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Examining How Middle School Science Teachers Implement a Multimedia-enriched Problem-based Learning Environment

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Abstract

This study examined how a group of ten middle school teachers implemented a technology enriched problem-based learning (PBL) environment. The goal was to understand their motivation, document their implementation techniques, and identify factors that teachers considered important in using technology-based PBL tools in their teaching.

The analysis identified four factors that provided the impetus for teachers to consider the adoption of technology-based PBL instruction. These factors are (1) the PBL program addresses the teachers' curricular needs and implementing it has campus administrative and technical support, (2) the method is aligned with teachers' pedagogical beliefs, (3) the PBL program offers a new way of teaching and promotes the development of higher-order thinking skills, and (4) the PBL program challenges students in a captivating manner and supports the learning needs of all students. Teachers' implementation techniques with over 1,000 sixth graders were documented in detail with regard to: 1) the teacher's roles, 2) the student's role, and 3) the classroom interactions during the implementation of the PBL program. In addition, a detailed description of contrasting narratives of two pairs of teachers is provided, illustrating the range of implementation techniques that can occur using the same PBL program to allow for individualized instruction to meet different students' needs. The goal of providing detailed implementation practices is to address the lack of "how to" in PBL implementation in K-12 classrooms as indicated in the literature and offer insights and ideas to those interested in adopting and implementing PBL. Findings are discussed within the theoretical framework and implications are provided.

Keywords: problem-based learning, motivation, middle school science, technology integration

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Introduction

Problem-based learning (PBL) is regarded by many as an effective instructional methodology (Hung, Jonassen, & Liu, 2008). Yet, researchers have pointed out that PBL use is still relatively uncommon in K-12 schools because of many challenges and barriers (Ertmer & Simons, 2006). There is a lack of research examining factors that motivate teachers to learn the appropriate skills and overcome barriers to implement technology-based PBL tools (Brush & Saye, 2000). There is also a lack of research describing "how to" in implementing PBL in classrooms (Ertmer, 2010; Ward & Lee, 2002) and providing examples of PBL implementation for other teachers who are interested in adopting the PBL approach.

This study examined how a group of middle school teachers implemented a technology enriched PBL environment in science. The goal was to understand their motivation, document their implementation techniques, and identify factors that teachers considered important in using technology-based PBL tools in their teaching.

Research Framework

PBL and Its Affordances

Problem-based learning (PBL) is a form of student-centered learning. In a comprehensive overview of PBL, Savery (2006) defines it as "an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (p. 12). Several characteristics of PBL position it as an attractive approach: In PBL, students assume a major responsibility for their own learning and teachers are facilitators; learning occurs in small groups and collaboration is emphasized (Barrows, 1996). PBL emphasizes solving complex problems in rich contexts and aims at developing higher order thinking skills (Savery & Duffy, 1995). In PBL, the problem is often ill-structured so that students must define the problem, plan a process to generate several possible solutions, evaluate these solutions, and finally, select the optimal solution (Barrows, 2002). The focus of learning is not only the knowledge outcome, but also the process by which students become self-reliant and independent; and learn to be collaborators and problem-solvers (Barrows, 1996; Hmelo-Silver, 2004; Savery & Duffy, 1995). In PBL, knowledge building develops in a collaborative context, and collaboration, both in person or computer mediated, can be practiced and enhanced through PBL instruction (Savery, 2006).

Numerous studies corroborate that PBL is an effective approach to cultivate critical thinking and problem solving skills (Brush & Saye, 2000; Gallagher, 1996; Hmelo & Ferrari, 1997; Mergendoller, Maxwell & Bellisimo, 2006). Studies show that PBL is effective for improving content learning when compared to traditional teaching approaches (Druckman & Ebner, 2008; Polanco, Calderón, & Delgado, 2004; Taradi, Taradi, Radic, & Pokrajac, 2005). For example, Bottge, Grant, Stephens, and Rueda (2010) reported that students taught using a problem-based learning methodology (specifically Enhanced Anchored Instruction for middle school math) outperformed students taught using traditional math methods. Because students develop their own path to solve the ill-structured task, their activities become meaningful as they work to meet the project goals and ultimately the learning objectives (Pedersen & Liu, 2003). PBL shows promise in a number of disciplines such as science, engineering, teacher education, social science, and business (Ravitz, 2009). Despite the recognized benefits and effectiveness of PBL, using PBL in K-12 education is difficult and, therefore, relatively uncommon (Ertmer & Simons, 2006; Hmelo-Silver, 2004). Savery (2006) stated: "The adoption of PBL (and any other instructional innovation) in public education is a complicated undertaking. Most state-funded elementary schools, middle schools, and high schools are constrained by a state-mandated curriculum and an expectation that they will produce a uniform product" (p. 17).

Challenges of Implementing Technology-Based PBL

While technology tools are not required in successful PBL instruction, they can be used to support PBL implementation and overcome some challenges of PBL delivery, as well as enhancing the realism of PBL (Hoffman & Ritchie, 1997). Promoting successful uses of technology in teaching requires the understanding and manipulation of a broad range of factors that interact in very complex ways (Wallace, 2004; Zhao & Frank, 2003). Not only are there challenges of PBL but also challenges of technology integration which combine to create even more complex challenges of technology-based PBL. Hew and Brush (2007) presented barriers typically found in using technology. They identified lack of time, lack of access to technology and technical support, the institutional environment, classroom management issues, and an assessment-focused culture that allows limited time for innovative teaching practice. The literature identifies challenges of PBL instruction to include lack of teacher training, insufficient hardware and limited access to Internet connectivity, lack of access to PBL software, and lack of technical support (Kramer, Walker, & Brill, 2007). Research emphasizes that overcoming the integration barriers and creating conditions conducive for technology use are particularly important for a technology-based PBL approach (Brinkerhoff & Glazewski, 2000; Park, Ertmer & Cramer, 2004; Sage, 2000). Because of the barriers and difficulties, "problem-based learning has yet to be widely adopted by K–12 teachers" (Ertmer & Simons, 2006, p. 41), and research documenting how teachers adopt and implement PBL, especially in a K-12 setting, is limited (Ertmer, 2010; Ertmer & Simons, 2006; Park & Ertmer, 2008).

Pedagogical Beliefs and Facilitation in PBL

Literature has indicated two important factors related to teachers' use of PBL: their pedagogical beliefs and the scaffolding they provide to their students (Ertmer, 2005; Hew & Brush, 2007; Pedersen & Liu, 2003; Windschitl & Sahl, 2002). Ertmer (2005) suggested teachers' pedagogical beliefs play an important role in high-level technology use such as student-centered learning environments like PBL. In a study using the path analysis statistical approach, Inan and Lowther (2010) found a positive correlation between technology integration and teachers' beliefs. When teachers believed in technology integration and student centered instruction, they were more likely to integrate technology (Park & Ertmer, 2008). More specifically, research has shown that teachers who hold a constructivist teaching philosophy make more effective use of technology (Becker, 2000; Becker & Riel, 2000; Park & Ertmer, 2008). Park and Ertmer (2008) found that expert PBL teachers practiced "(1) collaboration with other teachers, (2) engaged students in self-evaluation and reflection on the problem-solving process; and (3) provided students with self-monitoring guidelines" (p. 638).

In PBL, the role of the teacher shifts to facilitating instruction rather than directing instruction. Learning how to be a skillful facilitator and how to "do" PBL are challenging tasks. Teachers often struggle to find equilibrium between being too directive, giving the answer to students, or too hands-off, letting students struggle unproductively. As a facilitator, a teacher's ability to employ various scaffolding techniques is directly related to students' understanding of the learning objectives (Belland, Glazewski, & Richardson, 2008). Successful PBL requires facilitation and scaffolding on the part of the teacher (Brush & Saye, 2000; Marx et al., 1994). Teachers can rely on hard scaffolds that are often embedded within the PBL programs themselves or are paper hand-outs which students can reference. Soft scaffolds are typically provided by teachers. According to Saye and Brush, (2002), soft scaffolds are dynamic and just-in-time guidance teachers provide as they "continuously diagnose the understandings of learners" (p. 82) and hard scaffolds refer to "static supports that can be anticipated and planned in advance based on typical student difficulties with a task" (p. 81). Teachers need to be engaged in students' learning to gauge their progress and provide support for continued success (Xun & Land, 2004). Facilitation often takes on multiple forms and uses both soft and hard scaffolds. The goal of scaffolding is to encourage students to be self-reliant and develop higher order thinking skills to resolve learning challenges on their own.

Given the literature on the educational affordances as well as the challenges of implementing PBL in K-12, the purpose of this study is to examine and document how a group of middle school teachers implemented a technology enriched PBL program. We hope to understand their motivation and implementation techniques and identify factors that the teachers consider important and can contribute to integration of technology-based PBL tools in K-12 teaching. We asked the following research questions:

1. What are the factors teachers consider important in affecting their motivation to adopt and use a technology-based PBL program?
2. How do they implement a PBL program and what techniques do they use?

Method

Participants

Ten sixth-grade science teachers, two males and eight females, participated in this study. These teachers were selected from a pool of teachers who were provided access to the PBL software because they (1) taught at a public school, (2) showed a long-term commitment to using the PBL program (for at least three or more years despite technical difficulties they experienced with the PBL program), and (3) planned to use the PBL program again in the following year. Table 1 provides the demographic information of the five schools and ten

Table 1. Demographics of the participating schools and teachers.

		Teacher demographics		
School	Student ethnicities	Name	Gender	Years[a]
Texas school 1	69% White, 15 % Hispanic, 9% Asian/Pacific Islander, 7% African American, and, <1% American Indian/Alaskan Native	Trish Lauren Ellen	Female Female Female	13 6 5
Texas school 2	64% White, 6% Hispanic, 28% Asian/Pacific Islander, 2% African American, and <1% other	Yolanda Lani Yoko	Female Female Female	20 9 11
Texas school 3	42% White, 37% Hispanic, 4% Asian/Pacific Islander, 17% African American, and <1% other	Ann	Female	12
Pennsylvania school	90.7% White, 2.8% Hispanic, 3% Asian/Pacific Islander, 3.3% African American, and 0.3% American Indian/Alaskan Native	Earl	Male	13
Arizona charter school[b]	97% White, 1 % Hispanic, 1% Asian/Pacific Islander, 0% African American, and 1% American Indian/Alaskan Native	Scott Yvette	Male Female	6 3

[a]Years teaching experience in middle schools.
[b]Charter schools are public schools under the jurisdiction of the state education agency.

teacher participants. The teachers who participated in this study represented a spectrum of teaching experience. All teachers were familiar with basic computer operations such as word processing and searching the Internet. The student populations in these ten teachers' classrooms included talented and gifted (TAG) students, regular education students (RegEd), English as a Second language (ESL)/English Language Learners (ELL) students, and students with Section 504 learning accommodations and those with special needs. Having access to this group of teachers, who have prior experience with the program and plan to continue its integration, presented us an opportunity to examine their experiences in-depth with the PBL program (as described below).

Research Context

The teachers implemented a technology enriched PBL program for sixth-grade science, *Alien Rescue* (Liu, Williams, & Pedersen, 2002). The goal of the program is to engage students in solving a complex problem that requires them to gain specific knowledge about our solar system and the tools and procedures scientists use to study it. The PBL program begins with a science fiction premise: A group of six alien species, each with different characteristics, has arrived in Earth orbit because of an explosion in their home planets.

Students become scientists and their mission is to find new home planets for these aliens which can support their life forms and prevent them from dying. To identify a suitable home planet for the aliens, students must engage in a variety of problem-solving activities. They need to research the aliens' requirements for life and discover the physical characteristics of the planets and moons in our solar system. Students must also engage in planning and decision-making as they determine how to use the provided resources effectively. The software is designed as a science curriculum unit for approximately fifteen, 50-minute class sessions. To support students' problem solving, a set of fourteen hard scaffolds, in the form of cognitive tools are provided in the software (Liu, Horton, Toprac, & Yuen, 2011). These tools aim at (a) sharing cognitive load, (b) supporting cognitive processes, (c) supporting cognitive activities that would otherwise be out of reach, and (d) supporting hypothesis generation and testing (Lajoie, 1993). It is up to the students to decide how to use these tools. More information about the program is available at http://alienrescue.edb.utexas.edu.

In this study, nine teachers used the program in their daily science classes for three weeks and one teacher used it for two weeks. About 50% of the participating classes worked in a computer lab setting, while the other 50% of the participating classes used laptop computers in their science classrooms. In 80% of classes, each student had access to his or her own computer even when they worked in groups. In 20% of the classes, two to three students shared one computer.

Data Sources and Analysis

To address the research questions, a qualitative method was used with multiple data sources: (1) interviews with teachers, (2) classroom observations, and (3) researchers' reflexive journals for the purpose of triangulation (Creswell, 2009). Semi-structured interviews were conducted with each teacher after they completed the curriculum unit. Interviews with Texas teachers were conducted face-to-face while phone interviews were conducted with the out-of-state teachers from Arizona and Pennsylvania. All interviews were recorded and transcribed. Interview questions sought to understand teachers' experience in implementing the PBL tool. Questions addressed (1) background information, (2) teachers' experience with the PBL program, (3) students' experience with the PBL program, (4) school setting, and (5) follow-up questions (see Appendix A). Prior to the interviews, the questions were emailed to the teachers. The researchers followed a semi-structured interview protocol. During the interview, the teachers used the questions as a guide to discuss their teaching philosophies and practices. They were free to respond in any way they wanted, to elaborate, or to omit any questions as they wished. As necessary, the researchers asked follow-up questions. All interviews were approximately one hour long except for one that lasted 30 minutes due to the teacher's schedule.

To understand teachers' implementation techniques, the researchers observed classroom practices and student interactions in the classrooms of all seven Texas teachers. Observations in out-of-state schools were not feasible due to financial constraints. Each classroom was observed on three separate occasions (beginning, middle, and end of the PBL program). The researchers used two observation techniques: an observational chart (see Appendix B) and observational notes. Developed from prior research (Rowland, 2008), the observational chart was structured to focus on three aspects of the classroom activity: 1) student groupings (e.g. students working individually, in small groups, as a whole class or as a combination); 2) teacher behavior (e.g. lecturing, leading discussion, asking and answering questions), and 3) students' behavior (e.g. listening, note-taking, off task). To capture snapshots of classroom activities in a systematic manner, researchers alternated their observation techniques every five minutes for the entire class period. In the first five minutes, the researcher used the observational chart, checking off the activities she saw. The observational chart provided frequency data of classroom activities. For the next five minutes, the researcher wrote observational notes about what was happening in the class. These notes provided rich contextual descriptions of classroom activities. To ensure data reliability and observational consistency, all researchers performed the first two observations together and discussed their recorded notes to develop a common understanding of what to observe and how to record. The observation chart was revised to ensure expediency and clarity in recording what was observed. Then two researchers observed each teacher, compared their observations, discussed what went on in the classroom, and resolved any discrepancies. More than twenty-seven hours of observation were documented. In addition, each researcher kept a reflexive journal recording additional thoughts and questions.

The transcribed interviews were coded and categorized following the guidelines established by Miles and Huberman (1994). A multiple-level scheme was used. At an initial level, as a group, the researchers read one-third of the interview transcripts to get a sense of the data and generated a list of codes reflecting the data. Keeping the research questions in the forefront, the codes were reviewed and refined to make them more specific and consistent. Using this list of codes agreed upon by the researchers, the rest of the interviews were individually coded by each researcher and checked by a second researcher. During the coding process, the researchers constantly compared data, codes, categories, and themes (Creswell, 2009), and discussed and resolved any disagreements until the inter-rater reliability among the two coders reached 100%. Patterns from the data were extracted, and the relationships between coded segments were examined. Observation notes and researchers' reflexive journals were also compiled and analyzed using the same method. Descriptive statistics were calculated for part of the observation data. Interview and observation data were used as primary sources and researchers' reflexive journals were used as a supplementary data source. During the classroom observation and data collection process, researchers met regularly to discuss what they observed in different classrooms, shared insights, and performed peer debriefing.

Results

Findings: Factors Affecting Teachers' Motivations to Adopt and Use Technology-Based PBL

Our analyses identified four factors that affected teachers' motivation in adopting the PBL approach and, specifically, selecting *Alien Rescue* as a teaching tool. These factors are (1) the PBL program addresses the teachers' curricular needs and implementing it has campus administrative and technical support, (2) the method is aligned with teachers' pedagogical beliefs, (3) the PBL program offers a new way of teaching and promotes the development of problem-solving skills, and (4) the PBL program challenges students in a captivating manner and supports the learning needs of all students.

Addressing teachers' curricular needs and having campus administrative and technical support. This factor relates to the school environment, the context in which PBL implementation occurs. All participating teachers emphasized that for them to consider adopting technology-based instructional materials, the tools must address curriculum standards and meet teachers' curriculum needs. The fact that the program addresses

National Science Standards and aligns closely with Texas Essential Knowledge and Skills (TEKS) was a critical factor for the teachers as they considered their teaching materials. Mrs. Ellen stated, "AR [*Alien Rescue*] covers the TEKS in the sixth grade and we use it to teach the solar system TEKS." Mrs. Ann commented, "This covers almost everything I am required to teach my students so I would like to use it however I can." Mr. Earl elaborated on his decision to adopt the PBL program, saying, "We do one or two projects each semester and those grades are authentic grades, they're not just tests and quizzes. So the program is used as an authentic assessment for the earth and space and science course." Although these teachers were from different states, they mentioned the requirement of close alignment between the PBL program and the state curricular standards they must address, as well as the opportunities it offers to present instruction in an authentic way.

Having campus leaders who encouraged and supported teachers to be innovative and then empowered them to make curriculum-related decisions played an important role. Campus administration encouraged these participating teachers to identify and incorporate unique instructional approaches for delivering curriculum and fulfilling state-mandated objectives. Mr. Scott described how he decided to adopt the PBL program and used it to anchor his students' thematic unit for the semester:

> The center of our educational method is called an expedition which is an interdisciplinary, usually a semester long, learning expedition. We try and plan all of the education around a particularly compelling theme or topic . . . This semester the expedition is on astronomy and origin stories. . . And the science portion is on astrobiology, basic force and motion and astronomy . . . So that's where the software came into play.

Implementation of a technology-based tool requires access to technology resources. Each participating school had a computer lab or mobile computer cart with laptops, and teachers in Texas also had access to a technology specialist who shared his/her responsibilities across several schools. Although these teachers had access to computers, technical resources were not abundant and had to be shared by all grades and all teachers on one campus. The fact that the use of the software requires computer access for 15 consecutive days presented a challenge. Many participating teachers reserved computers at the beginning of the school year; this proactive teaching required advanced planning and a firm commitment to this teaching strategy. The implementation of this technology-based PBL program also required collaboration between teachers and technology specialists to address technical issues which may develop during the project.

Some schools considered integrating the software, but were concerned about their programmed daily schedules and preparation for various school, district, and state-level testing. Other schools had teachers who used it for a year or two, but decided not to continue because of school and/or district-wide decisions to follow a prescribed curriculum that left teachers little freedom to innovate new pedagogies.

Teachers' pedagogical beliefs. The student-centered learning approach used in the PBL program appeared to align well with these teachers' pedagogical beliefs. It offered opportunities where students were "doing their own discovery, doing their own research, they're drawing their own conclusions" according to Mr. Earl. Mrs. Ann pointed out: "I like the kids being responsible for their own learning." In teachers' views, students were provided an opportunity to pursue active and independent learning with the PBL program. Table 2 provides representative quotes of teachers' pedagogical beliefs reflecting their hopes to create student-centered environments through the implementation of the PBL program.

These teachers hold a constructivist pedagogical philosophy and are committed to this "messy" and chaotic teaching method. Stepping aside to become learning facilitators, the teachers scaffolded students' learning in non-directive ways. These teachers had confidence that problem-based learning was an effective teaching method and would prepare students for the state science assessment.

Offering a new way of teaching and promoting higher-order thinking skills (HOTS). This factor relates to teachers' desire of how they want to teach. All participating teachers discussed their motivation to incorporate engaging ways to help their students learn. Mrs. Yvette, who sought out the developers of the software, spent a significant amount of time evaluating the program before deciding to adopt it, stated: "I try to use creative ways to get my students to learn and feel that this software will be a big help." To the participating teachers, the program offered an innovative way, different from the standard textbook and lectures, to teach students about our solar system. They appreciated the multimedia elements within the program, which presents science content in an engaging way. Mrs. Yolanda said,

> The kids love it. It is just a different way to present the material. At this point, we are doing this every year. It's kind of nice for the kids to break away from other material and from the way we've done other stuff. It's nice to get a different format.

The problem-based approach presents sixth-graders with the type of vague problems scientists regularly encounter. Instead of working on worksheets, students are challenged to simulate the work of scientists to solve a complex problem. "The traditional way of teaching this unit would not provide them with a problem solving situation in which they follow the steps of the scientific method to solve," commented Mrs. Ellen. Mrs. Ann put it,

> I think that they'll learn more knowledge on the different planets and moons and I also think they learn problem solving strategies whereas for me when I

Table 2. Teachers' pedagogical beliefs.

Characteristics [a]	Representative quotes
Students control their own learning, and teachers as a guide	Students become the controllers of their learning and I tend to become more of a mentor than a leader. It allows me more time to support less able students while still challenging the more capable. (Mrs. Yvette) I have more of a student centered classroom. With this AR program, definitely, I like it a lot, because you are able to just kind of blend in with the kids and they really run with the information. (Mrs. Yoko) In fact they are at the beginning kind of mad at me. Because I will tell them at the beginning, you know, that we are going to find out information about magnetic field or temperature scale, and I am not going to tell you, someone in the room is probably gonna find it and when they do, we will have them share that with the whole class, but until then you are on your own. (Mrs. Yolanda)
Purposeful, meaningful, and discovery learning	It makes learning relevant as they have a reason to acquire the knowledge and then build on it to reach conclusions. (Mrs. Lauren) I would recommend that they [other teachers] use AR and they will become more comfortable with the discovery method of learning which AR uses. (Mrs. Trish) [I believe my role is to] Facilitate independent learning, being a role model, and create an environment where learning can occur. (Mrs. Ellen)
Collaborative learning	And it is kind of nice that they are forced to ask their peers. It is really fun, 'cause once they start it and see how it works, when somebody does discover something, [pretending students voice:] "ahh, I found where you can find the spectrum or how it works or whatever," and you will have them stand up and say, tell us what you found and they will share that with the whole class and then the whole class finds it. And then everybody is back on track and then helps everybody. (Mrs. Lani) We try to follow a constructivist approach in terms of students, social constructivism, students forming their meaning and learning together with their peers. (Mr. Scott)

[a] These are the characteristics of student centered pedagogy identified by teachers.

> teach them it would basically be the planets and moons and not necessarily a problem solving strategy or how to work out this problem so they're getting a little bit more than what they would probably get from my thing.

Students' performance is assessed by the justification of their solution to the problem, as well as their understanding of related science concepts. By working through the program, the students became immersed in an environment where they must acquire state-mandated science concepts, as well as use reading and writing skills to solve the problem. Although a set of cognitive tools (i.e. hard scaffolds) is provided in the program to assist problem solving (Liu et al., 2009), students must decide which cognitive tools to use, how to use them, and when to use them. The analysis also showed that because the software program provides many hard scaffolds (e.g., aiming at lowering cognitive load and supporting cognitive processes such as multimedia databases and a notebook tool), teachers can make best use of their time to address students' specific needs and promote higher-order thinking skills. Table 3 shows various ways teachers took advantage of the features in the program to scaffold students' higher-order thinking.

A common theme in these examples of higher order thinking activities is a multi-stepped process which results in the creation of a learning artifact. In several of the examples, the students made wrong decisions, which they self-identified and worked to correct. The ill-defined nature of the problem requires students to use collaboration, creativity, communication, and critical thinking skills, in tandem, to move towards developing a solution.

Challenging students in a captivating manner and supporting the learning needs of all students. This factor reveals the importance of adaptability of a PBL program and teachers' desire that students with different ability levels could participate and benefit from using it. The ability levels of the student populations in these classrooms were diverse. Mrs. Lani stated, **"**What I like about, the best things I like about it, it fits so many different kids, it can be so challenging and set a high bar, it can include so many kids that are low level; they are interested in it because it's sort of like a video game." Others provided additional examples of differentiated learning. For example, Mrs. Ellen stated, "I often see many of my students who don't shine during the year really find their niche using *Alien Rescue*," and Mr. Earl said, "It always surprises me that some students who struggle in learning science in a more traditional class setting really catch on to AR and do well."

The findings of this study also showed that teachers were motivated to use the program because their students enjoyed using it. Students liked the program because of its multimedia-rich, interactive, and game-like qualities. Teachers found students liked the program and thus were more engaged in the learning process. The following are a few examples of how teachers described their students' reaction during PBL instruction:

> The students love it and are very engaged in it and it is a good way to teach the solar system and space science. (Mrs. Trish)

> The interactiveness of it. It's sort of like playing a game. The students really love it and have fun. (Mrs. Lani)

> Students love trying to figure out where everything is and how it works, the problem solving aspect of it is really keeping them engaged. (Mrs. Yoko)

Table 3. Examples of promoting HOTS.

Representative quotes	Scaffolding practices
I had groups of students working on different aliens and each student had one alien they had to find a home for. For their presentation, they had to tell us about the body of the alien, what needs they had, what type of surfaces they had to live on . . . they told the class about what probes they created and why . . .	Grouping students on how many alien species they needed to find a home for and requiring students to share their findings on various characteristics of each species created a collaborative situation where each student was responsible for finding a piece of the puzzle while holding shared responsibilities towards each other.
I love the part about the probe where they actually had to use [scientific] tools; a lot of the kids created probes that used inappropriate instruments . . . and then they were shocked that it wouldn't work because they didn't take the time to scroll down and read through the entire thing. So, that was really good. One of the parts of the presentation I asked them to explain if they wasted any money during the process and there were a lot of kids. It was good for them because it made them realize, they had to really think ahead to do these things.	The probes were hard scaffolding tools to allow students to gather more scientific data. Probe malfunctions could occur if protocol was not followed. When malfunctions occurred, students were asked to review and explain their design decisions. Students had to consider budget constraints.
The biggest thing was the [students'] motivation and because it [AR] took the information and made them [students] use the information in a way that gave them a reason to use it. That was the whole thing. It wasn't just learning it for the sake of learning it; they were learning the information so that they could solve the problem. So it was a problem-solving activity and my kids usually respond very favorably to that.	The problem was complex and required research. The problem solving process was iterative, requiring numerous smaller solutions for the final solution. This authentic structure motivated students.
I did have some kids not picking the correct location but that again at least they had reasons for the locations they picked and tried to defend those as far as unsuccessful results. They still got something out of the program.	Errors or failed attempts were deconstructed to become learning opportunities during the complex problem-solving process.

Table 3 (cont.). Examples of Promoting HOTS

I liked that fact that they [students] had to figure out the alien computer [alien database] and the fact that the kids were motivated to research, which a lot of times, in a regular classroom, you don't see that, you don't see them with that goal, we have to try to do this, we have to get aliens a home. That's what I liked about it, I also liked the fact it tied so many things together, not only about the planets, there's so much you had to take into consideration.	The embedded research resources (e.g. databases, reference charts, notebook, probe designing and launching, scientific instruments), provides a data-rich environment from which students collected data to solve the problem.
I put them in teams of two and I chose the teams and students were initially disappointed that they didn't get to work with their friends. The work they did together was really surprising. I think the structure of the process of having to do the research, take notes, and but all the while knowing what they were looking to do helped them work together in a productive and open-minded way.	The nature of the complex, scientific problem required group work, collaborative research, and communication and interpersonal skills.
. . . There were some surprises and some students who are typical underachievers and get distracted easily and I would pair them with somebody who is less distracted. Those teams did really well and one team in particular did very well. One kid who sees class as free work time during class, worked on AR when his partner was gone, he was still engaged and doing great work with sending out probes; that was a great success for me to see some of these kids who are typically not engaged being engaged both with one another and their partners and the self directed, self-paced learning.	The embedded tools (e.g. sending probes) motivated underachievers to engage in the project and develop confidence to continue researching and learning.

The findings indicate that some students showed a more favorable attitude toward science as a result of their experience in using the program and that their fondness lasted beyond the three-weeks they used it. Seventh and eighth graders remembered the fun times working on the project during their sixth grade. For example,

> When I see 7th and 8th graders in the hall and I tell them that we are doing AR. They say, "Oh, I remember doing that. It was fun!" (Mrs. Trish)

> [I asked] if they remember one thing [of their activities] and I actually had kids last year recall what they remembered the most and 75% said *Alien Rescue*. (Mrs. Ann)

Some students looked forward to going to science class so that they could work on their project and other, less engaged students, found a new appreciation for science as a discipline. Ms. Yoko shared with us, "Some [students] said, 'I cannot wait to get to science.'" Mr. Scott commented, "One of my favorites was a comment at the beginning, by a student who is typically disruptive during any kind of group work or . . . she said to me on day 2 [of using the program], 'I am so mad at you, you're making me like science.' That was a great comment" (Mr. Scott).

Parents and future students showed admiration for the type of learning experiences offered at the campuses. According to Mrs. Ann, parents would ask her at the open house, "Well, I heard about this science program . . . " and the 5th graders coming to visit middle schools see 6^{th} graders working on the program and get excited and ask, "When are we going to do that?"

Having identified the factors teachers consider important in affecting their motivation to adopt and use a technology-based PBL program, we proceed to address our second research question: how teachers implemented the PBL program and the techniques they used.

Findings: Teachers' Implementation Techniques in Using PBL

Our classroom observations showed that teachers spent a significant amount of time facilitating students' learning (Brush & Saye, 2000). Observed facilitation techniques included asking questions (without providing direct instruction and/or answers to students' questions), answering questions with questions, guiding students to use the computer-based scaffolding tools, or encouraging students to seek help from others. Furthermore, teachers created a classroom environment where collaborative interactions were promoted. In the process of learning, students were engaged in their project by working with their peers, seeking guidance from their teacher, and interacting with the computer program. We observed that students were actively constructing their understanding of the science content.

To document these implementation techniques, we describe and present our observations in two different ways. Our first description is a compilation of all seven teachers whose classrooms we observed. This description is structured to describe the role of the teacher, classroom interactions, and the role of the student. In the second description, we present contrasting narratives of two pairs of teachers. These two pairs of teachers were selected because they illustrated different implementation techniques, the first pair while teaching in classrooms with similar student population and the second pair while teaching different student populations. We hope these in-depth descriptions and comparisons will describe the fine art of PBL facilitation (Ertmer, 2010; Ward & Lee, 2002), and offer insights and ideas to both novice and experienced teachers interested in implementing a complex technology-based learning environment such as PBL while dealing with challenges and constraints often found in public K-12 education.

Profiles of All Participating Teachers' Implementations

Teacher's role. The participating teachers received similar professional development prior to using the PBL program. The professional development included a workshop and teacher's manual. Despite the commonality of preparation, teachers used different implementation techniques. The teachers all described that their role was that of a facilitator and that they used the practices that they believed would best meet their students' needs. Mrs. Ellen described her facilitation responsibilities as, "facilitate independent learning, being a role model, and create an environment where learning can occur."

Our classroom observations showed that lecturing represented a small amount of time, 8% (see Table 4). Instead, these teachers spent a significant amount of time using techniques to scaffold students' learning by asking and answering questions, encouraging students to seek help from each other and sharing, providing limited direct answers, redirecting students' questions to the PBL program, group or whole class, and encouraging discussions at different levels. Ms. Yoko described a specific situation she encountered,

> I have to remind them to share information and that you can't just be in your own little world. Some of the students are like, yeah, I have researched my part and am done, but I have to tell them, if you know someone in your team is not finished, you need to help them and share the information.

Some teachers began their day with a whole class session followed by students working at the computer. Others started their day with students working in groups and then ended their day with a whole-class session. Students spent the vast majority of class time working independently with the computer and collaborating with their groups. When students needed guidance, some teachers asked probing question, while others directed peers to address questions. During class time, teachers monitored progress by moving from group to group while others remained at their own desks and were available for questions. Ms. Yolanda described her physical presence:

> It is also one of those things when you have to be really on your toes, 'cause you let them be on their own, you got to make sure they are getting it done. Majority of our kids are self-motivated and self-disciplined and will get done what we asked them to do, but there are going to be one or two sitting in the back of the room, pretending they are working on the computer, you have to spot check to make sure they are on it.

Classroom interactions. Our observation data showed that working in groups comprised the largest portion of classroom time and that collaboration occurred both as a whole class and in small groups (see Table 4). Collaboration is a key element in PBL, yet it is not always easy to implement in a K-12 classroom (Hmelo-Silver, 2004). We observed that through the use of the program, group work was encouraged and promoted. The interview data showed that teachers were successful in initiating collaborative learning among students. In responding to our question, "How and to what extent were students able to collaborate effectively with their peers?" Mrs. Trish answered, "Very effectively. They were willing to listen to each other and discussed differences of opinion using evidence in their arguments." Mrs. Yolanda stated, "The kids work together and solve their own

Table 4. Classroom activities of observed teachers and two pairs of selected teachers.

		Trish	Lauren	Yolanda	Ann	All[a]
Classroom interactions	Whole class	29%	24%	16%	14%	19%
	Small group (heterogeneous)	12%	33%	37%	86%	37%
	Individuals (working at computer)	53%	24%	24%	0%	15%
	Whole class with individuals	6%	0%	0%	0%	4%
	Small group with individuals	0%	19%	23%	0%	15%
	Whole class with small group	0%	0%	0%	0%	6%
	Whole class +small group + individuals	0%	0%	0%	0%	4%
Teacher Role	Lecturing (including giving directions)	14%	5%	10%	8%	8%
	Leading discussion (e.g. asking open-ended questions)	5%	5%	8%	0%	3%
	Listening/watching	0%	9%	33%	36%	22%
	Demonstrating (e.g. how to use the tool)	5%	0%	6%	0%	3%
	Soft Scaffolding[b]	52%	48%	31%	39%	52%
	Other[c]	24%	33%	12%	17%	12%
Students' Role	Helping each other					18%
	Listening/note-taking					22%
	Asking and answering questions/ discussing					48%
	Other[c]					9%

[a]All represents seven Texas teachers who were observed in the classroom.
[b]Soft scaffolding includes asking questions (often without providing direct instruction), answering questions (often with questions), encouraging students to seek help from others, guiding students to embedded reference materials and cognitive tools within Alien Rescue, discussing with individuals/groups.
[c]Examples of "Other" including housekeeping, logging in and out of computers, checking homework, moving to computer/science lab, distributing/collecting folders.

problems. I step in to clarify and help with research." Other teachers used the program as an opportunity for sixth-graders to learn to work together. For example, Mrs. Ann said, "I like for my students to learn to collaborate and work in groups or teams for lab activities. AR is perfect for this type of teamwork."

The availability of computer resources was different at each school. In the 2-pair highlighted cases (as described below), we saw four different hardware configurations. These configurations affected the classroom setup, as well as the student-student and teacher-student interactions. Students in Mrs. Trish's class went to a traditional computer lab to use the PBL software, where desktop computers were placed around the perimeter of the room. Students' collaboration was limited to neighbors on either side. Collaboration beyond the immediate proximity required that students leave their assigned work station and walk to another part of the classroom. Mrs. Trish could easily see student monitors and thus informally assess student progress in the program.

Mrs. Lauren's students remained in their classroom and used laptops from a laptop cart. Since students remained in their own classroom, they had access to all the other reference materials and note-taking materials commonly used throughout the year. A 17-inch diameter laptop was assigned to each student pair (2 students per laptop). Students sat at tables designed for 2 students. Because students were sharing a laptop, there were more opportunities for collaboration throughout the project. When students needed Mrs. Lauren's input, they brought the laptop to her and were able to collaborate at her desk. Students were observed working at their desks, as well as on the floor in many different student groupings. Students often took their laptops to other groups for collaboration. These groups were dynamic with membership changing based on their progress in the program and the type of questions a student needed help with.

Mrs. Yolanda's students remained in their classroom and each student received a laptop from a laptop cart. Each group of four to six students sat at large, round tables. Students worked independently while collaborating with the group members sitting at their table. Mrs. Yolanda circulated between groups to monitor project progress. Meeting in a large science laboratory, students in Mrs. Ann's class worked in pairs with one laptop per pair. They sat at long work tables designed to seat two students. Collaboration for each pair was designed into the project by assigning one laptop per pair and requiring that each pair, rather than each student, recommend one solution for the problem presented in the program. When students needed help from Mrs. Ann, they brought their laptop to her desk.

Students' roles. Students were actively engaged in using learning materials to construct their solution to the complex central problem. We observed students actively asking questions, answering others' questions, discussing among the group members, referencing databases and other instructional materials, and helping each other. In describing the students' roles in the classrooms, Mrs. Yoko stated,

> The students help each other and discuss the aliens' needs, aspects of the planets and moons as they discover these. Some catch on much quicker and I encourage these students to help the others on their team and share information and especially how to design probes.

Mrs. Lani commented:

> The students have to collaborate because we divide up the jobs. Or you know, they divide them up, so if they are all researching different aliens and planets, they have to come together with the information and share that information with each other. If they are not sharing it, there is no way they can solve the problem. So, they are forced into it.

The way students collaborated was affected by the hardware they were using and the group assignments. Students could only easily collaborate with their neighbors when working in a computer lab where the workstations were arranged around the perimeter of the room. Students who worked with laptops were able to bring their laptop with them as they sought to collaborate with others. Students working in pairs often sought others student pairs because they needed more collaboration than they could obtain from just their partner. Students working in groups of four to six often remained in their groups because there was sufficient collaboration within the group.

Having discussed the implementation techniques by all teachers, in the following we present contrasting narratives of two selected pairs of teachers.

Profiles of Two Pairs' Contrasting Scenarios

The first pair of teachers, Mrs. Trish and Mrs. Lauren, are highlighted because of the differences in their implementation techniques while teaching a homogeneous student population in the same school. The second pair of teachers, Mrs. Yolanda and Mrs. Ann, teach in the same district but at different schools with quite different student demographics. Implementing a technology-based PBL is not only a complex but also intricate task. By providing these detailed descriptions, we hope to offer a glimpse of how these teachers adapt the tool to fit their teaching goals while meeting their students' needs.

Mrs. Trish and Mrs. Lauren. Mrs. Trish and Mrs. Lauren taught at the same school, were experienced middle school teachers, and each had four sections of 30-student regular education classes. The 6th grade science team at their school conducted team-planning and developed a sequence of lesson plans. The team has used the software for three years. Although both teachers valued student-centered curricula and taught similar groups of students, mainly regular education group, their facilitation techniques were different.

A Day in Mrs. Trish's class. In Mrs. Trish's class, we observed lecturing and whole class interaction with individual facilitation (see Table 4). In each session, Mrs. Trish typically used her lectures to form the base for her students to begin their research. The lectures often included reviews of important science concepts, directions to students, or sharing of information about current issues in space exploration. Mrs. Trish's lectures were followed by students working at his/her computer while Mrs. Trish circulated among students. Mrs. Trish taught in the computer lab where each student sat at a workstation which was arranged in a U-shape along the perimeter of the lab.

In interacting with her students, Mrs. Trish provided individualized instructions, answered students' questions, and clarified misconceptions. Often, three to four students had raised hands and were waiting for Mrs. Trish. During these one-on-one interactions, Mrs. Trish used a variety of methods to answer students' questions. At times, she asked probing questions or responded to questions with questions while other times she provided a more straightforward answer so that the student could continue his/her progress. Scaffolding represented 52% of Mrs. Trish's time during the class period. Teacher-student interaction was high. Mrs. Trish described her teaching experience as, "Participation is generally good. Some students, especially reluctant readers, lose their focus and attention especially in writing notes and keeping track of the characteristics of the aliens, planets, and moons. These students have to be helped along to refocus."

Student-to-student interaction was relatively restricted in Mrs. Trish's classroom, as compared to Mrs. Lauren's classrooms (see discussion below). Because Mrs. Trish's students were accustomed to working in a more structured environment, Mrs. Trish had to teach collaborative techniques to her students and encourage their collaboration when using the PBL program. She said, "Most students collaborated with their peers. Other students do not like to work with others and prefer to work alone the entire time and I have to ask them to share help or share with their team." Student collaboration was further limited by the physical layout of the computer lab. Students sat at individual computers arranged around the perimeter of the room. Students could easily talk to the students on their right or left, but venturing any further would have been disruptive to the classroom. Each student was asked to find homes for two aliens, and there was no explicit instruction to share their results with their classmates.

A Day in Mrs. Lauren's Class. Mrs. Lauren worked mainly with groups, which represented over 50% of her interactions with students. When Mrs. Lauren provided scaffolded instruction, it was structured to involve the small group. For example, one student asked Mrs. Lauren a question; she walked with the student to his group and coached the group to develop an answer. On another occasion, a student asked a question, and she moved to the group and responded to them with a question, "have you asked each other, have you checked the AR databases, have you checked your notes?" While this is a non-answer, it forced the students to become self-directed and utilize embedded resources within the program to find the answer themselves.

Mrs. Lauren taught in her classroom where students with their laptops sat at two-student tables aligned in rows. Most groups in Mrs. Lauren's classes were able to work without extensive or sustained interaction with Mrs. Lauren. Mrs. Lauren spent most of her time observing groups, working at her computer, submitting several repair orders, and for a brief period of time, meeting with another teacher. Students primarily interacted with their group members and with the program. Her classroom was highly animated; it was noisy and students moved around within their groups and between groups. Students checked with each other at every phase of the program, discussing their findings and looking at each other's screens. Often, students would walk to another group and ask what the group had discovered. Two groups of students, feeling that the desks were physical barriers, moved themselves and their laptops to the floor. They sat in a circle to facilitate their collaborative efforts. Using laptops also made moving around easier. In addition, Mrs. Lauren's students were assigned roles within their group: a project manager, a probe designer, and a communication specialist. Each job had unique responsibilities. On several occasions, Mrs. Lauren taught a skill to the job holder and the student was then responsible for teaching the other members in his/her group.

The majority of students stayed on task, but there was one group of boys who vacillated between being on- and off-task. Mrs. Lauren did not intervene. She seemed to have confidence that the group would self-correct and complete the work. The fact that *Alien Rescue* allows students to work at different speeds allowed students to engage in off-task behavior and still complete the project successfully.

Both Mrs. Trish and Mrs. Lauren provided guidance for student's learning by creating small and manageable learning goals. Table 5 presents a comparison of techniques we observed in Mrs. Trish and Mrs. Lauren's classrooms. Mrs. Trish worked primarily with individual students, assessing what he/she needed and providing individualized instruction. Her approach was more directive and perhaps more efficient with the limited class time. Mrs. Lauren, on the other hand, asked lots of questions, intervened less, and took the risk that students might deviate from the program as they searched for answers. At the end of the project, students in both classrooms found solutions to the aliens' problems and learned the science concepts while collaborating with their classmates.

By definition, problem-based learning is student-centered and driven by the students. Teachers often struggle with determining their level of control. In the pair examples of Mrs. Trish and Mrs. Lauren, we demonstrate that a problem-based learning activity can be successful with high level of teacher control, as in Mrs. Trish's case, as well as a low level of teacher control, as in Mrs. Lauren's case, given teachers' preferred way of teaching to meet their students' needs.

Mrs. Yolanda and Mrs. Ann. Mrs. Yolanda and Mrs. Ann were among the first group of teachers to pilot the software in their classrooms (about seven years ago) and they have

Table 5. Implementation techniques observed in Mrs. Trish's and Mrs. Lauren's classrooms.

Factors	Mrs. Trish	Mrs. Lauren
Group composition	Groups assigned by teacher, mainly by gender, one or two groups were mixed gender	Groups assigned by teacher, mainly by ability to work together.
Student-teacher interaction	Students raised hands and waited for teacher's attention	Students approached teacher's desk, sometimes with computer.
Teacher-student interaction	Teacher answered student questions with guidance, questions, and sometimes facts	Teacher typically answered student questions with questions prompting students to recall prior learned content. At times, students referred to his/her group.
Student-student interaction	Different levels of interaction. Most students worked independently and, at times, shared their findings with group members. One group of boys was especially collaborative, but other groups were more controlled in their interactions.	Students were constantly sharing information, looking at other's screens, worksheets, etc. Students helped each other and often explained scientific concepts to each other (students teaching students).
Activity level of students	Students remained mainly at their workstations working on the AR project.	Students mainly worked at desks with laptops but could freely walk around room to look at the work of other groups. Two groups moved themselves and laptops to the floor to work together.
Activity level of teacher	Constantly moving around; typically 3-4 hands were raised waiting for teacher attention	Casually moved around the classroom observing students' work; at times at her desk observing or working at her computer.
Noise Level	Quiet classroom	Noisy, lots of on-task talking.
Off-task behavior	Very little. Off-task behavior involved sitting quietly at work station doing nothing.	Groups moved from off-task to on-task without teacher intervention; teacher accepted off-task behavior and waited for students to self-correct and begin working on project. Off-task behavior involved students socializing.

continued to use the program as part of their science curriculum every year. They taught in the same school district but at two different schools with differing demographics. Table 6 delineates these school differences.

The observations of these two teachers' classrooms showed that while both teachers implemented the PBL program differently to address their students' needs, they each succeeded in using the program to achieve the curriculum goals. In their interviews, both emphasized that they liked using the program because of its focus on student-centered learning and developing problem-solving skills. Collaboration was an important technique both teachers encouraged through their use of the program.

The following descriptions of a typical day in these teachers' classrooms revealed key differences in the classroom environment and the teachers' approaches.

A day in Mrs. Yolanda's class. The physical arrangement of Mrs. Yolanda's classroom was well suited to the collaborative small-group approach she used for implementation. Each group of four to six students sat at large round table. Each student had a laptop.

Prior to starting work with the program, Mrs. Yolanda explained that each student had an individual goal of finding a home for one alien in addition to a group goal of finding homes for all six aliens. To encourage collaboration, Mrs. Yolanda recommended that students share all their findings so that they could achieve their group goal. Once students had finished researching the aliens and habitats, she had a class workday during which groups shared their research results with each other. The emphasis on collaboration extended to student grades. All group members shared the same grade that Mrs. Yolanda assigned based on her evaluation of the group folder that each group turned in. Students also earned grades for individual assignments as indicated in each group member's worksheets and research results.

A typical day in Mrs. Yolanda's class began with a short lecture reviewing the previous day's lesson and outlining the objectives for the current class period. After this lecture, students worked with their groups.

As students worked on the software, Mrs. Yolanda facilitated by visiting each group, observing students, and addressing questions. When students discovered a new concept

Table 6. Comparisons of schools, Mrs. Yolanda and Mrs. Ann.

Demographics	Mrs. Yolanda	Mrs. Ann
Passed State standardized tests of math and reading	98% of student body	84% of student body
Economically disadvantaged	6%	38%
At-risk classification	11%	39%
Special Education classification	8%	11%
Laptops per student	1 per student	1 per 2 students

in the program, she stopped the class and asked the student to explain what s/he found. Although students worked individually on their own computer, collaboration was evident by continuous group conversations at their own tables.

Shortly before the end of class, students began their closing activities: turn-in folders, return laptops, and prepare for review. Mrs. Yolanda then reviewed the day's activities with the whole class and outlined the next day's class objectives.

A day in Mrs. Ann's class. Mrs. Ann's students met in a large science laboratory where they sat in pairs at long work tables. Each student pair shared a laptop. While Mrs. Ann allowed students to pick their partners, she off-set the potential for distractions and off-task behavior by providing a set of instructions for the student pairs to follow. Each student pair had a folder that included worksheets and a timeline of activities. The folder also contained written information to guide students through the program.

Each student pair's goal was to find a planet for one alien. If there was time, they could place other aliens for extra credit. Mrs. Ann provided a checklist to each group and used it to ensure that students had completed the research needed for the next stage of problem solving. As students worked through the program, Mrs. Ann had several checkpoint days when she checked each pair's progress and assigned grades to ensure students were making adequate progress.

Mrs. Ann mostly monitored students from her desk. Students approached her as questions developed; most often, she referred students to the information and instructions contained in their folder. While her approach appeared to be relatively hands-off, she facilitated student-centered learning by encouraging students to reference the information they already possessed.

On a typical day, students entered Mrs. Ann's classroom and checked the daily objectives on the whiteboard. They got their folders, laptops, and started working on the program. During class, Mrs. Ann called student pairs to her desk to review and record their progress and provide individual instructions and direction if needed. Mrs. Ann also periodically redirected off-task students. Students spent almost the entire class period working on the program.

Although both Mrs. Yolanda and Mrs. Ann emphasized collaboration, a key difference was group size and assignment. Mrs. Yolanda's class worked in groups of four to six, and she selected and assigned the groups. The students in Mrs. Ann's class worked in pairs and selected their own partners. The observation data indicated the group members (either pairs or groups of 4-6) seemed to collaborate well within their groups. Although the group size in Mrs. Yolanda's class was larger than recommended by the developers of the program, Mrs. Yolanda indicated her students had prior group experience and were prepared for collaboration. In her case, groups of four to six seemed to better facilitate wider and more diverse interaction within and across the groups.

While both teachers started class with a review of the day's goals and then let the students direct their own learning, Mrs. Yolanda addressed the class as a whole at the end of the class period to summarize the lesson and discuss significant discoveries and accomplishments. Mrs. Ann developed a folder containing reference materials (timeline, checklist, templates, questions, etc.) based upon her previous experience in using the program. Mrs. Ann stated her students for this year needed more guidance and scaffolding than those embedded in the program. For her students, this approach seemed to work well. Table 7 summarizes the different implementation techniques we observed.

Both teachers appeared to be comfortable letting the students pursue their own learning path through the program and neither tried to actively direct the experience. However, Mrs. Yolanda was a more hands-on facilitator while Mrs. Ann was more hands-off. Mrs. Yolanda walked around the classroom visiting each group and encouraging them to collaborate. When Mrs. Yolanda found a student with a question or issue that applied to the whole class, she would pose the question or provide the answer to the whole class. On the other hand, Mrs. Ann spent most of her time at her desk and when students approached with questions, she would often refer them to their references or group member.

Students in both classes had access to laptops, but the student-to-laptop ratio differed. The one-to-one ratio seemed to keep students on task. We observed that sharing a laptop was a distraction that required students to negotiate access to the computer in addition to working on the tasks. However, we observed that successful implementation and effective teaching strategies can compensate for unfavorable environmental factors such as limited technology resources and a student population that required more guidance.

Mrs. Yolanda's and Mrs. Ann's schools represent opposing socio-economic classrooms. With a one-to-one student/computer ratio, Mrs. Yolanda's students were expected to develop one solution and share the solution with a small group. Mrs. Ann's students worked in pairs because they shared one laptop. Each pair developed one solution. Despite the unequal computer resources, both teachers structured and implemented a successful and authentic problem-based learning experience.

Discussion and Implications

Although there is much discussion in the literature on the benefits of student-centered approaches like PBL, there is a need for more research examining factors that motivate K-12 teachers to adopt PBL and providing examples of PBL implementation practices (Brush & Saye, 2000; Ertmer, 2010; Ward & Lee, 2002). This study investigated how a group of middle school teachers implemented a technology enriched PBL program in science. Our two research questions were: 1) What are the factors teachers consider important in affecting their motivation to adopt and use a technology-based PBL program? and 2) How do they implement a PBL program and what techniques do they use?

Table 7. Implementation Techniques Observed in Mrs. Yolanda and Mrs. Ann's Classrooms

Factors	Mrs. Yolanda	Mrs. Ann
Group composition	Groups of 4-6 students; assigned by teacher	Student selected pairs; (some assigned Special Ed-Regular Ed pairings)
Student-teacher interaction	Students raise hands and wait for teacher's attention	Students approach teacher's desk, sometimes with computer
Teacher-student interaction	Teacher usually refers student questions to groups or to the class or answers with a question.	Teacher usually refers students to references in their AR folder.
Student-student interaction	Students worked independently, at times sharing their findings with their group.	Students mostly shared information only with their partner.
Activity level of students	Students mainly at their laptop working on the AR project.	Students often at their laptops, but also walking around to pick up worksheets to use with AR.
Activity level of teacher	Mostly moving around, watching students.	Mostly at her desk. Students would approach her (both at her request and on their own).
Noise level	Steady buzz	Noisy, lots of talking
Off-task behavior	Very little	Some students were off-task. Teacher had to redirect students throughout the class period.
Beginning of class	Students entered regular classroom and waited for directions, which occurred immediately after bell rang.	Students entered classroom, checked the board for assignment instructions and started working.
Individual jobs within group	Each group member assigned to place one alien.	Students worked in pairs to place one alien.
Classroom goals as written on the board	Goals stated on board each day.	Goals stated on board each day.

The findings identified four factors that affected teachers' motivation in adopting the PBL teaching approach and solidified their motivation to incorporate this teaching approach in future years. The factors are (1) the PBL program addresses the teachers' curricular needs and implementing it has campus administrative and technical support, (2) the PBL method is aligned with teachers' pedagogical beliefs, (3) it offers a new way of teaching and promotes the development of problem-solving skills, and

(4) it challenges students in a captivating manner and supports the learning needs of all students.

In order for teachers to consider adopting any technologies, technology-based instructional materials must align closely with national and state curriculum standards and the teaching approach needs to be aligned with teachers' pedagogical beliefs. Campus, district, state, and national emphasis on assessment and accountability requires this close alignment and it is crucial as teachers are expected to integrate cross-curricular objectives with limited class time. Literature indicates that the teacher's pedagogical belief is a factor in understanding how and why teachers use certain technology in their classrooms (Becker, 2000; Ertmer, 2005). The findings of this study showed that these participating teachers adopted the PBL program and continued its use year after year because they believe the program helps them achieve curricular goals and substantiates their educational philosophies. The analyses of the teachers' interviews and their implementation techniques documented the participant teachers' desire to create student-centered learning activities where students become self-regulated and collaborative learners while teachers adopt the role of a facilitator, relinquishing teacher-centered responsibilities.

Integrating technology tools requires sufficient technology resources, including hardware, software, technical support, and user guides. The findings suggest that adequate technical resources need to be accessible, but they do not need to be ubiquitous to implement a PBL technology tool meaningfully. The detailed descriptions of the two different pairs of teachers' implementation techniques and the ways they implemented the program, given the resources they had, describes the challenges many teachers face in a public school setting and how they utilized the available resources to achieve optimal results. Apart from the alignment with the standards and teachers' pedagogical beliefs, and having adequate technical resources, the findings indicate the necessity of having a supportive campus administration that encourages teachers to seek effective and innovative ways to teach their students, rather than require teachers to use standardized teaching materials. Without the confidence of campus administration, it will be very difficult for teachers to sustain their drive to test and adopt new teaching approaches, especially those as complex as PBL.

These results highlight the need to identify and define the conditions conducive for teachers to adopt and implement student-entered approaches such as PBL while addressing technology integration barriers (Brinkerhoff & Glazewski, 2000; Park, Ertmer & Cramer, 2004; Sage, 2000). The findings also support the literature discussing the conditions when technologies can be used as an effective instructional tool. These conditions include when teachers (1) have access to technology, (2) are adequately prepared, (3) have some freedom in decision-making of the curriculum, and (4) hold a constructivist philosophy of teaching (Becker, 2000; Becker & Reil, 2000; Cope & Ward, 2002; Ertmer, 2005).

Solving complex problems and working collaboratively are two essential 21st century skills. Yet, teaching such higher-order thinking skills and creating a collaborative environment is not a simple task in a sixth grade classroom. A factor informing the adoption of a PBL program is that the program supports the learning and practice of these 21st century skills. Given the often overscheduled school day and many other challenges a teacher manages on a daily basis, the findings underscore the importance of providing embedded hard scaffolds in PBL programs which support students' self-regulation of their learning and allowing the teacher to provide soft scaffolds and individualize instructional practices. In this case, fourteen cognitive tools are provided in the program as hard scaffolds to support a range of cognitive skills from lower level skills (such as sharing cognitive load) to higher level skills (such as supporting hypothesis generation and testing). Since these tools are continuously accessible to students, teachers can concentrate on addressing students' individual needs. The descriptions of various facilitation techniques (i.e. soft scaffolds) employed by two pairs of teachers illustrated the skillful and practical ways to address students' different needs. Being a good facilitator is a crucial part of PBL implementation. Teachers will need to observe students and determine when it is appropriate to step in. They will need to model questioning techniques until students themselves become skillful inquisitors (Hmelo-Silver & Barrows, 2006). The results showed both hard and soft scaffolds are necessary in supporting students' learning (Ertmer & Simons, 2006; Saye & Brush, 2002), and technology-based PBL tools should be used to provide various scaffolds to help teachers teach higher-order thinking skills. We hope such detailed descriptions will not only provide insights on how the teachers implemented a PBL program but also offer ideas to other interested teachers and encourage the discussion on identifying helpful and practical facilitation techniques for PBL implementation in a K-12 setting. The results of this study provided empirical evidence to support the practices of successful technology integration as Dias and Atkinson (2001) described: (1) instruction is situated within an authentic context and includes in-depth problem solving projects, (2) when and how to use technology is determined by teaching goals, (3) use of technology supports collaboration and building a community of learners, and (4) teachers become facilitators and provide scaffolding to students.

Another important factor that motivated teachers to adopt and use technology-based PBL is that their effort is rewarded by their students' enthusiasm in using the program. Solving the central problem in *Alien Rescue* requires a lot of reading, a significant amount of research, and multiple steps of problem solving, which typically are challenging tasks for sixth graders. Our research found that teachers reported fewer classroom management issues and higher levels of engagement, even for those students who struggled with school, in general and science specifically. Teachers perceived that students learned more as a result of the PBL instruction as compared to traditional instruction. Although verifying such perceptions is not the focus of this study, the clear indication of students' enjoyment of the program and motivation to use it is an important step to help students learn. This finding is consistent with other studies that examined the effects of the PBL program on students' learning and motivation, showing significant gains in science knowledge (Liu, Hsieh, Cho, & Schallert, 2006; Liu et al, 2009; Liu, Horton, Olmanson, & Toprac, 2011).

All teachers in this study received the same software program and the same comprehensive teacher's manual outlining suggested lesson plans, classroom activities, additional science topics, and other problem-solving activities. Although the same materials were provided, the ultimate responsibility is on teachers to adjust and adapt the tools to their students' specific needs and campus resources. This requires teachers to devote more time and effort (when compared to more traditional instruction), to be flexible, and to be willing to adapt and deal with challenges. Our investigation showed that teachers' customization of the PBL program helped them implement it successfully in their particular situations to accommodate different student needs, different technology resources, different schedules, and different teaching styles.

We observed variation in implementation on a number of dimensions. Some teachers had students form small groups and others had them form pairs. Some classrooms had sufficient computers for each student while some required students to share. The timeframe for using the program ranged from the intended three weeks to two weeks. Some teachers followed suggested lesson plans and used all of the provided materials (e.g. assignments, assessments, and additional science content), while others used selected materials and still others created their own additional materials. Based on their perception of students' needs, teachers relied on individualized soft scaffolding and provided more hard scaffolds (i.e. paper instruction and question prompts) in addition to those embedded in the program. The types of students these teachers taught varied from year to year and teachers used different scaffolding techniques to adjust and adapt the program to meet their students' needs. Our findings revealed the importance and necessity of "allowing for local adaptation" (Barab & Luehmann, 2003).

Implications

The findings of this study have implications for instructional designers, teachers, and administrators. For designers, it is important to consider the following when creating technology-based PBL tools for K-12: 1) in planning a technology product, the state and/or national standards must be clearly reflected and identifiable in learning activities, and close alignment is critical; 2) in designing the problem-solving experience, hard scaffolds need to be available at different levels during the process so that teachers may concentrate on providing soft scaffolds; 3) the programs need to be flexible, comprehensive, and ideally interdisciplinary, so teachers can address their curriculum goals in different ways while meeting their students' needs, and finally 4) take advantage of technologies to create immersive, media-rich, and interactive learning environments which students find engaging and fun to use.

Although the barriers for technology integration are diminishing, technology-enhanced learning appears still to be entrenched in low-level activities (Ertmer, 2005). For teachers who hope to integrate high-level technology projects, the findings of this study offered insights and strategies as well as examples of "best practice" for PBL. Teachers should carefully select a technology-enhanced PBL program that overtly meets instructional objectives. Teachers will need to be proactive in reserving computer access (especially when it is limited) as well as be creative in setting up student-to-technology assignments. To be successful with PBL, teachers will need to adopt a constructivist pedagogical belief that supports learning in an authentic environment and students in control of their own learning while collaborating with their peers. This type of learning is not linear and teachers will need to accept a certain level of chaos in their classrooms. Student-centered learning experiences such as PBL aim at supporting high-order thinking skills and moving teaching beyond traditional memorization to a synthesis of knowledge and skills. The process, in and of itself, is time-consuming and requires teachers to consider a variety of scaffolding. The findings of the study have shown that teachers can successfully adapt a pre-packaged learning tool to address students' needs and plan a PBL activity within the constraints of a school setting.

An important factor for successful technology integration is to have the support of campus administrators. Hew and Brush (2006) found that school leadership can hinder the integration of technology for teachers. To transform education and prepare students for the 21st century, administrators should be open-minded, encourage creative teaching approaches, and allow teachers the freedom to pursue the most effective ways of instruction to address students' diverse needs. To support innovative technology integration into classrooms, school leaders should develop a shared vision of teaching with technology, encourage constructivist pedagogical beliefs, conduct needed professional development, and reconsider grading and assessment policies. For learning to take place, it requires the coordination and collaboration of all factors involved: teachers, administrators, teaching materials, and (technology) tools used.

Limitations of the Study

This study is limited in that it examined one technology-enhanced PBL program and ten teachers who were willing to try and adopt a PBL tool. It focused mainly on adopters rather than non-adopters of PBL pedagogy. Examining why some schools and/or teachers decided not to adopt or discontinued to use the PBL program will provide useful insights from a different perspective. Our future research intends to replicate the research with a larger sample and examine multiple perspectives both from adopters as well as non-adopters. In this study, we observed seven teachers and their implementing practices with over 1,000 sixth graders. Given the dynamic nature of the classroom interaction in this case, video-taping the observations, which would provide more detailed data for analysis, is not possible. However, a future direction can be to focus on two to three teachers and a few student groups to understand specific facilitation techniques such as what questions are asked and answered through the digital video technology.

Conclusion

This study identified four factors that affected teachers' motivation in adopting and using the PBL program in a middle school setting. Teachers' implementation practices are documented in detail. Given the findings of this study, we recognize that understanding and evaluating the effectiveness of technology-based PBL is a more challenging and nuanced task than merely comparing learning outcomes based on the presence or absence of a technology-based PBL program. A full understanding of the effectiveness of such PBL tools requires understanding and evaluating within the framework of the specific implementation contexts. As other researchers have indicated (Zhao & Frank, 2003; Wallace, 2004), it is necessary to study the complex and dynamic nature of the technology integration process as it relates to the context, innovation, and innovator. It is also necessary to identify the factors that both favor and inhibit PBL adoption. Future research should concentrate on identifying the most common implementation strategies to promote more widespread PBL implementation by creating the right conditions and providing the right information to inspire teachers to adopt PBL for their students.

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Appendix A

Interview Questions

Background Questions

1. How long have you been a middle school teacher?
2. What do you see as the most important aspects of your role as the teacher in your classes?
3. Who determines what activities go on in your class?
4. How often do you use computers in your class?
5. Can you give some examples of computer use you had in the past 2-3 years?
6. What other similar products have you considered using in your class? How does AR compare to these?
7. How do technology-based tools in general affect your teaching?
8. How do you think computers should be used in the classroom?
9. Before AR, how did you normally teach the solar system?
10. What activities did you normally use and how long was this unit?
11. How were students normally assessed on your solar system unit?

How Teachers use *Alien Rescue* (AR)

1. Why did you decide to try this program?
2. How did you hear about it?
3. How is this program used within your curriculum?
4. How does it fit into your teaching schedule?
5. How many days do you use the program?
6. Describe how your use of AR fits in with other aspects of your teaching.
7. How do you structure the activities?
8. Does AR enhance your teaching? How and why?
9. How does your role differ between class periods when you use *Alien Rescue* and other class periods?
10. What are specific things that you do as a teacher when using AR?
11. Can you describe a typical day of AR use?
12. Did you read the training manual before using the program?
13. If so, was the manual helpful? In what way?
14. What are the difficulties, challenges of using AR and how did you solve these problems? Will you use AR again? Why or why not?
15. Please compare AR with the traditional science curriculum?

16. What are some specific features of the software that you like/dislike?
17. How would you improve AR?

Students Use *Alien Rescue*

1. How do the students respond to the program?
2. What do your students like or dislike about AR?
3. Does the program help your students?
4. Describe some examples of successful student learning resulting from your use of AR.
5. Describe some examples of unsuccessful results from your use of AR.
6. What surprised you about how students worked/behaved during *Alien Rescue*?
7. Describe how you think students will view the topics they studied in *Alien Rescue* after the program was over? How would their view differ if they had just studied the solar system through a traditional unit?
8. What differences did you see in students' actions? Did you see more on-task behavior? Misbehavior? Participation?
9. What types of discipline problems occurred when students used AR?
10. How would you describe the interest and attention levels of your students when using AR?
11. Would you describe them as actively involved in their learning, or passive?
12. How and to what extent were students able to collaborate effectively with their peers?
13. Can you send us the comments your students have expressed about AR?
14. Can you share with us any assessment data of your students—how they performed in an anonymous way?

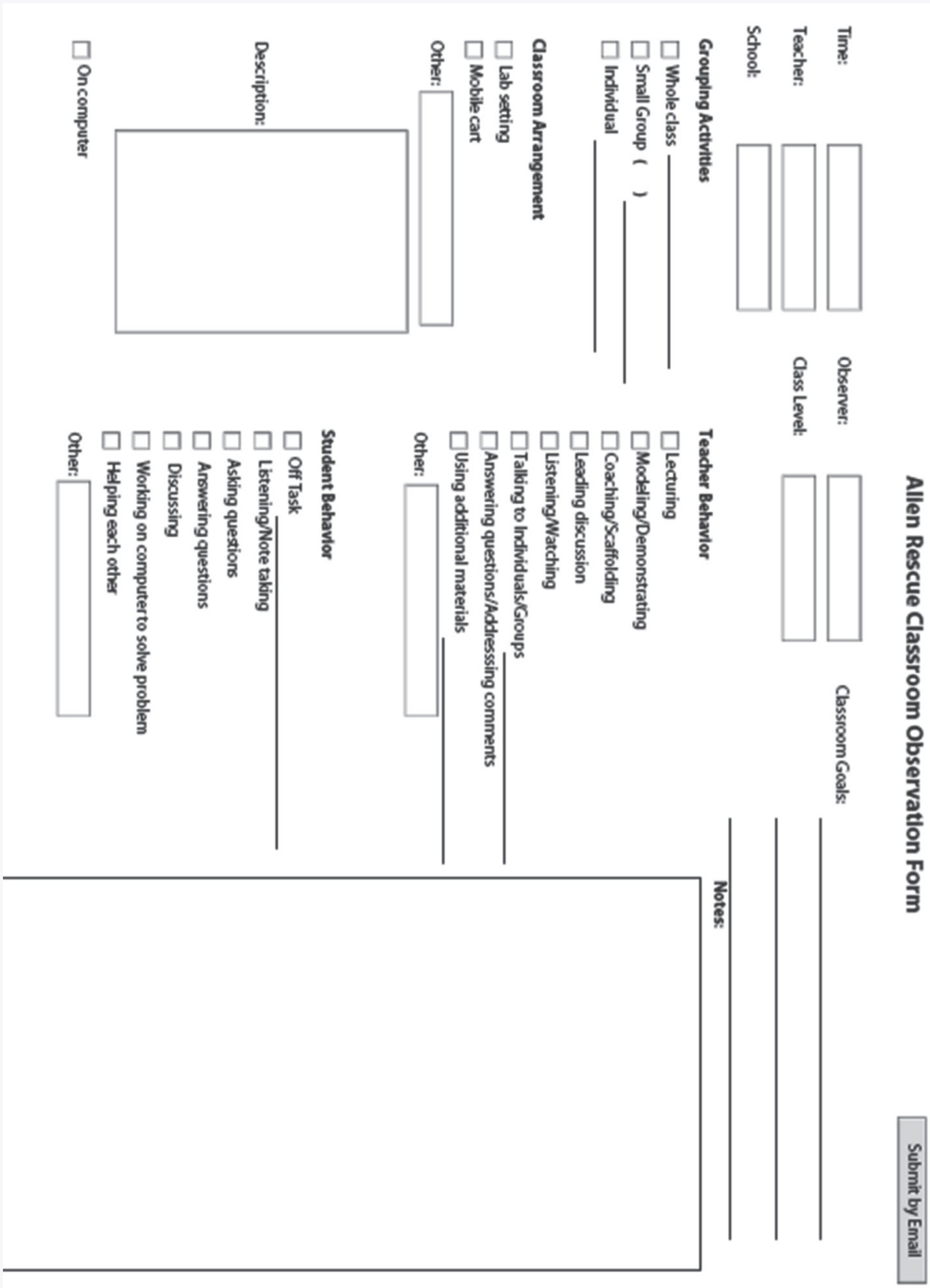
School Setting

1. Does the district require you to use technology in teaching and if so how often?
2. Who makes decisions in choosing technologies?
3. How supportive is your school's administration of technology integration in general? Of using AR in particular?
4. Can you describe the type of technology you have available to use in you class?
5. What type of technology training is available to teachers?
6. What type of technology staff development have you taken?
7. Do you have a technology coordinator at your district and what type of support does he or she offer?
8. How does your use of technology compare to other teachers in your school?
9. How do other staff at your school/district use AR or other technology-based tools?

Follow-up questions

1. Do you believe that most teachers would be willing to change their role to that of facilitator? Why or why not?
2. Do you believe student-centered learning can work? If so, under what conditions?
3. Have your opinions on this changed after using *Alien Rescue* with your students?
4. What recommendations would you give to other teachers about whether and how to use AR in their classrooms?

Appendix B



Allen Rescue Classroom Observation Form

Submit by Email

Time:
Teacher:
School:

Observer:
Class Level:

Classroom Goals:

Grouping Activities
- ☐ Whole class
- ☐ Small Group ( )
- ☐ Individual

Classroom Arrangement
- ☐ Lab setting
- ☐ Mobile cart

Other:

Description:

☐ On computer

Teacher Behavior
- ☐ Lecturing
- ☐ Modeling/Demonstrating
- ☐ Coaching/Scaffolding
- ☐ Leading discussion
- ☐ Listening/Watching
- ☐ Talking to Individuals/Groups
- ☐ Answering questions/Addressing comments
- ☐ Using additional materials

Other:

Student Behavior
- ☐ Off Task
- ☐ Listening/Note taking
- ☐ Asking questions
- ☐ Answering questions
- ☐ Discussing
- ☐ Working on computer to solve problem
- ☐ Helping each other

Other:

Notes: