	.08
IIA	.10	.05
IIIB	.11	.08
IIIA	.08	.08
IVB	.12	.10
IVA	.11	.07
VB	.16	.09
VA	.09	.09
VIB	.12	.09
VIA	.06	.07
VIIB	.11	.07
VIIA	.06	.04
VIIIB	.02	.01
VIIIA	.09	.05
Average		

When we compare subjects we notice very significant differences. In domestic science the per cent of failures is only a fraction above 1 per cent. In the sciences the average per cent of failures is 3.3 per cent. From these two subjects the per cent of failures increases to 18.7 per cent for history. The reason for this large variation in the per cent of failures is not easily explained. The position has been taken by Judd in his *Psychology of High School Subjects* (page 19) that such variation is due to a difference in the mental processes which the several subjects require. That the mental processes in the several subjects are different no one would deny. We do not, however, know that the basic abilities of these processes are distributed in fundamentally different ways among the same group of children. For example, we do not know that the distribution of mathematical ability in a given group is fundamentally different in shape from the distribution of linguistic ability or historical ability. Our best evidence is that both tend to conform to the normal curve of distribution. This being the case it is difficult to understand how the variation in the per cent of failures can be explained by the difference in the mental processes which the subjects call out.

Success in any subject depends upon several factors. The first factor, of course, is the ability of the pupil. A very important factor is the effort which he exerts in his pursuit of the subject, or, as we commonly say, the interest which he takes in it. The degree of interest which the pupil exhibits in turn depends upon several factors: the teacher, the morale of the class, the textbook, the equipment, and so forth. The pupil's success also depends upon a number of factors, such as the order in which the subject is taken up, the assistance which the textbook affords him, and finally upon the standard of success. This standard for most subjects, particularly in the high school, is generally an arbitrary one fixed by the teacher. This makes it subjective and indefinite.

In view of the fact that success in any subject depends upon such a large number of factors, it is not possible to say that any one is the cause of failure. It is possible that the variation in the per cents of failure between the several subjects is due largely to differences in standards in the different subjects. It is, however, probable that this is not the only case and there is no way of knowing the extent of its contribution to the condition which exists. The determination of the reason for these variations would make interesting and valuable study.

Relation of Course of Study in Elimination and Progress. Several writers have given the course of study as a fundamental cause of elimination and the retarded progress of school children.[14] That the character of the course of study is an important factor in the holding power of the school

[14] See Cubberley, E. P. *Public School Administration*, p. 295.

TABLE XVIII

SHOWING ENROLLMENT, WITHDRAWALS, AND PROMOTIONS BY SEX, SUBJECT, AND GRADE IN THE HIGH SCHOOL IN FOUR INDIANA CITIES

Subject	Number Enrolled in Subject During Term			Per Cent Dropped to Quit School			Per Cent of Failures of Those Enrolled			Per Cent of Total Failures and Dropped to Quit School of Those Enrolled			Per Cent Conditioned		
	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total
English—															
English IX B. . .	187	162	349	12.2	6.2	9.4	11.7	9.9	10.8	24.0	16.1	20.3	5.8	3.1	4.8
English IX A. . .	199	247	446	12.0	7.6	9.6	12.5	4.8	8.2	24.5	12.5	17.2	2.5	1.6	2.0
English X B. . . .	107	145	252	14.9	7.5	10.7	13.0	5.5	8.7	28.0	13.1	19.4	0.8	......	0.3
English X A. . . .	134	198	332	11.9	5.0	7.8	8.2	4.5	6.0	20.1	9.5	13.8	2.2	3.5	3.0
English XI B. . .	60	83	143	15.0	6.0	9.7	10.0	7.2	8.3	25.0	13.2	18.1	3.3	1.2	2.0
English XI A. . .	81	167	248	11.1	2.3	5.2	4.9	1.7	2.8	16.0	4.1	8.0	2.4	0.5	1.2
English XII B. .	28	74	102	......	1.3	0.9	7.0	6.7	6.8	6.7	8.1	7.8	3.5	1.2	1.9
English XII A. .	43	67	110	4.6	4.5	4.5	......	......	....	4.6	4.5	4.5	......	......	....
Totals.	839	1,143	1,982	11.8	5.5	8.2	10.0	5.1	7.2	21.8	10.6	15.3	3.0	1.7	2.3
History—															
Ancient IX B. . .	65	84	149	10.7	7.1	8.7	27.6	9.5	17.4	38.4	16.6	26.1	1.5	......	0.7
Ancient IX A. . .	76	117	193	3.9	2.5	3.1	10.5	4.2	6.7	14.4	6.8	9.8	......	0.8	0.5
Modern X B. . . .	40	52	92	10.0	9.6	9.8	2.5	3.8	3.3	12.5	13.4	13.0	......	......	....
Modern X A. . . .	14	14	28	7.1	......	3.5	......	......	....	7.1	......	3.5	7.1	......	3.5
American I.	82	96	178	2.4	5.2	3.9	7.3	6.3	6.7	9.7	11.5	10.6	10.1	......	5.1
American II. . . .	71	92	163	5.6	2.2	3.6	2.8	......	1.2	8.4	2.2	4.9	......	......	....
American III. . .	78	112	190	3.8	0.9	2.1	3.8	0.9	2.1	......	0.9	0.5	......	0.8	0.5
Civics.	50	90	140	6.0	1.1	2.8	12.0	4.4	7.1	18.0	5.6	10.0	2.0	......	0.7
English.	10	18	28	......	......	....	......	......	....	......	......	....	......	......	....
War.	10	18	28	20.0	16.6	18.7	20.0	16.6	18.7	......	......	....	......	......	....
Totals.	496	681	1,177	5.8	3.5	4.5	8.2	3.6	5.6	14.1	7.1	10.1	0.8	0.3	0.5

TABLE XVIII—Continued

SHOWING ENROLLMENT, WITHDRAWALS, AND PROMOTIONS BY SEX, SUBJECT, AND GRADE IN THE HIGH SCHOOL IN FOUR INDIANA CITIES

Subject	Number Enrolled in Subject During Term			Per Cent Dropped to Quit School			Per Cent of Failures of Those Enrolled			Per Cent of Total Failures and Dropped to Quit School of Those Enrolled			Per Cent Conditioned		
	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total
Mathematics—															
Algebra IX B...	166	141	307	8.4	10.6	9.4	16.8	17.7	17.2	25.3	28.3	26.7	6.6	2.8	4.8
Algebra IX A...	209	177	386	12.8	7.9	10.6	11.9	10.7	11.3	24.8	18.6	22.0	2.3	3.3	2.8
Algebra X......	39	33	72	......	3.0	1.4	17.9	9.0	13.9	17.9	12.1	15.3	......	3.0	1.4
Algebra XI.....	9	3	12	44.4	......	33.3	......	......	......	44.4	......	33.3	......	......	......
Geometry X B..	102	141	243	13.7	9.9	11.5	17.6	19.1	18.5	31.3	29.0	30.0	1.9	2.1	2.0
Geometry X A..	107	130	237	14.9	3.8	8.8	5.6	11.5	8.8	20.5	15.3	17.7	0.9	0.5	0.8
Geometry XII..	23	20	43	8.6	......	4.6	13.0	......	6.9	21.7	......	11.6	......	......	......
Commercial Arithmetic....	69	94	163	17.4	9.6	12.8	13.0	9.6	11.0	3.0	1.9	2.4	......	......	......
Trigonometry...	25	......	25	12.0	......	12.0	4.0	......	4.0	16.0	......	16.0	......	......	......
Teacher's Arithmetic....	......	9	9	......	......	......	......	......	......	......	......	......	......	......	......
Totals........	749	748	1,497	12.2	7.7	10.0	12.9	13.1	13.0	25.2	20.8	23.0	2.5	2.0	2.3
Science—															
General Science I.....	75	14	89	9.3	7.1	8.9	5.3	......	4.4	14.6	7.1	13.4	1.3	......	1.1
General Science II....	56	11	67	8.9	36.3	13.4	7.1	......	5.9	16.0	36.3	19.3	......	......	1.1
Biology I.......	47	5	52	8.5	......	7.6	6.3	......	5.7	14.8	......	13.4	......	......	......
Biology II......	34	1	35	5.8	......	5.5	......	......	......	5.8	......	5.5	......	......	......

Physiology	13	21	34	15.3		5.8		4.7	2.9	15.3	4.7	8.8			
Chemistry I	33	23	56	12.1	4.3	8.9	3.0	21.7	10.7	15.1	26.0	19.6	3.0		1.7
Chemistry II	61	47	108	8.2	4.2	6.4	3.3		1.8	11.4	4.2	8.3	1.6	6.3	3.7
Physics I	38	22	60	5.2		3.3				5.2		3.3			
Physics II	74	45	119	2.7	2.2	2.5	1.3	2.2	16.1	4.0	4.4	4.2			
Physics III	16		16	12.5		12.5				12.5		12.5			
Psychology I	23	32	55	13.0		5.4				13.0		5.4			
Psychology II	3	23	26		25.0	4.5									
Physiography	18	4	22	8.6		5.5	5.5	50.0	13.6	5.5	75.0	18.1			
Botany I	23	13	36	12.1	6.2	8.1	8.6		5.5	17.3		11.1	4.3		2.7
Botany II	41	81	122				4.8	1.2	2.4	17.0	7.4	10.6		1.2	0.8
Totals	555	342	897	8.1	4.3	6.7	3.6	2.9	3.3	11.7	7.3	10.0	7.1	11.2	8.8
Latin—															
Latin IX B	87	68	155	14.9	11.7	13.5	29.9	17.6	24.5	44.8	29.4	38.0	1.1	2.9	1.9
Latin IX A	46	52	98	6.5	1.9	4.1	21.7	9.6	15.3	28.2	11.5	19.3	2.1	3.8	3.0
Latin X B	22	29	51	9.0	6.8	7.8	18.1	24.1	21.5	27.2	31.0	29.4			
Latin X A	17	51	68	11.7	3.9	5.9	5.8	13.7	11.7	17.6	17.6	17.6			
Latin XI B	3	8	11												
Latin XI A	17	29	46												
Latin XII B	3	6	9												
Latin XII A	3	11	14												
Totals	198	254	452	10.1	5.1	7.3	20.7	12.2	15.9	30.8	17.3	23.2	10.0	15.2	13.1
German—															
German I	23	18	41	11.1		4.8	30.4		17.0	30.4	11.1	21.9			
German II	50	88	138	14.0	15.9	15.2	24.0	7.9	13.7	38.0	23.8	28.9			
German III	31	48	79	6.4	8.3	7.6	38.7	10.4	21.5	45.1	18.7	29.1		4.1	2.5
German IV	38	72	110	7.8	2.8	4.5	2.6	8.3	6.3	10.5	11.1	10.9			
German V	8	19	27		5.2	3.7	12.5		3.7	12.5	5.2	7.4			
German VI	4	17	21												
Totals	154	262	416	7.7	8.7	8.4	15.9	6.8	12.2	29.2	15.6	20.6		0.7	0.4

TABLE XVIII—Continued

SHOWING ENROLLMENT, WITHDRAWALS, AND PROMOTIONS BY SEX, SUBJECT, AND GRADE IN THE HIGH SCHOOLS IN FOUR INDIANA CITIES

Subject	Number Enrolled in Subject During Term			Per Cent Dropped to Quit School			Per Cent of Failures of Those Enrolled			Per Cent of Total Failures and Dropped to Quit School of Those Enrolled			Per Cent Conditioned		
	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total
Domestic Science—															
Domestic Science I	......	54	54	......	11.1	11.1	......	3.7	3.7	......	14.8	14.8	......	1.8	1.8
Domestic Science II	......	107	107	......	11.2	11.2	......	0.9	0.9	......	12.1	12.1	......	4.6	4.6
Domestic Science III	......	29	29	......	6.8	6.8	......	......	......	......	6.8	6.8	......	......	......
Domestic Science IV	......	37	37	......	13.5	13.5	......	......	......	......	13.5	13.5	......	......	......
Totals	......	227	227	......	11.0	11.0	......	1.3	1.3	......	12.3	12.3	......	2.6	2.6
Manual Training—															
Manual Training I	36	......	36	19.4	......	19.4	22.2	......	22.2	41.6	......	41.6	2.7	......	2.7
Manual Training II	58	......	58	15.5	......	15.5	1.7	......	1.7	17.2	......	17.2	8.6	......	8.6

Manual Training III..	14	......	14	28.5	......	28.5	......	......	......	28.5	......	28.5	......	......	......
Manual Training IV...	20	......	20	......	......	......	......	......	......	......	......	......	......	......	......
Totals........	128	......	128	15.6	......	15.6	7.0	......	7.0	22.6	......	22.6	4.6	......	4.6
Commercial—															
Shorthand I....	29	65	94	17.2	9.2	11.7	13.7	13.8	13.8	31.0	23.1	25.5	6.8	1.1	3.2
Shorthand II...	18	72	90	......	6.9	5.6	5.5	12.5	11.1	5.5	19.4	16.7	......	5.5	4.4
Shorthand III...	4	25	29	25.0	8.0	10.3	25.0	4.0	6.8	50.0	12.0	17.2	......	......	......
Shorthand IV...	2	11	13	......	......	......	......	......	......	......	......	......	......	......	......
Typewriting I...	14	26	40	7.1	3.8	5.0	......	......	......	7.1	3.8	5.0	......	......	......
Typewriting II..	17	19	36	......	......	......	......	5.2	2.7	......	5.2	2.7	......	......	......
Commercial Law	16	9	25	6.2	......	4.0	......	11.1	4.0	6.2	11.1	8.0	......	......	......
Commercial Geography....	19	15	34	26.3	6.6	17.6	......	13.3	5.8	26.3	20.0	23.5	......	......	......
Salesmanship...	24	26	50	......	......	......	......	......	......	......	......	......	......	......	......
Bookkeeping I...	21	33	54	23.8	18.1	20.0	14.2	6.0	9.2	38.0	24.2	29.6	......	6.0	3.7
Bookkeeping II..	34	53	87	5.8	3.7	4.5	2.9	5.6	4.6	8.8	9.4	9.2	......	1.9	1.1
Bookkeeping III	9	4	13	......	......	......	......	......	......	......	......	......	......	......	......
Bookkeeping IV.	3	4	7	......	......	......	......	......	......	......	......	......	......	......	......
Totals........	210	362	572	9.5	6.3	7.5	4.7	7.7	6.6	14.2	14.0	14.1	0.9	2.2	1.7

after children pass the limit of compulsory attendance, probably no teacher or superintendent who has had experience with such children will deny. However, it is certain that a number of other factors affect elimination and the relative importance of the course of study is a problem which is worthy of study.

In the case of the progress of children in school the course of study is not a determining factor unless it is thought of as including standards of promotion. Standards of promotion constitute a fundamental item of school policy. As they are grouped for instructional purposes children differ widely. There are a few who have relatively little ability and a few who have exceptional ability. Those having average ability are much more numerous. In general the distribution of children according to their ability (both general and specific) is represented by the normal curve which is shown in Figure 9. The general shape of the curve is maintained thruout all the grades. The most significant change is a slight flattening of it as we advance thru the grades.

Fundamentally, standards of promotion specify what per cent of those children at the lower end of the curve shall be called failures and asked to repeat the work of the grade and what per cent at the upper end shall be permitted to skip a grade.

Teachers and superintendents probably do not think of standards of promotion in these terms but they are the only logical and defensible ultimate bases. What the per cent of failures and the per cent of accelerations shall be is an item of educational policy and should be treated as such. Ayres[15] has pointed out that from the standpoint of equipment and cost of instruction the greatest economy is secured when the per cent of failures is equal to the per cent of accelerations. Maintaining this balance, the standard should be set at the point where the most favorable conditions for instruction will be secured. It appears reasonable that the most favorable conditions will not exist if retardation and acceleration are reduced to zero and all children promoted. It is equally reasonable that they would not exist if 40 per cent were failed and 40 per cent were accelerated, leaving 20 per cent normal

[15] Ayers, L. P. "The Effect of Promotion Rates on School Efficiency," *Bulletin* E130, Russell Sage Foundation. Also in *American School Board Journal*, May, 1913.

promotions. Somewhere between these extremes is the point at which the most favorable conditions will be found.

It will be recognized that the setting of standards of promotions in the way just suggested raises the whole question of marking systems. Space does not permit a consideration of this topic. Those who may be interested will find a good account together with a bibliography, "Teachers' Marks and the Reconstruction of the Marking System", by H. O. Rugg in *Elementary School Journal,* Vol. 18, pp. 701-719.

It is possible to use several different "policies of promotion" with the same course of study content. Thus a group of twenty cities having identical course of study content, children of equivalent ability and teachers equally efficient might exhibit twenty different rates of promotion simply because they had different promotion policies. In one city it might be the policy to promote practically all children. In another city it might be the policy to fail a large per cent.

Thus, we must not conclude from Table XVI that the Indiana cities have better courses of study or more efficient teaching than the Kansas cities. This may be true but the data presented here are not sufficient to show that it is. The facts simply show that a larger per cent of the pupils are promoted in Indiana. This may be due to any one or a combination of these causes: (1) promotion policy, (2) quality of instruction, (3) ability of pupils, and (4) indirectly the course of study.

Age, Years-in-School Progress Tables. It has been pointed out that an age-grade table is an unsatisfactory basis for computing the retardation of children unless we interpret retardation in terms of overage rather than progress. No method of computing "overage" and "underage" will give results which can be considered to represent a true statement of actual retardation and acceleration. Therefore, if one wishes a reliable basis for computing retardation and acceleration one must have a table which shows the relation between the years in school and the grade reached. Such a table would be similar in form to Tables I to VI, the years in school taking the place of the ages. From such a table the computation of retardation and acceleration would give true results.

TABLE XIX

Showing the Modified Form of Age-Grade Tables[1]

Grade	Progress	5 yrs.	5½ yrs.	6 yrs.	6½ yrs.	7 yrs.	7½ yrs.	8 yrs.	8½ yrs.	9 yrs.	9½ yrs.	10 yrs.	10½ yrs.	11 yrs.	11½ yrs.	12 yrs.	12½ yrs.	13 yrs.	13½ yrs.	14 yrs.	14½ yrs.	15 yrs.	15½ yrs.	Total
IB	Slow			20	99	102	61	23	6	3		1												
	Normal	3	49	1,097	538	156	49	21	6	4			1	1										317
	Rapid												1	1	1									1,926
IA	Slow		1	5	11	155	116	66	20	16	3	7	3			1								404
	Normal		3	31	576	299	72	27	16	5	3		1											1,033
	Rapid		1	4	9	2	1																	17
IIB	Slow					30	73	118	72	38	23	14	8	5	1	3								385
	Normal		1	8	36	721	474	131	66	27	17	10	1	2	2		1					1		1,498
	Rapid		1	4	22	9	7		1															44
IIA	Slow				1	5	17	161	183	93	63	29	12	14	4	1	1							584
	Normal				3	50	370	309	113	35	25	10	4	5	1									925
	Rapid			1	3	20	24	5	9															62
IIIB	Slow						3	32	63	147	96	64	32	24	14	6	3	3			1			480
	Normal				1	4	30	509	416	117	72	35	25	7	4	2	2	1	4	2				1,231
	Rapid					3	14	12	4	4	1	3			1									42
IIIA	Slow						1	8	24	114	139	124	68	28	21	14	9	8	3					561
	Normal						6	40	300	308	107	56	27	32	5	12	6	2	1	1	1	1		905
	Rapid						1	27	14	11	5			6										64

[1]Taken from an unpublished report by Assistant Superintendent, J. P. O'Hern, Rochester, New York.

A Modified Method of Tabulating Progress Data. A number of school systems are now using a combination of the age-grade table and the age-years-in-school table. For each grade group there are three divisions: slow, normal, and rapid progress. Thus in any age-grade table such as shown in Tables I to VI there would be three lines for each grade group and three distributions of the pupils in each grade. The slow progress pupils would be those who had failed one or more times. The normal progress pupils would be those who had never failed or who had both failed and been accelerated. The rapid progress pupils would be those who had skipped a grade. From such a table one can compute both the actual per cent of retardation and acceleration and the overage and the underage. For this reason it is a much more valuable table. It makes clear the distinction between retardation and acceleration on the one hand and overage and underage on the other. Table XIX illustrates this method of tabulating progress data. It represents conditions in the first grades of Rochester, N.Y., September, 1916.

Summary. With reference to the particular cities studied we may mention the following points by way of summary:

1. The age-grade tables show that the pupils in any grade vary widely in age and that the pupils of any age are to be found in a number of different grade groups.

2. In studying elimination by means of the age distribution, we find that most pupils start to school at the age of six. Altho attendance at school is required by law up to the age of fourteen, there is a tendency in the school systems having semiannual promotion to anticipate the age of fourteen by leaving at the age of thirteen. Relatively few pupils stay in school beyond their eighteenth year, which means that relatively few retarded pupils complete the high school.

3. Girls stay in school better than boys.

4. Systems having annual promotion hold pupils better than systems having semiannual promotion.

5. In the school systems having annual promotion practically all the pupils reach the eighth grade, but only one out of three reach the fourth year of high school. In systems having semiannual promotion a little more than half reach the eighth grade and one out of five reach the fourth year of high school.

6. In a comparison with similar data from other systems conditions in these Indiana school systems are shown to be somewhat more satisfactory.

7. In comparing the different systems studied in either of the groups there is only a moderate amount of variation.

8. In studying the progress of school children it is necessary to distinguish between overageness and retardation. Only overageness can be computed from age-grade tables and when we infer the amount of retardation from the amount of overageness, it is necessary to bear in mind that we are dealing with two different things. Different methods of computing overageness yield different results.

9. In Indiana school systems studied, boys are more retarded than girls.

10. There is a greater per cent of retardation in systems having semiannual promotion than in systems having annual promotion.

11. The variation between school systems is not great.

12. In comparison with similar data from other states these Indiana systems exhibit less retardation.

13. The average promotion rate is about 91 per cent. Of this 91 per cent about 4 per cent are promoted on trial. In general these make good. The promotion rate for girls is higher than for boys.

14. In the high school the per cent of failures decreases from the lower grades to the higher grades. The per cent of failures is higher for boys than for girls. The per cent of failures varies from 13.1 per cent.

15. A number of factors contribute to the promotion rate. One is not justified in attributing a high per cent of failures to a poor course of study. The standard of promotion is believed to be a determining factor. It appears that different standards of promotion are held by the teachers of different subjects.

16. For studying the progress of pupils a modification of the age-grade tables is recommended.

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