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ARTICLE

Examining Science Learning and Attitude by At-Risk Students After They Used a Multimedia-Enriched Problem-Based Learning Environment

Min Liu, Sa Liu, Zilong Pan, Wenting Zou, and Chenglu Li

Abstract

Most of the previous problem-based learning (PBL) studies have been conducted with gifted or regular education students and have shown successes. However, little research on PBL exists for disadvantaged middle school students, especially students who are considered to be at risk of failing academically. In this study, we examined the use of a multimedia-enriched PBL science environment by at-risk middle school students. The results, using a mixed-methods design, showed that these students significantly improved their science knowledge and attitude toward science after they engaged in PBL learning. While there were no differences in the scores between the genders, the gain scores from pre- to post-tests in science knowledge and attitude toward science for the girls were larger. A strong positive relationship between attitude toward science and science knowledge was also found. Such research should provide much needed insights on the effect of PBL for all students, not only the gifted but also the underrepresented populations.

Keywords: problem-based learning, science, attitude, at-risk students, economically disadvantaged, STEM, STEAM

Introduction

Literature on problem-based learning (PBL) has shown many benefits such as increasing content knowledge and critical thinking, communication, and collaboration skills (Lajoie et al., 2014; Sánchez & Olivares, 2011; Şendağ & Odabaşı, 2009). In most PBL studies conducted in the K–12 setting, the research participants often were gifted or regular (general) education students. While many of these studies have shown successes, there are few studies on PBL for disadvantaged middle school students (S. A. Gallagher & Gallagher, 2013) or at-risk students who are considered to have a higher probability of failing academically or dropping out of school. Can PBL benefit all students, especially those students who perform poorly at school? In this study, we examined a group of at-risk middle school students' science learning and attitude toward science after they were exposed

to a 3D immersive multimedia-enriched PBL environment. All these participants were from failing schools according to the state academic standards and were at risk of educational failure or otherwise in need of special assistance and support (U.S. Department of Education, 2012). In addition, these students were from Title I schools with a very high percentage of economically disadvantaged population, and the schools were receiving government funding that aimed to help ensure all students meet challenging state academic standards. We were interested in any changes in these students' science learning and attitude toward science after they used a PBL science environment, and in the relationship between learning and attitude for these at-risk students. Such research should provide much needed insights on the effect of PBL for all students, not only the gifted but also the underrepresented populations, and critical factors that relate to learning in a PBL setting.

Relevant Literature

Problem-Based Learning in K–12 Education

Problem-based learning (PBL) is a student-centered constructivist instructional method, in which teachers act as facilitators and utilize authentic ill-structured problems to guide student learning (Hmelo-Silver & Barrows, 2015). Many studies have reported the benefits of applying PBL to middle school subjects for the past two decades (Brown, Lawless, & Boyer, 2013; Diggs, 1997; Liu, Hsieh, Cho, & Schallert, 2006; Merritt, Lee, Rillero, & Kinach, 2017). In a recent review of literature, Merritt et al. (2017) reviewed nine experimental studies to explore the effectiveness of PBL for K–8 students (ages 3–14) in mathematics and science classrooms. Their review suggested PBL was an effective instructional method for improving student academic achievement, including knowledge retention, conceptual development, and attitudes. For example, one of the nine reviewed studies showed PBL had significant positive effects on student academic achievement ($F(1,112) = 46.78, p < .001$) and knowledge retention ($F(1,112) = 35.24, p < .001$) (Karaçalli & Korur, 2014).

Research has also shown that implementing PBL in K–12 classrooms is challenging for both teachers and students (Ertmer & Simons, 2006). Teachers often lack the pedagogical knowledge on how to implement a student-centered environment effectively (deChambeau & Ramlo, 2017), and students usually lack the necessary collaborative learning and self-regulation skills as required by PBL to be independent learners and take control of their own learning (Bransford, Brown, & Cocking, 1999). Technologies have been used to create and deliver technology-enhanced PBL environments through technology-based scaffolds to engage students and support teachers' use of PBL (Liu, Wivagg, Geurtz, Lee, & Chang, 2012). Numerous studies have shown technology-enhanced PBL can have a positive impact on middle school students' learning interest (Brown et al., 2013; Hwang, Wu, & Chen, 2012), learning attitude (Hwang et al., 2012), achievement (Hwang et al., 2012; Kimmons, Liu, Kang, & Santana, 2012), and self-efficacy (Brown et al., 2013; Liu et al., 2006). Hwang et al. (2012) developed an online game-based PBL environment for fifth- and sixth-grade natural science students in Taiwan. Students used this game-based PBL environment to complete a learning task on butterfly ecology. The researchers investigated student flow experience, learning attitudes, learning interest, learning achievements, and technology acceptance degree using an experimental group and a control group. The results showed student learning attitudes and learning achievements were significantly increased after

using the online game-based PBL. Meanwhile, student flow experience, learning attitudes, learning interest, and technology acceptance degree in the experimental group were significantly higher than for students in the control group.

Learners in PBL

While PBL has been applied in different subject matter areas and to learners of different ages, the participants of most PBL studies in K–12 were gifted and general education students (Hmelo-Silver, 2013; Merritt et al., 2017; Strobel & Van Barneveld, 2009). In PBL, learners are presented with an ill-structured problem and challenged to learn and apply content knowledge as well as problem-solving ability, which requires them to be independent and exercise both cognitive and metacognitive skills. Research has suggested such a learning process is more suitable to gifted students' "inquiry-oriented learning style" (S. A. Gallagher, 2008; S. A. Gallagher & Gallagher, 2013; Sak, 2004). Few studies have examined PBL use from at-risk students' perspective or with economically disadvantaged middle school students (S. A. Gallagher & Gallagher, 2013). Brown et al. (2013) looked at middle school students with different socioeconomic status in using a technology-based PBL environment, GlobalEd 2, a 14-week simulation on global water resource issues. They compared 99 students from a suburban school with higher socioeconomic status and 105 students from an urban school with lower socioeconomic status. Their findings indicated the PBL environment had a positive impact on students' science interest and self-efficacy for both groups and there were no significant differences between these two groups regarding students' science interest and self-efficacy. S. A. Gallagher and Gallagher (2013) examined the performance of 271 students from two low-income middle schools after they used two PBL units. The researchers compared student performance in English, math, and social studies among three groups using both academic tests and teacher ratings: (1) gifted students who were identified using the school district criteria, (2) teacher-identified advanced academic potential students (AAP) who showed higher order thinking during two PBL units, and (3) the rest of the general education students. The results showed that while the gifted students outperformed the other two groups in certain measures (e.g., gifted students scored higher in English), there were no significant differences in others (e.g., no difference in math between the gifted and general education students). Moreover, in terms of teacher ratings, the advanced academic potential students scored higher than the gifted and general education students, indicating

“the teachers recognized a different quality of performance unique to the AAP group during the PBL lessons” (S. A. Gallagher & Gallagher, 2013, p. 125). Their findings suggested PBL could encourage more students to reveal their academic potential. Although such findings are encouraging, studies examining PBL use by economically disadvantaged middle school students and especially by students who are at risk of failing academically are scarce.

Besides the consideration of learners’ socioeconomic and academic status, gender difference in PBL is also an important research topic. A few studies examined gender difference in K–12 students’ use of PBL and the findings were not consistent. A study by Brown et al. (2013) did not show any gender difference in that the PBL environment had a positive impact on both male and female students’ science interest and self-efficacy. Pol, Harskamp, and Suhre (2008) conducted a PBL experiment with fifth-year secondary school students (ages 15–16) in the Netherlands. Students in the experimental group used a computer PBL program, PhysHint, while students in the control group used textbooks in learning physics. The results revealed that students in the experimental group finished significantly more tasks than the control group. There was a significant gender effect on the knowledge-based post-test scores in that male students significantly outperformed female students for both groups. But there was no gender effect on the problem-solving test scores.

Attitude and Learning

Attitude is a component of motivation that is conceptualized as the combination of effort plus desire to achieve the goal of learning (Gardner, 1985). Attitude is often considered as a factor that can significantly influence motivation and performance. Having an internal drive and a positive mindset toward the learning tasks often sustains enjoyment and motivation (Liu et al., 2006). Since the 1980s, researchers have investigated the correlation between subject-related attitudes and achievement. Marsh’s (1992) study of Australian boys in grades eight and ten reported a strong relationship between science-related self-concept (a subconstruct of attitudes) and science achievement. Germann (1988) reported that attitudes toward science impacted students’ attainment, consistency, and quality of work.

However, the research findings regarding attitude toward science and achievement are not particularly encouraging over the past decade. A study by Barmby, Kind, and Jones (2008) showed that the largest decline in student attitude

toward school was their attitude toward learning science at school, whereas their attitude toward “practical work in science” and the “importance of science” remained relatively unimpaired. This finding is consistent with earlier research that suggested many students considered science itself interesting and meaningful but regarded science classes as boring (Ebenezer & Zoller, 1993; Osborne, Simon, & Collins, 2003). Christidou (2011) reviewed more than 100 articles and found that students rapidly lost their interest in science and stopped considering it a viable option for their future aspirations as they advanced from elementary to secondary education. Hillman, Zeeman, Tilburg, and List (2016) argued that attitude was key to one’s career choices in the future, yet the number of students in the United States choosing science, technology, engineering, or mathematics (STEM) careers was declining. PBL, as a successful pedagogical approach, is often used to motivate and engage students in learning science. Kimmons, Liu, Kang, and Santana (2012) examined student attitude toward science and their achievement in a PBL environment and found a positive relationship. Yet, sufficient evidenced-based research in this regard is lacking.

It is clear much research has been conducted in investigating the effect of both traditional and technology-enhanced PBL environments on different aspects of learning (e.g., knowledge gain, problem-solving skills, attitude, and self-efficacy). However, there is a lack of research examining the use of PBL by economically disadvantaged students, especially students who are considered at risk of failing academically. While literature has shown a correlation between subject-related attitudes and achievement, research has also documented a decline in attitude toward science at middle school level. More research is needed to find out if PBL can help increase middle school students’ attitude toward science learning. In addition, research is needed to examine gender differences in using PBL in K–12 education given the inconsistent findings in the literature. To address these gaps, in this study we aimed to investigate at-risk middle school students’ attitude toward science and their science learning after they used a 3D immersive multimedia-enriched PBL science environment. We asked the following research questions:

1. Are there any differences in these at-risk students’ science knowledge and attitude toward science after they used a multimedia-enriched PBL science environment? Are there differences between boys and girls?
2. What is the relationship between students’ science knowledge and attitude toward science after they engaged in a multimedia-enriched PBL science environment?

Method

Participants

Participants were 32 students, 24 in 5th or 6th grade and 8 in 9th or 10th grade, including 17 boys and 15 girls. These students were all from three priority (or failing) schools, according to the state academic standards, in a northeastern state of the United States. All three schools were Title I schools with a very high percentage of students on free/reduced lunch as well as a very high percentage of minority populations. Table 1 provides the demographics of these schools. These students were enrolled in a free science, technology, engineering, arts, and mathematics (STEAM)-based summer program funded by a state grant that served at-risk youth. This state-funded grant program supported the academic, social-emotional, and career-readiness development of these students during the school year and provided free enrollment to this STEAM summer program in the summer of 2017. The PBL environment (described below) was used as part of the summer curriculum.

Multimedia-Enriched PBL Environment

The PBL used is a 3D immersive multimedia-enriched PBL environment called Alien Rescue, designed as a 15-hour curriculum unit in sixth-grade space science. Alien Rescue (AR) is a PBL program designed and developed by the faculty and students in the Learning Technologies Program at the University of Texas at Austin. The program has been in existence since 1998. Over the past 19 years, the program has evolved with numerous iterations to incorporate contempo-

rary technologies, but the underlying pedagogical approach using PBL remains the same (Liu et al., 2014).

The participants in this study used a newly completed version (Version 6.1, 2017) that is delivered entirely online using WebGL technologies. In this 3D immersive environment, which integrates text, graphics, videos, and 3D models, middle school students assume the role of young scientists and are tasked with participating in a rescue operation to find suitable relocation sites for six displaced alien species within our solar system. The goal of AR is to engage middle school students in solving a complex problem that requires them to use the tools and procedures scientists use, and to use knowledge of space science. Simultaneously, students apply processes of scientific inquiry to learn about our solar system. Through inquiry-based activities, students practice problem-solving, self-directed, and collaboration skills using a range of built-in multimedia-enriched cognitive tools (Kim & Reeves, 2007; Lajoie, 2000). These tools are designed to provide scaffolding in facilitating students' problem-solving process (see Table 2 for the description of each tool). However, how and when to use these tools are entirely students' decisions. Designed as an open PBL environment, Alien Rescue emphasizes student-centered learning, encouraging students to freely discover, explore, make mistakes, and refine their processes and knowledge over time. An important design characteristic is that Alien Rescue couples a real-world scientific inquiry process with a playful experience delivered through a 3D immersive, discovery, and sensory-rich approach to promote learning while students are having fun. Figure 1 provides screenshots of some of the tools in the environment.

Table 1. Demographics of the Participating Schools

School	Student Ethnicities					% of Free & Reduced Lunch	State Standard Assessment	
	African American	Hispanic	Asian	White	Multi-racial			
1	31%	53%	5%	10%	1%	Free Lunch: 81% Reduced Lunch: 5%	<i>English Regents</i>	<i>Algebra Regents</i>
							Grade of 55: 86%	Grade of 55: 89%
							Grade of 65: 75%	Grade of 65: 89%
2	6%	87%	3%	4%	N/A	Free Lunch: 86% Reduced Lunch: 4%	Grade of 85: 0%	Grade of 85: 0%
							<i>ELA Assessment</i>	<i>Math Assessment</i>
							Level 1: 50%	Level 1: 56%
							Level 2: 33%	Level 2: 31%
							Level 3: 15%	Level 3: 10%
3	26%	60%	3%	10%	1%	Free Lunch: 91% Reduced Lunch: 3%	Level 4: 2%	Level 4: 3%
							<i>ELA Assessment</i>	<i>Math Assessment</i>
							Level 1: 52%	Level 1: 49%
							Level 2: 30%	Level 2: 31%
							Level 3: 13%	Level 3: 13%
							Level 4: 5%	Level 4: 7%

(a) Alien Information Center—Alien Species

(b) Alien Information Center—Alien Food

(c) Probe Design Center

(d) Solar System Database

(e) Concepts Database

(f) Notebook

(g) Mission Control Center

(h) Periodic Table

Figure 1. Screenshots of tools in Alien Rescue to support scientific inquiry.

Science Knowledge. A 20-item science knowledge test, measuring student understanding of the various scientific concepts introduced in the PBL environment, was used. It included both factual knowledge and application questions. This test has been used in previous studies using the same PBL environment for similar age groups (Liu, Horton, Olmanson, & Toprac, 2011; Liu, Rosenblum, Horton, & Kang, 2014) and has an $\alpha = .77$. Because no direct teaching should be involved as a requirement of using this PBL environment, a gain in the science knowledge score would indicate that a student has acquired a good understanding of the scientific concepts needed for problem solving through his or her self-directed learning, classroom discussions, and/or peer interaction while using Alien Rescue. The raw scores were converted to percentage correct in the analyses.

Attitude Toward Science. To measure students' attitude toward science, the instrument Attitude Toward Science in School Assessment (ATSSA, Germann, 1988) was used. This instrument looked at student attitude toward science as a school subject from 7th grade to 10th grade and has a reported $\alpha = .95$. It consists of 14 Likert-scale items, with 1 being "strongly disagree" and 5 being "strongly agree." After reversing the coding for four negative statements, a higher score indicates the better attitude. Sample statements include "Science is fun" and "I do not like science and it bothers me to have to study it." In the postsurvey, "science" in each statement was defined as "science using Alien Rescue." For example, "Science is fun" became "Science like Alien Rescue was fun."

Table 2. Descriptions of Ten Cognitive Tools Provided in Alien Rescue

Tool Name	Tool Functions
<i>Available at Tool Bar</i>	
Solar System Database	Provides information on selected planets and moons within our solar system. Data is intentionally incomplete to support the ill-structured nature of the problem-solving environment and foster the need for hypothesis testing.
Missions Database	Provides information on past NASA missions, including detailed descriptions of probes used on these missions.
Notebook	Provides a notebook to store student notes about their research findings. This tool has a notes-comparison feature to facilitate comparing alien needs and planet requirements.
Concepts Database	Provides instructional modules on 10 selected scientific concepts designed to facilitate conceptual understanding. This tool is for just-in-time learning. Students access this tool when they encounter an unfamiliar science concept that is needed for Alien Rescue.
Periodic Table	Provides a periodic table of the elements.
Spectra	Provides information to help students interpret spectra found in the Alien Database.
<i>Available Through Navigating Using 4 Arrow Keys</i>	
Alien Information Center	Provides information, via 3D imagery and text, on the aliens' home planet, their journey, species characteristics, and habitat requirements.
Probe Design Center	Provides information on scientific equipment used in both past and future probe missions. Students construct probes by deciding probe type, communication, power source, and instruments.
Mission Control Center	Displays the data collected by the probes. Students analyze and interpret this data in order to develop a solution. Equipment malfunction can occur, and poor planning may lead to mission failure and budget waste.
Communications Center	Provides students with a Solution Form to submit their solution for each alien species. Students must also use the form to provide a rationale for their choice of alien habitat. It also contains messages from the director of the space station and all six aliens.

Open-Ended Questions and Interviews With Students and the Teacher. Two open-ended questions were given as part of the postquestionnaire to the students. The two questions were: (1) What have you learned from Alien Rescue? and (2) Did you LIKE or NOT LIKE Alien Rescue? If so, Why? During the last day of this summer program, interviews were conducted with a total of 25 students (male = 15, female = 10), one per student, randomly selected and interviewed by the summer program staff. The interviews used the following guiding questions provided by the researchers:

1. What do you think of Alien Rescue?
2. How do you describe Alien Rescue? (Or What would you tell your friends about Alien Rescue?)
3. Have you learned anything from using Alien Rescue? If so, what have you learned? If not, why have you not learned anything?
4. Do you like Alien Rescue? Why or why not? (Be specific. Which part(s) do you like/dislike, why?)
5. How do you compare Alien Rescue with other science classes you have taken so far?
6. If you can choose, which would you prefer to do and why?
7. After using Alien Rescue, do you like learning science better, the same, worse? Why?

In addition, two interviews with the teacher were conducted by the researchers after each course ended.

Procedure

There were two courses that used AR, one for 5th–6th graders and one for 9th–10th graders, taught by the same lead teacher with three supporting staff (college students). Two weeks prior to their use, the lead teacher and staff went through professional training to get familiar with the student-centered learning approach, AR environment, and the teaching materials. The teacher and program staff were provided detailed 15-day lesson plans, teaching tips, and science materials needed to use AR by the Alien Rescue team. They also used AR themselves as learners. Alien Rescue designers had three conference calls and ongoing email communications with the lead teacher to address any questions they had. They were advised by the designers of AR to avoid direct instruction, and instead to encourage collaboration among students and to use the various cognitive tools and resources provided in the PBL environment to facilitate student learning. Students then used the PBL environment for three hours every day for six days with a total of 18 hours for each course. Alien Rescue was the only program the participants used for this three-hour block each day. The teacher stated in the postinterview that he “basically set the stage, explained the situation, and let the students play with it. They worked in small groups.”

Both the science knowledge test and attitude questionnaires were given before and after the use of the PBL environment. Interviews with the students were conducted by the program staff toward the end of this summer program. Based upon the postinterviews, it was clear the teacher followed the provided lesson plans closely and used them as the designers intended. Interviews with the teacher were conducted by the AR team after the use of Alien Rescue.

Data Analysis

To answer the first research question, two-way ANOVAs were run to see if there were changes in student science knowledge and attitude toward science scores from pre- and posttesting. Gender served as the independent variable (IV) and science knowledge and attitude pre- and postscores served as dependent variables (DVs), respectively. To answer the second research question, two regression analyses were conducted to determine whether students' attitude toward science would predict student science knowledge and whether student science knowledge would predict student attitude toward science.

To supplement the quantitative data, the responses to the open-ended questions and interviews were analyzed following the qualitative data analysis framework by Miles, Huberman, and Saldaña (2013) and the constant comparative method (Creswell & Poth, 2018). Responses to each open-ended question were coded by two researchers. Each researcher coded the responses independently and created a list of codes and definitions of each code. Then two researchers compared the coding, highlighting any inconsistencies, and revised/refined the coding. The coded data were presented to the entire research team for checking. Further revisions were made and all disagreements were discussed among the team members until 100% inter-rater reliability was reached.

Interviews were first transcribed. Each interview was then coded by at least two researchers following the same coding procedure as with the responses for open-ended questions. The codes generated from the two open-ended questions were used for interview questions 3–4 as they were about the same topics (learning and attitude), and new codes were added if necessary. Open-coding was used for interview questions 1–2 and 5–7. During the coding process, the research team met frequently to discuss the codes to ensure their alignment with the research questions. Quotes from the qualitative data are presented below, unedited.

In addition to the traditional qualitative data analysis of coding as discussed above, we also used a Web-based digital text analysis tool, Voyant Tools, to visually demonstrate the findings. Given the coded responses from each student in the interviews, we chose TermsBerry, Mandala, and StreamGraph visualizations to present the findings (Sinclair & Rockwell, 2016). TermsBerry visualization is used to

provide a way of exploring high-frequency words and their collocates (words that occur in proximity). Mandala is a conceptual visualization to show the relationships between words and document(s) that contain those words. Each word pulls a document or documents containing the word toward it based on the word's relative frequency in the document. The shorter distance between the word and the document (shown in the middle of the graph) represents a higher frequency of the word in the document. We also used Stream-Graph visualization to depict the change of the frequency of words within a single document.

Results

This study examined science learning and attitude by a group of at-risk middle school students after they used a multimedia-enriched PBL science environment. Our research questions focused on any differences in student science knowledge and attitude toward science after their use of the PBL environment and the relationship between student science knowledge and attitude toward learning. Both quantitative and qualitative data were used.

Differences in Students' Science Knowledge and Attitude Toward Science Scores

ANOVA indicated that there was a significant main effect for the time of testing for science knowledge and attitude toward science: students' science knowledge scores increased significantly from pretest to posttest: $F(1, 30) = 10.26$, $p < .01$, $ES = .26$ ($M_{\text{pretest}} = 45.78$; $M_{\text{posttest}} = 52.03$). Student attitude toward science also increased significantly: $F(1, 30) = 5.24$, $p < .05$, $ES = .15$ ($M_{\text{pretest}} = 3.66$; $M_{\text{posttest}} = 3.94$, see Table 3). However, there were no differences in the scores between boys and girls. That is, both boys and girls significantly increased their science knowledge and attitude toward science scores from pre- to posttesting. Although boys had higher prescores than girls ($ScienceKnowledgePreScore_{\text{boys}} = 49.71$; $ScienceKnowledgePreScore_{\text{girls}} = 41.33$; $AttitudePreScore_{\text{boys}} = 3.84$; $AttitudePreScore_{\text{girls}} = 3.97$), the gain scores from pre- to posttests for girls were bigger ($ScienceKnowledgeGainScore_{\text{boys}} = 4.7$; $ScienceKnowledgeGainScore_{\text{girls}} = 8$; $AttitudeGainScore_{\text{boys}} = 0.11$; $AttitudeGainScore_{\text{girls}} = 0.46$) (see Table 3 and Figure 2).

Table 3. Students' Science Knowledge Test and Attitude Toward Science Scores

Measure	Boys		Girls		Total	
	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>
Science Knowledge Score (scale of 0–100)	17		15		32	
Pretest		49.71 (19.56)		41.33 (13.69)		45.78 (17.33)
Posttest		54.41 (20.38)		49.33 (16.02)		52.03* (18.35)
Attitude Toward Science (scale of 1–5)	17		15		32	
Pretest		3.86 (.76)		3.44 (0.85)		3.66 (.82)
Posttest		3.97 (.58)		3.90 (0.73)		3.94 ** (.65)

* Significant different from the pretest, $p < .01$.

** Significant different from the pretest, $p < .05$.

^a Significantly different from the pretest, $p < .01$.

^b Significantly different from the pretest, $p < .05$.

Figure 2. Student science knowledge test and attitude toward science scores.

Relationships Between Students' Science Knowledge and Attitude Toward Science

Regression analysis showed a strong significant R^2 of .72, $F(2, 29) = 36.47$, $p < .001$, with attitude toward science pretest scores significantly predicting science knowledge posttest scores while controlling science knowledge pretest: $b = 5.88$, $t(29) = 2.58$, $p < .05$. That is, there was a strong positive relationship between attitude toward science and science knowledge—the higher the attitude prescores, the higher the student science knowledge posttest scores.

Regression analysis also showed a moderate significant R^2 of .38, $F(2, 29) = 8.99$, $p < .01$, with science knowledge pretest scores predicting attitude toward science posttest scores at a near significant level, while controlling attitude toward science pretest: $b = .01$, $t(29) = 2.02$, $p = .053$. That is, the higher the student science knowledge prescores, the more likely their attitude toward science postscores would be higher.

Findings from Qualitative Data

Qualitative data sources consisted of open-ended questions and interviews, which provided more detailed insights into the two research questions.

Student Learning. Student responses to the open-ended question, "What have you learned from Alien Rescue?"

showed three primary themes from the 72 coded responses: knowledge (85%), skills (10%), and fun (3%). There was also empathy (1%), and negative comment (1%) (see Table 4).

With regard to knowledge learned, students indicated they learned about science knowledge (53%) and about aliens (32%). Interview data corroborated these findings. For example, Girl A stated, "I learned a lot more about planets, and there's moons on different planets, and stuff like that I never knew about, so that was quite interesting." Boy A said, "I learned about, that other moons, that other planets have and their atmosphere, gravity, and temperature of it. Well, and I know what the probe is now. About the aliens, look strange but it's kind of fun." Students also indicated they learned collaboration and problem-solving skills (see Table 4). From the interviews, sample students' comments to "Do you like Alien Rescue? Why or why not?" included the following:

I do. Because I get to work with my friends, and I get to do research and learn more of the solar system. (Boy B)

I do like Alien Rescue. What I liked about it is that it kept me thinking, and it kept me busy. I like mysteries and stuff, so we had to figure what planet our alien had to live on. That was interesting to me. (Girl B)

Table 4. Students' Responses to "What have you learned from Alien Rescue?"

Themes	% of Total Codes (<i>n</i> = 72)	Codes	Sample Quotes (unedited)
Knowledge	53	Science Knowledge	"I learned many things about the solar system and planets."
			"I learned about the planets and their moons, about their atmospheres, temperature, magnetism, and their gravity."
			[I learned] "How probes and tools work, and a little bit more about planets and what makes them habitable."
Skills	32	About Aliens	"I learned that all alien has different features and they have to be in different part they all have to live different ways."
		Collaboration	"I learned how to research more information on whatever specimen I am assigned with and of how to work with others more diligently to complete the assignment."
		Problem Solving	"I learned how to research for the stuff i need to do in projects similar to this." "FROM ALIEN RESCUE, I LEARNED MORE ABOUT PLANETS AND HOW TO STUDY THEM."
Fun	3		"I learned that science can be fun in many different ways. Also that science can be both fun and informational."
Empathy	1		"In Alien Rescue I learned that helping others is really important."
Negative Comments	1		"Aliens are boring."

We also asked students in the interviews to compare their use of Alien Rescue to other science classes/activities and if they had learned science better, the same, or worse (see interview questions above). As shown by the TermsBerry visualization in Figure 3(a), more students stated they learned science better after using Alien Rescue. Mandala visualization in Figure 3(b) indicated students' reasons for learning better with AR: knowledge, fantasy, new, experience, computer, fun, and interesting. Students' interview responses provided further evidences. More students cited fun in providing their reasons (see Figure 3(b)). Girl C said, "I like science better because it gives you a new perspective of science, so, I mean, you get to learn more about gasses and about the planets, and a lot of other stuff." Girl D stated "[I prefer] Alien Rescue. Because, I guess, science class is fun and everything, but Alien Rescue gives me a new chance to have even more fun, and come up

with new things that you get to learn about." We further examined the positive words the students used to describe AR and the frequency of these coded responses by genders. The coded responses by female students were presented first in the figure, followed by those by male students (see Figure 4). That is, the left side of the X-axis in the StreamGraph visualization showed the codes for female students (X-axis from 0 to 3), while the right side of the X-axis indicated the codes for male students (X-axis from 4 to 9). More units on the X-axis represented a larger corpus by boys because more boys participated in the interviews. The Y-axis indicated the relative frequency each code appeared among all the codes. The StreamGraph visualization showed both the boys and girls listed these reasons: "fun," "computer," "new." The girls also listed "knowledge" while the boys listed "experience," as well as "fantasy" when they explained why they liked Alien Rescue.

Figure 3. Students stated they learned science better in (a) and the reasons for learning better with Alien Rescue in (b).

Figure 4. CAPTION NEEDED.

Student Attitude. The responses to open-ended question, “Did you LIKE or NOT LIKE Alien Rescue? If so, Why?” consisted of a total of 84 coded responses. Out of these, 95% reflected students’ likes and 5% reflected students’ dislikes (see Table 5). This finding was also reflected in the interview responses to the question “After using Alien Rescue, do you like learning science better, or maybe the same as before, or worse?” The StreamGraph visualization, based upon the positive codes, showed both boys and girls consistently favored AR compared to other science classes (see Figure 5).

Five themes emerged in the students’ likes category: knowledge (50%), skills (17%), fun (24%), confidence (3%), and instructor (1%). Consistent with the above discussion on learning, they liked AR because they learned science knowledge, general knowledge, and about aliens, as well as collaboration and problem-solving skills. Students also liked AR because they considered it fun. Students elaborated on this finding in the interviews. For example, boys stated, “I think it is really fun and enjoyable to work in a group and participate in science stuff, because usually in school we really don’t do much science,” and, “In 3D form, when I saw Alien Rescue, it looked so much better, and it’s just in the 3D form, and, well, it was like a new way for me . . . Of learning science for me.” The girls commented, “I think Alien Rescue’s a very interest-

ing project and I learned some things while having fun,” and “I would describe it as being really fun, and kids get to learn about new things and all that.” Another student said:

I like the parts that we were doing research on the aliens and where to put them, more than finding out about the aliens because I felt like we were doing something. We were creating the information instead of taking the information of others. We were creating something new. We were inventing something. We were discovering something new, so it just felt exhilarating.

Interestingly, a few students also indicated using Alien Rescue increased their confidence, as shown in these comments: “I personally like alien rescue because i was able to interact with it and it taught me that i can really get a A+” and “I would prefer Alien Rescue. Because it’s a lot of fun and I get to work with other people. Like instead of . . . If I was in a science class, I would have to work alone, think alone and not like do anything. In Alien Rescue, we get to work in a group and I could participate in stuff too.”

Of the 5% negative comments, lack of interest in science comprised 2%, as shown in this comment, “i dont really like it because i dont really like science but i do like expiermenting” and some considered AR boring (2%) or did not like the graphics (1%) (see Table 5).

Table 5. Students' Responses to "Did you LIKE or NOT LIKE Alien Rescue? If so, Why?"

Themes	% of Total Codes (<i>n</i> = 84)	Codes	Sample Quotes (unedited)
Like	15	Science Knowledge	"i like it because u can learn many different things about many different planets."
	25	About Aliens	"I liked the ALIEN RESCUE because I learned new creatures that were in the outer space."
	10	General Knowledge	"I LIKED ALIEN RESCUE BECAUSE IT TAUGHT ME MANY THINGS WHILE I WAS HAVING FUN."
	5	Collaboration	"Yes, I believe this was a very nice activity because it helps you understand of how to research information better and of how to work with others."
	12	Problem Solving	"I liked Alien Rescue because you could explore three different and unique rooms that helped you on achieving your ultimate goal on finding a good home for your alien species."
	24	Fun	"I like alien rescue because is fun and you can learn more from them and help them find a new planet for them to live and plant."
	3	Confidence	"I personally like alien rescue because i was able to interact with it and it taught me that i can really get a A+."
Dislike	1	About Instructor	"Now, i was probably biased since i love space and planet science, but i still enjoyed it. the site was rather fun and an interesting way to delegate all the needed information, and the instructors made it pretty fun overall."
	2	Lack of Interest in Science	"i dont really like it because i dont really like science but i do like expiermenting."
	1	Graphics	"I did not like Alien Rescue because of the graphic narrative."
	2	Boring	"i dont really like it its was boring and gave me many problems."

Teacher's Perspective. When describing this PBL experience in the interviews, the teacher said his students “loved the program, they loved using the computers, and they loved working in groups.” He elaborated that it was “a wonderful opportunity for both teachers and students because it creates a different dynamic in the classroom, and a lot of responsibility, a lot of the ownership for the learning is placed on the student.” He further commented, “[M]any of the students do not really do much science in their schools for lack of resources in schools” and “this is really a unique opportunity for them, just sort of whet their appetites for wanting to learn more in the future.” He considered this was a different experience because the students “kept saying how it was so different from their usual science classrooms where everything, or most everything is sort of textbook, and here they had access to computers and all the relevant data and information that they could possibly want for their research purposes.” According to the teacher, “freedom,” “responsibility,” and “kids are in charge” made this a better learning experience.

When describing 5th and 6th graders as compared to 9th and 10th graders, the teacher stated, “[I]t was interesting watching the younger students. I think they were just in awe of the entire program. They really had very little prior knowledge of our solar system. To them that was part of really what amounted to an amazing learning experience because it's learning about Mercury, Venus, Earth, Mars, etc. [It] was a totally new experience for them.” For the older group, the teacher said, “They like doing the research. They like knowing that there wasn't an exactly correct answer. That there were many possible solutions to the given problem.” At the end of the program, the students made presentations and presented to their parents, many of whom were of the Spanish-speaking population. “We couldn't communicate directly but they were attentive during the entire presentations, they applauded enthusiastically, they really were very pleased and proud of what their children accomplished,” the teacher commented.

Discussion

In this study, we examined the use of a multimedia-enriched PBL science environment by a group of at-risk students. The results, using both quantitative and qualitative data, showed these students significantly improved their science knowledge and attitude toward science after they engaged in the PBL environment. While there were no differences in the scores between boys and girls, the gain scores from pre- to posttests in science knowledge and attitude toward science for the girls were larger. The findings also indicated a strong positive relationship between attitude toward science and science knowledge. The higher the attitude prescores, the higher the students' science knowledge posttest scores.

Learning in PBL by At-Risk Students

A significant amount of research on problem-based learning in K–12 education has shown that PBL, as a student-centered teaching method, can have a positive impact on learning such as improving content knowledge and higher order thinking skills (Brown et al., 2013; Diggs, 1997; Hwang et al., 2012; Liu et al., 2006; Merritt et al., 2017). However, the majority of learners in typical PBL studies are gifted or regular (general) education students. There is a lack of research on PBL use by disadvantaged middle school students (S. A. Gallagher & Gallagher, 2013). Additionally, little research is found on PBL use by at-risk students who are often from the disadvantaged and minority groups. This study aimed to fill this gap.

The findings of this study with a group of at-risk students have shown a positive impact in that these students, who were from failing schools and considered to need additional academic support, can perform well in a challenging PBL environment. This finding is in line with the study by S. A. Gallagher and Gallagher (2013) in that all students can possibly develop and reveal their academic potential through PBL. What is also noteworthy is that there were no significant differences in the scores in science knowledge and attitude toward science between boys and girls, which supports the research by Brown et al. (2013). In this study, the girls, though having lower prescores, increased more at the posttest. The findings of this study contribute to the limited research on PBL use with underrepresented populations (Brown et al., 2013; S. A. Gallagher & Gallagher, 2013) and provide empirical evidences that the benefits of PBL can be extended to all students, not just the gifted and general education students. The findings also showed not only that students' science knowledge improved, but that they could also articulate clearly what they had learned through this PBL approach, as shown in the qualitative data. In addition to science knowledge, both boys and girls stated they had learned problem-solving and collaboration skills. This finding is consistent with the previous research investigating the effect of *Alien Rescue* as a 3D immersive multimedia-enriched PBL environment on learning with regular education middle school students (Liu et al., 2011; Liu et al., 2014). The qualitative data also revealed that when comparing to other science classes, students stated they learned better after the PBL experience and preferred AR to other science classes. Students exercised their collaborative learning and self-regulation skills to become independent learners (Bransford et al., 1999). PBL characteristics such as students in control of their learning, working collaboratively, and solving an ill-structured problem in an authentic context make this learning “different from the usual science classes” as confirmed by the teacher. What is also encouraging is that some students

even indicated the experience enhanced their confidence in learning. Such findings provide further evidence that using PBL can possibly increase student self-efficacy (Brown et al., 2013; Liu et al., 2006).

Attitude and Learning by At-Risk Students

Research has shown the importance of attitudes with regard to learning (Gardner, 1985). If students have a positive attitude toward learning, they are more likely to put in more effort in achieving a desired learning goal. Attitude can significantly influence motivation and performance (Germann, 1988; Marsh, 1992). The findings of this study are consistent with the literature. The results showed student attitude toward science were improved for both boys and girls after using the 3D immersive multimedia-enriched PBL environment. The increase for the girls was larger. Ninety-five percent of the 84 coded responses indicated the students enjoyed the PBL experience (see Table 5 and Figure 5), because they had learned knowledge and skills and the experience was “fun.” Having fun while learning is a consistent theme from both open-ended questions and interview responses (Liu, Horton, Kang, Kimmons, & Lee, 2013). Our previous research examining student attitude toward science and their achievement using Alien Rescue with regular education students also found a positive relationship (Kimmons et al., 2012). The results also revealed a strong positive relationship between attitude toward science and science knowledge in that the higher the attitude prescores, the higher the student science knowledge posttest scores. These findings are encouraging, especially in the context of literature on attitude, which has shown a decline in attitude toward science classes at the middle school level (Barmby et al., 2008; Ebenezer & Zoller, 1993; Osborne et al., 2003) and the need of STEM workforces in the 21st century (Hillman et al., 2016). Literature has shown students tend to lose their interest in science and do not consider it in their future aspirations as they advance to secondary education (Christidou, 2011; Osborne et al., 2003). Yet, having a positive attitude is critical to one's career choices (Hillman et al., 2016). The results of this study have shown it is possible to use student-centered pedagogical approaches such as PBL to engage students in learning and improve their attitudes.

Literature has shown that implementing PBL in K–12 classrooms can be challenging for both teachers and students (Ertmer & Simons, 2006). Technologies are often used to create and deliver a PBL environment (Liu et al., 2012). Design is a critical factor to consider for a successful PBL

implementation. In this study, the PBL program is a 3D immersive multimedia-enriched environment. A key design feature is that it combines a real-world scientific inquiry process to engage middle school students as young scientists with a sensory-rich, playful, and fantasy-oriented experience for this age group (Lee & Liu, 2017). Students used such words to describe their reasons for learning better with and liking AR: knowledge, fantasy, new, experience, computer, fun, and interesting. Such design elements are found effective to motivate middle school students as shown in the previous research (Liu et al., 2011, 2014). In addition, a set of 10 multimedia-enriched cognitive tools (Kim & Reeves, 2007; Lajoie, 2000) are provided to scaffold student problem-solving processes. Research has shown scaffolds are needed to support students and teachers in implementing an open environment such as PBL (Ertmer & Simons, 2006; Kim & Hannafin, 2011; Liu et al., 2012).

Limitations

This study is limited in that the participants were an intact group enrolling in a summer program from three priority (failing) schools. All participants used the PBL program and having a control group for experimental purposes was not an option. Therefore, the sample size was limited. In addition, a few students (mostly 9th–10th graders) did not complete all instruments or entered wrong IDs, which made matching all data impossible. The elimination of these students further reduced the sample size. Regression analysis showed a moderate significant effect, suggesting the higher the student science knowledge prescores, the more likely student attitude toward science postscores would be higher. But this finding is preliminary. A larger sample size is needed. Readers are cautioned to keep these limitations in mind.

Conclusions

The findings of this study add to the limited research examining PBL use by an underrepresented middle school population, especially students who are considered to be at risk of failing. The encouraging results for this group of at-risk students indicate a well-designed PBL can benefit all students, including those on the borderline of failing. Both boys and girls can be successful in a challenging PBL environment. The results should provide much needed insights into the overall understanding of PBL use in K–12, especially at the middle school level.

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