The effect on final achievement in a beginning calculus course resulting from the use of programmed materials written to supplement regular classroom instruction

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF EDUCATION
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Abstract:
This investigation resulted from the belief that programmed materials written to supplement regular classroom instruction of beginning calculus would significantly improve the final achievement of students studying these materials in addition to their regular classroom instruction, The author consulted pertinent literature as a means of investigating the extent to which the general area of the problem had been explored. The literature revealed no evidence which supported or denied that programmed materials of the type specified would significantly effect the learning of beginning calculus. Hence an experiment was designed to measure the effect on final achievement in a beginning calculus course resulting from the study of programmed materials written to supplement regular class room instruction. The first step of the experiment was the preparation of a set of preliminary programmed materials written to cover the critical areas of beginning calculus which cause students the greatest learning problems. These preliminary materials were used in a pilot study to detect flaws in construction as well as to provide the author with experience in conducting the experiment. Following the pilot study the materials were revised to correct discovered inadequacies.

An experimental group was then selected to use the revised materials as a supplement to regular classroom instruction. The students of the experimental group were volunteers from the beginning calculus course and were chosen on the basis of their mathematical achievements in previous college mathematics courses. For one college quarter the programmed materials were administered to the experimental group in addition to their regular classroom instruction. At the end of this quarter the final examination scores earned by members of the experimental group were recorded as a measure of individual student achievement.

The control group was next selected. Standards for admission into this group were similar to those for the experimental group with the exception that the control group did not have access to the programmed materials. The measure of the final achievements of the members of the control group was by means of the same final achievement examination taken by members of the experimental group. The final achievement scores of the two groups were compared by appropriate statistical tests.

As a result of reviewing literature the author concluded: (1) Modern scientific-technological pressures have brought about many changes in the emphasis and content of current mathematics. Since these changes have influenced the teaching of calculus, a need has developed for more effective calculus teaching techniques. (2) The results of research done on the effectiveness of supplementing class-room teaching of mathematics by using programmed materials has been inconclusive. From his investigation the author concluded that the effect on the final achievement of students in a beginning calculus course resulting from the study of programmed materials prepared by the author was not significantly above the corresponding achievement of students not studying such materials.

THE EFFECT ON FINAL ACHIEVEMENT IN A BEGINNING CALCULUS COURSE RESULTING FROM THE USE OF PROGRAMMED MATERIALS WRITTEN TO SUPPLEMENT REGULAR CLASSROOM INSTRUCTION

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ABSTRACT

This investigation resulted from the belief that programmed materials written to supplement regular classroom instruction of beginning calculus would significantly improve the final achievement of students studying these materials in addition to their regular classroom instruction. The author consulted pertinent literature as a means of investigating the extent to which the general area of the problem had been explored. The literature revealed no evidence which supported or denied that programmed materials of the type specified would significantly effect the learning of beginning calculus. Hence an experiment was designed to measure the effect on final achievement in a beginning calculus course resulting from the study of programmed materials written to supplement regular classroom instruction. The first step of the experiment was the preparation of a set of preliminary programmed materials written to cover the critical areas of beginning calculus which cause students the greatest learning problems. These preliminary materials were used in a pilot study to detect flaws in construction as well as to provide the author with experience in conducting the experiment. Following the pilot study the materials were revised to correct discovered inadequacies.

An experimental group was then selected to use the revised materials as a supplement to regular classroom instruction. The students of the experimental group were volunteers from the beginning calculus course and were chosen on the basis of their mathematical achievements in previous college mathematics courses. For one college quarter the programmed materials were administered to the experimental group in addition to their regular classroom instruction. At the end of this quarter the final examination scores earned by members of the experimental group were recorded as a measure of individual student achievement.

The control group was next selected. Standards for admission into this group were similar to those for the experimental group with the exception that the control group did not have access to the programmed materials. The measure of the final achievements of the members of the control group was by means of the same final achievement examination taken by members of the experimental group. The final achievement scores of the two groups were compared by appropriate statistical tests.

As a result of reviewing literature the author concluded: (1) Modern scientific-technological pressures have brought about many changes in the emphasis and content of current mathematics. Since these changes have influenced the teaching of calculus, a need has developed for more effective calculus teaching techniques. (2) The results of research done on the effectiveness of supplementing classroom teaching of mathematics by using programmed materials has been inconclusive.

From his investigation the author concluded that the effect on the final achievement of students in a beginning calculus course resulting from the study of programmed materials prepared by the author was not significantly above the corresponding achievement of students not studying such materials.

CHAPTER I

INTRODUCTION

There has been good reason to refer to the present age as a scientific-technological era. Never before in the history of man has the destiny of the future been so closely controlled by scientific technology. In the past twenty years single nations have come to possess, through scientific means, the machines of war capable of destroying entire civilizations. In fact the grasp of modern science has reached into the lives of people everywhere in the form of television, automobiles, satellites, electric dishwashers, medical drugs, and dozens of other areas of everyday life. Thus for the citizen of tomorrow to understand, appreciate, and properly use these tools he must be well qualified to judge them and must possess the technical ability to devise other efficient machines which will help him design a more compatible tomorrow.

However, the ability to properly judge, use, and design the complex scientific devices of this modern era has been found to be strongly dependent upon the degree of comprehension of the supporting science, mathematics. With the current shift to an increasingly automated world where tolerance for error has been found to be small, the society of today has turned to the truths of mathematics to guide the way to scientific understanding and utilization.

Naturally this heavy concentration on mathematics has had far-reaching effects. In fact, so much pressure has been brought to bear on the subject that the resulting vast changes in mathematics have been aptly described as a true revolution. This point was clearly stated in

1961 by mathematician G. Baley Price, Chairman of the Department of Mathematics at the University of Kansas, when he wrote:

> The changes in mathematics in progress at the present time are so extensive, so far-reaching in their implications, and so profound that they can be described only as a revolution.[1]

With such intense focus on mathematics by mathematicians and non-mathematicians throughout this country, the impact on education has been inescapable. In the past few years mathematicians and educators have found it necessary to work in close harmony in attempting to devise effective teaching programs capable of meeting modern needs. With the acceleration in scientific advancements, mathematics educators have been pressed to present the subject to the learner in the most effective way possible so that the subject matter presented will be in harmony with future expansion of mathematical knowledge. Numerous instructional improvement projects have been put into operation through federally sponsored institutes for teachers, in-service education courses, lecture series, educational television programs, and whatever other means have seemed appropriate.

Actually this revolution has repeatedly complicated itself because not only has each major advancement in mathematics implied

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[1] Price, G. Baley, "Progress in Mathematics and Its Implications for the Schools," in _The Revolution in School Mathematics_, A Report of Regional Orientation Conferences in Mathematics by the National Council of Teachers of Mathematics, p. 1.

a need for a curriculum revision at graduate level study, but each curriculum revision at the graduate level has in turn implied a need for curriculum revision at all prerequisite levels. This snowballing effect has severely challenged educational efforts to keep teaching up-to-date and in line with future needs.

Since the primary problem has become one of preparing more and more students with a broader mathematical background, it has become increasingly clear that ways need to be found to improve the transmission of mathematical knowledge from the instructor to the student at all levels. One critical level which has been found to demand such improved learning-teaching effectiveness is at the early college level where the beginning calculus is encountered.

Statement of the Problem

The problem of this study was to determine the effect on final achievement of students in a beginning calculus course who had worked through asseries of lessons of programmed instruction which had been written to teach certain basic ideas in the calculus.

The existence of the problem investigated had its origin in the fact that the learning of beginning calculus by the student has been recognized to be largely governed by the teaching he receives in class, by the reading he does out of class, and by his homework. Since so many students have failed to perform satisfactorily in calculus, the learning in general has either been incomplete or the information learned has been incorrect. In view of this learning problem the question was posed: to what extent would programmed materials written to cover the areas of calculus which cause the greatest learning problems be a significant learning aid to the student? This question in turn led to the statement of the hypothesis (H_o) with which this investigation was concerned: there is no significant difference in the final achievement of students in a beginning calculus course who have studied programmed materials as a supplement to conventional classroom instruction of topics which ordinarily cause learning problems over students who have not studied such materials.

Procedures

In order to determine if programmed materials specifically written to cover the topics which cause learning problems for the student in a beginning calculus course would be a favorable supplementary learning aid for the student the following procedures were used:

1. Pertinent literature was examined to provide background information which would orient the study in terms of past and present practices and problems involved in teaching beginning calculus and to summarize other investigations which have dealt with the effects of programmed materials which have resulted from their uses.

2. An identification was made of the topics of beginning calculus which cause students learning problems.

3. A set of programmed materials was written which possibly would assist the student in learning these difficult topics.

4. An evaluation of the effectiveness of the preliminary programmed materials was made following the administration of these materials to a pilot group. This evaluation involved a rating system whereby items of the programmed materials were ranked according to their effectiveness.

5. Sections of the preliminary programmed materials which indicated lack of teaching effectiveness were rewritten.

6. The rewritten programmed materials were administered to a carefully chosen and regulated experimental group.

7. A study of the effect of the programmed materials on final achievement was made by statistically comparing the final achieved scores of an experimental group which used the prepared materials with the final achieved scores of a control group which did not use the prepared materials.

The control and experimental groups were initially of comparable background and ability.

In order to determine the areas of beginning calculus which cause students learning problems, a list of topics covered in a typical first quarter calculus sequence was prepared. This list was given to twelve people well qualified to judge the learning problems of students in a beginning calculus sequence. This same jury then ranked the topics which in their judgment caused the greatest learning problems.

The topics of the list were then tabulated according to the frequency of items marked. By considering possible available student time it was decided that no more than seventeen evening meetings could be expected of students desiring to work through the programmed materials which would be written. Thus the seventeen topics most frequently indicated were denoted and programmed materials were written to cover each of these areas.

The seventeen programmed lessons were administered to students requesting assistance in a beginning calculus course. These students kept a record of the items of the programmed materials with which they had difficulty. By using Holland's 10 percent permissible error ratio[2] those items of the materials which displayed over 10 percent error were rewritten to insure greater clarification of subject matter.

In order to test the hypothesis (H_0) an experimental group was next selected from the following quarter's beginning calculus sequence enrollment at Montana State College. On a weekly schedule during the quarter these students were provided with fifteen lessons of programmed materials written to correct the faults of the original seventeen lessons. At the end of the quarter the entire beginning calculus class was given the same comprehensive final examination for the course. Scores on this final examination were recorded and statistically studied to test the hypothesis (H_0) that there was no significant difference in the final achievement of students in a beginning calculus course who have studied programmed materials as a supplement to conventional classroom instruction of topics which ordinarily cause learning problems over students who have not studied such programmed materials. Teaching

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[2] Fry, E. G., Teaching Machines and Programmed Instruction, p. 4.

of all of the beginning calculus students was done by five experienced and well qualified instructors, and general supervision of all teaching was carefully carried out by one individual whose extensive qualifications included forty years of college mathematics teaching and fifteen years as head of a mathematics department.

Limitations

The following limitations were imposed on the investigation:

1. The number of students in the experimental and control groups was limited to twenty-one and twenty-two respectively. These sample sizes were judged large enough to give the statistical tests sufficient discrimination power.

2. The experimental portion of the investigation was limited in time to the duration of the winter quarter of the 1964-65 college academic year. This period of investigation was judged sufficient because during that quarter the experimental group had ample time to carefully study enough programmed materials to master those topics selected as being essential to success in beginning calculus.

3. The topics of beginning calculus which were programmed for use by the experimental group were fifteen in number. The choice of these particular fifteen topics was judged appropriate because a rating system was used to identify them as being critical to the learning of beginning calculus.

4. The regular classroom instruction of the experimental and

control group was limited to instruction by five experienced and competent members of the mathematics staff at Montana State College. Supervision of the instruction was kept uniform and of high quality by a competent and experienced supervisor.

5. The measurement of the final achievements by the members of the experimental and control groups was limited to one comprehensive examination. This limitation was necessary in order that the investication could be carried out within the structure of existing mathematics departmental policies at Montana State College.

6. The level of significance for the statistical tests was set at 5 percent. This level was judged appropriate in view of the nature of the investigation.

Under these limitations the investigation was made to discover the effects on final achievement of students in a beginning calculus course who have studied programmed materials as a supplement to conventional classroom instruction of topics which ordinarily cause learning problems over students who have not studied such programmed materials. The first step of this investigation, a review of related literature, is reported next.

CHAPTER II

REVIEW OF LITERATURE

The purpose of the review of literature was to provide background information which would orient the study in terms of past and present practices and problems involved in teaching beginning calculus and to summarize other investigations which have dealt with the effects of programmed materials resulting from their application under similar circumstances and for purposes similar to those of this study. In organizing the results of the literature reviewed four major topics were selected and correspondingly developed through reference to pertinent literature: (1) recent changes in the content and spirit of beginning calculus, (2) learning problems associated with current beginning calculus, (3) the role of programmed instruction in learning current beginning calculus, and (4) a brief summary of investigations similar in manner and purpose to that of this study. The first topic is developed in the following section.

Recent Changes in the Content and Spirit of Beginning Calculus

In the 1950's serious changes began to take place in the mathematics curriculum which had been established in the United States since the 1890's.[3] One of the first major breaks with the traditional mathematics curriculum came in 1951 when the Mathematics Department

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[3]Dyer, H. S.; Kalin, Robert; and Lord, F. M.; Problems in Mathematical Education, pp. 18-19.

at the University of Illinois reacted to the poor mathematical preparation of students in the engineering curriculum by forming a committee to specifically look into college preparatory mathematics.[4] Typifying the reports of these investigations was the following observation:

> Few freshman students had any insight into the structure of mathematics; they regarded the subject as a collection of unrelated and often inconsistent rules. . . . Textbooks were often written as though mathematics were a completed thing, there to be learned, rather than a growing subject in whose development one might take part.[5]

In an attempt to correct this shortcoming the University of Illinois Committee on School Mathematics, usually referred to as the U. I. C. S. M., was formed with Max Beberman as its director. Soon this active group was busy writing texts and devising a curriculum to meet the modern mathematical needs of society. It was significant that the U. I. C. S. M. singled out the importance of student understanding through discovery of mathematical facts as a major factor in learning mathematics. The emphasis on this aspect of learning mathematics can be traced throughout the writings of this group in such places as the first sentence of the first page of their High School Mathematics where they state to the teacher: "We believe that students should be given an

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[4] Henderson, K. B., et al., Mathematical Needs of Prospective Students, p. 5.

[5] American Association for the Advancement of Science, Science Education News, Miscellaneous Publication No. 65-7, citing one of the members of the University of Illinois Committee on School Mathematics, p. 1.

opportunity to discover a great deal of mathematics which they are expected to learn."[6]

Shortly after the U. I. C. S. M. began its attempt to design a better mathematics curriculum other groups and agencies began to show interest in these same areas. In 1952 the Board of Governors of the Mathematical Association of America appointed a Committee on the Undergraduate Program to look at what the undergraduate program in mathematics should be like.[7] Among their recommendations which later became published in text form for the first year college calculus students was the unique feature of an intuitive approach to calculus to aid the student gain good insight into what was being presented. Secondly, they agreed on a carefully written formal development of the calculus through definitions, axioms, theorems, and mathematically complete proofs.[8]

These early efforts by the Committee on the Undergraduate Program in Mathematics and the U. I. C. S. M. set the stage for much of the mathematical spirit and curriculum content which was soon to blossom forth into what many writers referred to as a revolution in school mathematics. From this beginning the emphasis on understanding

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[6]University of Illinois Committee on School Mathematics, Unit I: Arithmetic of Real Numbers, High School Mathematics, Teacher's Edition, p. I.

[7]Begle, E. G.; MacLane, Sanders; Price, G. B.; Lectures on Experimental Programs in Collegiate Mathematics, p. 4.

[8]Ibid., p. 17.

through intuition and discovery and the careful attention paid to mathematical structure has continued to dominate the mathematical scene in curriculum revision up to the time this study was made.

A later group which was very influential in continuing and emphasizing this same spirit of modern mathematics was the School Mathematics Study Group. It was formed in 1958 by the president of the American Mathematical Society with the approval of the National Council of the Teachers of Mathematics and the Mathematical Association of America.[9] The School Mathematics Study Group singled out the importance of mathematical structure as one of their primary concerns. In fact structure was identified as being their major objective in the first sentence in the "Preface of the Teacher's Commentary" of the First Course in Algebra:

> The principal objective of this First Course in Algebra is to help the student develop an understanding and appreciation of some of the algebraic structure exhibited by the real number system, and the use of this structure as a basis for the technique of algebra.[10]

With this strong emphasis on structure and complete understanding at all academic levels as the spirit of modern mathematics the content of mathematics courses was changed from the problem oriented approach to a logical development with student awareness

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[9] Wagner, John, "The Objectives and Activities of the School Mathematics Study Group," The Mathematics Teacher 53:454, October, 1960.

[10] School Mathematics Study Group, First Course in Algebra, p. i.

approach. This was particularly true at the college calculus level. Agnew, Professor of Mathematics at Cornell University and well known calculus author, aptly portrayed the spirit and content of calculus prior to 1900 by stating: "Problems were the important things, and meaningful formulations of axioms, postulates, definitions, hypotheses, conclusions, and theorems either were not written or played minor roles."[11] Agnew went on to describe the transition which took place during the next fifty years as a direct contrast to the earlier attitudes:

> Through most of the first half of the twentieth century, elementary textbooks in our subject taught unexplained but "well motivated" intuitive ideas along with their problems. Enthusiasm for this approach to calculus waned when it was realized that students were not nourished by stews in which problems, motivations, fuzzy definitions, and fuzzy theorems all boiled together while something approached something else without ever quite getting there. About the middle of the twentieth century, precise formulations of basic concepts began to occupy minor but increasingly important roles.[12]

Finally Agnew indirectly characterized the current spirit and content of modern calculus by stating in his 1962 calculus text:

> Each student is expected to read the text and problems of each section as carefully as an alert physicist reads an account of a newly developed nuclear reaction, and to learn as much as he can. . . . The text, problems, and remarks frequently give students quite unusual opportunities and incentives to think and to become genuine authorities on developments of ideas, terminologies, notations, and theories.[13]

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[11] Agnew, R. P., Calculus, p. v.

[12] Ibid., p. v.

[13] Ibid., pp. v-vi.

As to the future of mathematical course content and spirit some extrapolations have been made. In 1963 under the financial support of the National Science Foundation twenty-five prominent and well-qualified mathematicians assembled at Cambridge, Massachusetts to assess the potential of mathematical learning and to set tentative goals towards which mathematical education should attempt to direct its efforts in the next thirty years. The goals of particular courses were specifically spelled out, and the role of structure permeated the entire system at all levels as was indicated by the statement:

> We hope to make each student in the early grades truly familiar with the structure of the real number system and the basic ideas of geometry. . . . Moreover, we want to make students familiar with part of the global structure of mathematics.[14]

Furthermore, the Cambridge group endorsed the method of teaching mathematics which results in discovery by the students:

> Even modestly endowed students can recreate larger parts of mathematics if they can remember just a few basic ideas. This fact repeatedly has been demonstrated in the classroom by the proponents of the so-called discovery method. The building of confidence in one's own analytical powers is another goal of mathematics education.[15]

Hence, a study of the literature pointed out that the spirit of contemporary mathematics at the level of beginning calculus as well as

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[14] Educational Services Incorporated, The Report of the Cambridge Conference on School Mathematics, Goals for School Mathematics, p. 8.

[15] Ibid., p. 9.

at all levels has been largely associated with complete mathematical understanding of the subject from a structural viewpoint. That is, the modern trend in mathematics has placed a premium on clear insight into the structure of mathematics rather than on mathematical ability without understanding. Student discovery and development of mathematical truths were frequently referred to as the best means of developing this structural awareness.

In the next section the current problems associated with learning mathematics with this emphasis on structure by means of student discovery are discussed.

Learning Problems Associated with Current Beginning Calculus

The literature reviewed clearly reflected a recent swing to emphasis on mathematical structure and student development of mathematical ideas. A considerable number of authors of the present widely used calculus texts have agreed to this principle.[16] However, not all of the students currently enrolled in beginning calculus have had a background in mathematics which emphasizes structure to the degree

[16] Randolph, J. E., Calculus and Analytic Geometry, pp. v-vii; Protter, M. H. and Morrey, C. B., College Calculus with Analytic Geometry, pp. v-vii; Agnew, op. cit., pp. v-vii; Apostol, T. M., Calculus, Vol. 1, pp. vii-ix; Goodman, A. W., Analytic Geometry and the Calculus, pp. v-vii; Thomas, G. B., Calculus and Analytic Geometry, pp. v-vi.

modern calculus courses demand. Hence, the student whose background is entirely traditional often has had difficulty catching the spirit of modern mathematics. This fact was well substantiated when Zant, in discussing problems facing beginning college mathematics students in Oklahoma, stated:

> Another problem. . . is that of the good student who has studied only traditional mathematics courses in high school. Somehow and as quickly as possible, these students must be taught the point of view towards mathematics and the basic concept involved in a modern program in secondary mathematics. If our college courses beginning at the analytics-calculus level have been modernized, then these students, even though they have studied traditional mathematics for three or more years in high school, are not prepared to enroll in such a course.[17]

Along with this emphasis on structure the major unifying ideas of mathematics have often been expressed using notation not commonly found in the traditional mathematics. For example, Randolph of the University of Rochester in his 1961 calculus text has stated:

> The introduction into elementary courses of the well-established notation for the set of elements, each satisfying a given condition is long overdue and rapidly finding favor. Even though some books state once and for all that 'the line $x = -2$' means 'a point (x, y) is on the line if and only if $x = -2$', some students will be confused about how x and y

[17] Zant, J. H., "Effects of New Mathematics Programs in the Schools on College Mathematics Courses," The American Mathematical Monthly 63:200, February, 1963.