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ABSTRACT

The purpose of this study was to investigate the effects of a laboratory-centered inquiry program on laboratory skills, science process skills, and knowledge/understanding. The inquiry approach used in the Foundational Approaches in Science Teaching (FAST) program and a traditional science textbook approach were compared in terms of the three major evaluative points mentioned above. During the 1987-88 school year, the FAST 1 program was integrated into a regular science curriculum in the FAST group as a treatment at both sixth and seventh grades, while traditional textbook approaches were predominant in the non-FAST group for each grade level. At the end of the school year, post-tests were administered to both FAST and non-FAST groups. Results indicated that laboratory skills, science process skills, and science achievement as a whole ability were affected by the FAST 1 instruction at each grade level. It was concluded that a laboratory-centered inquiry program (FAST) can enhance student total ability in science and especially laboratory skills and specific science process skills such as graphing and interpreting data. (CW)

EFFECTS OF A LABORATORY-CENTERED INQUIRY PROGRAM ON LABORATORY SKILLS, SCIENCE PROCESS SKILLS, AND UNDERSTANDING OF SCIENCE KNOWLEDGE IN MIDDLE GRADES STUDENTS

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Abstract

The purpose of this study is to investigate the effects of a laboratory-centered inquiry program on laboratory skills, science process skills, and knowledge/understanding. The inquiry approach used in the Foundational Approaches in Science Teaching (FAST) program and a traditional science textbook approach are compared in terms of three major evaluative points mentioned above.

The sixth grade sample (85 students) consisted of a FAST group (47 students) and non-FAST group (38 students). The seventh grade sample (141 students) consisted of a FAST group (83 students) and non-FAST group (58 students). During the 1987-88 school year, the FAST 1 program was integrated into a regular science curriculum in the FAST group as a treatment at both sixth and seventh grades, while traditional textbook approaches were predominant in the non-FAST group. At the end of the school year, post-tests were administered to both FAST and non-FAST groups at each grade level.

Post-tests measures included three evaluative instruments: the Laboratory Skills Test (LST) by Curriculum Research and Development Group of the University of Hawaii (1978); the Performance of Process Skills (POPS) Test by Pottenger, Mattheis, Jones, and Nakayama (1987); and the FIN Test which measures the understanding of basic science knowledge by Fukuoka, Pottenger, Ishikawa, and Nakayama (1987). The LST consists of three subdivisions--the measures of laboratory skills (six items), specific science process skills (six items), and knowledge/understanding (four items)--which are related to the FAST 1 context. The POPS test (21 items) is a measure of integrated science process skills in a general context. The FIN test (six items) is a measure of understanding of the extended contexts or FAST 1. The California Achievement Test (CAT) scores of individual students were also obtained from the teachers.

The Multivariate Analysis of Covariance (MANCOVA) to examine the main effects of FAST treatment was conducted. The overall omnibus F on five dependent variables (LST lab skills, LST process skills, LST knowledge/understanding, POPS, and FIN) with covariate CAT was significant using Wilk's criterion in the sixth grade group [$F(5,78) = 5.53$, $p < 0.001$] and in the seventh grade group [$F(5,134) = 11.14$, $p < 0.001$]. These results indicate that laboratory skills, science process skills, and science achievement as a whole ability are affected by the FAST 1 instruction at each grade level.

The univariate Analysis of Covariance (ANCOVA) to examine the effects of FAST treatment on each dependent variable with covariate CAT was conducted in each grade. At the sixth grade level, the effects of FAST treatment were significant on laboratory skills by the LST [$F(1,82) = 19.05$, $p < 0.001$], process skills by the LST [$F(1,82) = 8.44$, $p < 0.01$], and knowledge/

understanding by the LST [$F(1,82) = 4.58$, $p < 0.05$]. At the seventh grade level, the effects of FAST treatment were significant on laboratory skills by the LST [$F(1,138) = 43.29$, $p < 0.001$] and process skills by the LST [$F(1,138) = 7.40$, $p < 0.01$]. These results indicate the FAST 1 instruction especially affects laboratory skills and specific process skills at both grade levels, although no significant effects were found on process skills and knowledge/understanding in general contexts measured by the POPS and FIN tests.

It could be concluded that a laboratory-centered inquiry program (FAST) can enhance student total ability in science and especially laboratory skills and specific science process skills such as graphing and interpreting data.

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Introduction

Development of laboratory skills and science process skills required in the processes and procedures of science and understanding of basic knowledge in science, as products, are considered to be major goals of science instruction at all levels. The laboratory activity has been viewed as an important role in order to attain these goals. However, learning in the laboratory has been and still is a highly controversial issue among science educators (e.g. Hofstein and Lunetta, 1982; Woolnough and Allsop, 1985).

Many of the science curricula developed in the 1960's (e.g. PSSC, CHEM Study, BSCS, S-APA, SCIS, SCISP, Nuffield) assigned a central role to the laboratory with emphasis on the process of science. Hodson (1988) noted that a significant feature of most of the science curriculum development in the past quarter century was a major shift of emphasis away from the teaching of science as a body of established knowledge toward science as a human activity with increasing emphasis on experience of the processes and procedures of science. Process skill learning has been considered to become an important component of science curricula at all levels by many educators (e.g., Gagne, 1965; Renner, 1966; Herron, 1970; NSTA, 1971; Okey, 1972; Padilla, 1980).

However, Friedler and Tamir (1986) pointed out that, by and large, the outcomes of studying science by laboratory-oriented programs fell short of expectations. Woolnough and Allsop (1985) argue that one reason for the failure of many science courses is the attempt to use the practical work to achieve aims for which it is ill suited, such as teaching theoretical concepts instead of focusing on the real aims of practical experience. The results of the surveys conducted by the Assessment of Performance Unit (APU) in England also revealed that it is often assumed that either basic practical skills are skills that have been acquired or that they can be acquired in the process of learning about the body of knowledge that is taught (APU, 1984). Furthermore, Padilla, Okey, and Garrard (1984) argue that in recent years with the increased popularity of texts and programs that emphasize an even more traditional approach toward science, students have been getting even less experience with the integrated science process skills, and that without a good amount of practice, expectations of skill mastery are probably unreasonable.

Laboratory skills and science process skills cannot be developed just by transmitting the body of knowledge without "minds-on" experience through laboratory-centered inquiry activities. Students need to be involved in scientific investigations, thereby developing simultaneously those procedural skills in science and gaining a deeper understanding of scientific concepts, laws, and theories.

Purpose of This Study

The present study was designed in response to the relative scarcity of laboratory-centered inquiry activities in regular science curriculum. The major purpose of this study was to compare the effects of a laboratory-centered inquiry approach to a traditional textbook approach on laboratory skills, science process skills, and understanding of science knowledge in middle grades students. The Foundational Approaches in Science Teaching (FAST) 1 program was integrated into the existing regular middle school curricula at the sixth and seventh grades during the whole school year.

FAST 1, developed by the Curriculum Research and Development Group of the University of Hawaii, is a sequential laboratory- and field-centered inquiry science program. It was designed to provide common foundational experiences in the concepts and methods of science for students in middle school, and its content is selected on the basis of interdisciplinary utility which consists of physical science, ecology, and relational study. Approximately 60 to 80% of class time is spent on student investigation in the laboratory and field, and the remainder of time is spent on analysis of data and discussion (Pottenger and Young, 1983). FAST instructional strategy adopts a sequential inquiry learning cycle derived from the research on learning styles which includes a discrepant event (anomaly), hands-on investigation, concept development, and application (Young, 1982).

Related Research Review

A large portion of the reported research efforts focused on some aspect of the instructional methods used by science teachers such as problem solving instruction, experiential learning, laboratory experience, teacher demonstrations, etc. The influence of these factors has been primarily measured in terms of student achievement rather than other learning outcomes, and the results seem to be almost consistent and identical. For example, the results of a meta-analysis of experimental studies to determine effects of problem solving instruction conducted by Curbelo (1985) show the positive effect of problem solving instructions over no instruction in problem solving in enhancing student achievement. Several studies comparing the effect of student-centered, hands-on inquiry approaches to traditional teacher-centered, lecture-demonstration approaches showed that students in the inquiry group attained a significantly higher level of achievement than did students in the traditional group (e.g. Selim, 1982; Awodi, 1984; Ohanenye, 1986).

Furthermore, through a review of research documents focusing on effective instructional practices among students of intermediate grades, Cotton and Savard (1982) reported the most consistent finding is that student performance is enhanced when conventional instructional approaches are supplemented with experiential components; performance is superior to that obtained through use of either method alone. Ivins (1986) examined the sequence and composition of laboratory activity, student use of text materials, and discussions and lectures in the seventh grade science classroom. He found that a sequence of laboratory exercises followed by textbook readings and classroom discussion (inductive approach) was more effective than a sequence of textbook reading or teacher lecture followed by verification laboratories (deductive approach) in terms of science achievement and retention. Saunders and Shepardson (1984) examined the effect of hands-on activities organized around the three-phase learning cycle (exploration, conceptual invention, and discovery) compared to oral and written language instruction among the sixth grade students. They found that the concrete instruction group scored higher on science achievement and reasoning skills (cognitive development) than did the formal instruction group.

Evidences provided by the previous studies to investigate the effects of different instructional strategies on student achievement suggest the following possibilities related to this study:

1. Laboratory-centered inquiry approaches in instruction can enhance student achievement.

2. Integration of a laboratory-centered inquiry program into a textbook-oriented regular curriculum can result in increased student achievement.

3. Inquiry activities organized around a sequential cycle of learning can promote student achievement in science and cognitive development.

Research on teaching science process skill abilities has taken many directions since the early 1960's. Most typical studies were to investigate the effects of (1) different ways of teaching student abilities, (2) a specific activity or module designed to enhance process skills, and (3) a specific science curriculum on science process skills in students. In a study that examined different ways of teaching process skills, Wagner (1984) compared the effect of an inquiry approach to a reading-recitation approach on process skills and achievement gains of science students in the fourth and fifth grades. It was reported that significant differences were found in process skills and achievement gains between methods. McKenzie (1984) assessed the effects of three instructional strategies on the graphing skills achievement of eighth grade students. Treatments were a series of hands-on laboratory activities designed to teach graphing skills, written simulations that paralleled the hands-on laboratories, and a combination of both hands-on and written simulation lessons. The results showed that instructional strategies involving hands-on activities resulted in higher skill achievement than the written simulation strategy.

A recent study by Friedler and Tamir (1986) investigated the effects of a learning module for high school students designed to teach inquiry skills such as problem identification, hypothesis formulation, and experimental design. Students involved in this module showed substantial gains in understanding and in their ability to plan investigations and formulate deductions. Padilla, Okey, and Garrand (1984) investigated different patterns and amounts of instruction on planning experiments with sixth and eighth grade students. Treatments included a two-week introductory unit on integrated process skills followed by a one-period process skill activity per week for 14 weeks (Treatment One), only the same two-week introductory unit (Treatment Two), and only content-oriented instruction (Treatment Three). Results showed that both sixth and eighth grade students can learn to use certain integrated process skills (i.e., identifying variables and stating hypotheses). Differences generally favored Treatment One over Treatment Three.

At the elementary level, several studies have been conducted to show the favorable effects of the Science Curriculum Improvement Study (SCIS) on individual integrated science process skills (e.g., Weber and Renner, 1972; Allen, 1973; Boyer and Linn, 1978). At the secondary level, studies of the impact of a curriculum on process skill ability have proven inconclusive (e.g., Stronck, 1971; Butzow and Sewell, 1972).

Few research studies that examined the effects of different instructional strategies on practical laboratory skills can be found. For example, Peterson (1978) compared the effects of manipulative scientific inquiry training to verbal inquiry training and to non-inquiry training. The results showed that both types of inquiry training were superior to non-inquiry training in terms of hands-on manipulative and practical laboratory skills. He suggested the value of concrete experience for some aspects of science inquiry instruction and also suggested the value of focused and specific training in scientific inquiry as opposed to more general curriculum.

Evidence provided by the previous studies to investigate the effects of instructional strategies and curriculum on science process skills and practical laboratory skills suggests the following possibilities related to this study:

1. Laboratory-centered inquiry approaches in instruction can enhance student process skills and laboratory skills performance.

2. Integration of a laboratory-centered inquiry program into a textbook-oriented regular curriculum can result in increased student process skills and laboratory skills performance. Further, the addition of an appropriate amount of specific inquiry skill activities can result in increased abilities.

3. A certain type of science curriculum which includes inquiry activities organized around a sequential cycle of learning (e.g., SCIS) can promote the development of science process skills.

Support is clear for an activity-centered, hands-on inquiry approach to teaching science for gains in science achievement, process skills and laboratory skills. There was a need for a comprehensive research study to examine the effects of laboratory-oriented inquiry activities in a specific science curriculum on laboratory skills and science process skills as well as science achievement in middle grades students. The present study was designed in response to the relative lack of inquiry-oriented instruction in "regular" science curricula. It is still very necessary to provide prescriptive data for the development and implementation of science curricula in schools in order to improve these student abilities.

Support has been provided for the Foundational Approaches in Science Teaching (FAST) program which was integrated into the "regular" science curriculum in this study. DelliColli (1979) found that FAST students in grades six and seven performed significantly better on basic process skills. Evaluation of FAST and non-FAST seventh-grade students was conducted in 1978. The results showed that FAST students scored significantly higher than non-FAST students on basic process skills and laboratory skills (Young, 1981). A follow-up study in 1984 also showed the same results as in 1978 (Young, 1984). Most recently, Young (1986) found favorable effects of the FAST program compared to a traditional science textbook approach on basic process skills, verbal creative thinking, and figural creative thinking.

Further, Tamir and Yamamoto (1977) compared high school students who had taken FAST to those who had not and found that FAST students showed significantly higher biology grades and greater interest in science. FAST students also showed a significantly lower preference for recall and a higher preference for questioning and principles than non-FAST students. Dekkers (1978) compared eighth grade FAST students to non-FAST students and found that FAST students had higher preferences for questioning and for field and laboratory work in terms of cognitive preferences.

It may be indicated from these results that the "laboratory-centered inquiry approach" to science learning as formulated by the FAST developers appears successful in that students seem to perform better on laboratory skills, thinking skills, and science achievement and to show favorable attitudes toward science. Yet, no single comprehensive research study can be found to examine the effects of the FAST integration into a regular science curriculum on laboratory skills, integrated science process skills, and understanding of science knowledge. Thus, the present study could also provide additional information for curriculum validation as well as evaluation of instructional strategies and student learning.

Method and Procedure

Two FAST and two non-FAST teachers in sixth grades classes and two FAST and five non-FAST teachers in seventh grades classes were involved in this investigation. All FAST teachers were certified for teaching FAST 1 through a two-week FAST 1 teacher training workshop and had at least one year of experience to implement the FAST 1 program in their science classes before this investigation. All non-FAST teachers, on the other hand, had neither of these experiences.

A total of 85 sixth grade students consisting of 47 FAST students (two classes) and 38 non-FAST students (two classes) and a total of 141 seventh grade students consisting of 83 FAST students (six classes) and 58 non-FAST students (five classes) were involved in this investigation. The sample group involved was heterogeneous to provide representation across ability levels, socio-economic levels, gender, and race from a relatively rural school district in the eastern part of North Carolina.

During the 1987-88 school year, the FAST 1 program as a laboratory-oriented inquiry approach was integrated into regular science classes in both the sixth and seventh grades (experimental groups). A total of approximately 30% of the FAST 1 content was covered through this integration at each grade level. This total included approximately 40% of physical science--Unit One: Introduction to the Properties of Matter (problems 1 to 17 at the most)--and approximately 20% of ecology--Seed Germination and either Soil and Water or Field Survey. Each activity was introduced in the manner of intended sequence and learning cycle under the instruction of the FAST 1 Teacher Guide (Pottenger, Young, and Kyselka, 1980) and the FAST Instructional Guide (Pottenger and Young, 1983). It was intended that approximately 60 to 80% of class time was spent for laboratory and practical work, and the four-phase learning cycle (a discrepant event, hands-on investigation, concept development, and application) was introduced. Integration was started at the beginning of the school year (September 1987).

In regular science classes (control groups), it was assumed that traditional teacher-oriented, lecture-demonstration approaches would be predominant, and students would get less hands-on experience of laboratory-oriented inquiry compared to experimental groups. In both experimental and control groups, the same textbook was used at each grade level; i.e. Holt Science (Holt, Rinehart, and Winston, 1984) was used in the sixth grade; and Principles of Science, Book One (Merrill Publishing Company, 1983) was used in the seventh grade. Both of these books were recommended as state-adopted basic textbooks by the North Carolina Department of Public Instruction. The characteristics of these textbooks are described below:

The Holt Science series presents a balance of life, earth, and physical science concepts including interdisciplinary and health-related topics. Science process skills are emphasized through activities and developed throughout the program. Student texts are organized so that each chapter is divided into sections which take two to three days to cover. The section format includes a chapter opener, prestated objectives, "read about" content, activities stressing "hands-on" science experience, summary of main ideas, and application questions (NC Department of Public Instruction, 1985. Excerpt from p. 19).

The Principles of Science, Book One covers the topics of matter and energy, mechanics, earth science, animals and plants, ecology, and conservation. Each chapter begins with a brief intro- ductory paragraph and goal statement and contains four or five supporting activities that foster the development of problem solving skills. There are review questions at the end of chapters and sections. This book accommodates either a lecture or a "hands-on" approach to instruction (NC Department of Public Instruction, 1985. Excerpt from p. 23).

The characteristics of both textbooks described seem to show that activities follow textbook reading as a verification of content taught (deductive approach). The content related to the density concept, which was designed to be taught in the FAST 1 program, was not included in the textbook used in the sixth grade but was included in the textbook used in the seventh grade.

In order to examine the effects of the FAST integration, comparisons were made of the post-test scores at the end of the school year--April 1988 for the sixth grade and June 1988 for the seventh grade--between experimental and control groups at each grade level. For the post-tests, three evaluative instruments were used to assess student laboratory skills, integrated science process skills, and understanding of science knowledge.

Evaluative Instruments

All subjects were given the following three evaluative instruments as post-tests.

The first, Performance of Process Skills Test (POPS), developed by Pottenger, Mattheis, Jones, and Nakayama (1987), consists of 21 items designed to assess six integrated process skills in science in a general context (content free). They are identifying experimental questions (three items), formulating hypotheses (three items), identifying variables (six items), designing investigations (three items), graphing data (three items), and interpreting data (three items). The questions are answered through multiple choice selection out of four possible answers. This test was adapted from the Middle Grades Integrated Science Process Skills Test (MIPT) developed by Cronin and Padilla (1986).

The second test, FIN Test, developed by Fukouka, Pottenger, Ishikawa, and Nakayama (1987), consists of six relatively general items designed to evaluate the understanding of basic science knowledge in the extended context of FAST 1. They are existence of buoyancy, conservation of weight, direction of gravitational force, equilibrium of system (subsurface floating of object), water pressure as force, and density. The questions are ansered by writing appropriate explanations on each item.

The third, Laboratory Skills Test (LST), developed by Curriculum Research and Development Group, University of Hawaii (1987), consists of three parts (total of 16 items) which are relatively related to the FAST 1 context. LST-Part 1 consists of six items designed to assess the practical laboratory skills--measuring height, area, mass, volume displacement, and calculation of density. LST-Part 2 consists of six items designed to assess the process skills of graphing and interpreting data. LST-Part 3 consists of four items designed to assess knowledge and understanding of the density concept. The questions are answered by writing the appropriate answer on each item.

In addition to these, the California Achievement Test scores (national percentile of the CAT total battery) of individual students were gathered from each teacher in order to establish an equivalency between experimental and control groups.

Construct Validity of Measures

To evaluate the construct validity of measures, the scores of the three instruments were subject to a factor analysis by grade. The SPSSX-Factor Program, employing the principle components method with varimax rotation to simple structure of all factors having eigen values greater than 1.0, was used. Results of this procedure could provide evidence for convergence and discriminance. Convergent validity between variables is exhibited by high loadings for variables on the same factor, whereas discriminant validity among variables is supported by high loadings coupled with modest loadings on the same factor (modest-high couple). In this study, a high loading is $\geq$ .60, a medium loading is $\geq$ .40 and $\leq$ .59, and a low loading is $\leq$ .39.

The results of the POPS, FIN, and LST tests for the sixth grade students are shown in Table 1. High loadings on the same factor (factor 1) are observed for the POPS total score with the corresponding LST-Part 2 score. Therefore, substantial evidence for convergent validity between integrated process skills in a general context and individual process skills in a specific context was found. This suggested that the POPS and LST-Part 2 test items provide a measure on a common underlying structure (dimension) which is defined to be science process skill ability. On the other hand, high loadings on the same factor are not observed for the FIN total score with the corresponding LST-Part 3 score; the FIN total score and LST-Part 3 score by themselves exhibit a high factor loading on factor 2 and factor 3, respectively. Therefore, little evidence for convergence between the two knowledge/understanding measures is present. The LST-Part 1 (a laboratory skill measure) does not exhibit a high factor loading on any factors; it exhibits a medium loading on both factor 1 and factor 2. Therefore, little evidence for convergence between laboratory skill and process skill measures, or between laboratory skill and knowledge/understanding measures, is observed.

Modest-high factor loading couples for the LST-Part 2 score (a process skill measure) with the FIN total score and LST-Part 3 score (knowledge/ understanding measures), and for the POPS total score (a process skill measure) with the FIN total score, are observed, whereas only half the modest-high couple is seen for the POPS total score with the LST-Part 3 score. The POPS total score exhibits a medium factor loading on factor 3, which exhibits a high loading for the LST-Part 3 score. Thus, substantial evidence for discriminant validity between science process skills and knowledge/understanding measures is found.

The evidence for convergent and discriminant validity provided by the results in sixth grade students indicated that the POPS and LST-Part 2 test items provide a measure on a common underlying structure defined as science process skills, which is a differentiated dimension from that of knowledge/understanding measured by the FIN and/or LST-Part 3 test items.

The results of the POPS, FIN, and LST tests in the seventh grade students are shown in Table 2. High loadings on the same factor (factor 2) are observed for the LST-Part 1 score with the LST-Part 3 score. Therefore, substantial evidence for convergent validity between the two measures of laboratory skills related to the density concept and specific knowledge/ understanding of the density concept is found. This suggests that the LST-Part 1 and Part 3 test items provide a measure on a common underlying structure (dimension) which is defined to be the density concept. On the other hand, high loadings on the same factor are not observed for the FIN total score with the corresponding LST-Part 3 score; the FIN total score exhibits a high loading on factor 3 by itself. Therefore, little evidence for convergence between the two knowledge/understanding measures is present. High loadings on the same factor are not observed for the POPS total score with the corresponding LST-Part 2 score; the LST-Part 2 score exhibits a high loading on factor 1 by itself, while the POPS total score exhibits a medium loading on both factor 1 and factor 3. Therefore, little evidence for convergence between the two process skills measures is observed.

Modest-high factor loading couples for the LST-Part 1 score with the FIN total score were observed. Therefore, substantial evidence was provided for discriminant validity between the two measures of laboratory skills related to the density concept and general knowledge/understanding.

The evidence for convergent and discriminant validity provided by the results in seventh grade students indicates the LST-Part 1 and Part 3 test items provide a measure on a common underlying structure defined as the density concept, which is a differentiated dimension from that of general knowledge/understanding measured by the FIN test items.

Inspection of both sixth and seventh grade data shown in Table 1 and Table 2 reveals that, in common, the tests used in this investigation measure three distinctive underlying dimensions: science process skills (the POPS and/or LST-Part 2 tests), specific knowledge/understanding related to the density concepts (the LST-Part 3), and general knowledge/understanding (the FIN test). The LST-Part 1, designed to measure laboratory skills related to the density conepts, tends to be associated with the dimensions of science process skills and/or specific knowledge/understanding related to the density concepts.

Results

To examine the main effects of the FAST treatment by each grade, the Multivariate Analysis of Covariance (MANCOVA) was conducted by using the SPSSX MANOVA subcommand. The overall omnibus F-value, which represents the main effect of the FAST treatment on three dependent variables (the POPS, FIN, and LST total scores) with the CAT total score as a covariate, showed significance using Wilk's criterion in the sixth grade group [$F(3,80) = 6.80$, $P < 0.001$] and in the seventh grade [$F(3,136) = 13.30$, $P < 0.001$]. In addition, as the LST test was divided into three subtests, a significant main effect of FAST treatment was also found on five dependent variables (the POPS, FIN, LST-Part 1, LST-Part 2, and LST-Part 3 tests) with covariate CAT, both in the sixth grade group [$F(5,78) = $ [illegible]$.53$, $P < 0.001$] and in the seventh grade group [$F(5,134) = 11.14$, $P < 0.001$]. These results indicate the student laboratory skills, integrated science process skills, and understanding of science knowledge as a whole ability seem to be affected by the FAST 1 instruction utilized at each grade.

To examine the effects of the FAST treatment on each individual dependent variable by each grade, the univariate one-way Analysis of Covariance (ANCOVA) was conducted by using the SPSSX MANOVA subcommand. The adjusted mean scores of each test by the CAT score and the results of ANCOVA with covariate CAT are shown in Table 3. Significant differences on the LST total score were formed between the FAST and non-FAST groups for both the six graders [F(1,82) = 19.45, P < 0.001] and the seventh graders [F(1,138) = 28.74, P < 0.001]. However, no significant differences on the POPS and FIN total scores were found between the two treatments with either grade level.

Closer analysis of the LST test where significant effects of the treatments were found at both grade levels was possible through examining abilities tested and the degree to which the FAST instruction influenced them. To accomplish this, the LST test was divided into three subtests: a subtest of laboratory skills related to the density concept (Part 1); subset of specific science process skills, i.e. graphing and interpreting data (Part 2); and subtest of specific knowledge/understanding of the density concept (Part 3). The subtest scores were analyzed using the univariate one-way Analysis of Covariance (ANCOVA) covarying on the CAT total score. The adjusted mean scores of the subtests by the CAT scores and the results of ANCOVA are also contained in Table 3.

Significant differences on the laboratory skills subtest (LST-Part 1) were found between the FAST and non-FAST groups for both the sixth graders [F(1,82) = 19.05, P < 0.001] and the seventh graders [F(1,138) = 43.29, P < 0.001]. Significant differences on the process skills subtest (LST-Part 2) were also found between the two treatments for both sixth graders [F(1,82) = 8.44, P = 0.005] and the seventh graders [F(1,138) = 7.40, P = 0.007]. However, no significant differences due to treatment were obtained on the knowledge/understanding subtest for the seventh grade students [F(1,138) = 1.89 , P = 0.171], whereas significant differences were found for the sixth grade students [F(1,82) = [illegible].58, P = 0.035].

These results showed that the FAST 1 instruction integrated into regular science classes seemed to significantly affect, especially on laboratory skills (the LST-Part 1) and specific process skills such as graphing and interpreting data (the LST-Part 2) from students at both grade levels. However, the FAST integration did not seem to significantly affect the integrated science process skills as a whole (the POPS total) and knowledge/understanding in general contexts (the FIN total). Yet, support was obvious for the main effects of the FAST instruction on laboratory skills, science process skills, and understanding of science knowledge as a whole for students in both the sixth and seventh grades.

Summary and Discussions

To examine the effects of laboratory-centered inquiry instruction compared to traditional textbook-centered instruction on the student laboratory skills, science process skills, and understanding of science knowledge, the Foundational Approaches in Science Teaching (FAST) 1 was integrated into the existing regular science curriculum for the whole school year in the experimental group, while in the control group FAST 1 was not used and it was assumed that traditional teacher-centered, lecture-demonstrated approaches would be predominant as compared to the experimental group. In both groups, the same textbook was used by the different teachers. All FAST teachers were certified through a two-week workshop and had at least one year's experience to implement the FAST 1 program in their classes before this investigation, while non-FAST teachers had neither of these. A total of approximately 30% of the FAST 1 content was covered through the whole year integration. Each activity was introduced in a manner of intended sequence and learning cycle under the instruction of the teacher guide. The students in the sixth and seventh grades involved in this investigation were heterogeneous to provide representation across ability levels, socio-economic levels, gender, and race. In terms of the California Achievement Test (CAT) scores of individual students, both FAST and non-FAST groups were considered to be equivalent at the sixth grade ($t = 0.882$, $df = 83$, $p > 0.05$) and the seventh grade ($t = 0.371$, $df = 139$, $p > 0.05$).

Yet it might still need to be considered that there are unknown factors influencing the student outcomes measured by the post-tests after the instruction was completed. Student characteristics, teacher characteristics, instruction, materials, educational environment, and interactions among these factors all have a bearing on the learning outcomes of students.

Through a review of related research studies, it was hypothesized that the intervention of a laboratory-centered inquiry program (FAST 1) into a textbook-oriented regular curriculum could result in increased student abilities dealing with laboratory skills, science process skills, and understanding of science knowledge. To test this hypothesis, the post-tests including three types of measures which were a measure of manipulative laboratory skills (the LST-Part 1), two measures of science process skills (the LST-Part 2 and the POPS), and two measures of knowledge/understanding (the LST-Part 3 and the FIN) were administered to both FAST and non-FAST students at the end of the school year after the treatments were completed.

Construct validity for these three types of measures was examined by a factor analysis employing the principal component method with varimax rotation. It was indicated that the LST-Part 2 and POPS test items could provide a measure on a common underlying structure defined as science process skills ability, and the LST-Part 3 could provide a measure of specific knowledge/understanding of the density concept, which were differentiated from the dimension of general knowedge/understanding measured by the FIN test. Laboratory skills measured by the LST-Part 1 tend to be associated with the dimensions of science process skills and/or specific knowledge understanding of the density concept.

The effects of the FAST treatment on each individual ability were examined by grade by conducting the univariate one-way Analysis of Covariance (ANCOVA) with the CAT total score as covariate. The main effects of the FAST treatment on total ability as a whole were also examined by grade by conducting the Multivariate Analysis of Covariance (MANCOVA) covar ing on the CAT total score.

Laboratory skills as one of the student learning outcomes were measured by the LST-Part 1. This subtest of the LST (six items) was designed to assess the manipulative basic process skills (four items) dealing with measuring height, area, mass and volume of liquid displaced and the abilities (two items) dealing with calculating and comparing the density of liquids, which requires the knowledge/understanding of the density concept in the process. All of these abilities were intended to be taught in the context within which the FAST instruction was presented. Therefore, the LST-Part 1 is considered to be a measure of specific transfer of manipulative laboratory skills into a similar situation for the FAST students. The scores of the LST-Part 1 might be differentiated because of two reasons. First, if the students do not get enough hands-on experience to deal with manipulative basic process skills, then inevitably the scores would be differentiated in favor of the FAST treatment. Second, if the students do not understand the knowledge of the density concept as a prerequisite, they cannot deal with calculating and comparing the density, thus the scores would be differentiated in favor of the FAST treatment. The content related to the density concept was not included in the textbook used in the sixth grade but was included in the textbook used in the seventh grade.

The scores of the LST-Part 1 (six items) were compared for each grade. The results showed that significant laboratory skills differences were found in favor of the FAST treatment for both sixth and seventh grade students. These results implied that non-FAST students might get less hands-on experience to deal with manipulative basic process skills and/or they might get less knowledge and understanding of the density concept as a prerequisite as compared to the FAST students. Manipulative basic process skills are considered not to depend on the context, and the evidence was provided, especially by the seventh grade results, which showed that even though the density concept was included in both FAST and non-FAST groups, significant differences were still found. Therefore, it could be suggested that the intervention of the FAST program into a regular class as a laboratory-centered inquiry approach seems to result in increased student laboratory skills. Yet, as indicated by the inspection of construct validity of measures which showed that laboratory skills measured by the LST-Part 1 tend to be associated with the dimensions of science process skills and/or specific knowledge/understanding of the density concepts, a closer analysis of the LST-Part 1 test items might still be necessary.

Science process skills as one of the student learning outcomes were measured by the POPS and LST Part 2. The POPS (21 items) was designed to assess six integrated science process skills dealing with identifying experimental questions, identifying variables, formulating hypotheses, designing investigations, graphing data, and interpreting data. This test is a non-curriculum-specific measure and contains content-free test items which are referenced to a general context. Therefore, the POPS is considered to be a measure of general transfer of science process skills beyond the specific context. On the other hand, the LST-Part 2 (six items) was designed to assess specific individual process skills dealing with graphing and interpreting data in a familiar context related to mass and volume, within which the FAST instruction was presented. These process skills such as linear graph construction, direct reading of graph, interporate and extraporate from graph, and calculation of density using graphed data were intended to be taught directly through the FAST instruction. Therefore, the LST-Part 2 is considered to be a measure of specific transfer of individual process skills into a familiar context for the FAST students.

Yet, the inspection of contruct validity of measures showed that the LST-Part 2 and POPS test items could provide a measure on a common underlying structure defined as science process skills ability, and this dimension was differentiated from those of general knowledge/understanding and specific knowledge/understanding of the density concept. Through a review of related research studies, support is clear that science process skills can be taught and learned if the students have an appropriate amount of experience exposed to the situation dealing with this ability. Therefore, in general, if the students do not get enough laboratory-oriented inquiry experience to deal with science process skills, the process skills scores would be differentiated in favor of the FAST students.

Each of the POPS (21 items) and LST-Part 2 (six items) scores were compared between the two treatments by grade. The results showed that significant differences on the LST-Part 2 were found in favor of the FAST treatment for both sixth and seventh grade students. However, no significant differences were found on the POPS total scores with either grade level. These results imply that the FAST student might transfer specific individual process skills into a familiar context but not total integrated process skills into a general context and that non-FAST students might get less experience to deal with specific individual process skills. The differentiation of the LST-Part 2 scores and non-differentiation of the POPS total scores also imply that specific individual process skills might depend on the context familiarity within which instruction was presented. It could be suggested from these results that the intervention of the FAST program into a regular class as a laboratory-centered inquiry approach seems to result in increased specific individual process skills, i.e. graphing and interpreting data. Little evidence for the acquisition of total integrated science process skills ability in a general context is present. Closer analysis of the process skills ability might be necessary through examining specific skills and the degree to which the instruction influenced them by dividing the POPS test into its subtests.

Understanding science knowledge (science achievement), as one of the student learning outcomes, was measured by the FIN and LST-Part 3. The FIN (six items) was designed to assess knowledge and understanding about conservation of weight, direction of gravitational force, and water pressure as force in a general and outside context from the FAST instruction (three items) and knowledge and understanding about existence of buoyancy, subsurface floating, and density of object in the extended context from the FAST instruction (general transfer or application) which are relatively in a general context (three items). The LST-Part 3 (four items) was designed to assess knowledge and understanding about floating/sinking and density in a specific context relatively related to the FAST instruction (specific transfer). The inspection of construct validity showed that the FIN could measure on a general knowledge/understanding dimension, which is differentiated from that of specific knowledge/understanding of the density concept measured by the LST-Part 3. The acquisition of knowledge and understanding can be directly influenced by the content instruction plus process instruction associated with the content. Through a review of related research studies, support is clear that laboratory-oriented inquiry approaches can enhance student achievement in science. Thus, if the students get less or none of the content instruction, it would result in the differentiated scores on these tests. Further, if the student got less or none of the process instruction associated with the content, the content achievement scores would be differentiated. The content related to the density concept was not in the sixth grade textbook but in the seventh grade textbook.

Each of the FIN (six items) and the LST-Part 3 (four items) scores were compared between two treatments by grade. The results showed that significant differences on the LST-Part 3 were found in favor of the FAST students in the sixth grade. This result implied that the FAST students might transfer the specific knowledge/understanding which was directly taught through the FAST instruction into a related context, whereas the non-FAST students might not get the specific content instruction, thus the scores were differenetiated. However, the results showed that no significant differences were found on the LST-Part 3 in the seventh grade. Further, no significant differences were found on the FIN total scores with either grade level. Therefore, little evidence for the acquisition of knowledge and understanding in science is present. Additional information about what and how the content was taught in the science classes might still be necessary for further analysis.

Total ability in science--laboratory skills, science process skills, and understanding of science knowledge as a whole--was measured by all tests combined. Through a review of related research studies, it was assumed that laboratory skills and science process skills could not be developed just by transmitting the body of knowledge without hands-on experience through the laboratory-centered inquiry activities and that the students would need to be involved in scientific investigation thereby developing simultaneously these procedural skills in science and gaining deeper understanding of science knowledge. Thus, it was hypothesized that the intervention of a laboratory-centered inquiry program (FAST 1) into a textbook-oriented regular curriculum could result in increased student total ability in science. The scores of the combination of all tests were compared between two treatments by grade. The results obviously showed that significant main effects of the FAST treatment were found on the total ability in science for both sixth and seventh grade students. Therefore, the hypothesis was supported by this evidence.

Conclusion

The present study was designed in response to the relative scarcity of laboratory-centered inquiry activities in regular science curricula. The major finding from this study is that the integration of the FAST program into a regular science curriculum as a laboratory-oriented inquiry approach seems to result in increased student total ability in science, i.e. laboratory skills, science process skills, and understanding of science knowledge as a whole, over a long period of time. In a more general statement, it appears that an integration of science content and process instruction through laboratory-oriented inquiry activities seems to result in great benefit to students. Hopefully, this study could provide an additional support for positive encouragement of science curriculum and instruction with emphasis on laboratory-oriented inquiry.

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As part of the preparation for this cooperative project, Nakayama, one of the authors of this paper, was certified for teaching FAST 1, 2, and 3 through a five-week workshop in Hawaii during the summer of 1987 and was also certified for training FAST 1, 2, and 3 teachers through a five-week workshop in Hawaii during the summer of 1988.

The data analysis in the present investigation was conducted by using the SPSSX statistical program at the University of Hawaii Computing Center while Nakayama was there as a visiting research scholar in August 1988.

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Table 1.

Rotated Three-Factor Pattern of POPS, FIN and LST Scores in Sixth Grade Students (N = 85)

Variable (Ability*)	Factors		
	1	2	3
POPS (PS)	.71	.09	.48
FIN (KU)	.04	.78	.34
LST-Part 1 (LS)	.55	.41	.32
LST-Part 2 (PS)	.80	.18	.09
LST-Part 3 (KU)	.10	.55	.76
Eigen Value	1.45	1.13	1.04
Percent of Variance Accounted For	29.03	22.57	20.76

* Ability Tested:
PS: Integrated Science Process Skills
KU: Knowledge and Understanding in Science
LS: Practical Laboratory Skills

Table 2.

Rotated Three-Factor Pattern of POPS, FIN and LST Scores in Seventh Grade Students (N = 141)

Variable (Ability*)	Factors		
	1	2	3
POPS (PS)	.54	.04	.52
FIN (KU)	.42	.34	.62
LST-Part 1 (LS)	.51	.74	.05
LST-Part 2 (PS)	.78	.11	.37
LST-Part 3 (KU)	.48	.63	.49
Eigen Value	1.55	1.08	1.03
Percent of Variance Accounted For	31.09	21.65	20.59

* Ability Tested:
- PS: Integrated Science Process Skills
- KU: Knowledge and Understanding in Science
- LS: Practical Laboratory Skills

Table 3.

Adjusted Mean Scores of the Post-tests by the CAT Score and Results of ANCOVA with Covariate CAT by Grade

Test	Maximum Score	6th Grade Treatment FAST 1 (N=47)	6th Grade Treatment Non-FAST (N=38)	6th Grade F-value (df=1,82)	7th Grade Treatment FAST 1 (N=83)	7th Grade Treatment Non-FAST (N=58)	7th Grade F-value (df=1,138)
Dependent Variables:							
POPS Total	21	8.88	8.11	1.64 (NS)	9.22	10.32	3.69 (NS)
FIN Total	6	1.19	0.99	1.24 (NS)	0.95	1.21	2.83 (NS)
LST Total	16	2.51	0.82	19.45 ***	3.79	1.83	28.74 ***
LST-Part 1	6	0.71	0.12	19.05 ***	1.49	0.30	43.29 ***
LST-Part 2	6	1.37	0.48	8.44 **	1.86	1.21	7.40 **
LST-Part 3	4	0.43	0.23	4.58 *	0.44	0.32	1.89 (NS)
Covariate:							
CAT Total (Observed Mean)	100	50.28	45.92		50.23	51.91	

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$
NS: not significant