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MECHANICAL DRILL AND MEANINGFUL DRILL IN ARITHMETIC
FOR THE
PRIMARY GRADES

BY

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A THESIS
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[Signatures]
INTRODUCTION

The record made by arithmetic in the elementary school curriculum is an exceedingly unenviable one. The percentage of failures by grades has been shown to increase throughout the intermediate grades in the case of arithmetic, but to decrease in the case of other school subjects. Something, evidently, is wrong with current methods of instruction in arithmetic.

Arithmetic is probably one of the most complicated subjects that children face in the elementary school. Number is hard to understand because it is abstract. There is no concrete quality of "six-ness" in six dogs which may be heard, seen, or handled. Color, weight, shape, and barking may be grasped through the senses, but the "six-ness" is not open to immediate observation. Neither is there any "six-ness" in ..., or in "six," or in "6." In each case the "six-ness" is the creation of the observer; it is a concept or an idea which the observer imposes upon the objective data. Furthermore the observer cannot impose the number idea "six" upon objects unless he has acquired the thought pattern which stands for "six."

Difficulty with arithmetic begins with the first instruction in arithmetic and continues through the elementary grades. The evidence is convincing that the nature of early school experience with number is a powerful factor in conditioning later success in arithmetic.

The explanation of pupils' difficulties in arithmetic is to be found in the difference between the mental processes and capacities required to understand arithmetic on the one hand and
the mental processes and capacities that children have at their command on the other hand. At one extreme is a highly perfected number system requiring of the learner control of the most abstract mental processes. At the other extreme is the child with his undeveloped powers and his immature capacities. When he first needs number at all, his needs are satisfied by the least complex of the number processes, namely, counting. The school has overlooked an important responsibility in failing to realize the gap between this simple use of number and the precise abstract thinking which the school urges upon the child. We have left a large uncharted area across which the pupil must in a large measure find his own way.

This thesis has been written to emphasize the differences in two methods of teaching arithmetic -- mechanical drill and meaningful drill -- and attempts to present a psychologically and theoretically sound proposal for instruction in number skills in the primary grades of the elementary school.
CHAPTER I
MECHANICAL DRILL

The term "mechanical drill" is here used to describe a theory of arithmetic instruction which makes mechanical repetition of number combinations on the part of the pupil the essential feature of learning.

According to this view, children have learned arithmetic when they have committed to memory one hundred addition facts, one hundred subtraction facts, etc., the number of facts depending on the investigator or writer who is propounding the theory. The teacher gives little time to instructing the pupil in the meaning of what he is learning; the ideas involved are either so simple as to be obvious, or else they are so difficult as to suggest the postponement of explanations until the child is older and better able to grasp their meaning.

The main points in this theory are: (1) arithmetic may be analyzed into a great many units of knowledge and skill which are comparatively separate and disconnected; (2) the pupil is to master these numerous elements, whether he understands them or not; (3) the pupil will attain these ends most completely through mechanical repetition of number combinations.

In the classroom the popularity of the "drill theory" is shown in the common reliance upon flash cards, and other types of

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drill exercises, in the widespread use of workbooks and other forms of unsupervised study, and in the greater interest of the teacher with the pupil's speedy computation and correct answer rather than with the processes which lead to that computation and that answer.

Acceptance of this theory is probably due to two misleading interpretations of arithmetic ability: analysis of adults' uses of arithmetic and the "bond" theory of learning.

In purchasing a pound of sugar for six cents and a box of crackers for twenty-one cents, an adult seldom, if ever, hesitates in finding the total. Even less does he inquire into the reason why six and twenty-one are twenty-seven or into the method of reasoning by which he secures the sum. Arithmetic teachers, observing the automatic and instantaneous quality of adult reactions to number situations, conclude that since adults use number so, so the child should learn it. They forget their own difficulty in learning arithmetic. They probably do not realize that they never learned "6 and 21 are 27" as a number fact.

According to the bond theory, all learning consists in the establishment of connections or bonds between specific stimuli and specific results. For example, one connects the response "4" with the stimuli "2 and 2," the response "10" with the stimuli "5 x 2," and so on. Each arithmetic fact represents such a bond. It seems to follow, therefore, that the way to teach arithmetic is to teach directly the bonds which are to be established. Mechanical drill, then, becomes the instructional method best adapted to this end, and mechanical repetition becomes the essential method of learning.
The bond theory leads many to assume that Thorndike would teach number combinations as a discrete bond without any justifying reason. But Thorndike protests against any such interpretation, for he says,

"I hasten to add that the psychologists of to-day do not wish to make the learning of arithmetic a mere matter of acquiring thousands of disconnected habits nor to decrease by one jot the pupils' genuine comprehension of its general truth. They wish him to reason not less than he has in the past but more. They find, however, that you do not secure reasoning in a pupil by demanding it, and that learning of a general truth without the proper development of organized habits back of it is likely to be, not a rational learning of that general truth, but only a mechanical memorizing of a verbal statement of it. They have come to know that reasoning is not a magic force working in independence of ordinary habits of thought, but an organization and cooperation of those very habits on a higher level."

Experimental studies are quite unanimous in reporting a beneficial effect of systematic mechanical drill. The amount of improvement varies in the different experiments, apparently depending on the conditions under which the drill was carried out.

One experiment was reported by Brown, who gave a series of five-minute drills on the number combinations. These drill periods were a part of the regular lessons, the drill always preceding the lesson. The investigation dealt with the sixth, seventh, and eighth grades and was checked by means of control classes. Fifty-one pupils were included in the experiment, which extended over a period of thirty days. The effect of the drill was most marked in the sixth grade and least marked in the eighth grade but was positive as compared with the results in the case of the non-drill group in all three of the grades. The

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value of the drill exercises was shown to persist even after a
vacation period of twelve weeks. Brown followed this investigation
by a second experiment with 222 sixth-grade pupils. In this case
the conditions were the same as in the first experiment except
that there were twenty drill periods instead of thirty. Improve-
ment was measured by tests given at the beginning and at the end
of the drill period. The largest gain made by the drill class was
made in division, the gain being 34.2 per cent, more than double
the gain in division made by the non-drill class. The gains in
subtraction were 32.0 per cent for drill group, 11.9 per cent for
non-drill group; in addition, 18.5 per cent for drill group, 6.8
per cent for non-drill group; in multiplication, 24.1 per cent
for drill group, 10.9 per cent for the non-drill group.

Phillips studied the effect of drill in the case of sixth,
seventh, and eighth-grade pupils. He divided the pupils into
drill and non-drill sections, and his results show that the drill
group made a much better gain than the non-drill group, its
superiority being 15 per cent in the fundamentals, 50 per cent in
the reasoning tests, and 31 per cent in the combined tests.

Wimmer conducted an experiment with pupils from grades five
to eight, giving two six-week periods of drill. The subjects were

3 Joseph C. Brown, "An Investigation on the Value of Drill Work in
the Fundamental Operations of Arithmetic," Journal of Educational
Psychology, II (February, 1911), 81-88; III (November and
December, 1912), 485-492.

4 H. H. Phillips, "Comparison of the Work Done in the Successive
Minutes of a Ten-Minute Practice Period in the Fundamentals of
Arithmetic," Journal of Educational Psychology, VII (May, 1916),
271-277.
divided into drill and non-drill groups and the results compared. The differences in favor of the drill group were 4.3 per cent in the fundamentals and 32.7 per cent in reasoning.

Additional experiments could be cited which show results in agreement with those to which reference has been made. It is evident that specific drill will, in the majority of cases, produce noticeable improvement. Many of the drill experiments simply demonstrate the possibility of increasing efficiency through special training provided in a mechanical drill period. This type of drill has an effect similar to that of cramming, although, as was shown in the experiment of Brown, some permanent effect remains.

One gets the impression from the reports of the experiments with drill that the investigators have been more concerned with what could be done under specific conditions than with determining the place of drill in the total program of teaching arithmetic.

Three objections may be raised to mechanical drill as the principal method of arithmetic instruction. The first objection is that this type of drill does not always produce in children the kind of reaction it is supposed to produce. The second one is that even if under conditions of drill the proposed kind of reaction was implanted, this reaction would constitute an inadequate basis for later arithmetical learning. The last one is that mechanical drill does not provide a consistent program of remedial treatment for the pupil who uses roundabout methods.

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(a) The reaction produced by mechanical drill is not always satisfactory. When a teacher provides drill in arithmetic combinations, she does so on the assumption that the pupils will practice certain prescribed reactions. For example, when she uses flash-card drill on such number combinations as \( 5 + 4 = 9 \), \( 6 + 7 = 13 \), etc.; she expects all pupils to think or say \( 5 + 4 = 9 \), \( 6 + 7 = 13 \), and so on. It is her belief that the pupil will come to respond only and always "9," "13," etc., on presentation of the corresponding number combinations. In other words, the administration of drill by the teacher presupposes repetition by the pupil. This assumption is not warranted by facts presented in a recent investigation.

A week after the beginning of the school year fifty-seven third-grade children were given a written test in the 100 simple addition combinations. These children had been taught in grades one and two by methods which agree closely with the mechanical drill theory of instruction. According to the results of this test, 32 children were selected for individual study — 10 with high scores, 13 with average scores, and 9 with very poor scores. An interview was held privately with each child to determine how he secured his answer. For these interviews, 16 of the combinations were used, consisting of 10 of greatest difficulty and 6 of average difficulty on the group test. There was a total of 512 responses in the interviews. The interviews revealed that 116 combinations (22.7% of the 512) were counted; that seventy-two (14.1%) were solved indirectly (e.g., "6 + 4 = 10 because

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$5 + 5 = 10$); that 122 (23.8%) were incorrectly guessed; and that only 202 (39.5%) were known as memorized associations.

After two years of drill these pupils counted and solved nearly as many combinations (36.7%) as they knew directly as combinations (39.5%). Unknown to the teacher they had not repeated the formulas but had trained themselves in other ways of thinking of number facts. Drill by the teacher had not resulted in repetition by the pupils.

In the month following this first group test, drill on the addition combinations was administered each day. Then came the second group test on the 100 addition combinations and the second interview with the same thirty-two children on the same sixteen combinations. At this time 48.8% of the combinations, as compared with 39.5% on the first interview, were known, that is to say, were responded to as they are supposed to be responded to under mechanical drill conditions. On the other hand, counting and indirect solution still accounted for 37% of the answers (as compared with 36.7% on the first interview). If at the time of the first test they counted their combinations, they persisted in counting a month later, in spite of the daily drill which was to require repetition. If at the time of the first interview they solved them, they solved the combinations a month later.

If mechanical drill had been provided by the child, it would have increased only the speed and the accuracy of the reaction, good or poor; it could not have taken the place of instruction which is responsible for comprehension.

(b) Premature mechanical drill is an inadequate basis for
later arithmetical learning. Arithmetic is best viewed as a system of quantitative thinking. If one is to be successful in quantitative thinking, one needs a fund of meanings, not a number of automatic responses. Mechanical drill does not develop meaning nor lead to understanding. Suppose that a pupil through repeating the formula has memorized "12" as the answer to "what is 7 + 5?" Suppose, further, that in the absence of other types of experience than repetition, the pupil is asked, "What does it mean to say that 7 + 5 = 12?" His reply might be, "I don't know --- just that 12 is the answer to 7 + 5." The meaning of "7 + 5 = 12" is for him restricted to merely making the appropriate noises and to reading and writing the symbols which stand for the combination.

The pupil who can give the correct answers to 5 + 7 = ?, 5 x 7 = ?, 5 x ? = 35, ? x 7 = 35, ? + 7 = 12, may nevertheless be unable to solve such simple problems as the following:

I had twelve cents and lost seven; how many did I have left?
If each of seven boys had five marbles, how many marbles have they all?
Children need thirty-five marbles in a game that five are to play; how many should each child bring?

To know a number fact in isolation is one thing; to make it function in a real situation is another.

(c) The mechanical drill conception of arithmetic fails to provide a sound, consistent teaching procedure in the case of pupils who do not immediately develop the specific, direct connections which they are expected to develop. Mechanical drill does not cure the use of roundabout methods. It merely constitutes an
opportunity for the child who counts to learn to count more rapidly and more accurately; it cannot provide for him better procedures. Furthermore, in case his processes lead him to faulty answers, drill comes to be drill on errors.

The function of mechanical drill is best conceived as that of fixing something which has previously been comprehended and increasing the speed of recall.
CHAPTER II
MEANINGFUL DRILL

Probably even the best arithmetic teachers in the past have assumed that some things are easily understood by a child which in fact are difficult to understand. Children have been required to take long steps from an easy, known, and well-understood process to a difficult and distantly related process. If teachers had understood all the steps in learning involved, the intermediate steps between the things known and the things to be learned would have been taught and easily understood. Then a teacher takes the position that a pupil who has learned to do subtraction ought to be able to solve any example in subtraction, and that the only way to secure skill in subtraction is to give more drill generally on that operation, this teacher has no right to expect uniformly satisfactory results.

A method of teaching in arithmetic that is frequently used is somewhat as follows: The teacher presents a new process to the pupils without adequately tying it up or relating it to previously known and understood processes. Instead of relating the processes, many teachers attempt to fix the processes in the mind of pupils only by blind, unanalyzed drill; so practice is begun on new processes and continued until all, or most, of the pupils can do the process with some facility.

When the teacher judges that enough time has been spent on this part of the course, the class goes on to a new process, many times without further drill on the process just studied except as
it happens to be used in the new process. In other words, the understanding of a process is not secured by relating it to what is previously learned, but rather by drilling on it. This is making use of drill for the wrong purpose and failing to do first teaching as it should be done.

Meaningful drill would associate number processes and seek to make the child understand the meaning of a process before going on to mechanical drill. The child would be led to see relationships in number and thus provide a basis for transfer of learning in similar situations. Meaningful drill includes repetition, but it adds the elements of understanding and reasoning, elements which mechanical drill does not include.

Meaningful drill is definitely a teaching procedure, not a memory procedure. It depends for its success on a knowledge of the laws of learning, the child's ability to reason, the ability of the teacher to generalize children's number experiences, and the proper use of mechanical drill.

"An Experimental Study in Improving Ability to Reason in Arithmetic" has been reported by C. W. Stone. The experiment was performed in the fifth, sixth, and seventh grades mainly of Spokane, Washington. The Stone Reasoning Tests in Arithmetic were used as survey tests to measure each pupil's ability to reason in written arithmetic problems. The diagnostic tests enabled each pupil to think by graduated steps into and through his individual difficulty. The practice tests enabled each pupil to rethink the reasoning involved in his individual difficulty. The effects of the diagnostic and practice tests were measured by using survey tests before and
after experimentation.

The experimental group used the diagnostic and practice tests, while the control group was given regular class work in arithmetic.

The results showed that the use of these tests produced greater gains in ability to reason in arithmetic than did the regular class work in arithmetic. The gain in reasoning ability secured by these tests transferred to reasoning demanded by other problems of similar nature. The transfer was greater than the transfer secured by an equivalent amount of regular arithmetic work.

It should be noted here that the very intelligent child can make a transfer of training from one number situation to another similar one unaided; the mediocre child can make it with the aid of the teacher; the very stupid child cannot do it even with the aid of the teacher and will try to get the sum by counting. Transfer of training depends on three things: (1) the intelligence of the child, (2) the number of identical or similar elements in the two situations, and (3) the method of teaching.

Kirkpatrick has reported an experiment to determine the type of drill which gives the best results in learning the multiplication tables. He compares the memorizing of the tables with the incidental learning of the combinations from a key sheet and, again, with the method of figuring out each combination through its actual application in practice. He found that the poorest method is the memorizing of the tables, while the method of computing or the method of memory

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plus practice secures the best results. His finds are of particular
interest in view of the very common method of memorizing the
2 multiplication tables.

Springer has reported an experiment in the learning of denominate
numbers in which one class used the traditional method of drill,
while a second class was given problems the solution of which
required the use of the table being learned. The results of the
two methods show that the traditional-drill class averaged 58 per
cent, while the applied-drill class averaged 64 per cent. The
experiment covered too short a period to produce conclusive results.
The author tried to check his work by reversing the methods of the
two classes. After the change of method the traditional-drill
class averaged 62 per cent, while the applied drill class averaged
68 per cent. Since the total drill period was in each case only
three days, one cannot be sure as to how much of the superiority
of the applied-drill class was due to the novelty of the situation
and how much was due to the actual nature of the method employed.

Are children in the primary grades capable of reasoning in
terms of number? Thorndike evidently thinks so, for he states,

"I conclude, therefore, that school children
may and do reason about and understand the manipulation
of numbers in this inductive, verifying way without
being able to or at least without, under present
conditions, finding it profitable to derive them
deductively. I believe, in fact that pure arithmetic

2 E. A. Kirkpatrick, "An Experiment in Memorizing versus Incidental
Learning," Journal of Educational Psychology, V (September, 1914),
405-412.

3 Isidore Springer, "Teaching Denominate Numbers," Journal of
Educational Psychology, VI (September, 1915), 630-632.
as it is learned and known is largely an inductive science. At one extreme is a minority to whom it is a series of deductions from principles; at the other extreme is a minority to whom it is a series of blind habits; between the two is the great majority, representing every gradation but centering about the type of the inductive thinker." 4

Drummond reports an interesting case study on Donald, a five-year-old pupil in her school. He made many number discoveries through manipulating blocks. He was playing with twelve blocks when he suddenly called out, "Look, there are two sixes in twelve." He had the blocks arranged in two lines with six in each. He then pushed each two together and exclaimed, "And there are six twos." He was asked if he could make anything else. For some time he worked away and in the end found, unaided, that three fours and four threes make twelve. In all he had spent at least an hour and a half at work. You will say that Donald is an exceptionally intelligent child. That is true. But exceptional intelligence is not required for excellence in elementary or even higher number work. The application of quite an ordinary intelligence in this definitely limited subject produces remarkable results.

In any case, this stage which one can distinguish in the development of Donald is the same one through which every child passes, although the rate of advance varies greatly.

Two recent experiments in regard to reasoning have been made which might be of interest to review here. In an experiment by C. L. Kulp, "A Study of the Relative Effectiveness of Two Types

__4__ Edward Thorndike, op. cit., p. 69.

of Standard Arithmetic Practice Materials," four classes used the practice material which did not provide practice in arithmetical reasoning, while six classes used the material which did. A total of 113 fourth-grade pupils took the final tests. From the figures given in the report of the investigation the experiment and control groups were initially equivalent in computational ability, but the group receiving the training in reasoning was initially superior in reasoning ability. The experiment lasted from October to April. The difference in gains in achievement are apparently significantly in favor of the type of material which provided practice in arithmetical reasoning in connection with calculation drill.

J. C. Rosse used two groups of eighteen sixth-grade pupils who were equivalent with respect to initial arithmetic reasoning ability and with respect to intelligence as measured by the Otis Reasoning Test and the National Intelligence Test. One group used practice sheets which provided drill in reasoning problems, while the other used an ordinary arithmetic text. At the end of fifty-eight days the same form of the Otis Arithmetic Reasoning Test was administered. The difference in achievement favors, but not significantly, the method in which the practice sheets which provide drill in reasoning problems were used.

There has been much discussion as to the value of counting in


7 J. C. Rosse, "An Experiment to Test the Increase in Reasoning Ability from the Use of Test and Practice Sheets in 6A Arithmetic," Journal of Educational Research, XXII (October, 1930), 210-213.
learning the combinations and as to how soon after the period of enumeration the combinations should be taught.

When children come to school, they can usually count. However, to say that because a six-year-old child learns to count to one hundred before starting to school does not mean that this child understands the meaning of number. He may have the most rudimentary sort of number concept. The child may understand numbers only as rote counting or merely by naming the number words --- one, two, three, etc. By rational counting we mean the actual identification of groups of objects or individuals through the use of number words, that is, the ability to associate eight with eight books, boys, pencils, etc.

Training in counting alone is insufficient to develop number ideas. Too commonly, however, instruction in counting is immediately followed by drill on the addition and subtraction combinations.

The meaningful drill theory interposes a definite period of instruction between counting and the number combinations. The purpose of this period of instruction is to provide for the child activities and experiences which will lead him from counting to meaningful ideas of numbers as groups.

Eventually he comes to think of concrete numbers in terms which are essentially abstract. At the conclusion of this period of learning, "8" is as much a unit in his thought process as is "1." The "8" does not need to be broken down into eight ones. Equipped with this number concept, the child is ready for combinations.

If the number combinations were "number facts," as they are frequently said to be, children would encounter little difficulty
in learning them. They can easily learn "four dogs and four dogs are eight dogs," for this is a fact. But "4 and 4 are 8" is not a fact; it is a generalization. If it were a fact, children could, as mechanical drill advocates desire them to do, memorize it as they would a fact in history. However, it is much harder to learn a generalization than it is to learn a fact.

The presence of four objects and four other objects in the same situation does not automatically suggest to the child 4 - 4 - 8. If the child is to think of the "4" and "4" in the form of an abstract combination, he must be taught to see it so. Instead of telling the child "4 - 4 - 8" and of urging him to memorize it, the teacher should lead the child to discover it. He must discover it many times and in connection with many different situations. He may have to count at first. This type of reaction should not be forbidden if it is necessary to the child, for it may be his only means of relating the numbers. As fast as may be, however, he should be helped to eliminate counting until he comes to the point where he reaches the generalization 4 - 4 - 8. Now is the time for him to memorize the combination if he needs to. It is far more likely that the many experiences he has had with the combination have served to fix it in his mind without memorization.

Meaningful drill also encourages the understanding of arithmetic by adapting the rate of instruction to the difficulty of learning. At first, when the new ideas and processes are unfamiliar, the rate is kept slow. The teacher develops a firm foundation and understanding of number concept and proceeds slowly through the first experiences with number.
CHAPTER III

PROPOSED PROGRAM FOR INTRODUCING NUMBER SKILLS IN

THE PRIMARY GRADES

Most of the investigations on drill cited in this thesis were conducted in the later elementary grades. This constitutes a limitation to any proposed program drawn from them. However, in the light of these experiments and the theory of meaningful drill and mechanical drill, the following basic steps in introducing a number process are proposed:

1. Develop the skill in concrete situations, using many different types of objects and activities, leading the child slowly into a generalization of the skill. Make this change gradually so that the child is not conscious of a change from concrete to abstract number.

2. If there is a transfer of learning that can be made from a previously learned skill to the present one, point this out to the child and lead him to look for such transfers. Relationships between known skills and unknown skills help the child to understand an unknown skill.

3. Apply the skill to real problem situations that are familiar to the child in his home and school life. Make him feel that there is a need for this number skill.

4. By individual diagnostic tests determine the remedial work which each child should have. Use the method of meaningful drill to give remedial work.

5. After each child thoroughly understands the process, then use mechanical drill at intervals for attainment of reasonable
speed and to provide for maintenance of the number skill.

A caution should be added here that the teacher who uses mechanical drill which results in efficiency considerably in excess of the standard for the grade will be considered as wasting effort and time. The teacher should see how nearly her class can be trained to reach the established standard and little, if any, more.

Recommendations

In making this study, several questions for investigation in primary number work have occurred. These topics could be profitably investigated:

An effective method of developing quantitative modes of thinking by arithmetical instruction.

The comparative amounts of time spent in meaningful drill and mechanical drill in the primary grades.

With a well-planned system of investigation in the teaching methods of arithmetic and the psychology of number, we may hope to have results which will change the status of number work from being merely a tool subject to a content subject. We will be able to see less of mechanization and memory and more of reasoning and meaning.
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