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The Effect of Multimedia Learning Environments On Well-Structured and Ill-Structured Problem-Solving Skills

Namsoo S. Hong[1], Steven McGee, & Bruce C. Howard

NASA Classroom of the Future™
At Wheeling Jesuit University

Introduction

In the science education community, educators have put forth considerable effort towards improving students' problem-solving abilities (National Research Council, 1996). Instructional strategies that engage students in scientific inquiry offer great promise for enhancing student problem solving in science (Geban, Askar, & Ozkan, 1992). These inquiry-based instructional strategies emphasize important aspects of scientific problem solving, namely identifying questions to investigate, designing investigations, conducting investigations, formulating conclusions and communicating results (Robitaille et. al., 1993). Multimedia learning environments provide a useful vehicle for engaging students in scientific inquiry. They make it possible to expose students to problem-solving experiences that are difficult to create in classroom situations (Geban, et al., 1992; Zietman & Hewson, 1986).

Many studies have shown that inquiry-based instructional strategies produce significantly greater science achievement and problem solving than conventional instructional strategies (Anderson, DeMelo, Szabo, & Toth, 1975; Gabel et al., 1977; Tobin & Capie, 1982, Bredderman, 1983; Szymansky, Kyle, and Alport, 1983; Cavin & Lagowski 1978; Bolick, 1972; Hughes, 1974). Unfortunately, the measures of achievement and problem solving for most of these studies provide only a broad-scale description of learning. Without fine-grained measures of learning it becomes difficult to investigate how students develop problem-solving abilities.

Researchers have argued that problem solving is a complex skill that is influenced by a set of related skills, namely, conceptual understanding in a domain, general metacognitive abilities, and attitudes towards science (Hong, 1998). The extent to which these related skills contribute towards successful problem solving depends on the nature of the task. In one study, a dichotomy between well-structured and ill-structured problem solving was achieved through the development of problem-solving assessments in astronomy (Hong, 1998). In general, ill-structured problems have more than one valid solution and can be solved in more than one way (Simon, 1973). In contrast, well-structure problems have one correct answer and typically only one way to reach a final solution (Simon, 1978 & 1979). Using the astronomy assessment instruments, researchers found that the largest predictor of well-structured problem-solving performance was conceptual understanding (Hong, 1998). However, for ill-structured problems, metacognitive ability and attitude towards science also became important predictors of problem-solving performance.

The purpose of this research study is to investigate the effects on various learning outcomes of an inquiry-based, multimedia learning environment called *Astronomy Village®: Investigating the Universe*™. The students were pre/post tested on their conceptual understanding, well-structured problem solving abilities, and ill-structured problem solving abilities.

[1] For further information, please contact: Steven McGee, 316 Washington Avenue, Wheeling, WV 26003, (304) 243-2388

Methods

Subjects

The participants in this study were 119 9th-grade students attending a high school in a small working-class community near a large, Midwestern city. All 9th-grade students enrolled in the earth and space science course were invited to participate.

Procedure

Astronomy Village uses the metaphor of living and working at a mountain-top observatory (the village) as the primary interface from which students investigate contemporary problems in astronomy (see Pompea and Blurton, 1995). The environment includes ten investigations covering a broad cross-section of current research areas in astronomy. In this study, students used *Astronomy Village* for three weeks. The teacher randomly assigned students to conduct one of two *Astronomy Village* investigations, Nearby Star or Variable Star. In the Nearby Star investigation students use the concept of parallax to measure the distance to nearby stars. In the Variable Star investigation, students use the inverse square law to determine the distance to a nearby galaxy.

For each investigation, students progressed through five phases of research: background research, data collection, data analysis, data interpretation and presentation of results. In the background research phase, students collected information by reading articles in the virtual library and listening to lectures in the virtual theatre. In the data collection phase, students went to the virtual observatory to collect images necessary for their investigation. In the data analysis and data interpretation phases, the students analyzed their images and interpreted the results of this analysis. Finally, each student team presented its results to the class. During the investigation, students used an electronic LogBook for recording their scientific notes and observations during their investigation.

Instruments

There were four assessment instruments used for this study—two well-structured problems and two ill-structured problems (see Hong, 1998 for a description of how the instruments were developed). One well-structured problem focused on extensions to the Nearby Star investigation and the other one focused on extensions to the Variable Star investigation. The ill-structured problems were developed to assess students' problem-solving skills using two novel problems that do not have a single correct solution. One of the two problems is similar in content to the Nearby Star and Variable Star investigations. It is called a "less-structured" problem. This problem asks students to propose how they would determine whether an incoming asteroid was in danger of hitting Earth. The other ill-structured problem requires more structural understanding, such as scientific principles and processes, than content understanding in order to reach a successful solution. In this problem, called an "ill-structured" problem, students had to consider alternative, competing goals by proposing a site for a new telescope from three alternatives. For each well-structured problem students were asked to classify important concepts related to the problem as a measure of their concept understanding in the domain.

Before students used *Astronomy Village,* the teacher and an investigator spent two classroom periods administering the problem-solving tests. There was no time limitation and students were permitted to spend as much time as necessary to solve the problems and answer the questionnaires. After finishing *Astronomy Village*, a posttest was administered during two classroom periods. In the both pre- and post-tests, each student took all of the tests, which included conceptual understanding, the Nearby Star well-structured problem, the Variable Star well-structured problem, and the two ill-structured problems. Two raters scored students' responses individually, based on an agreed upon scoring systems. The overall inter-rater reliability was .82.

Results

In the first analysis we looked at the impact of *Astronomy Village* on conceptual understanding and well-structured problem solving. Since students conducted only one investigation (either Nearby Star or Variable Star) and they took both well-structured tests, the test that is based on the path that they did not complete serves as a within subjects control. Table 1 presents the means and standard deviations of the dependent variables for both groups and pre- and post-test.

		Conceptual Understanding		Well-Structured Problem Solving	
Groups	N	Pretest	Posttest	Pretest	Posttest
Treatment	119	1.09 (.928)	2.46 (1.34)	.21 (.41)	1.45 (1.41)
Control	119	1.25 (.989)	1.46 (1.13)	.27 (.40)	.39 (.69)

Table 1: Comparison of Pretest and Posttest means between the treatment and control (standard deviations are show in parentheses)

A two-way analysis of variance was employed to analyze the differences between students' improvement on conceptual understanding and well-structured problem solving. The results revealed a statistically significant interaction effect for both conceptual understanding ($F = 32.36$, $p = .000$) and for well-structured problem solving ($F = 53.95$, $p < .000$). At pretest time, the treatment scores were significantly lower than the control scores for both content understanding and well-structured problem solving. However, the treatment scores improved statistically from pre- to posttest and were statistically higher than the control scores on both content understanding and problem solving.

Finally, Table 2 shows the means and standard deviations of pretest and posttest differences on the less- and ill-structured problems. Using a t-test, no statistically significant differences were found between the mean scores of the pretest and those of the posttest for either the less-structured ($t = .60$, $p = .55$) or ill-structured ($t = .65$, $p = .51$) problem-solving tests.

	Less-Structured Problem Solving			Ill-Structured Problem Solving		
	N	M	SD	N	M	SD
Pretest	117	3.60	3.09	117	4.59	1.96
Posttest	114	3.35	3.28	115	4.42	2.17

Table3: Comparison of pretest and posttest differences on the ill-structured problems (standard deviations are shown in parentheses)

Discussion and Implications

The results of this study indicate that *Astronomy Village* is an effective tool for helping students learn important astronomy content and well-structured problem-solving skills. Since the well-structured problems on the assessment instrument were slightly different than the problems encountered in the software, students had to adapt their understanding of parallax or the inverse square law to successfully solve the problems. The authors argue that having students engage in image analysis activities that are analogous to the techniques that scientist use provides students with a better understanding of the underlying concepts. The inquiry-based approach also provides for a more robust understanding of the problem so that concepts and problem-solving strategies can be applied in a new context.

However, the results of this study also indicate that there is a limitation in how far this knowledge will transfer. Students were not able to generalize the process of scientific inquiry to other areas of astronomy that were not directly related to the investigations that they conducted. There are two significant implications that can be drawn from the lack of transfer to ill-structured problems.

The first implication is that more work needs to be done on *Astronomy Village* so that it will better support the process of scientific inquiry. Students using *Astronomy Village* typically take from 3-4 weeks of class time to complete one investigation. Unless *Astronomy Village* is used in the context of an astronomy course, teachers typically have students conduct only one investigation (McGee, Howard, & Hong, 1998). This does not provide much opportunity for students to generalize about the nature of scientific inquiry across multiple investigations. *Astronomy Village* provides scaffolding for students to complete an investigation, but there is little opportunity for fading as prescribed in the cognitive apprenticeship model (Collins, Brown, and Newman, 1989), which would allow students to learn more about the general processes of problem solving. In a subsequent version of *Astronomy Village*, designers have created opportunities for students to pursue one topic across multiple investigations (McGee & Howard, 1999). Future research will investigate whether this improves the students' ability to generalize the processes of scientific inquiry.

The second implication is that this study provides further evidence that there are differences in how students approach well- vs. ill-structured problems. In *Astronomy Village*, the investigations presented students with well-structured problems, whereas the problems that students did not improve on were ill-structured, which students were never exposed to during *Astronomy Village*. Since the students were accustomed to only well-structured problems, it is possible that they might have used well-structured strategies in their attempts to solve the ill-structured problems. This result supports other research that argues that well- and ill-structured problems engage different problem-solving processes (Sinnott, 1989; Voss & Post, 1988; Voss, 1981; Wood, 1994; Reitman, 1965).

There are three main areas for future research on well- vs. ill-structured problem solving. The first set of research questions should focus on the role of well-structured problem solving in solving ill-structured problems. A second set of questions to be explored relates to how students integrate new information into prior knowledge for solving problems. A third set of questions should focus on the role of multimedia learning environments, such as *Astronomy Village*, in helping students to develop scientific ill-structured problem-solving abilities.

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