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AUTHOR Gibson, Helen L.; Van Strat, Georgena A.
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ABSTRACT

This paper documents a 3-year longitudinal study designed to track changes in preservice teachers' attitudes toward teaching and learning mathematics and science while enrolled in an Urban Preservice Degree Articulation in Teacher Education (UPDATE) Project. The primary goal of this project was to provide a pathway for urban para-educators of color to become certified teachers. The pilot project was designed to address the need for more teachers that reflect the ethnicities of the student population in urban public school districts. Data indicate that constructivist instructional methods used in science and mathematics courses had a positive impact on preservice teachers' understanding of mathematical and scientific concepts and their attitudes. (Contains 42 references.) (ASK)

# A LONGITUDINAL STUDY OF THE IMPACT OF CONSTRUCTIVIST INSTRUCTIONAL METHODS ON PRESERVICE TEACHERS' ATTITUDES TOWARD TEACHING AND LEARNING MATHEMATICS AND SCIENCE

Dr. Helen L. Gibson
Science Specialist for the Holyoke Public Schools
Kelly School
216 West Street
Holyoke, MA 01040
413-534-2312
hgibson@k12s.phast.umass.edu

Dr. Georgena A. Van Strat
Director of Special Academic Projects
Springfield Technical Community College
One Armory Square
Springfield, MA 01105
413-781-7822 ext. 4470
vanstrat@stccadm.stcc.mass.edu



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A Longitudinal Study of the Impact of Constructivist Instructional Methods on Preservice Teachers' Attitudes Toward Teaching and Learning Mathematics and Science

This paper documents a three-year longitudinal study designed to track changes in preservice teachers' attitudes toward teaching and learning mathematics and science while enrolled in an Urban Preservice Degree Articulation in Teacher Education (UPDATE) Project. This project was funded for three years jointly by the US Department of Education Fund to Improve Postsecondary Education (FIPSE) and the Massachusetts Eisenhower Higher Education Development Program. The primary goal of this project was to provide a pathway for urban paraeducators of color to become certified teachers. This pilot project was designed to address the need for more teachers that reflect the ethnicities of the student population in urban public school districts.

During the first year of the project, preservice teachers – all of whom were paraeducators - were exposed to mathematics content using constructivist instructional approaches: collaborative group work; problem solving; the use of manipulatives; and calculators. Three mathematics courses were redesigned as part of the UPDATE Project and offered during Summer and Fall 1998, at Springfield Technical Community College. Previous research documents that these reformed mathematics courses had a positive impact on the preservice teachers' attitudes toward mathematics (Gibson, Brewer, Magnier, McDonald & Van Strat, 1999). In Summer 1999, preservice teachers enrolled in an introductory Biology course where content was delivered through traditional pedagogy consisting of lectures and note taking. This Biology course resulted in a negative impact on preservice teachers' interest in teaching science

(Gibson, & Van Strat, 2000). The following year, Summer 2000, preservice teachers enrolled in a redesigned introductory Physical Science course taught using constructivist instructional methods. The focus of this paper is to present changes in: preservice teachers' attitudes towards mathematics and science; preservice teachers' critical thinking skills; and preservice teachers' conceptual understanding of physical science.

Mathematics and science reform movements endorse inquiry-based instruction grounded in constructivist pedagogy. The National Council of Teachers of Mathematics (NCTM, 1989; 1991; 1995), the Mathematical Association of America [MAA] (Tucker & Leitzel; 1995), the National Research Council (NRC, 1996; 2000), the National Science Foundation (NSF, 1996), and the American Association for the Advancement of Science (AAAS, 1993) advocate using a constructivist method of teaching, in which learners construct knowledge through inquiry. "Scientific Inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientist study the natural world." (National Science Education Standards, 1996, p. 23.)

The research literature on teacher education indicates that teachers tend to teach the way they were taught when they were students (Brown & Borko, 1992; Kennedy, 1991; NRC, 1996). Typically, future teachers spend untold hours in college classrooms with instructors who model traditional pedagogy. Consequently, they develop beliefs about teaching based on their in-class experiences. This places specific emphasis on the importance of redesigning mathematics and science courses at the college level. If we expect K-12 teachers to change the way mathematics

and science are taught college faculty must model inquiry-based, student centered pedagogy (NRC, 1997).

Research studies comparing the difference between traditional and constructivist teaching methods using different groups of secondary school students abound in the literature. In most of these studies, a control group of students is exposed to traditional methods of science instruction, while the experimental group of students is exposed to constructivist methods of science instruction (Chang, Chun-Yen & Mao, Song-Ling, 1998; Ertepinar & Geban, 1996; Geban, Askar & Ozkan, 1992; Gibson, 1998; Jaus, 1977; Mattheis & Nakayama, 1988; Padilla, Okey & Garrand, 1984; Purser & Renner, 1983; Saunders & Shepardson, 1987; Scheider & Renner, 1980; Selim & Shrigley, 1983; Shrigley, 1990; Wollman & Lawson, 1978). These studies conclude that inquiry-based science activities have positive effects on students' science achievement, attitudes toward science and school, cognitive development, laboratory skills, science process skills and understanding of science knowledge as a whole when compared to students taught using a traditional approach.

Much research has focused on comparing the two methods of instruction. However, one limitation to these studies experimental design is the failure to study the impact of pedagogy on the same group of students over time. Research that looks at the impact of the two different types of instruction on the same group of students has rarely, if ever, been conducted. In this study we documented the experiences of preservice teachers who were exposed to both types of instructional methods (constructivist and traditional approaches; reformed and non-reformed courses) and have tried to understand how instructional methods impacted preservice teachers' attitudes toward teaching and learning mathematics and science.

## Background

Project UPDATE is a collaboration between Springfield Technical Community College (STCC), the University of Massachusetts-Amherst School of Education, the University of Massachusetts (UMass)/University Without Walls (UWW) and the Springfield Public Schools. The project was designed to address key issues, for teachers and students in urban school districts, involving equity and multiculturalism. Specifically, urban districts have a disproportionately low number of teachers of color with respect to the student population. Further, urban districts are in need of teachers who combine sensitivity to issues of diversity with technological competency. Additionally, urban districts are in need of teachers capable of bridging the social gap between themselves and their students to assist children from many ethnic backgrounds cope with the complex social issues facing them (Weiner, 1993). Preliminary outreach efforts revealed that many paraeducators in the Springfield Public Schools were people of color who were interested in becoming teachers.

Project UPDATE provides the pathway for paraeducators to work toward an Associate of Arts degree via a curriculum designed to meet the educational challenges of urban schools. The project incorporates a curriculum designed around constructivist methodologies for the delivery of multiculturally rich, technologically relevant courses to adult learners working in urban public education who want to earn a teaching certificate.

UPDATE Scholars, as the preservice teachers became known, continue to work full time as paraeducators while attending college part time. Individuals with little or no college experience begin at STCC and work towards an Associate of Arts degree. Upon completion of their Associate of Arts degree, UPDATE Scholars continue to work toward their Bachelor of

Arts degree from the University of Massachusetts-Amherst through the UWW program. Paraeducators who already have a significant amount of college experience go directly into the UWW program. Through UWW, students may acquire credit for experiential learning. UPDATE Scholars also acquire a Teaching Certificate (Early Childhood or Elementary) through the University of Massachusetts School of Education. Most courses are offered in Springfield at STCC. UPDATE Scholars are eligible for both federal and state financial aid.

## Methodology

### Description of the Courses

In the first year of project UPDATE, three redesigned mathematics courses were offered at STCC during Summer and Fall 1998: Elementary Algebra I; Elementary Algebra II; and Math for Early Childhood/Elementary Teachers. Sixteen preservice teachers completed these three mathematics courses. Instructors of all three mathematics courses employed a wide range of instructional strategies, which included collaborative group work, problem solving, the use of manipulatives, and calculators. This series of constructivist mathematics courses had a positive impact on preservice teachers' attitudes towards mathematics (Gibson, Brewer, Magnier, McDonald & Van Strat, 1999).

In the Summer of 1999, a non-reformed Principles of Biology course was offered. Fourteen of the preservice teachers who completed the redesigned math courses enrolled in Principles of Biology. This course provided a significant contrast with the three reformed mathematics courses offered during Summer 1998, in that the biology course used a traditional lecture and note-taking approach. This biology course was found to have a negative impact on the preservice teachers' interest in teaching science (Gibson, & Van Strat, 2000).

During Summer 2000, a reformed college level Physical Science course was offered. This course was taught using constructivist instructional methods which included hands-on activities, manipulatives, real life applications, field trips, group work, and authentic assessments (peer assessments, self-assessments, performance assessments, portfolios and journals). Physical Science is a 4 credit, one semester class that met eight hours per week. The course was designed to introduce students to basic concepts of physical science. Nearly every class included hands-on science activities. These inquiry-based activities were followed-up with classroom discussions and reflective writings. A textbook was used to supplement the in-class activities (Conceptual Physical Science - Hewitt/Suchocki/Hewitt). The textbook was used to reinforce concepts introduced during class activities, and to address many important ideas not specifically covered in class. In addition, students were given weekly homework assignments to engage and challenge them to improve their breath and depth of understanding of physical science concepts.

Journal writing assignments were given at each class meeting. At times journal assignments required students to think about science concepts before formal presentations. At other times, journals were used to make students reflect on observations made in class as well as asking them to make new observations outside of class. Journals were reviewed during one-on-one meetings several times during the term. At the start of class the instructor asked students if they had any comments or questions about their journal assignments. This opening dialog set the tone and provided an introduction to the day's class.

A significant percentage of the final grade was based on self-assessment, peer assessment, and performance assessment. Written quizzes and tests emphasized placed on explanations rather than on recall of facts. In addition, different ways of knowing and teaching

scientific ideas were explored. As the final assignment for the course each student was required to select a physical science concept, prepare a lesson, and make a short presentation to the class.

Participants

All fourteen preservice teachers were women and worked full-time as paraeducators in an urban school district. Two were Russian emigrants, one was African American, five were Hispanic, and six were White. Seven of the fourteen UPDATE preservice teachers completed the Introduction to Physical Science course, the three reformed mathematics courses, and the Principles of Biology course. Thirteen were working on their Associate's degree at STCC, while one had already matriculated to the University of Massachusetts Amherst and was working on her Bachelor's degree. Paraeducators take courses during late afternoon and/or early evening to accommodate their work schedules. In addition, many of the paraeducators have children and were single mothers. Usually paraeducators take 3 to 6 credits per semester. All but one of the preservice teachers expressed an interest in teaching at the elementary school level. Only one expressed interest in teaching at the middle/secondary school level.

Data Sources

UPDATE Scholars enrolled in Introduction to Physical Science completed three questionnaires: a *Science Questionnaire* (Rea-Ramirez, Stillings, Vining, & Khan, 2000; Fermann, Stamm, Maillet, Nelson, Codden, Spaziani, Ramirez, & Vining, 2000) and a *Scientific Thinking Survey* (Rea-Ramirez, et al., 2000; Fermann, et al., 2000) and the *Test of Conceptual Understanding* (Gibson, Bernhard, Kropf, & Van Strat, 2001). All three instruments were administered twice: once during the beginning of the course, and once near the end of the course. A focus group and an interview were conducted to capture qualitative data on the perspectives of

both the preservice teachers and the instructor. Each preservice teacher kept a reflective journal recording her experiences in this course.

The *Science Questionnaire* measures students' attitude towards the teaching and learning of science. It contains 38 statements that preservice teachers were asked to agree or disagree with, on a 6 point Likert scale, ranging from 1 = "Strongly Agree" to 6 = "Strongly Disagree". Students completed the pre-administration of the questionnaire on-line in a computer lab during a class meeting. Due to technical difficulties with the computer lab, post-surveys were administered on paper and sent through the mail to students after the course ended. Differences in preservice teachers' response pre and post identified any change in their attitudes toward science as a result of their experiences in this course.

The *Scientific Thinking Survey* contains four open-response questions that measure critical thinking skills. Each question contains multiple tasks, such as understanding experimental design, identifying underlining assumptions, interpreting graphical information, and designing follow-up experiments. Students completed the pre-administration of the questionnaire on-line in a computer lab during a class meeting. Due to technical difficulties with the computer lab, post-surveys were administered on paper and sent through the mail to students after the course ended. Changes in preservice teachers' responses pre and post to these four items indicated any development in preservice teachers' critical thinking skills as a result of their experiences in this course.

The *Test of Conceptual Understanding* contains 24 questions that measure conceptual understanding of physical science. The physical science course instructor designed this instrument. This questionnaire contains 12 multiple-choice questions, 6 definitions, and 6 open-ended questions requiring a scientific explanation. Preservice teachers completed both pre and

post-administrations of the survey during class time. Changes in preservice teachers' responses to these 24 items were used to identify any change in their conceptual understanding of physical science.

A focus group with preservice teachers enrolled in Physical Science was conducted at the end of the course. The focus group collected information from preservice teachers about project UPDATE and specifically about the Physical Science course. Participation in the focus group was voluntary and no members of the STCC staff were present. The focus group was audiotaped for transcription purposes only. The session lasted about 90 minutes. In addition, an informal interview was conducted with the instructor of the Physical Science course after the course had been completed.

In addition, preservice teachers' journals were collected at the end of the course. For the purposes of this study the journals were photocopied and returned. Also there was an exit survey administered requesting the following information: 1) Comment on the usefulness of the journals for learning, 2) How would you like to see this class be different? What changes do you suggest? 3) What should definitely not be changed?

## Results

### Science Questionnaire

A paired t-test was used to determine statistically significant changes in preservice teachers' responses to items on the pre and post administrations of the *Science Questionnaire*. The following Table presents the five items that where statistically significant differences in preservice teachers' responses to the pre and post survey ($p \leq .05$). Of the fourteen preservice teachers in the physical science course only nine completed the pre and post surveys ($n = 9$).

Table 1
*Statements from the Science Questionnaire that revealed statistically significant differences between pre and post survey responses.*

| Statements |
| --- |
| 1. Even if I forget the facts I'll still be able to use the thinking skills I've learned in science. |
| 10. The job of science instructors is to explain the things we are expected to know. |
| 14. If there is conflict in science, the most commonly held belief is the correct one. |
| 24. I can do well in science. |
| 37. Lab experiments are used to confirm facts studied in the science class. |

The results from this survey indicated that preservice teachers shifted some of their beliefs about science. They went from believing that remembering facts was important to believing that thinking skills were more important. They shifted from believing that the job of science teachers was to explain what students should know to believing that science teachers should not explain what students are expected to know. They went from believing that commonly held scientific beliefs are correct to believing that commonly held scientific beliefs are not necessarily correct. They shifted from believing they could not do well in science courses to believing that they could do well in science courses. And lastly, they went from believing that lab experiments were used to confirm facts studied in science classes to believing that lab experiments are not used to confirm facts.

Scientific Thinking Survey

To determine any differences in preservice teachers' critical thinking skills over time, a paired t-test was used to look at the items on the *Scientific Thinking Survey*. A paired t-test showed that there was statistically significant difference ($p \leq .05$) in preservice teachers' critical thinking skills between the beginning and the end of the Physical Science course. Preservice teachers pre mean score on *the Scientific Thinking Survey* was 12 and their post-mean score was 19. This data indicates that preservice teachers enrolled in this course improved their critical thinking skills. Individual item analysis of the questions on this survey indicated that preservice teachers' skills improved in the following categories: their ability to analyze data improved ($p \leq .05$) and their understanding of controls and variables improved ($p \leq .05$).

Test of Conceptual Understanding

To determine differences in preservice teachers' conceptual understanding of science over time, a paired t-test was used to look at the items on the *Test of Conceptual Understanding.* A paired t-test showed that there was a statistically significant difference ($p \leq .05$) in preservice teachers' conceptual understanding of physical science between the beginning and the end of Introductory Physical Science. Preservice teachers pre test mean was 29% correct (7 out of 24) and their post test mean was 50% correct (12 out of 24). These results indicate that preservice teachers' learned some physical science concepts as a result of taking this Physical Science course.

Focus Group

Responses of the preservice teachers during the focus group revealed that the ways the instructional practices used in this course helped the preservice teachers to learn physical science concepts, to improve critical thinking skills, to improve attitudes toward science courses, and to improve their understanding of science. The following are excerpts from the focus group:

- *We used a lot of manipulatives in this course and that helped us learn science.*
- *The instructor always made sure to include examples of how physical science concepts were applicable to our everyday lives.*
- *A lot of time was spent on fewer science concepts.*
- *The instructor made them like science more because of the way the course was taught.*

Journals, Exit Surveys and Interviews

Journal entries support the findings that the instructional practices used in this course helped preservice teachers appreciate science in their everyday lives, as well as helping learn science concepts. Their scientific knowledge began to deepen as they developed new understandings. The following are a few excerpts from the reflective journals:

- *I want to understand the science concepts we learned about in class today. I never had a true understanding before. I now understand friction, normal force and gravity.*
- *Since this class started I have to admit that I am viewing things differently. For example, I think about chemical and physical changes that happen in my kitchen while I am cooking.*

- *Newton's laws of motion, potential and kinetic energy have more meaning to me now.*

Preservice teachers responses on the exit surveys suggested that they found keeping a journal useful to learning. Following are quotes from the exit surveys:

- *It helped me think more about what we had discussed in class.*
- *It made me feel safe to express my own opinion. I didn't have to worry about being right or wrong.*

Overall, the journals were useful because they made them think more about the science concepts they were introduced to in class. There is no doubt that students need to take time to understand science concepts. The following quotation was taken from the interview with the course instructor, "The use of journals engages students outside of class and keeps their minds on the topics at hand. Keeping a journal requires students to reflect on their learning and this can lead to deeper conceptual understanding."

## Conclusions and Implications

The three mathematics courses UPDATE students took during Summer and Fall 1998 were taught using a constructivist approach. This method of teaching had a positive impact on preservice teachers' attitude towards mathematics (Gibson, Brewer, Magnier, McDonald & Van Strat, 1999). In addition, the data indicated that these instructional methods also helped preservice teachers learn mathematics. Constructivist teaching methods improved preservice teachers' attitudes toward mathematics and it also helped them learn mathematics. This user-friendly method of instruction was important to preservice teachers developing good attitudes

toward mathematics. In contrast, Principles of Biology taught using a traditional approach (lecture and note taking) had a negative impact on preservice teachers interest in teaching science (Gibson & Van Strat, 2000).

The data presented in this paper indicates that constructivist instructional methods used in Introductory Physical Science had a positive impact on preservice teachers' understanding of physical science concepts, attitude toward science teaching and learning, and critical thinking skills. It is fortunate that these preservice teachers had a positive experience in their Physical Science course especially after the negative experience they had the previous year in the traditionally taught Biology course. The data we have collected, over the last three years, indicates that reformed college mathematics and science courses that use constructivist instructional strategies have had a positive impact on these future educators' attitudes toward mathematics and science.

Research has shown that prospective teachers' attitudes and beliefs toward mathematics and science are key influences on how they teach (Ball, 1990a, 1990b; Moreiri, 1991; Peterson, Fennema, Carpenter & Loef, 1989; Oshima, 1966; Roth-McDuffie et al., 1996; Schoenfeld, 1985, 1989; Silver, 1985; Strawitz, 1976; and Watters & Ginns, 1997). If the educational community wants to increase the number of teachers that can use constructivist instructional strategies to teach math and science then the ways that math and science are taught at the college level must change. Despite programs funded through NSF Collaborative for Excellence in Teacher Preparation such as STEMTEC at the University of Massachusetts, Amherst, traditionally taught college level math and science courses continue to perpetuate the belief that knowledge should be passed down from teacher to student and that learning involves memorizing facts and information. Students are seen as empty vessels waiting to be filled, and

teachers should do the filling. Lecturing informs students what they need to know, and students listen and memorize what they have been told.

Many undergraduate science courses continue to be fact-laden, non-inquiry oriented with cookbook laboratories. Because many preservice teachers learned science by attending lectures and taking notes, it is not surprising that they view science as a body of knowledge which they are expected to transmit to children. When preservice teachers finally begin teaching science in their own classrooms, they will remember how they were taught. Many preservice teachers have biased views about how science should be taught. In contrast, research supports the idea that preservice teachers who participate in science courses taught using constructivist instructional methods (inquiry-based) will develop a positive attitude toward science, and this may translate into their interest in teaching science in the elementary classroom. The goal is to prepare teachers who can encourage children to ask their own questions and to allow children to find their own answers, not to tell children a bunch of facts and information about science so they can pass a test.

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