Promoting Self-Efficacy and Science Learning for All Middle School Students Using a Technology-Enhanced Problem-Based Environment

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Descriptors: Problem-based learning, technology-enriched learning environment

Abstract
This study examined the relationships between 146 sixth graders’ achievement and self-efficacy after they used a technology-enhanced problem-based learning (PBL) environment in a school with a high economically disadvantaged population. ANOVA measure indicated that this group of students’ science knowledge test scores increased significantly from pretest to posttest, while student self-efficacy decreased slightly. In addition, the results from multiple regressions showed that the higher the self-efficacy pre-scores, the higher the student science knowledge posttest scores. Furthermore, the qualitative analysis on student interview data showed that majority of the students had positive attitudes towards the PBL environment and gained more knowledge on the content compared to other skills after using the technology-enhanced PBL environments.

Relevant Literature
Emerging technologies have provided designers the opportunities to create technology-enhanced problem-based learning (PBL) environments. Studies have reported that these technology-based PBL environments can help increase student self-efficacy, critical thinking, communication, and collaboration skills (Brown, Lawless, & Boyer, 2013; Lajoie et al., 2014; Neo, M. & Neo, 2001; Şendağ & Odabaşı, 2009). For example, Neo, M. and Neo (2001) studied 46 college students who were asked to design a PBL using multimedia technologies in their class. By embedding student learning in this real-world problem, students were expected to “exercise analytical, critical and creative thinking in their work” (p. 21). The post-survey and interview data suggested that students became active participants and gained collaboration experiences in their learning process. Lajoie and her colleagues (2014) also examined cross-cultural medical students—in Canada and Hong Kong—during PBL using online digital tools and videos. In this study, they used AdobeConnect to facilitate synchronous communication among students, and the results indicated that the affordance of the technology provided opportunities for just-in-time communication without having students to travel across the globe.
For middle school students, literature has shown promising benefits after students used these technology-enhanced PBL environments—such as increasing student self-efficacy, learning interests, problem-solving, and collaboration skills (Brown et al., 2013; Sánchez & Olivares, 2011). In a recent review of literature, Merritt, Lee, Rillero, and Kinach (2017) summarized nine experimental studies to explore the effectiveness of PBL for K–8 students (ages 3–14) in mathematics and science classrooms. Their review suggested that PBL was an effective instructional method for improving these students’ academic achievement, including knowledge retention, conceptual development, and attitudes. For example, one of the nine reviewed studies was conducted by Tandogan and Orhan (2007). They used both quantitative and qualitative methods to determine whether PBL would affect student academic achievement and concept learning in a 7th grade science classroom. The results indicated that PBL had positively affected student academic achievement and attitudes towards the science course. In addition, PBL positivity affected student conceptual development and kept student misconception at the lowest level. Karaçalli and Korur (2014) also investigated academic achievement, attitude, and retention of knowledge of 9-11 years old students while they were using PBL. The results showed PBL had significant positive effects on student academic achievement, \( F(1,112) = 46.78, p = .000 \) and knowledge retention \( F(1,112) = 35.24, p = .000 \).

Self-efficacy refers to the beliefs about one’s capabilities to produce designated levels of performance (Bandura, 1994). Research indicated student self-efficacy often acted as a predictor of academic achievement and motivation (Graham & Weiner, 1996; Jackson, 2002; Lane, J. & Lane, 2001; Pajares, 2003; Pintrich & DeGroot, 1990). For example, Jackson (2002) found that for college students, self-efficacy was significantly related to their learning performance (i.e., exam scores in his study) on introductory psychology exams. Pajares (2003) specifically reviewed student self-efficacy regarding writing, and he pointed out that research findings have consistently shown that student writing self-efficacy are related to their writing performance. As for PBL, Dunlap (2005) suggested that college students had improved self-efficacy after completing a 16-week PBL course for software development. Yet, with respect to middle school students, researchers suggested that middle school students with lower self-efficacy tended to be reluctant to take on challenges presented in a typical PBL environment (Hsieh, Cho, Liu, & Schallert, 2008). On the other hand, Brown et al. (2013) suggested technology-enhanced PBL environments had a positive impact on students’ science interest and self-efficacy.

Despite many efforts, many urban, minority students lag behind academically compared to their white counterparts (Connell, Spencer, & Aber, 1994). Previous literature showed that PBL was used and enjoyed primarily by adult and adolescent learners who demonstrated comparatively higher levels of academic proficiency (Barrows, 1987), and with gifted students (Stepien & Gallagher, 1993; Coleman, 1995). While low-income, minority population was not thoroughly studied regarding how they respond to the high academic challenge as presented by PBL. In one study, the researchers (Gordon, Rogers, Comfort, Gavula, & McGee, 2001) found that when used as an enrichment activity for just two percent of the curriculum in a public middle school that had 96 percent of low-income minority and low-performing students, PBL improved behavior and increased science performance of students, specifically on the active learning and teamwork. The individuals involved in PBL activities felt that the problem-based approach made learning more relevant and enjoyable. The effects of PBL were especially obvious middle school in science, but there were no consistent changes in academic performance in other subjects. However, this kind of PBL practices were not prevalent among economically disadvantaged students, partly due to insufficient teachers’ professional development. A study by Rillero et al. (2017) found most of the teacher preparation programs were inclined to focus narrowly on content knowledge teaching and specific methods with little focus on how to integrate PBL effectively.

Given the benefits of using technology-enhanced PBL in improving student learning outcomes, and the lack of empirical evidence of its effectiveness in economically disadvantaged middle school students (Gallagher, S. A., & Gallagher, 2013), our study aimed to fill in the gap by investigating the use of technology-enhanced PBL for economically disadvantaged middle school students.

**Research Questions**

To understand whether technology-enhanced PBL environments can promote all students’ self-efficacy and science learning, we looked at achievement and self-efficacy of middle school students from a school with a minority and economically disadvantaged population. We asked these research questions:

1. Are there any differences in students’ science knowledge and self-efficacy before and after they used a technology-enhanced PBL environment?
2. Is there a relationship between students’ science knowledge and self-efficacy after they engaged in a technology-enhanced PBL environment?
Method

Participants and PBL Environment

Participants were 146 sixth graders from a middle school in a mid-sized southwestern city (Hispanic, 53.1%; African-American, 13.4%; White, 26.1%; Other races, 7.4%. See Table 1 for the demographic information). They used a technology-enhanced PBL environment designed for middle school space science as their curriculum over a three-week period in Spring 2017. Through inquiry-based activities, students learned about space science while practicing problem-solving, self-directed learning, and collaboration skills. See Figure 1 for the screenshots of the PBL environment.

Table 1.

Demographics of the Participating School

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hispanic</td>
<td>53.1</td>
</tr>
<tr>
<td>African-American</td>
<td>13.4</td>
</tr>
<tr>
<td>White</td>
<td>26.1</td>
</tr>
<tr>
<td>Other races</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Figure 1. Screenshots of the PBL environment
Data Sources

A 20-item science knowledge test, used in previous studies with similar samples engaged in the same PBL environment (Liu, Hsieh, Cho, & Schallert, 2006; Liu, Horton, Olmanson, & Toprac, 2011), was used to measure student understanding of the scientific concepts introduced in the curriculum (Cronbach’s alpha = .77). Eight items from the Motivated Strategies for Learning Questionnaire (Pintrich, Smith, Garcia, & McKeachie, 1993) were used to measure self-efficacy (Cronbach’s alpha = .91). Both instruments were given before and after the use of the PBL.

Qualitative data were also collected to understand the differences after students used this technology-based PBL environment, as well as the relationship between students’ science knowledge and self-efficacy. Students were asked to answer three questions in the post-survey, including:
1) How would you describe the environment to a friend?
2) What did you learn from the environment?
3) Do you like this environment or not and Why?
To ensure the trustworthiness of the qualitative data analysis, the survey responses were coded by one researcher first, and verified by other two researchers separately to reach the 100% agreement. A codebook was also generated during the analysis.

Findings

To answer research question one, ANOVA was used. The results indicated there was a significant main effect for the time of testing for science knowledge and self-efficacy: students’ science knowledge scores increased significantly from pretest to posttest (F(1,144) = 113.06, p < .0001, ES =.44; M_{pretest} = 42.67; M_{posttest} = 56.88); students’ self-efficacy decreased slightly: F(1,144) = 6.72, p < .01, ES =.05; M_{pretest} = 3.96; M_{posttest} = 3.80). Interestingly, girls had lower self-efficacy and their self-efficacy, though not significant, decreased slightly more than boys. However, overall, these changes did not depend on gender (see Table 2).

Table 2.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Boys</th>
<th>Girls</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Knowledge Score</td>
<td>n</td>
<td>M (SD)</td>
<td>n</td>
</tr>
<tr>
<td>(on 0-100 scale)</td>
<td>73</td>
<td>45.34 (20.94)</td>
<td>73</td>
</tr>
<tr>
<td>Pretest</td>
<td>73</td>
<td>58.63 (20.64)</td>
<td>73</td>
</tr>
<tr>
<td>Posttest</td>
<td>3.96 (0.79)</td>
<td>3.97 (0.59)</td>
<td>3.96 (0.70)</td>
</tr>
<tr>
<td>Self-Efficacy (Scale of 1-5)</td>
<td>3.84 (.78)</td>
<td>3.76 (0.82)</td>
<td>3.80** (.80)</td>
</tr>
</tbody>
</table>

* Significantly different from the pretest, P < .0001.
** Significantly different from the pretest, P < .01.

As for research question two, multiple regressions showed a significant moderate $R^2$ of .48, $F (2, 143) = 66.66, p < .0001$, with self-efficacy pretest scores significantly predicting science knowledge posttest scores while controlling science knowledge pre-test: $b = 7.69, t(143) = 4.29, p < .0001$. That is, the higher the self-efficacy pre-scores, the higher the students’ science knowledge posttest scores.
To further understand how this environment affected student self-efficacy and the relationship between student science knowledge and self-efficacy, the researchers analyzed the qualitative data. Based on the interview data, over half of the students (i.e., $N = 77$, 52%) would describe this environment positively to their friends. For example, one student suggested that she would tell her friends that “it is fun, interesting, and easy to use”. Admittedly, 10.8% of the students had negative comments about this environment, such as “It’s really boring. And that you get to use computers with it.” However, majority of the students showed positive attitude towards this PBL environment. See Table 3 for the definitions of codes and examples.

Table 3.

<table>
<thead>
<tr>
<th>Code (N = 148)</th>
<th>Boy (N= 73)</th>
<th>Girl (N=75)</th>
<th>Definition</th>
<th>Code Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive (N = 77)</td>
<td>40</td>
<td>37</td>
<td>Participant positive comments about the environment, such as fun, good, and interesting.</td>
<td>it is fun. interesting. and easy to use.</td>
</tr>
<tr>
<td>Neutral (N = 49)</td>
<td>21</td>
<td>28</td>
<td>Participant comments that are neutral about the environment.</td>
<td>It’s ok</td>
</tr>
<tr>
<td>Negative (N = 16)</td>
<td>7</td>
<td>9</td>
<td>Participant negative comments about the environment, such as Boring, Pointless</td>
<td>It’s really boring. And that you get to use computers with it.</td>
</tr>
<tr>
<td>Null (N = 6)</td>
<td>5</td>
<td>1</td>
<td>Participant comments that are not valid for consideration.</td>
<td>go to google classroom</td>
</tr>
</tbody>
</table>

When asked what they have learned from the environment, students gave a variety of responses. These responses were coded into seven categories that emerged, such as solar system, game elements, scientific concepts, motivation, learning strategies, nothing and null (see Table 4 for the definitions of codes and examples). According to the data, students learned about the actual content knowledge the most (i.e., solar system, such as the planets, moon, space, and so on), followed by game elements and scientific concepts. For example, one student wrote “i learn about that there are different types of moons and i learn the planets,” which indicated he learned about the “Solar System.” Another student wrote “I also learned about the different possible species for aliens and where their home would be,” which was coded as learning about the “game elements.” A few students also indicated they improved their motivation and learning strategies, such as “What I learned in alien rescue [the name of the technology-enhanced PBL environment] was that I should pay attention more.” In addition, five students said that they did not learn anything in the environment, which accounted for 2.82% of the codes, such as “to be honest i didn’t really learn anything”.

Table 4.

<table>
<thead>
<tr>
<th>Code (N = 177)</th>
<th>Boy (N = 89)</th>
<th>Girl (N = 86)</th>
<th>Definition</th>
<th>Code Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar System (N = 105)</td>
<td>45</td>
<td>60</td>
<td>Participants describe they learn about the solar system, such as planets, moon, space, and so on.</td>
<td>i learn about that there are different types of moons and i learn the planets</td>
</tr>
</tbody>
</table>
Game Elements \((N = 27)\)
- 17 Participants describe they learn about the game elements in the environment, such as Aliens, Alien habitat, and so on. I also learned about the different possible species for aliens and where their home would be.
- 10

Scientific Concepts \((N = 14)\)
- 6 Participants describe they learn about the scientific concepts, such as instruments, probes, barometer, and so on. How to work with many different instruments like the seismograph, the infrared camera, and the barometer. I was able to research multiple things at once with another person. We worked together to get our research done.
- 8

Motivation \((N = 9)\)
- 7 Participants describe their motivation elements, such as they had fun in the environment, or they got bored, and so on. It was a fun way to learn new stuff
- 2

Learning Strategies \((N = 7)\)
- 3 Participants describe they learned the strategies, such as paying more attention, research, problem-solving, and so on. What I learned in alien rescue was that I should pay attention more
- 4

Null \((N = 7)\)
- 7 Participant comments do not make sense for what they have learned.
- 0

Nothing \((N = 5)\)
- 4 Participants describe they learn nothing. to be honest i didn’t really learn anything
- 2

In the post-survey, we also asked the students whether they liked this environment or not. The codes indicated that the majority of the students \((N = 106, 72.6\%)\) liked the environment. For example, a student wrote, “liked. It. A lot”. There were also 22.6% \((N = 33)\) of them disliked the environment—“I hated it; It was boring.” (see Table 5 for the definitions of codes and examples).

Table 5.

<table>
<thead>
<tr>
<th>Whether students like this environment or not?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code ((N = 146))</td>
</tr>
<tr>
<td>Like ((N = 106))</td>
</tr>
<tr>
<td>Dislike ((N = 33))</td>
</tr>
<tr>
<td>Neutral ((N = 6))</td>
</tr>
</tbody>
</table>
In support of the literature, the findings showed this group of minority and economically disadvantage students gained significantly more science knowledge after using the PBL environment. As for student self-efficacy, interestingly, girls had lower self-efficacy and their self-efficacy, though not significant, decreased slightly more than boys. However, these differences were not significant. In addition, the results also indicated that self-efficacy is an important factor affecting achievement for both boys and girls. Therefore, such findings suggest the importance of promoting student self-efficacy.

With respect to qualitative data, over half of these minority and economically disadvantage students showed positive attitudes towards the technology-enhanced PBL environment. Most of them also commented that they liked this environment “a lot.” These positive attitudes could have contributed to their significant learning gains during the learning process. In addition, student explicitly expressed that they learned more about the solar system, which is consistent with the quantitative data showing that students had gained significantly more science knowledge.

It is interesting that student self-efficacy slightly decreased despite they showed positive attitude towards the PBL environment. Therefore, there is a need to explore different approaches to promote student self-efficacy, such as improving the design of the technology-enhanced PBL environment or providing appropriate scaffolding for both teachers and students while they are using the environment.

Further qualitative research could be directed to inquire female students’ overall learning experiences, especially their different feedback compared to male students. It will shed more lights on PBL environment design as well as scaffolding in terms of female students’ learning preference, thus to clarify the association between learning flow and their self-efficacy fluctuation. More research with longer time range and larger student population should be conducted, in order to reduce the novelty effects of such learning environments due to disadvantaged students’ limited exposure of PBL environments.

Reference


