The Influence of Inquiry-Based Multimedia Learning Environment on Scientific Problem-Solving Skills Among Ninth-Grade Students Across Gender Differences

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Abstract

This study investigated the use of inquiry-based multimedia learning environment as a way to increase students' problem-solving skills, especially female students in a ninth-grade astronomy course. Using a pre- and posttest design, the study used multiple choice and written essay questions to measure students' content understanding and problem-solving skills. The results of ANOVA conclude that inquiry-based multimedia learning is viable and effective for improving content understanding and problem-solving skills with all students, especially females.

Introduction

The investigation of gender differences has been a significant area of study for many researchers in science (American Association of University Women [AAUW], 1992; Craig, 1999; Mael, 1998; Scanlon, 2000). After years of research outlining inequities, there still remains a discrepancy between the performance of females and males in science courses (Shymansky, Hedges, & Woodworth, 1990; Third International Mathematics and Science Study, 1998). More efforts are needed to remove the obstacles to gender equity (Kirkpatrick & Cuban, 1998; Littleton, Light, Joiner, Messer, & Barnes, 1992; Whitelock et al., 1995). Researchers indicate that females often become uncomfortable and uninterested in science early in the educational process (Jewett, 1996; Valentine, 1998). AAUW (1992) and National Assessments of Educational Progress (1979) report that females have lower achievement scores in science knowledge, hold a less positive attitude toward science, and participate in far fewer science-related activities than do males (Schibeci & Riley, 1986). Hill, Pettus, and Hedin (1990) cite that females in science-related fields exhibit a high level of science anxiety.

A variety of factors contribute to the poor performance of female students in science. These factors include social expectations related to gender-role in career choice, teacher bias, and discrepancy in the amount of hands-on experiences (Jewett, 1996). Researchers believe that a primary reason for gender differences is that females are not given the same opportunities to learn as male students (Valentine, 1998). Females receive an inferior education to males in the use of science equipment and materials. In a science laboratory, for example, male students more often work with the equipment while female students write down the observations (Rosser, 1990). As a result, females do not gain experience or confidence in the manipulation of science equipment (Hill, Pettus, & Hedin, 1990; Kahle, 1996; Rosser, 1990; Sjoberg, 1993).

This lack of experiences lowers females' self confidence in their science abilities and fosters negative attitudes toward science (Kahle, 1996). It might account for a large portion of the differences between males and females in science achievement (Jewett, 1996; Kahle, 1996). Researchers suggest that females' performance in science will improve by using instructional methods such as inquiry-based approaches (Greenberg-Lake, 1991; Hill et al., 1990; Lock, 1992; McLaren & Gaskell, 1995; Shakeshaft, 1995). These methods provide a wider variety of science experience for all students, particularly females. These opportunities include practice observing, measuring, and testing hypotheses (Eccles, 1989; Freedman, 2001; Matyas, 1985; Shakeshaft, 1995). Inquiry-based approaches are a key to keeping females interested in science and participating in hands-on experience (Freedman, 2001; Jenkins & MacMonald, 1989; Matyas, 1985).

Inquiry Learning

Inquiry-based approaches have been described as a "pedagogical method combining intellectual questioning with student-centered discussion and discovery of pivotal concepts through laboratory activities" (National Research Council, 1996). Inquiry emphasizes observing, classifying, formulating hypotheses, identifying and controlling variables, experimenting, and making valid conclusions (Gagne, 1970). Inquiry has been shown to be a successful intervention technique in science (Anderson, 1993; Doran, Boorman, Chan, & Hejaily, 1993; Lock, 1992; Sjoberg, 1993; Thomas, 1986). Inquiry-based activities facilitate scientific problem solving because they let students question their own observations, generate and refine hypotheses, deal with experimental data, test those hypotheses by experimentation, and evaluate evidence (Bybee, 1993; Collins, 1998; Kuhn, Amsel, & O'Loughlin, 1988; Moore, 1993; National Research Council, 1996; Uno, 1990; Windschitl, 2000).

Many studies have shown that inquiry-based approaches produce significantly greater science process skills than conventional approaches (Chiappetta & Russell, 1982; Glasson, 1989; Krajcik et al., 1998). Moreover, some groups report that students' cognitive ability, science achievement, and scientific problem solving improve if students experience inquiry-based approaches (Bredderman, 1983; Greenberg-Lake, 1991; Haury, 1993; Hill et al., 1990; Lindberg, 1990; Lock, 1992; McLaren & Gaskell, 1995).

In addition, research has shown that inquiry-based, hands-on strategies increase the science success of female students (Bredderman, 1982; Shymansky et al., 1990). The inquiry activities enable females to participate in hand-on experiences, to see relevance in the application of science, and to make science important for them to learn (Anderson, 1993; Greenberg-Lake, 1991; Hill et al., 1990; Lock, 1992; McLaren & Gaskell, 1995; Thomas, 1986). Researchers have demonstrated that increasing these experiences for female students boosts their attitudes toward science and their achievement (Shakeshaft, 1995; Simpson & Oliver, 1985). For instance, Eccles (1989) reports that females who have more inquiry-based experiences and opportunities can develop greater confidence in their abilities, more interest in subjects, and more interest in pursuing careers in mathematics and science-related fields.

Inquiry-based approaches have been applied in many innovative ways to assist science instruction. Most notably computer technology lets students experience authentic problem-solving activities that are difficult or impossible to create in real classroom situations (Geban, Askar, & Ozkan, 1992; Windschitl, 2000; Yager, 1995; Zietsman, 1986). Inquiry-based approaches that incorporate new technologies allow students to experience authentic science, and they result in improved science achievement (Bybee, 1993; Collins, 1998; Kuhn et al., 1988; Kuhn.D., Amsel, & O'Loughlin, 1988; Mayer, Moreno, Boire, & Vagge, 1999; Moore, 1993; National Research Council, 1996; Pea, 1993; Uno, 1990; Windschitl, 2000).

Purpose of the Study

Based on prior research findings, inquiry learning incorporating technology improves students' achievement, especially females (Greenberg-Lake, 1991; Hill et al., 1990; Jenkins & MacMonald, 1989; Lock, 1992; McLaren & Gaskell, 1995; Shakeshaft, 1995; Simpson & Oliver, 1985). This study investigates two specific research questions:

- Does a multimedia program designed around inquiry-based approaches improve students' conceptual understanding and problem-solving skills?
- Does a multimedia program designed around inquiry-based approaches have a differential effect on the conceptual understanding and problem-solving skills of male and female students?

Instructional Context

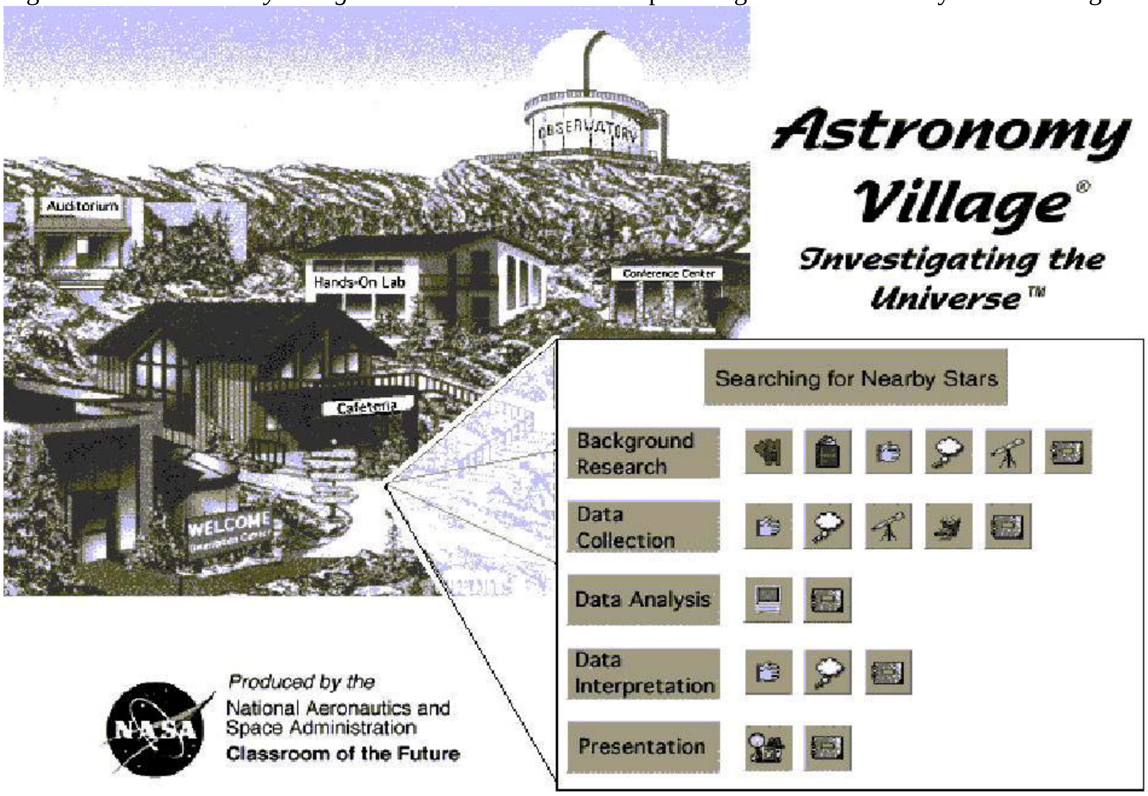
This study was conducted within the context of *Astronomy Village®: Investigating the Universe*™ (see http://www.cotf.edu/AV/av1.html). *Astronomy Village* uses the metaphor of living and working at a mountaintop observatory (the village) as the primary interface from which students investigate contemporary problems in astronomy (Pompea & Blurton, 1995 Jan/Feb). The environment includes 10 investigations covering a broad cross-section of current research in astronomy. In *Astronomy Village* a student research team is aided by a virtual mentor who immerses team members in science concepts and science inquiry skills. The research path diagram provides an overall guideline for the use of the program (see figure 1). Student teams proceed along a path of activities represented by various icons in the research path diagram. Each icon guides them to the village's virtual research facilities. At each facility the students gain information relative to their investigation.

The design principles of *Astronomy Village* come from inquiry processes emphasizing observing, classifying, experimenting, and making valid conclusions (Gagne, 1970). For example, *Astronomy Village* used four phases to support the inquiry process: (1) identifying questions to investigate in the background research phase, (2) designing investigations, (3) conducting investigations in the data collection, data analysis, and data interpretation phases, and (4) formulating and communicating conclusions in the presentation phase (Howard, McGee, Shin, & Regina, 2001; Robitaille et al., 1993). Within each phase students may complete up to six activities, such as simulations, hands-on experiments, thought questions, LogBook entries, and library research.

In the phase of identifying questions to investigate, students are presented with contemporary issues in astronomy. The questions are currently important to the scientific community and not fully answered by scientists.

In the Nearby Stars investigation, for example, students are asked to measure the distance to nearby stars, using a technique based on the parallax angle.

Figure 1. The *Astronomy Village* interface and the research path diagram for the Nearby Stars investigation.



The background research phase encourages students to examine articles and other sources of information to see what is already known in light of experimental evidence. The activities in this phase include reading articles in the virtual library and listening to lectures in the virtual theater. The library contains a large number of resources directly or indirectly relevant to the investigation.

As part of the designing investigations phase, investigations were developed to allow students to use multiple methods to address the problem. The virtual environment provides an authentic research context based on Kit Peak Observatory in Arizona.

In the conducting investigations phase the environment provides scaffolding to help students successfully complete the investigation. The students' virtual mentors send e-mail messages providing scaffolding on how to analyze the image data using an image-processing software program. This gives students an expert's suggestions and encouragement for pursuing their investigation. The software contains all the resources students need to conduct the investigation, including articles, data analysis tools, and organizational help. Moreover, students are given choices in selecting activities most beneficial for solving the problem.

In Nearby Stars, for instance, students collect from the virtual observatory images showing stellar movements. In the computer lab they use image-processing techniques to analyze these images taken at different time periods. Stars that move during a six-month period are nearby stars. Using the movement, students calculate the parallax angle of the nearby star. That angle then lets them calculate the star's distance from Earth. Students see how they can measure the distance to nearby stars. They then propose answers, explanations, and predictions.

In the phase of formulating and communicating conclusions, students have opportunities to develop formative conclusions and receive feedback from their peers and the teacher. The LogBook provides a place for students to jot down their observations, formulate written conclusions, and draw diagrams about their investigation. Students are encouraged to develop verbal conclusions as well as draw diagrams within their LogBook. At the end of the investigation, students host a virtual press conference in which they click on virtual reporters who ask them questions about the investigation. Students respond in written form to the questions and store the responses in their LogBook. Finally, students present their findings to their classmates in an oral presentation. It lets them articulate their understanding by discussing their results with their team members as well as the entire class. It also supports a social environment that allows students to get feedback by comparing their works to others.

Many aspects of *Astronomy Village* can be identified as potentially appealing to females' interests, therefore their achievement. For example, the program deals with investigation questions based on contemporary issues. The real-life contexts enable all students, especially females, to support social interaction and to see relevance in the application of science (Anderson, 1993; Freedman, 2001). Additionally, the main techniques of *Astronomy Village* emphasize observing, measuring, and hypothesis testing, which female students lack exposure to and experiences in the current science classrooms (Jenkins & McDonald, 1989). Increasing these experiences has been demonstrated as a successful intervention technique for all students, especially females (Simpson & Oliver, 1990; Shakeshaft, 1995). Finally, students in *Astronomy Village* conduct their own experiments and activities using provided information and virtual mentor's messages. The environment provides students pupil-centered experiments, which is a preferred teaching style by females (Freedman, 2001).

Method

Subjects

The participants in this study were 122 ninth-grade students attending a high school in a small working-class community near a large, Midwestern city. All ninth-grade students enrolled in the Earth and space science course were invited to participate. Ninth-graders were chosen because *Astronomy Village* was designed to support ninth-grade science classes. The school used *Astronomy Village* in regular science classes consisting of mixed high- and low-ability students.

Of the 122 students who completed surveys, 103 (84 percent) students were Caucasian (white). One male student (1 percent) was black. One male student (1 percent) was Asian-American. Two male students (2 percent) were Hispanic. Five females and two males (6 percent) were other races. Eight students (7 percent) did not indicate their race. The gender breakdowns of the sample were 62 females (51 percent) and 57 males (47 percent). Three students (2 percent) did not indicate their gender.

Instruments

In this study instruments were developed to measure the students' problem-solving skills and content understanding, using multiple choice and written essay questions. The test items were subjected to an extensive construct validation process (Hong, 1998; Shin, Jonassen, & McGee, in press). Subject matter experts, curriculum developers, educational researchers, and teachers iteratively reviewed the test items with regard to content accuracy, readability, vocabulary level, and appropriateness for ninth-grade students. In addition, the test items were pilot tested with students using think-aloud protocols.

As a measure of content understanding, students were asked to classify important concepts relating to a research study by selecting relevant concepts from a list (Clark, 1990; Hong, 1998). Students were required to analyze the problem statement to determine which concepts are relevant to the solution. Additionally, to gauge how the concepts are organized in a meaningful way, students were asked to describe the relationships between the chosen concepts (Jonassen, Beissner, & Yacci, 1993).

Two problems are developed to measure students' problem-solving skills in astronomy. On the assessment students are required to present and explain their approach for solving given open-ended questions (Hong, 1998). One of the problems focuses on extensions to the Nearby Stars investigation; the other focuses on extensions to the Variable Stars investigation. These represent 2 of 10 research investigations in *Astronomy Village*. In the Nearby Stars investigation students use the concept of parallax to measure the distance to nearby stars. In the Variable Stars investigation they use the inverse square law to determine the distance to a nearby galaxy.

The scoring rubric was developed similar to other rubric systems (Baxter, Glaser, & Raghavan, 1993). It was reviewed by content experts, educational researchers, curriculum developers, and teachers to make sure it was developed appropriately and includes all important aspects for measuring students' problem-solving skills in astronomy. The scoring rubric was tested for construct validity using the method of instructional sensitivity, which compares differences in the response of experts and novices (Gall, Borg, & Gall, 1996). The result of construct validation indicated that the scoring rubric can discriminate differences between students who demonstrate a well-organized problem-solving process and those who demonstrate a disorganized process in given problem situations ($p < .000$) (Hong, 1998; Shin et al., in press). In addition, the instrument has been shown to correlate with measures of metacognition, science-related attitudes, and motivation (Hong, 1998). Three raters scored the students' responses individually. The average overall interrater reliability was .82.

Procedure

The study was conducted during a two-month period. The teacher and students were asked to provide demographic information and complete a release form before any data was collected. Before students used *Astronomy Village*, the teacher and an investigator spent two classroom periods administering the pretest.

During science classes the research team worked closely with school district members and teachers to support the effective implementation of *Astronomy Village*. The research team provided all the technical support through the entire program. One team member assisted teachers in designing classroom activities, including lesson plans. Another team member monitored the classroom activities to determine if the program was being implemented properly. This team member also helped to resolve any technical issues students experienced in the implementation.

All students used a PC computer and *Astronomy Village.* They worked in 55-minute class periods, five times per a week, for a total of 15 class periods. The teacher taught five classes. Each class had 23-26 students. The teacher had previous experience teaching *Astronomy Village.*

The teacher randomly assigned students to conduct one of two *Astronomy Village* investigations, Nearby Stars or Variable Stars. Each investigation took students through five phases of research: background research, data collection, data analysis, data interpretation, and presentation of results. During the investigation students used an electronic LogBook to record their scientific notes and observations. At the end of the program, each student team presented its results to the class.

After students finished *Astronomy Village*, a posttest was administered during two classroom periods. In both the pre- and posttests, each student took all the tests. These included conceptual understanding, the Nearby Stars problem, and the Variable Stars problem. In the tests the problems were printed individually for each student. After the tests were distributed, the students read the introduction before being told to solve the problems. Students were not allowed to use computers or any resources while completing the tests. There was no time limitation to finish all the instruments.

Data Analysis

The research sought to explore how the inquiry-based multimedia program would affect students', especially females', problem-solving skills in science. Dependent variables included content understanding and problem solving. The data was analyzed separately using analysis of variance (ANOVA). In the study students conducted only one investigation (either Nearby Stars or Variable Stars), and they took tests in conceptual understanding as well as Nearby Stars and Variable Stars problem solving. Thus, the scores on the test that is based on the path that students did not conduct serves as a control group. The analysis for conceptual understanding and problem solving was a 2 (treatment: experimental vs. control) x 2 (test occasion: pretest vs. posttest) analysis of variance in which the treatment was between subjects variables and the test occasion was a within-subjects variable. Within the treatment group, 2 (test occasion: pretest vs. posttest) x 2 (gender: females vs. males) analysis of variance was conducted as well.

Results

Conceptual Understanding

Table 1 shows the means and mean proportions of problems answered correctly on the pretest and posttest and the standard deviations for these means. It also provides descriptive statistics of two dependent variables based on gender. Using scores of experimental and control groups as the between-group factor and the pretest and posttest as the within-subject factor, a two-way ANOVA was employed to analyze the differences between students' improvement on conceptual understanding. Examination of the results for the significant interaction revealed that disordinal interaction existed between the two independent variables, test occasion and treatment, $F (1, 474) = 53.28$, $MSE = 1.616$, $p < .000$. On the pretest the control group ($x = 1.28$) had higher scores than did the experimental group ($x = 1.13$). However, the experimental group ($x = 2.73$) did achieve significantly higher scores as compared to the control group ($x = 1.54$) on the posttest.

Using the scores of the experimental group, females and males were analyzed separately to obtain more precise data on the gender difference of the improvement from instruction. The results of ANOVA indicated that there were significant differences for gender F (1, 231) = 4.40, p = .037, and test occasion F (1, 231) = 79.6, p < .000. For test occasion, subjects' scores were significantly higher for the posttest (x = 2.35 for males and x = 3.12 for females) than those of the pretest (x = 1.16 for males and x = 1.13 for females). The scores of the posttest revealed that the females statistically outperformed the males. Additionally, ANOVA yielded a significant two-way interaction for gender factor by test occasion, F (1, 231) = 5.05, p = .03. This interaction reflects the fact that the female group received more benefits for understanding basic concepts from the multimedia program than the male group. What these two results indicate is that students working with the multimedia program improved their conceptual understanding regardless of the gender difference and that females received slightly higher benefits.

Table 1. Descriptive Statistics of Conceptual Understanding and Problem-Solving Tests by Gender

	Conceptual Understanding			Problem Solving		
	n	M	SD	n	M	SD
Control						
Pretest	119	1.28 (26 %)	1.02	119	.55 (3%)	.82
Posttest	119	1.54 (31%)	1.24	119	.80 (4%)	.14
Treatment						
Pretest	119	1.13 (23%)	.98	119	.42 (2%)	.82
Posttest	118	2.73 (54%)*	1.72	118	2.92 (15%)*	2.84
Treatment						
Pretest						
Male	57	1.16 (23 %)	.88	57	.47 (2 %)	.97
Female	61	1.13 (23 %)	1.06	61	.37 (1 %)	.66
Posttest						
Male	56	2.35 (47 %)	1.39	56	2.57 (13 %)	2.57
Female	61	3.12 (62 %)*	1.89	61	3.28 (16 %)	3.05

Note. * P < .05. ns vary because of missing data. M: mean. SD: Standard Deviation. Mean proportion of correct responses is shown in parentheses.

Problem Solving

With regard to conceptual understanding, the 2 (treatment: experimental vs. control) x 2 (test occasion: pretest vs. posttest) ANOVA yielded significant interaction, F (1, 474) = 149.44, MSE = 2.82, p < .000, in problem solving as well. While the experimental group (x = .42) performed lower than did the control group (x = .55) in the pretest, the experimental group (x = 2.92) had significantly higher scores than did the control group (x = .80) in the posttest. In the analysis of the gender differences, females scored higher than males on well-structured problem solving (x = 2.57 for males, and x = 3.28 for females). However, ANOVA indicates this gender difference is not statistically significant. Both the female and male students in the experimental group significantly outperformed those of the control group on well-structured problem solving in the posttest. In both groups the scores of the posttest were significantly different from those of the pretest, F (1, 231) = 84.6, p < .000, indicating that participants in the multimedia program improved their problem-solving skills after instruction.

Discussion and Implications

As noted by comparing overall results, students working with the multimedia program improved their conceptual understanding and problem-solving skills after instruction regardless of their gender. The findings show that the multimedia learning environment, *Astronomy Village*, designed around inquiry is an effective tool for helping students learn astronomy content and problem-solving skills. It was speculated that having students engage in inquiry-based activities similar to what real-life scientists undertake would help students better understand underlying concepts and improve their problem solving. The results demonstrate this and support previous research about the positive effect of inquiry-based approaches incorporating multimedia technology (Bybee, 1993; Collins, 1998; Kuhn et al., 1988; Kuhn.D. et al., 1988; Mayer et al., 1999; Moore, 1993; National Research Council, 1996; Pea, 1993; Uno, 1990; Windschitl, 2000).

Moreover, the results showed that female students outperformed male students on the conceptual understanding posttest. This finding speculates that the female group received more benefits from the inquiry-based multimedia program than the male group. It also provides empirical support that female students received more benefits from the inquiry activities than male students (Anderson, 1993; Greenberg-Lake, 1991; Hill et al., 1990; Lock, 1992; McLaren & Gaskell, 1995; Thomas, 1986). Overall, this study supports inquiry-based multimedia technology as a learning and teaching tool with a high potential for facilitating students' learning, especially for females.

The results point to what science educators can do to improve students' problem-solving skills, particularly for females in science. The findings presented in this study also indicate that the inquiry-based approaches offer promising methods for improving problem-solving skills among all science students, especially female students. It will be a prescriptive method to counter the obstacles in science education that impinge on gender equity in science instruction. Future empirical studies should examine whether results are consistent with those of this study.

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