Motivating Students Through Problem-based Learning

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Research Framework

Problem-based learning (PBL) is an instructional approach that exemplifies student-centered learning. It emphasizes solving complex problems in rich contexts and aims at developing higher-order thinking skills (Savery & Duffy, 1995). According to Barrows (1996), PBL has these characteristics: (a) learning is student-centered; (b) authentic problems form the organizing focus for learning; (c) new information is acquired through self-directed learning; (d) learning occurs in small groups; and (e) teachers act as facilitators.

The successful use of PBL in medical education has sparked the interests of educators in different fields. PBL has been shown to be more effective than some traditional classroom instruction in providing opportunities for transferring knowledge and skills from the classroom to the workplace (Stepien, Gallagher, & Workman, 1993). It results in better long-term content retention than traditional instruction (Norman & Schmidt, 1992), higher motivation and better attitudes toward learning (Albanese, & Mitchell, 1993); and it supports the development of problem-solving skills (Gallagher, Stepien, & Rosenthal, 1994; Hmelo & Ferrari, 1997). These successful uses are primarily non-technology based.

Implementing PBL without technology proves to be challenging (Farnsworth, 1994). Its implementation challenges include ineffective ways to present the central problem through oral or written means, large investment in time and effort to develop PBL units, initial discomfort with the methodology from the learners and instructors, and the need for new forms of assessment (Farnsworth, 1994; Hoffman & Richie, 1997). The constraints in a K-12 setting such as large class sizes, short class periods, and full and fixed schedules by teachers and students make it especially difficult to use PBL in a K-12 classroom.

Technology has been suggested as a way to address some of these challenges. Hoffman and Richie (1997) recommended the use of hypermedia to deliver problem scenarios to help "students comprehend the situation and see the relevance of various contextual elements" (p. 102). The nonlinear, associative, and interactive capabilities of hypermedia can allow students to access information according to their own learning needs and provide rich information resources through different media in a more efficient way (Hoffman & Richie, 1997). Hypermedia enhanced PBL can engage students in cognitive activities that would be out of their reach otherwise, and assist learners to generate and test hypotheses through simulations. When hypermedia-based tools are used to enhance the cognitive powers of learners during their thinking, problem-solving, and learning, they become cognitive tools (Jonassen & Reeves, 1996; Pea, 1985; Salomon, Perkins, & Globerson, 1991). Cognitive tools can enhance PBL delivery and provide necessary support to learners. In this study, we examined the impact of a hypermedia PBL application on sixth graders' learning. We also looked at factors that are of importance to learning such as motivation, attitudes, and gender.

Motivation

Literature on motivation and classroom learning has shown that motivation plays an important role in influencing learning and achievement (Ames, 1990; Dweck, 1986). If motivated, students tend to approach challenging tasks eagerly, persist in difficulty, and take pleasure in their achievement (Stipek, 1993). Research has also shown that instructional context strongly affects students' motivation. Instructional materials that are challenging, give students choices, and promote perceived autonomy and self-determination can have a positive effect on students' motivation (Deci & Ryan, 1985; Hidi & Harackiewicz, 2000).

Attitude

Students with positive attitudes are more likely to sustain their efforts and have the desire to be involved in the learning tasks. There is some evidence that attitude toward science relates positively with achievement (Mattern & Schau, 2002) and attitudes may influence students' attainment, consistency, and quality of work (Germann, 1988). In reviewing the literature about attitudes toward science over the past 20 years, Osborne, Simon, and Collins (2003) noted that research indicated a decline in attitudes toward science from age 11 onwards and an apparent contradiction between students' attitudes toward science in general and their attitudes toward school science. Students consider science itself interesting and useful but regard science classes as boring (Ebenezer & Zoller, 1993). Osborne, et al. reviewed factors that can influence attitudes such as gender, teachers, curricula, and culture; and emphasized that how science materials are taught can affect students' attitudes.

Gender

The concern over the shortage of highly qualified scientists, especially female scientists, has highlighted the need of science education for all students (Jarvis & Pell, 2002). The belief is that if students develop positive attitudes toward science and enjoy learning science during their middle school years, they will be more likely to pursue a career in science later on. Research on gender and attitudes toward science is, however, mixed. Some studies have shown girls' attitudes toward science are significantly less positive than boys (Breakwell & Beardsell, 1992; Hendley, 1996). Other studies have indicated that girls are confident of their ability to take science classes and are doing as well as boys in the traditionally 'masculine' subjects (Harvard, 1996; Whitehead, 1996). The inconclusive finding on gender, attitude, and learning is an indication that more research is needed.

Purpose of the Study and Research Questions

The purpose of this study is to examine the effectiveness of a hypermedia PBL application built for sixth graders. A previous study investigated how students with different ability levels performed in this hypermedia environment (Liu, 2004). This study replicates the previous research by increasing the sample size from one middle school to four middle schools. In addition to examining any change in students' attitudes and science knowledge from pretest to posttest, this study extends the previous one by looking at students' retention of science knowledge and their motivation. Three research questions guided this study:

1. What is the effect of the hypermedia PBL environment on sixth graders' acquisition and retention of science knowledge? Are there any differences in science knowledge between male and female students after using the program?
2. What is the effect of the hypermedia PBL environment on sixth graders' motivation toward learning and attitude toward science? Are there any differences in attitude and motivation between male and female students after using the program?
3. Is there a relationship between students' attitudes toward science learning, motivation, and science knowledge?

Method

Participants

The participants were 437 sixth graders from four middle schools in a mid-sized southwestern city. The schools are from the same district and share similar demographics: 16% Hispanic, 6% African-American, 73% Caucasian, and 5% other ethnic backgrounds. Of the 437 students, 51% (n =222) were female students. All participants in this study were from regular education. About 5% of the students were labeled as English as Second language students. Four teachers taught these twenty-two science classes. The study took place over a three-week period in the later part of the school year. The teachers indicated that these students were familiar with basic computer applications such as Microsoft Word and Powerpoint.

A Hypermedia Application

The program used in this study was Alien Rescue(2002), a CD-based hypermedia PBL environment. Guided by the theories and research on problem-based learning in its design, the goal of Alien Rescue is to engage sixth grade students in solving a complex problem that requires them to gain specific knowledge about both our solar system and the tools and procedures scientists use to study it. The program begins with a multimedia presentation of an ill-structured problem for students to solve. A group of six species of aliens, different in their characteristics, have arrived in Earth orbit, due to the destruction of their home planets. They must find new homes that can support their life forms or they will die. Students, acting as scientists, are asked to participate in this rescue operation, and their task is to determine the most suitable relocation site for each alien species. To solve this problem, students must engage in a variety of problem-solving activities. They need to research the aliens' needs, what planets in our solar system can offer, and find possible matches. Students must sift through the vast information to decide what is relevant and important, and engage in planning and decision-making as they determine how to use the resources of the solar system effectively. More information about Alien Rescue can be found in an article by Liu, Williams, and Pedersen (2002) and on its web site http://jabba.edb.utexas.edu/alienrescue/.

To assist students in their problem-solving, a set of cognitive tools performing various functions is provided. Based upon Lajoie's categorization of cognitive tools (1993), these tools can share cognitive load, support cognitive processes, support cognitive activities that would be out of reach otherwise, and allow hypotheses generation and testing. Examples of tools that share cognitive load in Alien Rescue are the four databases. These are carefully constructed and well-organized knowledge databases enhanced with graphics, animations, and 3-D videos. If students want to search for what a species looks like, where they live, the atmosphere and gravity on a planet, or past NASA missions, they can access such information readily in the *alien database, solar database, and mission database*. If they come across a scientific concept with which they are unfamiliar, they can look it up in the *concept database* that provides visually illustrated tutorials on various science topics. Such tools help reduce the memory burden for the students and put the multimedia-enriched information at students' fingertips. Examples of tools supporting cognitive processes are the *notebook* tool that allows students to take notes and the *expert* tool. Presented in the video format, the expert is available at four critical points to model expert thinking process in solving the central problem. Examples of the tools supporting cognitive activities that would be out of reach otherwise are the *probe builder* and *launcher rooms*. They allow students to equip probes with various scientific instruments and launch them. Such tools enable students to perform activities that they would not have access to in a regular classroom. Finally, examples of the tools allowing hypotheses testing are the *control room* and *solution form*. In the control room, students study the data coming back from probes to test their hypothesis and then write up their solution using the solution form (see Figure 1).

Setting

Students used Alien Rescue in their daily 45-minute science class. This program was aligned with the national science standards on scientific investigation and problem-solving. The teachers used it in place of the regular teaching materials on the solar system unit. Students worked in the computer labs and had access to computers for their own use. Students were assigned to groups of two or three by the teachers to solve the central problem collaboratively.

The four teachers are experienced science teachers, but novice computer users. They participated in a two-day training workshop, during which the philosophy and different attributes of a student-centered learning environment like Alien Rescue and its PBL approach were discussed in depth. This is the second year they used Alien Rescue in their classrooms. In day one, after watching the video scenario, the teachers and the students held a discussion about their primary task. For the rest of the 15 days, teachers allowed the students to decide what their learning tasks were for each day and how to approach the problem. Though each teacher had her own ways of facilitation, classroom observations showed that each day the teachers began the lesson with a mini-discussion on what the students did in the previous day and addressed questions that came up. Students' questions were often answered by more questions from the teachers or answered by other students. Then, the students worked on the computer. The teachers answered students' questions, checked their progress, and ensured students were on task. Most days, the lesson ended with another short discussion about what the students accomplished that day, any questions that surfaced, and what the learning goal should be for the next day. Because all the necessary tools for students to work on the problem were provided via technology in this hypermedia environment, it was possible for the teachers to spend most of the class time interacting with the students individually. The teachers facilitated their students' learning through daily questioning, answering, and discussion.

Instrumentation

Science knowledge test. Students' understanding of the science concepts introduced in Alien Rescue was measured through a 25-item multiple-choice test. This science knowledge test has been used in several studies using Alien Rescue with similar samples (Liu, 2004) and has a KR(20) reliability coefficient of .73. Since no direct teaching was noted in using Alien Rescue (see the previous section), a good score on the test would indicate the student has acquired a good understanding of the scientific topics introduced in the program through his or her self-directed learning, classroom discussions, and/or peer interaction. This test was given both prior to and after using Alien Rescue. To measure students' retention of the knowledge, it was also given to the students from one school two weeks after the completion of Alien Rescue. Because the other three schools used the program close to the end of the school year, there was not sufficient time to administer the test again before the school year ended. Given that there were at least 15-days between the pretest and posttest, the pretest should not have served as a cue to the students. Students were not told about the retention test.

Motivation questionnaire. To assess students' motivation, a questionnaire was used consisting of 8 items from the *Motivated Strategies for Learning Questionnaire* (MSLQ, Pintrich, Smith, Garcia, & McKeachie, 1991). The questionnaire addressed two aspects of motivation: (a) intrinsic goal orientation (4 items), and (b) extrinsic goal orientation (4 items). Its reported reliability coefficients are .74 and .62 respectively. The MSLQ instrument was designed for measuring students' learning in a specific situation such as a classroom setting and has been widely used in motivation research (Pintrich & Garcia, 1991; Pintrich, McKeachie, & Lin, 1987). Sample statements are "In a class like this, I prefer course material that really challenges me so I can learn new things," and "Getting a good grade in this class is the most rewarding thing for me right now." A seven-point Likert-type scale is used, with 1 being "not at all true of me" and 7 being "very true of me." This instrument was given before and after the use of Alien

Rescue. In completing the post-survey, students were told that “this class” in each statement was defined as science classes taught like Alien Rescue.

Attitude toward science questionnaire. Students’ attitude toward science was measured using the *Attitude Toward Science in School Assessment* (ATSSA, Germann, 1988). The ATSSA assesses how students feel toward science as a subject (Germann). The instrument consists of 14 Likert scale items, with 1 being "strongly disagree" and 5 being "strongly agree." Sample statements include “Science is fun,” and “During science classes, I usually am interested.” According to Germann, it has been used with 7th to 10th graders in science classes in four different studies and has Cronbach’s alpha of 0.95. The instrument was given before and after the use of Alien Rescue. In completing the post-survey, students were told that “science” in each statement was defined as science classes taught like Alien Rescue.

Interviews. Toward the end of the study, interviews were conducted with 30% of the students, randomly selected, from each of the 22 classes. The interviews focused on two aspects: (a) what the students have learned from using Alien Rescue; and (b) why they liked or disliked Alien Rescue. Sample interview questions included “Do you like/dislike Alien Rescue and why?,” “Which part did you like the most/least and why?,” “What have you learned from using Alien Rescue?”

Analysis of the Data

Four two-factor, 2x2, mixed ANOVAs were performed with gender as a between-subjects independent variable and time of testing (pretest, posttest) as the repeated measure within-subject variable. Students’ science knowledge test, scores for intrinsic goal orientation, and extrinsic goal orientation, and students’ attitude toward science served as dependent variables respectively for each analysis.

For retention on science knowledge, a two-factor, 2x3, mixed ANOVA was run with gender as a between-subjects independent variable and time of testing (pretest, posttest, retention) as the repeated measure within-subject variable. The dependent variable was students' science knowledge test.

To determine if students' motivation and attitudes may have a relationship with their science knowledge, a correlation analysis was performed with post-scores of intrinsic goal orientation, extrinsic goal orientation, attitudes, and the science knowledge test. For each of the above analyses, missing and non-matched data were excluded.

The interview data were transcribed, then coded and categorized following the guidelines by Miles and Huberman (1994). Patterns from the data were extracted. The data were sorted into categories and sub-categories according to their common themes and shared relationships. The qualitative data were used to substantiate the results from the statistical analyses.

Results

Science Knowledge

The 2x2, mixed ANOVA indicated that there was not a significant two-way interaction between gender and time of testing (pretest, posttest) for the science knowledge tests: $F(1,415) = 3.94$, $p = .06$ (n=417). There was not a main effect for gender. However, there was a main effect for time of testing. The posttest scores for both male and female students were significantly higher than their pretest scores: $F(1,415) = 545.99$, $p < .01$ (see Table 1). The results of the 2x3, mixed ANOVA showed that there was not a significant two-way interaction between the gender and time of testing (pretest, posttest, retention): $F(2,196) = 2.65$, $p = .07$ (n=100) (see Table 1). However, there was a main effect for time of testing. For both male and female students, their posttest scores were significantly higher than their pretest scores ($t = -11.62$, $p < .01$) and their retention scores ($t = 6.98$, $p < .01$). Their retention scores were significantly higher than their pretest scores ($t = -7.62$, $p < .01$), but lower than their posttest scores.

Motivation and Attitude

Motivation. The results of the 2x2 mixed ANOVAs indicated that there were no significant two-way interactions between gender and time of testing (pretest, posttest) for intrinsic goal orientation and extrinsic goal orientation: $F(1, 418)_{\text{intrinsic}} = .20$, $p=.65$; $F(1,420)_{\text{extrinsic}} = .10$, $p=.75$ (see Table 2). However, there was a significant main effect for time of testing for intrinsic goal orientation: $F(1, 418)_{\text{intrinsic}} = 13.73$, $p <.01$. The intrinsic goal orientation scores at the posttest were significantly higher than those at the pretest time for both male and female students.

Attitude. The 2x2 mixed ANOVA indicated that there was no significant two-way interaction between gender and time of testing (pretest, posttest) for attitudes toward science learning: $F(1,419) = .36$, $p = .55$ ($n=421$). There was, however, a significant main effect for time of testing: $F(1,419) = 48.23$, $p < .01$ (see Table 2). The attitude scores at the posttest were significantly higher than those at the pretest time for both male and female students.

Motivation, Attitude, and Science Knowledge

The correlation analysis ($n= 374$) showed there was a moderate positive relationship between the intrinsic goal orientation and attitudes ($r=.42$, $p <.01$); and a small positive relationship between intrinsic goal orientation and science knowledge scores ($r=.21$, $p <.01$). A small positive relationship was also found between attitudes and science knowledge scores ($r=.11$, $p <.05$). There existed a small negative relationship between extrinsic goal orientation and science knowledge scores ($r= -.14$, $p <.01$).

Qualitative Data Findings

Interviews provided insights as to why the students liked or disliked using Alien Rescue. Almost all the students interviewed said they enjoyed using Alien Rescue and had fun with it. They mentioned different reasons for liking it, which included having fun, being able to use various hypermedia tools provided in the program, use computers, and work in groups. Table 3 listed three most frequently mentioned reasons for liking Alien Rescue. Only a few students were not as enthusiastic and said they were frustrated because the problem was difficult to solve and the teachers did not give the answers.

It is significant that a number of students cited being able to work independently and like a scientist as the most important reasons they enjoyed Alien Rescue. One student stated, "I liked how you got to investigate and hypothesize and experiment to come up with a solution, like a real scientist would. I also liked how you had to figure things out for yourself without a lot of help from the teacher." Another said, "It helps you learn a lot of things because you learn to take notes, which is really important. You learn to be more independent because you have to find out where to go on your own because there is not help. And it's also really fun to research and send up probes and stuff." Although being challenged, students also felt a sense of satisfaction after working hard and being able to solve the problem. "My best experience was when I figured out what planet my alien should go to. I was proud of myself for figuring out the problem."

Students' interest and motivation in using Alien Rescue were reflected in quotes such as: "After I got out of science or just at lunch, me and my friends, we'd talk a lot about where we'd think the aliens should go. When I come back to science, I'd tell my partner what I had learned the previous day and where I was going to research, and what I was going to do that day." Teachers also observed: "Kids are talking about science outside of the classroom. They talk about Alien Rescue in the halls and they talk about after school. All of the sixth graders are doing this, and so some of them have friends in different class periods that are working with Alien Rescue. They will say, 'what did you find out today or have you found where this alien can go?' I think that the most exciting thing is that they are talking science outside of the classroom."

When asked what they have learned from using Alien Rescue, students mentioned science concepts as well as research and problem-solving skills. They said:

> We learned a lot of science concepts. We had to convert temperatures and understand what it said about the planets. We had to know what each of those mean. We learned a bunch of concepts from the research and converting temperatures.

> I've learned to use all of the scientific method, and to really put my mind into it, just concentrating and focusing. It's kind of like you're a real scientist and it brings you to know how to do the specific things like the scientific method, and how to research and collect data.

Discussion

The results of the study showed that the students had significantly increased their science knowledge from pretest to posttest and also retained much of what they had learned after two weeks. Students' attitudes toward science and their intrinsic goal orientation were higher after using Alien Rescue. Students' science knowledge scores were positively related with their attitudes and intrinsic goal orientation. That is, the higher their attitudes and motivation, the higher their science knowledge scores. Such findings indicated that Alien Rescue had a positive impact on the sixth graders.

There was no gender difference in the posttest or retention test scores. Both male and female students increased their science knowledge understanding after using Alien Rescue. There was also no gender effect on attitudes and motivation. Such results are in line with the findings of other research (Harvard, 1996; Whitehead, 1996). It also confirmed the previous study that examined the same hypermedia application and found no gender differences in students' performance and their attitudes (Liu, 2004). The interview data indicated that girls were enthusiastic about using Alien Rescue. The few negative responses (as indicated above) were from boys.

Problem-based learning attempts to capitalize on students' active involvement in the learning process. The data from this study showed that many students liked Alien Rescue because they liked solving this complex problem where they were in control of their learning process and had to rely on themselves, rather than their teachers. Allowing students to take charge and keeping them challenged appeared to motivate them (Deci & Ryan, 1985; Hidi & Harackiewicz, 2000). At the same time, hypermedia-based cognitive tools facilitated students' problem-solving.

Students' reliance on using the built-in cognitive tools in Alien Rescue was evident in the interviews. Students mentioned the specific tools they used during the process of finding the solution. One student said: "I did research on the aliens first [using the alien database] and then I would go to the solar system [using the solar database] and find a planet that would match them and write it down in my notebook [using the notebook and bookmark]." Another stated, "after you send out the probe [using the probe builder and launcher rooms] and you get the mass spectrometer. It has the periodic abbreviations so you have to go on the periodic table with them [using the periodic table] and also you have to look under concepts on your toolbar [using the concept database] to find things that you don’t know about.” These tools have different functions and each offers some assistance to the students. They serve as information resources, means to record, organize, collect and display data, and allow students to perform activities that would be out of their reach otherwise. As an integral part of Alien Rescue, these hypermedia enriched cognitive tools provide necessary support to the sixth graders. Students can access the tools whenever needed. Teachers can spend their time interacting with the students individually, answering questions, and leading class discussions as shown in this study. The findings of the study showed that this hypermedia PBL environment offers sixth graders a new and effective way of learning – ways that would be difficult to accomplish without the assistance of technology.

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Table 1

Means and Standard Deviations (in Parenthesis) for the Science Knowledge Test

	n	Science Knowledge Test (score from 0 – 100)		
		Pre-	Post-	Retention-
Gender				
Male	205	45.39	67.22*	
		(17.02)	(19.65)	
Female	212	40.55	66.26*	
		(14.43)	(18.21)	
Male	50	45.44	66.48**	59.92**
		(17.29)	(22.35)	(21.60)
Female	50	40.72	68.88**	54.88**
		(17.87)	(16.41)	(18.43)

* $p < .01$ (partial Eta Squared = .57). ** $p < .01$ (partial Eta Squared = .48).

Table 2

Means and Standard Deviations (in Parenthesis) for Motivation and Attitudes Toward Science

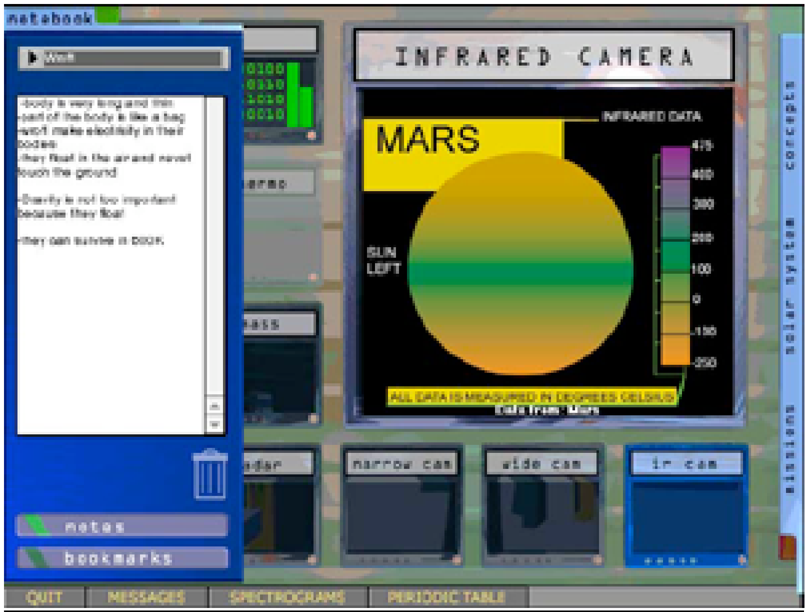
	Motivation (scale of 1 to 7)						Attitude (scale of 1 to 5)		
	n	Intrinsic		*n*	Extrinsic				
		Pre-	Post-		Pre-	Post-	*n*	Pre-	Post-
Gender									
Male	205	4.73	4.98*	202	5.56	5.51	204	3.61	3.89**
		(1.41)	(1.29)		(1.30)	(1.22)		(.67)	(.81)
Female	215	4.85	5.05*	220	5.66	5.58	217	3.57	3.81**
		(1.32)	(1.15)		(1.13)	(1.16)		(.63)	(.77)

* $p < .01$ (partial Eta Squared = .03). ** $p < .01$ (partial Eta Squared = .10).

Table 3

Three Most Frequently Cited Reasons for Liking Alien Rescue

I like it because	Sample Students' Comments
it is fun	• It's fun. It gives us a chance to work on the solar system. Some moons I have never heard of. I learned a lot from this program.
	• Having an interactive program to learn through was interesting and fun. I enjoy this type of learning.
tools are helpful	• I liked designing probes because it made me feel like a real life probe designer.
	• If you just read out of a book, you don't remember it. This way you remember it.
	• The scenario [video] was really cool.
	• I really enjoyed sending the probes and getting back information. I also enjoyed learning about planets and species.
	• The easy instructions helped me learn to create probes. The tab with concepts [concept database] also helped.
it uses computers	• I enjoy working on the computers…and so I liked it and I was looking forward to it.
	• It's cool that you get to be on your computer.



(a) Accessing notes in the Notebook while viewing data gathered from the launched probe in Control Room

(b) Accessing the Solar System Database while researching in Alien Database

Figure 1. Screen Shots Showing Some Cognitive Tools Provided In Alien Rescue