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Examining Project-Based Learning Successes and Challenges of Mathematics Preservice Teachers in a Teacher Residency Program: Learning by Doing

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ABSTRACT

This phenomenological study describes how secondary mathematics preservice teachers (PSTs) in a teacher residency program designed and implemented project-based learning (PBL) units. The Six A's, a framework used to evaluate the rigor and relevance of PBL units, helped capture the research question: What are the successes and challenges PSTs experience as they implement PBL units for the first time? This qualitative study illustrates how PSTs engaged students in relevant learning, wrestled with sustaining the rigor, and included the community to be partners in the projects. Findings indicate that high-quality implementation of PBL instruction requires involving the community, facilitating mathematical learning, and transforming the learning environment. PSTs recognized that a PBL approach requires a shift from traditional teaching practices and reconceptualizing both what it means for teachers to teach mathematics and for students to learn mathematics. This study contributes to the scarce body of knowledge on how teacher residency programs can utilize PBL as an instructional model to prepare PSTs for PBL environments.

Keywords: project-based learning, mathematics preservice teachers, teacher residency

Introduction

Mathematics education reform documents, such as Principles to Action: Ensuring Mathematical Success for All (NCTM, 2014), Catalyzing Change in High School Mathematics (NCTM, 2018), and the Common Core State Standards for Mathematical Practices (CCSSI, 2010) demand high expectations for mathematics education. Because mathematics is known to influence the kinds of opportunities students have, mathematics has a renewed importance; mathematical literacy is no longer a privilege but a necessity. Student-centered teaching that highlights mathematical literacy in which students communicate about mathematics and engage in thinking skills and processes (see Goodman, Sands, & Coley 2015; Wilhelm & Walters, 2008) are at the forefront of K-12 mathematics classrooms. Several documents (American Association for the Advancement of Science [AAAS], 1993; CCSSI, 2010; National Council of Teachers of Mathematics [NCTM], 2000, 2014; National Research Council [NRC], 2012) have emphasized the importance of understanding not only content but ways in which students engage themselves. Educational boards and councils advocate instruction where students are actively constructing their ideas and collaboratively engaging in tasks that emphasize the connection of knowledge to the contexts of its application (NCTM, 2000, 2014; NRC, 2012; NSTA, 2018).

In addition, in today's rapidly changing economy and tech-savvy industry, employers seek graduates who can solve problems, think critically, exercise creativity, and work in teams (KnowledgeWorks Foundation, 2018; Partnership for 21st Century Learning, 2018). These "soft skills" are imperative for jobs in the 21st century and often are not addressed in traditional methods of teaching (Condliffe, Quint, Visher, Bangser, Drohojowska, Saco, & Nelson, 2003). Indiana has become the national leader in state-wide project-based learning (PBL) instruction, a student-centered pedagogy that encourages collaboration, communication, critical thinking, and creativity, and this model is slowly gaining national recognition (CELL, 2012). Indiana has exploded in PBL implementation over the years partly because of the Indiana Department of Education is requiring 100% of Indiana K-12 teachers to be trained in project-based or other inquiry-based approaches to learning by 2025 (IDOE, 2018). This aggressive, strategic initiative affects the preparation of Indiana preservice teachers and warrants a careful analysis of how they implement instruction using the PBL approach.

The University of Indianapolis attempts to prepare mathematics preservice teachers (PSTs) to teach in 21st century schools by having them design and implement a project-based learning curriculum during their clinical residency teaching program. Thus, the question that motivates this study is: What successes and challenges do mathematics preservice teachers experience as they implement project-based learning for the first time? The purpose is to contribute to the body of knowledge on how teacher education programs can utilize PBL as an instructional model to prepare PSTs for PBL environments.

What is Project-Based Learning?

Many educators are responding to the need for change in mathematics instruction. One innovative and appropriate instructional framework is project-based learning (PBL). Unlike units in which a project is used as a culminating experience, PBL poses a realistic situation at the beginning of a unit and uses the need to create a deliverable product to drive the course content through an extended inquiry process (Markham, Larmer, & Ravitz, 2003). Markham et al. define PBL as "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic, questions and carefully designed projects and task" (p. 4). Students who learn in PBL environments learn rigorous mathematics, address relevant problems or topics, and build relationships with one another. Students in PBL environments are pulled through the curriculum by a Driving Question, or realistic problem to solve. Instruction is integrated into the problem as students need the information. Larmer, Mergendoller, and Boss (2015) describe the Gold Standard PBL Model with eight key features:

> 1) Key knowledge, understanding, and success skills: students learn important content standards and concepts, while exercising critical thinking, problem-solving, teamwork, and self-management skills and habits of mind.
>
> 2) Challenging problem or question: the project or unit starts with a Driving Question or challenge that addresses authentic concerns for students to investigate, solve, or explore and answer.
>
> 3) Sustained inquiry: students investigate the Driving Question through problem-solving and sustained inquiry by using a variety of resources. In the process they learn and apply important ideas specific in the discipline.
>
> 4) Authenticity: the project represents a real-world scenario and challenges students to use real-world tools. The project has an impact on students and the community.
>
> 5) Student voice and choice: Students have input on how to solve the problem. Students have a voice in the resources they use, what questions to ask, how each team member contributes, and/or products they produce.
>
> 6) Reflection: students and teachers examine what they are learning, how they are learning, and why they are learning. Reflection includes how to move forward.
>
> 7) Critique and revision: students receive and provide constructive peer feedback by using rubrics, protocols, and models in order to revise and improve the work.
>
> 8) Public product: students create tangible products or presentations that address the Driving Question and present them to their class and community members.

Hence, the model is based on the assumption that most academic content is learned best in the context of projects. PBL instruction, when done correctly, supports ways for students to construct their own understanding, and provides teachers opportunities to orchestrate conversations that get students to explore complex connections and relationships between ideas.

Designing and Implementing PBL Units

Research is scant on the implementation of teacher-designed PBL units, and even more on implementation and design of PBL units by preservice teachers (PSTs) and the supports they need. Because of the complexities in designing and implementing math PBL units and the need to prepare PSTs in this instructional method, we sought to answer the research question: What are the successes and challenges preservice teachers encounter as they implement math PBL units?

Literature related to PBL instruction provides researchers and practitioners with some important insights into the process of designing and implementing PBL units. Most research that deals with the successes and challenges of PBL implementation comes from the science education community where researcher-initiated PBL units have been developed (see Fogleman, McNeill, & Krajcik, 2011; Geier et al., 2008; Harris, Penuel, DeBarger, D'Angelo, & Gallagher, 2014; Mioduser & Betzer, 2007; Schneider, Krajcik, Marx, & Soloway, 2002; Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008; Tsybulsky and Oz, 2019). Research on this topic is almost non-existent for the mathematics education community, and there is little research related to teacher-initiated PBL units. The lack of research specific to teacher-designed PBL instruction in mathematics highlights the need for the study reported in this paper.

In previous research that has looked at the challenges of implementing PBL, researchers acknowledge that a barrier to effective implementation is the lack of prepared materials for classroom instruction and the varying fidelity to PBL (Condliffe, Visher, Bangser, Drohojowska, & Saco, 2017; Ward & Lee, 2002; Yetkiner, Anderoglu, & Capraro, 2008). They acknowledge that few training materials are available and curriculum guides and textbooks do not contain a variety of sample problems or assessment tools. This is problematic since few teachers have the time or the motivation to prepare all new materials and design PBL units for classes. In Marshall et al.'s study (2010), mathematics and science secondary preservice teachers reported time and curriculum restrictions as major barriers. Ertmer & Simons (2006) documented similar implementation challenges of K-12 teachers related to: 1) creating a culture of collaboration and interdependence, 2) adjusting the changing roles, and 3) scaffolding student learning and performance. These challenges rose from the teacher having to wrestle with what it means to teach and how students learn. These findings suggest that successfully enacting PBL units requires teachers to adopt and believe elements of PBL instruction. This state of affairs also provides justification for the need to conduct studies like the present one.

Several studies have examined the conditions needed for successful PBL implementation by preservice teachers. Researchers suggest that PSTs be provided with opportunities to apply PBL during their training and have called for the design of a pedagogical course using PBL (Baysura, Altun, & Yucel-Toy, 2015). Tsybulsky and Oz (2019) studied the emotional experiences of elementary science PSTs. They found that implementing PBL during the teaching practicum was an important step that led science PSTs to experience success and satisfaction and adopt several principles and aspects of PBL pedagogy in their pedagogical practices. Dag and Durdu (2017) studied PSTs from six different teacher education programs in a class where PBL was used. They found that experiencing a PBL process in a class contributed to PSTs' satisfaction with their academic learning, increased their theoretical knowledge, and enabled them to put their knowledge into practice. PSTs in their study also stated that they would implement a PBL environment in their future teaching. Marshall, Petrosino, and Martin (2010) studied mathematics and science secondary PSTs implementing PBL during student teaching. They found that teachers for whom enactment of PBL was presented as an explicit goal, and who were given support toward that end, were more likely to enact authentic implementations.

While there is abundant research on teacher clinical residency programs (see Drake, Moran, Sachs, Angelov, & Wheeler, 2011; Klein, Taylor, Onore, Strom, & Abrams, 2015; Mourlam, De Jong, & Shudak, 2019; Ricci, Persiani, & Williams, 2019), research on using PBL in a teacher clinical residency programs is dry. Interestingly, Martinez (2010) mentions two universities that trains their PSTs in PBL-specific teacher residency programs—the University of Texas at Austin's UTeach program places PSTs into a New Tech school for their long-term teaching experience, and the University of South Dakota trains all secondary majors in PBL methods while partnering with Project-Based Learning High School in Sioux Falls for their field experiences—but no research was found. Alter & Coggshall (2009) also mention High Tech High's Teacher Intern Program partnered with the University of San Diego, but no external evidence is available about the outcomes of this clinical teacher learning model. Again, while these articles show evidence that PSTs train in PBL-specific teacher residency programs, research in this field is absent.

One study, conducted by Zhang, Ridgway, and Sachs (2015), proposed a systematic way to prepare PSTs to incorporate PBL into their professional practice using a four-step approach: Observe It, Experience It, Create it, and Become it. Each step is explained briefly. Observe it—PSTs observe PBL in action and in practice to know more about this instructional model. Experience it—PSTs then experience PBL for themselves by going through the PBL curriculum and doing a PBL project. Create it—PSTs create a PBL unit and implement it. Become it—Going through this systematized process allows PSTs to become PBL-minded. Because research is scant on teacher residency programs that use PBL as their instructional model, this study addresses the need to examine PSTs' experiences in a teacher residency setting.

The Six A's Framework

An exemplary PBL unit ensures that both instruction and content enable learners to master core competencies. The Six A's (Markham, Larmer, and Ravitz 2003, p. 34) can be used as a guide for designing a math PBL unit:

- Authenticity: The project is situated in the real world—other professionals are tackling the same problem or question addressed by the project. In addition, the problem has meaning and relevance to learners, and there is an appropriate audience to view learners' products.

- Academic Rigor: The Driving Question is well-defined and tightly integrated to the content standards. The project also demands breadth and depth of both specific knowledge and central concepts. Learners develop habits that are indicative of efficient and effective problem solvers, such as questioning and posing problems, applying past knowledge to new situations, employing precision of language and thought, and maintaining persistence.
- Applied Learning: Learners use multiple high-performance work organization skills, such as working in teams, communicating ideas, applying new knowledge to the problem, and organizing and analyzing information. Learners are able to identify and apply the self-management skills needed to improve their group's performance.
- Active Exploration: Learners conduct field-based activities, such as interviewing experts, surveying groups, and exploring worksites. Learners gather information from various sources and use appropriate methods to obtain the needed data.
- Adult Connections: Learners are provided with mentorship opportunities, where they work alongside adults at a worksite relevant to the project. Learners develop meaningful relationships with members of the community who have expertise and experience in a particular field.
- Assessment Practices: Various formal and informal assessments occur intermittently throughout the project, and learners are given timely feedback from both peers and teachers. The project requires multiple products, all of which are aligned with the project's ultimate goal. The project culminates in an exhibition or presentation for an informed audience.

The Six A's framework provided a lens for examining both the math PBL units designed by the participants in this study and how they were implemented. In PBL curricula both the instruction and the content need to be rigorous so that students can master core competencies. As indicated by these criteria, a PBL curriculum attempts to also engage students in real, meaningful problems that are important to them while advancing their creativity and problem-solving abilities.

This framework was utilized in this study for various reasons. Lattimer and Riordan (2011) assert that when PBL is designed in this structured manner, there are high levels of student engagement, an increase in innovative and responsive teaching practices, and positive teacher-student relationships. Laundon (2105) used the Six A's framework to examine the effects of PBL on students learning Newtonian physics and found that students felt connected to their city and saw the applicability of physics in the real world, and students effectively collaborated throughout the unit and had an increased awareness of self-regulated learning. Similarly, Sutiadiningsih, Nurlaela, Hasan, and Sutadji (2017) used the Six A's framework to describe how the teacher's implementation of PBL activities helped students to build character while documenting their progress and achievement. Designing and implementing a PBL unit is a complex endeavor, and having a framework such as the Six A's provides useful guidance for development and to judge the effectiveness of implementation.

Methodology

A phenomenological inquiry approach (Creswell, 2013) was most appropriate for this study, given its focus on PSTs' experiences and perceptions of teaching mathematics through PBL. Group interviews centered on PSTs' PBL experiences allowed for open dialogue, and reflective writings documented their feelings and concerns. Data was analyzed in ways consistent with the methods described by Giorgi (1985) and Moustakas (1994). Five nonlinear, interlaced, recursive steps were involved: 1) reviewing the data; 2) transcribing the data; 3) determining significant statements in participants' responses; 4) clustering significant statements into themes; and 5) interpreting the themes as sources of individuals' lived experiences. This process helped balance subjectivity and objectivity, and the results provide detailed descriptions of PSTs' experiences with PBL.

Data Sources and Procedures

Primary data sources included four one-hour cohort-based group interviews and two written reflections. Secondary data sources included classroom observations, student-generated artifacts, and original and revised unit plans. Such data were necessary to capture how and why PSTs made decisions regarding the planning and implementation of PBL. Group interviews and reflective writings were always structured around the Six A's framework. During discussions and reflective writings, the participants would talk about their experiences based on each of the Six A's. For example, what is going well with your PBL unit in regards to Authenticity? What is not going well and why? Therefore, data was inherently clustered into 6 categories: Authenticity, Academic Rigor, Applied Learning, Active Exploration, Adult Connections, and Assessment. Written reflections documented PSTs' PBL journey and their PBL disposition.

Some reflection questions were: How have the experiences helped support and thwart your thoughts towards this type of instructional method? How has your PBL disposition over the past one or two semesters changed and why? According to the Six A's, what are your strengths and areas of improvement on the design aspect of your PBL unit (see Appendix A)? Using both the group interviews and reflective writings as primary data served to identify significant and repeated statements for each of the Six A's and aided the coding process. The findings (see Table 2) illuminate what the participants, as a collective whole, experienced as they taught math using PBL and how they experienced it.

Information was gathered in chronological order: (1) PSTs' original unit plan; (2) written reflection on the learning of designing a PBL unit; (3) classroom observation field notes of PSTs teaching the PBL units in their clinical residency settings; (4) group interviews about their PBL teaching experiences; (5) student-generated artifacts; (6) written reflections on the implementation of their PBL units; and (7) revisions to their PBL units. PSTs' original and revised PBL units, student-generated artifacts, and classroom observations assisted in learning about the context of each participant's wins and struggles. For example, if a participant stated the lack of assessments within his/her unit created a challenge, comparing the original and revised PBL units helped verify the urgency of that concern. Secondary data sources and colleague debriefing supported the data collection process. Such methods provided the necessary triangulation to ensure the conclusions drawn were reasonable.

Participants

This exploratory study involved ten mathematics PSTs across three cohorts who were in an accelerated, teacher residency-credentialing program, earning a Master of Arts in Teaching and a mathematics teaching license in 12 months. Faculty in the clinical residency teaching program at the University of Indianapolis delivered some of its courses using a PBL approach, so PSTs were familiar with this instructional model; that is, PSTs solved ongoing questions and challenges that were posed in the beginning of the course and/or class. PBL practices were also regularly embedded in all course activities such as providing feedback to one another, presenting products in front of an audience, and working as a team.

PSTs also took PBL-specific courses and learned about project-based learning in depth throughout the year. In the first semester, PSTs took a PBL course to learn about the nuts and bolts of PBL unit design (i.e., Driving Question, entry event, rubric, scaffolding) while going through a PBL curriculum themselves, and designed a PBL unit that they would implement in their clinical residency setting in the second semester. In addition to learning how to design a PBL unit, they learned about the Six A's, read articles and saw videos demonstrating what successful implementation looks like, and explored high-quality PBL units. During the design process, they received feedback from their mathematics professor to ensure the units were mathematically sound and rigorous. In the second semester, PSTs implemented these units in their clinical residency settings, and enrolled in a course where they further continued to explore PBL strategies with a particular focus on facilitating student learning in a PBL environment. In the summer, PSTs reflected on the implementation of their units and revised them. PSTs were also asked to reflect on this overarching question as they designed and implemented their PBL units over the course of one year: How can I as an innovative teacher design and implement an academically rigorous and relevant PBL unit so that my students are actively engaged in learning? Table 1 below illustrates the different PBL units PSTs created, type of community involvement, and his/her prior career before entering the teacher residency program.

Preservice Teacher	Description of PBL Unit	Community Involvement	Prior Career
Christine	Using logarithmic and exponential functions to find the best vehicle to purchase based on affordability.	Loan banking associates	Loan officer at a bank with 5+ years of experience.
Seth	Using trigonometry to calculate the ballistics of bullet trajectory from the John F. Kennedy assassination.	History professor at University of Indianapolis	Retired police officer with 20+ years of experience.
Kacey	Using surface area to design a floor plan for a new school.	Local architect company	Recent graduate.
Josh	Using properties of conic sections to design a functional solar cooker.	Local cooperative grocery store, local newspaper, and parents	Manager at local grocery store with less than 5 years of experience.
Mia	Using volume and mathematical modeling to design robust packages to protect shipping products.	Local manufacturing company	Recent graduate.
Sophia	Using exponential functions to model disease outbreak in a school, and devise an emergency plan.	School principal and school nurse	Recent graduate.
Viviana	Using exponential functions to advise incoming college students to avoid financial tuition burdens and working with the financial aid office.	Financial aid coordinator at University of Indianapolis	Recent graduate.
Adrian	Using statistics to advise high school principal and superintendent on using Google Chromebooks effectively at their school.	Principal, superintendent, and school board	Recent graduate.
Micah	Using data analysis to advise middle school principal and superintendent on using Google Chromebooks effectively at their school.	Principal, superintendent, and school board	Certified public accountant with 5+ years of experience.
Tucker	Using surface area to assist an engineering company in designing a new housing subdivision that blends with older houses in the area and attracts new residents.	Local engineering company	Civil engineer with 20+ years of experience.

Table 1: Snapshot of PSTs' PBL Units

Results

This section documents successes and challenges math PSTs encountered while they implemented their PBL units for the first time. These successes and challenges are anchored around each of the Six A's, and emanated as participants shared similar experiences. Quotations of the participants are included to embody the successes or challenges that many PSTs experienced. Quotations come from primary data sources—group interviews and written reflections—unless otherwise specified. Table 2 below shows a snapshot of PSTs' successes and challenges for each of the Six A's.

Authenticity

Successes.

There were three successes that emerged from the data. First, 8 PSTs shared that they designed units that tapped into students' personal lives and students were engaged because the problem was relevant to them. For example, Christine commented:

> The students were highly engaged in the process of researching and buying a new car while learning about exponential and logarithmic functions.... It was

Six A's	Successes	Challenges
Authenticity	Tapping into students' personal lives and making learning relevant. Including complexity and interconnectedness to other topics. Creating a public product for the community partner.	Finding a community partner that was invested. Focusing on the content of the math vs. the context of the problem.
Academic Rigor	Addressing the content standards. Studying mathematical concepts in-depth.	Balancing math content and project's context. Facilitating questions and probing deeper student thinking. Anticipating students' content roadblocks. Covering vs. going deep with the content standards.
Applied Learning	Learning new technology to uncover math concepts and keeping projects organized. Seeing students work independently and collaborating with their peers.	Managing student progress and facilitating classroom management. Learning new technology, which hampered progress on project. Guiding students on how to organize and present public product.

Table 2: Summary of PSTs' Successes & Challenges

Active Exploration	Advocating students to be proactive in their learning.	Lacking student engagement and having students take ownership of their own learning.
Adult Connection	Involving community partners throughout the PBL unit. Feeling supported and encouraged by the school administration.	Involving community partners who have STEM careers/ backgrounds.
Assessment Practices	Monitoring group and individual progress.	Monitoring group and individual progress. Providing rubrics with detailed project expectations.

Table 2 (continued): Summary of PSTs' Successes & Challenges

> relevant to them because they are now just reaching the age where they are getting their licenses and thinking about buying cars.

Second, 5 PSTs thought their PBL units were complex and interconnected to other subject matters or real life topics. Tucker reflected, "My PBL unit had a good level of complexity. It challenged the students to think about interconnected solutions rather than small discrete problems." Students had to think and interpret what their answers meant in context to the project.

Lastly, 5 PSTs felt their students worked hard on their projects because they were addressing a problem the community partner posed, and had to present their product to an informed audience. Micah reflected on his statistics unit for his 7th grade students:

> [Launching the project] consisted of our school principal visiting the classroom and giving students a challenge to help him and the school district administration learn about the students' and teachers' productive use of Google Chromebooks. Since my students were already using Chromebooks… this project was very authentic to students and had a great deal of meaning to them. Students were excited to work with their principal, superintendent, and other members of the school district administration. Students know who these individuals are and what they do. Therefore, the audience for this project was appropriate for students' work.

Challenges.

There were also two challenges with the authenticity of a PBL unit. First, 5 PSTs had a difficult time finding the appropriate community partner with the level of commitment they were seeking. For example, Viviana states, "Unlike Christine, it was hard for me to secure a community partner because I didn't have connections with the workforce. And when I finally had someone interested, she [community partner] couldn't come for all five periods." Some PSTs enrolled in the clinical residency program after having a job in an industry for several years, but many PSTs enrolled into the program immediately following their Bachelors and had no connections or experience in industry, making it difficult to find a community partner or make the PBL units real-world. Second, 4 PSTs were concerned that students tended to focus on the context of the problem rather than the content of the math. Students were so engrossed with the problem or challenge of the unit that at times the students did not transfer and demonstrate their understanding of mathematical concepts in other contexts. Kacey shared, "Students were more concerned about the project than the math," and Sophia stated, "I wished the entry event was more content focused so students would see where the math is going on in the project."

Academic Rigor

Successes.

There were two successes PSTs experienced. First, 8 PSTs felt their unit heavily addressed the content standards. Mia expressed, "I think the unit on geometric solids covers a lot of standards in spatial analysis and mathematical modeling. The project placed a lot of emphasis on calculation of volumes and surface areas." Second, 7 PSTs voiced that the content in their projects were rigorous, and the projects afforded students to study these concepts in-depth. For example, Christine reflected:

> I think [students saw] the point was to try to learn a real-life skill and the content together, and a lot of the students actually told me after the project that they thought that it was useful and that they felt like they had a better understanding of the content because they could think about it in terms of the project.

As PSTs designed their projects, they continuously consulted with their mathematics professor and PBL professor to ensure the academic rigor was foregrounded in the PBL units.

Challenges.

There were four challenges PSTs encountered, all centered around facilitating the mathematical learning. First, 9 PSTs had difficulty in getting students to engage in the mathematics while addressing the project's challenge. Kacey's students were "more concerned about the project than the math" and Viviana wished to find "a better way to integrate the math content and the project pieces so they don't feel like two separate things to the students." PSTs had difficulty navigating students' interest in the mathematical content while addressing the authentic problem of the project.

Second, as indicated in classroom observations and field notes, 6 PSTs struggled with how to ask questions and failed to probe deep into their students' thinking. For example, Seth, like many PSTs, would often ask leading questions, and his questions frequently assessed students' procedural fluency rather than conceptual understanding.

> Seth writes on the board: Simplify $\frac{(a^2-9)}{a^2+6a-27)}$ and find excluded values.
>
> Seth: The difference of two squares always factors how?
>
> Students: (x+y)(x-y)
>
> Seth: So we have a what?
>
> Students: (a+3)
>
> Seth: And a what?
>
> Students: (a-3)
>
> Seth: What about the denominator?
>
> Students: (a+9)(a-3)
>
> Seth: Ok, good. How I want to find the excluded values. What am I looking at for the excluded values?
>
> Students: The denominator.
>
> Seth: What values would make the denominator zero?
>
> Seth writes (a+9=0) and (a-3=0)
>
> Students: a=-9 and a=3
>
> Seth: What's next? Can I cancel?
>
> Students: Yes.
>
> Seth: Cancel what?
>
> Students: (a-3)
>
> Seth: Can I cancel anything else?
>
> Students: No.
>
> Seth: So my simplification is $\frac{(a+3)}{(a+9)}$.
>
> Here's what I want you to write in your math notebook. The excluded value of a rational expression is always found in the denominator and you want to find the values that make the denominator zero.

Third, as indicated in classroom observations, field notes, and written reflections, 7 PSTs could not anticipate students' content roadblocks. For example, during a class discussion, Sophia was reviewing how to find the area of a triangle given the following measures (see Figure 1), and the following conversation ensued:

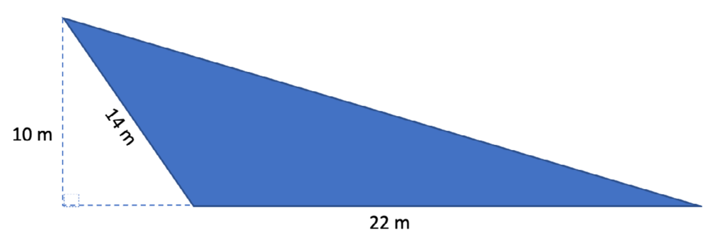

Figure 1: Finding the area of the triangle.

> Sophia: How do you find the area of a triangle?
>
> Student: One half, times base, times height.
>
> Sophia: Ok, so tell me what that is here.
>
> Student: One half, times 22, times 14.
>
> Sophia: No. You can't do this. The height is not 14. It's 10.

> Student is quiet.
>
> Sophia: It's one half times 22 times 10.
>
> Student is quiet.
>
> Sophia: You can't multiply by 14, you have to multiply by 10. The height of the triangle is 10.
>
> Student: Okay….
>
> Sophia: Alright? Okay?
>
> Student: Yeah.

Sophia did not understand how the student was interpreting the height of a triangle. Many students mistakenly think the height of the triangle is the side of the triangle that is the tallest. Instead, the height of the triangle is the length of a perpendicular line segment to the triangle's base.

Like other PSTs, Sophia shared the challenges with academic rigor during a lesson debrief:

> When I asked questions [to students] I got a lot of blank stares. When students asked me questions, I responded with questions to get them to think, but they kept getting frustrated and wanted to give up. It was a mess.

Lastly, 5 PSTs wrestled with covering versus going deep with the content standards. Many PSTs wanted to spend more time with the PBL unit, but they were tied to the school curriculum's pacing guide. Viviana shared her frustrations:

> If I had cut out some of the standards or lengthened the project, the students and I wouldn't have felt as rushed. I could have gone more in depth with the standards which would give the students more time to dig in the material.

It is important to note that these PSTs did not have teaching experience prior to implementing their PBL units. The semester prior to implementation, PSTs observed and assisted classroom teachers, and engaged in several co-teaching activities. PSTs' challenges in academic rigor were compounded due their beginning understanding of pedagogical content knowledge.

Applied Learning

Successes.

PSTs experienced two successes with their PBL units in Applied Learning. First, 8 PSTs liked how students learned new technology (such as using CAD [Computer Aided Designs], Geogebra, etc.) to uncover math concepts, and learned new technology to keep their projects organized (i.e., Google Apps for Education). Mathematics-specific technology was used to deepen students' conceptual understanding and construct experiences that allowed students to grapple with the mathematics. Google Apps such as Google Folders and Team Drive allowed students to save their work digitally for their peers to access at convenient times. Google Docs and Google Slides were uploaded to Google Folders where students could simultaneously work on documents collaboratively. Second, 8 PSTs enjoyed how students worked independently but also collaborated with their peers to complete the project. Seth's reflection illustrates how many PSTs felt in providing students opportunities to apply their learning:

> The PBL unit required students to work in groups and collaborate. It also empowered them to keep each other on task and be responsible for the work of the group. They were also required to keep a daily journal cataloging their progress through the project.

Challenges.

PSTs also experienced the hardest challenge in this area compared to all of the Six A's. The first challenge was related to classroom management and overseeing student progress: students struggled with managing time and keeping progress on their projects. Mia's statement embodies the same frustration that all 7 PSTs experienced, "Some students had horrible time management and did most of the project very last minute."

The second challenge became a common issue when students were new to the technology and were learning the technology while completing the project. Learning the technology hampered students' progress on the project, as indicated by 7 PSTs.

Lastly, 6 PSTs indicated students struggled with how to organize and present their material to an informed audience. For example, Mia shared, "I need to show the kids how to have a balance of information and pictures in their slideshows." It is important to note that all the PSTs in this study were in schools that did not fully embrace PBL practices. Therefore, this method of learning was a new process to the students. Presenting their product to an informed audience was very new to students, and they needed much guidance and direction.

Active Exploration

Successes.

PSTs reflected on the level of active exploration their students demonstrated. Six PSTs stated that students were proactive in asking for workshops or content help so they could complete the project, students used inquiry to learn concepts, and students took control of their own learning. Adrian explained:

> The project taught the students how to take control of their own learning. I realize now that teaching is not as much about having students learn the content as it is teaching them how to answer content questions on their own. Almost all of my students had zero experience with PBL before my project. I was very transparent with them, letting them know how the process worked. By doing this, I think I got their feet wet in the process. Whereas before the students had no clue what PBL was, they now know that PBL is a different way to learn the same standards.

Adrian's comment is pivotal because many PSTs started to see the uniqueness of this clinical residency program. One advantage of being a PST in this clinical residency program was learning what it means to learn and deviate from traditional didactic teaching methods. The PST's comment of "realiz[ing] now that teaching is not as much about having students learn the content as it is teaching them how to answer content questions on their own" is a pivotal shift in understanding and enacting PBL instruction. Teaching students the PBL process and "getting their feet wet" when little or no students had experience with PBL was a major success in Active Exploration.

Challenges.

Seven PSTs experienced challenges related to the lack of student engagement and students' inability to take ownership of their own learning. PSTs expressed their own frustrations when students who were given the opportunity to actively explore refused to do so. Josh voiced his frustrations:

> I emphasized that during this project, our emphasis would be on learning the material through asking and answering our own questions, learning to use our textbook and the internet as resources, and learning to stay organized during a three-week project. They initially pushed back and got frustrated when I didn't directly answer their questions, especially because the project allowed multiple solution paths to a problem. While the math is rigorous, the way it is applied can vary between groups. In particular, student choice was available in the presentation of [student work]. Some students embraced this, while others found it frustrating.

This sentiment was felt by seven PSTs as they implemented their units for the first time. They raised the concern of how to appropriately scaffold and structure student experiences so that they were actively exploring and taking the initiative to learn on their own. They questioned how to support students and their roles as facilitators of learning environments.

Adult Connections

Successes.

There were two successes that emerged from the data in Adult Connections. First, 10 out of 11 PSTs had community partners participate throughout the PBL unit. PSTs recruited various members from the community and built their partners' roles throughout the project so that students were given the opportunity to interact with adults. In particular, nine PBL units had community partners who were heavily involved with the implementation of the units during the launch of the project and during students' presentation of their products. Second, five PSTs experienced supportive administrators who were willing to cultivate community partnership experiences, and the administrators themselves attended the students' presentations. Josh said about his experience, "I like that I ended up with two community partners and a lot of parent involvement. I like that other teachers and staff at the school got involved in the project."

Challenges.

One recurring challenge PSTs expressed was the inability to involve more community partners who had STEM careers/backgrounds. For example, Sophia wished her project included "a member of the CDC [Centers for Disease Control and Prevention] or lab that deals with infectious diseases so that the students could see people working directly with mathematical models" and Adrian wondered if a "statistical researcher could show how these skills [i.e., data collection, survey] are actually used in real life." Three PSTs felt that having someone in a STEM field talk about how his/her work directly connected to the content would provide a means for authentic and relevant learning and exposure to how mathematics is used in the real world.

Assessment Practices

Success and Challenges.

Monitoring group and individual progress was a strength and challenge for all PSTs. All PSTs expressed their ability to closely monitor groups' work and assess individual students' understanding of content in various ways, but also voiced concerns of needing to create more benchmarks and daily checks throughout the duration of the project. For example, Viviana commented:

> PBL is hard work! It is VERY crucial to have everything scaffolded for the students. Don't assume that students know certain things like how to research before you begin [the project]. It is important to have either taught students the soft skills that are required or to make sure you build time into the PBL to teach the soft skills.

In addition, six PSTs felt they needed a more detailed rubric that laid out the expectations of project work and descriptions of what it meant for students to think more deeply.

Limitations of the Study

Limitation of this study was that success for designing and implementing PBL units was based on participants' perceptions. To mitigate self-reported response bias, PSTs were asked to reflect on their PBL experiences using the Six A's framework as a guide so that there was a common language. Furthermore, researchers conducted classroom observations to support or refute PSTs' perceptions of success. Nonetheless, only perceptions of PBL success could be reported.

Another limitation is that the instructor of the PBL courses heavily engaged in all research aspects of this study, including attending classroom observations, examining field notes, and facilitating group interviews. It is important to acknowledge that when group interviews are being conducted by an instructor, there is no anonymity of PSTs' statements and their level of contribution is affected because there are consequences of asymmetrical power relationships of interviewer and interviewee. In addition, group dynamics vary from cohort to cohort, and the sharing of PBL experiences could be affected by a cohort-based issue or outspoken PST.

Discussion

The results of this study raise several issues regarding the question that we posed earlier: that is, what successes and challenges do mathematics preservice teachers experience as they implement project-based learning for the first time? We elaborate on this question below based on prominent findings, and discuss the implications of the findings for PBL practice in clinical residency settings.

Involving the Community

PSTs felt that having a community partner made the project come to life because it involved real-world applications. Five PSTs in this study decided to pursue teaching careers after being in the workforce. All five of these PSTs used their workforce networks to include a community partner that they were familiar with, or used their workforce knowledge to design a unit. For example, Tucker, a civil engineer, partnered with a local engineering company, and Seth, a retired police officer, had students investigating bullet trajectories. While some PSTs felt that finding a community partner was difficult, one of the ways PSTs alleviated this problem was to utilize people that they were already connected with.

True partnerships with the community can take time to build. Finding and working with a community partner is one of the biggest challenges in the PBL process (Lee et al., 2014). Securing and recruiting community partners and maintaining these relationships over an extended period of time can be difficult, especially in the confines of an academic schedule. However, involving community members in a PBL unit raises the bar for students and increases their level of engagement (Lee, 2012; LIFE Science of Learning Center, 2018). Projects become extended processes of inquiry when students take on the role of helping community members solve a problem or question.

Facilitating Mathematical Learning

While math PSTs experienced students having high levels of engagement because of the rich context of the projects, they struggled to keep the content alive. Kacey and Viviana, among others, felt there was a disconnect between the mathematics and solving the project's challenge at times. Balancing context and content during the PBL process means being intentional and articulating how learning the content helps answer the context of the project (see Lee, 2018). For example, learners may learn about quadratics through a project that is situated in a projectile motion; learners also need to transfer and demonstrate their understanding of quadratics in other contexts that do not involve projectile motion. Guiding learners to make connections among disjointed activities and important key mathematical ideas supports high-level mathematical thinking and reasoning (Henningsen & Stein 1997; Staples 2007). Stein, Engle, Smith, and Hughes (2008) noted that a productive teacher practice in orchestrating whole-class discussion is for the teacher to help the class make mathematical connections between different class activities. Engle (2006) calls this "contextual scaffolding within PBL instruction" and says that teachers should support students in transferring the knowledge they gain in one setting to the project's context. Making connections between the content and the context of the project is extremely crucial in mathematics PBL instruction. It is important for future math teachers to study how to orchestrate whole-class discussions and facilitate students to make connections between different class activities so the mathematics is foregrounded.

PBL math instruction requires the teacher to have strong content and pedagogical knowledge. PSTs' beginning levels of pedagogical knowledge inhibited them to go deep with the mathematics. Seth asked procedural questions while Sophia missed an opportunity to clarify a student's misconception. PSTs did not anticipate the kinds of content roadblocks their students would have, and wished to have more scaffolding activities for their students. Research shows that teachers must identify and anticipate possible learning challenges in order to appropriately scaffold learning. One way to scaffold activities is to create cognitively demanding tasks that address content roadblocks, and support students' engagement with content without immediately giving the answer (Lepak, Wernet, & Ayieko, 2018; Staples, 2007). Thus, the challenge is for teachers to maintain a focus on student thinking, support students in demonstrating their understanding of the underlying mathematics with which they are engaging, and ensure that students are indeed able to engage with accurate information. Having future math teachers engage themselves in tasks that do not immediately have an answer and require them to problem-solve helps PSTs build strong content and pedagogical knowledge.

Transforming the Learning Environment

The findings indicate that transforming the learning environment in ways that would support successful implementation of PBL requires changes to curricula and instruction as well as shifts in teachers' thinking about how learning occurs. This shift takes time. This teacher residency program greatly scaffolded PSTs' learning about PBL. Zhang, Ridgway, and Sachs (2015) mention a systematic way to prepare PSTs to incorporate PBL into their profes¬sional practice using a four-step approach: Observe It, Experience It, Create it, and Become it. In this study, PSTs in a teacher residency program experienced PBL for themselves by doing PBL units in their program, and created and taught a PBL unit in their clinical setting, in hopes to ultimately understand what it means to become PBL-minded. Micah reflected on his "learning by doing" process:

> Implementing my PBL project has greatly enhanced my understanding of PBL. Prior to [the summer], I had heard about PBL from a prior cohort member but did not know anything more than the name and its acronym. Then, in [the summer], after learning what PBL is, I learned the benefits of this type of instruction. Then, [in the] fall, I learned about the elements of PBL and how to create a PBL unit. Then, [in] the beginning of the spring semester, I learned how to implement a PBL unit. Then, toward the end of the spring semester, I implemented my PBL unit. Through this implementation, I learned how to facilitate workshops, facilitate student work time, conduct [Need to Know] sessions, work with a community partner, create a final product, and facilitate student presentations to our community partners. Becoming familiar with PBL at this level would not have occurred for me without implementing a PBL unit on my own. I am someone who learns by doing and not just by listening to others or reading.

Students' change in thinking about how learning occurs and what mathematics entails also requires time and effort. Some PSTs were successful in getting students to reconceptualize what learning meant—taking ownership of one's learning and enjoying the learning process. Adrian shared how students took ownership of their learning:

> I realize now that teaching is not as much about having students learn the content as it is teaching them how to answer content questions on their own. Before this project, I did not think my students would ask the proper questions to get the content, but many students asked questions that went beyond the content as I saw it, so I actually was able to cover more content through the project than I expected.

Likewise, Mia shared how students started to see the value in enjoying the mathematical learning process, rather than the satisfaction of just getting the answer:

> One of my favorite moments from a [class] was when I had a student ask me if "this is the right answer" and I honestly did not know. The student was annoyed when I told him I did not know the answer, but he quickly understood when I had him explain to me how he got that answer that it was more important how to get to the result and not the answer itself.

PBL instruction can disrupt teachers' sense of identity, how they perceive themselves as a teacher, and what their role should be in the classroom environment. In this study, PSTs were learning to adopt PBL practices as they were student teaching and attempting to make it part of their repertoire. For any teacher doing PBL for the first time, shifting to a PBL approach is a challenging endeavor as it necessitates simultaneous changes in instructional materials and resources, pedagogical strategies, and assessment practices. When considerable amount of time and support is given to adopting PBL teaching practices, high-quality projects can increase engagement and help meet the needs of all learners.

Implications for PBL Practice in Clinical Residency Settings

This study suggests several implications for PBL practice in clinical residency settings. First, administrative support must be provided at the district level and at the classroom level. PSTs voiced frustrations that they had to "fit" their PBL units within the district's pacing guide and there was little room to negotiate how long they could spend with the PBL units. Marshall et al. (2010) also found that regimented, prescribed curriculum guides forced PSTs to limit the time they spent on their PBL units. Similarly, many PSTs were placed in clinical residency settings where their cooperating classroom teachers did not embrace PBL practices, and many mathematics classrooms still had students sitting in rows. While PSTs were learning about PBL, their PBL experiences may have been supported if ongoing professional development and mentoring was extended to cooperating classroom teachers. Like K-12 teachers, PSTs in this study indicated the need for systemic change that would support their use of PBL, including administrative support for implementation and reconsideration of what math teaching looks like (Ertmer & Simons, 2006; Paredes Scribner & Bradley-Levine, 2010).

Second, while PSTs took PBL-specific courses, they would have benefited by being in a PBL-practicing school. PSTs must have opportunities to have field experiences that are consistent with what they have learned in teacher preparation programs. Learning how the theory and practice intertwine would give PSTs first-hand experience on what it means to be a PBL teacher.

Third, questions remain regarding the sustainability of PBL over time given the essential role of community partnerships and the complexities of managing students and groups while keeping the mathematics rigorous and at the forefront of learning. Christina reflected on the reality of using PBL in her future classroom:

> PBL requires an incredibly high level of creativity in the math classroom to make genuine connections to the real world. I think that the PBL method can be highly effective but it is literally impossible to teach all of the standards for high school mathematics effectively because the application of many of the standards takes the learner pretty far from the objectives outlined in the standards.

Future Research

The intent of this study was to gain a deeper understanding of the successes and challenges PSTs experienced as they implemented PBL units in their math classrooms for the first time. Adrian, along with other PSTs, recognized that PBL "is teaching [students] how to answer content questions on their own" rather than being didactic and authoritative. Understanding and practicing this notion of what it means to be a PBL mathematics facilitator requires shifting one's lens of what it means to teach and learn mathematics, while creating classroom cultures that focus on flexible and robust understandings of math. This departure from conventional modes of mathematics teaching involves more than just a change in teachers' knowledge (see Lee et al., 2014; Lee, 2018); it requires that teachers (and students) reconceptualize what it means to teach and learn, and that they create new and different opportunities for learning in and out of classrooms. Future research that delineates PBL math dispositions would be helpful for teacher preparation and clinical residency programs. Doing so will help illuminate the kinds of activities and experiences PSTs need to engage in, and bolster support for PSTs to successfully experience new modes of instructional learning like PBL.

PSTs in this study were immersed in an intensive yearlong clinical residency PBL program. PSTs who experience a PBL curriculum are entering the teaching profes¬sion armed with knowledge of PBL as a creative and authentic methodology for engaging learners. PBL is known for transforming lives and school culture (Lenz, Wells, & Kingston, 2015). A longitudinal study that follows PSTs in a clinical residency PBL program is worthwhile. What impact does a clinical residency PBL program have? How do PSTs adopt and retain PBL practices as they become fledging teachers, and how do they contribute to their school community? Investigating these aspects would help strengthen clinical residency PBL programs, and ultimately improve the PBL experience of PSTs.

References

Alter, J., & Coggshall, J. (2009). Teaching as a clinical practice profession: Implications for teacher preparation and state policy. New York Comprehensive Center and National Comprehensive Center for Teacher Quality. Retrieved October 5, 2020, from https://gtlcenter.org/sites/default/files/docs/clinicalPractice.pdf

American Association for the Advancement of Science [AAAS]. (1993). Benchmarks for Science Literacy. Oxford University Press.

Baysura, O. D., Altun, S., & Yucel-Toy, B. (2015). Perceptions of teacher candidates regarding project-based learning. Eurasian Journal of Educational Research, 62, 33–54.

Center of Excellence in Leadership of Learning [CELL]. (2012). New Tech in Indiana: Education reform for economic development. Retrieved October 5, 2020, from https://www.inphilanthropy.org/resources/project-based-learning.

Condliffe, B., Visher, M. G., Bangser, M. R., Drohojowska, S., & Saco, L. (2017). Project based learning: A literature review. MDRC.

Common Core State Standards Initiative (CCSSI). (2010). Common Core State Standards for Mathematics. National Governors Association Center for Best Practices and the Council of Chief State School Officers. http://www.corestandards.org/the-standards/mathematics.

Creswell, J. W. (2013). Qualitative inquiry & research design: Choosing among five approaches (3rd ed.). Sage

Publications.

Dag, F. & Durdu, L. (2017). Pre-service teachers' experiences and views on project-based learning processes. International Education Studies, 10(7), 18–39.

Drake, J., Moran, K., Sachs, D., Smiley Angelov, A. D., Wheeler, L. (2011). The University of Indianapolis Woodrow Wilson Indiana Teaching Fellowship Program: Reviewing the policy implications of university-based urban clinical residency programs in stem teacher preparation. Planning & Changing, 42(3/4), 316–333.

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. Journal of the Learning Sciences, 14(4), 451–498.

Ertmer, P. A. & Simons, K. D. (2006). Jumping the PBL implementation hurdle: Supporting the efforts of K-12 teachers. Interdisciplinary Journal of Problem-Based Learning 1(1), 40–54.

Fogleman, J., McNeill, K. L., and Krajcik, J. (2011). Examining the effect of teachers' adaptations of a middle school science inquiry-oriented curriculum unit on student learning. Journal of Research in Science Teaching, 48(2), 149–169.

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. Journal of Research in Science Teaching, 45(8), 922–939.

Giorgi, A. (Ed.). (1985). Phenomenology and psychological research. Duquesne University Press.

Goodman, M. J., Sands, A. M., & Coley, R. J. (2015). America's Skills Challenge: Millennials and the Future. Educational Testing Service.

Harris, C. J., Penuel, W. R., DeBarger, A. H., D'Angelo, C., & Gallagher, L. P. (2014). Curriculum materials make a difference for next generation science learning: Results from Year 1 of a randomized controlled trial. SRI International. Retrieved October 5, 2020 from, https://assessment.sri.com/downloads/pbis-efficacy-study-y1-outcomes-report-2014.pdf

Henningsen, M., & Stein, M. K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematical thinking and reasoning. Journal for Research in Mathematics Education, 28, 524–549.

Indiana Department of Education [IDOE] STEM Council Members. (2018). Indiana STEM six-year strategic plan 2019-2015. Indiana Department of Education. Retrieved October 5, 2020 from, https://www.doe.in.gov/sites/default/files/wf-stem/stemcm06-final_draft_stem_plan_august_24_2018_v1.pdf

Klein, E. J., Taylor, M., Onore, C., Strom, K., Abrams, L. (2016). Exploring inquiry in the third space: Case studies of a year in an urban teacher-residency program. New Educator, 12(3), 243–268.

KnowledgeWorks Foundation (2018). Future forces affecting education. Retrieved October 5, 2020, from https://knowledgeworks.org.

Lee. J. (2018). Tips for teachers from a PBL mathematics educator. In Jean Lee & Enrique Galindo (Eds.), Rigor, relevance, and relationships: Making mathematics come alive with project-based learning (pp. 213–220). National Council of Teachers of Mathematics.

Lee, J. S. (2012). Making projects become real projects. The Indiana Mathematics Teacher, pp. 7–10.

Lee, J. S., Blackwell, S., Drake, J., & Moran, K. (2014). Taking a leap of faith: Redefining teaching and learning in higher education through project-based learning. Interdisciplinary Journal of Problem-based Learning, 8(2). https://doi.org/10.7771/1541-5015.1426.

Larmer, J., Mergendoller, J., & Boss, S. (2015). Setting the standard for project based learning. ASCD.

Lattimer, H., & Riordan, R. (2011). Project-based learning engages students in meaningful work: Students at High Tech Middle engage in project-based learning. Middle School Journal, 43(2), 18–23.

Lenz, B., Wells, J., & Kingston, S. (2015). Transforming schools: Using project-based learning, performance assessment, and common core standards. Jossey-Bass.

Lepak, J. R., Wernet, J., Ayieko, R. (2018). Capturing and characterizing students' strategic algebraic reasoning through cognitively demanding tasks with focus on representations. Journal of Mathematical Behavior, 50, 57–73.

LIFE Science of Learning Center. (2018). Outside experts boost project authenticity. Retrieved October 5, 2020, from https://www.edutopia.org/video/outside-experts-boost-project-authenticity.

Loudon, B. (2015). Creating authentic and relevant science curriculum through project-based learning. [Masters Thesis, Montana State University]. https://scholarworks.montana.edu/xmlui/handle/1/9273

Markham, T., Larmer, J., & Ravitz, J. (2003). Project based learning handbook: A guide to standards-focused project based learning (2nd Ed.). Buck Institute for Education.

Marshall, J. A., Petrosino, A. J. & Martin, T. (2010). Preservice teachers' conceptions and enactments of project-based instruction. Journal of Science Education and Technology, 19(4), 370–386.

Martinez, M. (2010). Teacher education can't ignore technology. Phi Delta Kappan, 92(2), 74–75.

Mioduser, D., & Betzer, N. (2007). The contribution of project-based-learning to high-achievers' acquisition of technological knowledge and skills. International Journal of Technology and Design Education, 18(1), 59–77.

Mourlam, D. J., De Jong, D., Shudak, N. J., Baron, M. (2019). A phenomenological case study of teacher candidate experiences during a yearlong teacher residency program. Teacher Educator, 54(4), 397–419.

Moustakas, C. (1994). Phenomenological research methods. Sage.

National Council of Teachers of Mathematics [NCTM]. (2018). Catalyzing change in high school mathematics. Author.

National Council of Teachers of Mathematics [NCTM]. (2014). Principles to actions: Ensuring mathematical success for all. Author.

National Council of Teachers of Mathematics [NCTM]. (2000). Principles and standards for school mathematics. Author.

National Research Council [NRC]. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas (committee on a conceptual framework for new K-12 science education standards. Board on science education, division of behavioral and social sciences and education ed.). The National Academies Press.

National Science Teachers Association [NSTA]. (2018). Preparing teachers for three dimensional instruction. NSTA.

Paredes Scribner, S. M. & Bradley-Levine, J. (2010). The meaning(s) of teacher leadership in an urban high school reform. Educational Administration Quarterly, 46(4), 491–522.

Partnership of 21st Century Learning. (2018). Framework for 21st century learning. Retrieved December 28, 2018, from http://www.p21.org/our-work/p21-framework.

Ricci, L. A., Persiani, K., Williams, A. D. (2019). From 'training wheels for teaching' to 'cooking in your mother-in-law's kitchen': Highlights and challenges of co-teaching among math, science, and special education teacher candidates and mentors in an urban teacher residency program. International Journal of Whole Schooling,15(2), 24–52.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. Journal of Research in Science Teaching, 39(5), 410–422.

Shwartz, Y., Weizman, A., Fortus, D., Krajcik, J., & Reiser, B. (2008). The IQWST experience: Using coherence as a design principle for a middle school science curriculum. The Elementary School Journal, 109(2), 199–219.

Staples, M. (2007). Supporting whole-class collaborative inquiry in a secondary mathematics classroom. Cognition and Instruction, 25, 161–217.

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. Mathematical Thinking and Learning, 10, 313–340.

Sutiadiningsih, A., Nurlaela, L., Hasan, A. S. K., & Sutadji E. (2017). The implementation of the good character and project-based learning to improve students' orientation towards task and achievement. International Journal of Management and Administrative Sciences, 4(9), 1–15.

Tsybulsky, D. & Oz, A. (2019). From frustration to insights: Experiences, attitudes, and pedagogical practices of preservice science teachers implementing PBL in elementary school. Journal of Science Teacher Education, 30(30), 259–279.

Ward, J. D., & Lee, C. L. (2002). The Journal of Family and Consumer Sciences Education, 20(1), 16–26.

Yetkiner, Z. E., Anderoglu, H., & Capraro, R. M. (2008). Research summary: Project-based learning in middle grades mathematics. Retrieved December 28, 2019, from http://www.nmsa.org/Research/ResearchSummaries/ProjectBasedLearninginMath/tabid/1570/Default.aspx

Zhang, G., Ridgway, A., & Sachs, D. (2015). Cultivating preservice secondary teachers for project-based learning: A four-step model. AILACTE Journal, 12(1), 1–15.

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APPENDIX A. PBL UNIT REVISIONS TEMPLATE

Answer the questions below. Then, reflect on your PBL unit and type directly in the matrix below. Bullets prompt you to include responses to those specific aspects, although do not feel that your responses are limited to only those.

1. How did the project enhance your students' understanding of PBL?
2. How did the project enhance your understanding of PBL?
3. How do you feel about PBL in general?

	What you liked	**What you wonder**	**What you plan as next steps**
Authenticity • Complexity of the unit • Effectiveness of Entry Event • Authenticity/meaning to the students • Appropriate audience for students' work			[What revisions would you make? Why?]
Academic Rigor • Quality and use of Driving Question • Selection of content standards • Scope and depth of central concepts, knowledge and skills, and Standards			
Applied Learning • Use of technology • Selection of appropriate 21st century skills • Ability of students to work well in groups and independently			

Active Exploration • **Levels of student engagement** • **Ability of students to use inquiry skills and thinking deeply** • **Student-centered instruction**			
Adult Connections • Number of subjects/ people/ organizations involved • Involvement of other adults • Adequacy of resources			
Assessment Practices • Enhancement of skill • retention or standards mastery • Selection of culminating products and performances • Quality of rubrics • Quantity and mix of scaffolding and learning activities • Structured levels for students to self-assess their progress • My management of the process, coaching of students, and providing support			