

# A Case Study Analysis of Problem-Based Learning within a Fabrication Laboratory in a Southwestern Secondary Charter School

## Abstract

*The purpose of this study was to explore how teachers at a southwestern secondary private charter school utilize the on-campus fabrication lab to promote the implementation of problem-based learning (PBL). Guided by the theory of constructivism, I qualitatively explored the processes teachers engage in when implementing a PBL lesson using a multi-case study design. Five teachers and two fabrication lab directors from various content areas were interviewed and observed. Five overall themes emerged from the data: 1) the differing emphasis on PBL framework components; 2) conflicts, limitations, and constraints perceived with PBL; 3) teachers use of PBL for cognitive development; 4) the role of the environment in PBL; and 5) the role of reflection in the PBL framework. Research recommendations include further exploration into the factors that contribute to a positive environment conducive to PBL, in-depth investigation into the role of each step in the PBL framework, and additional observation periods to elicit the impacts of PBL over time. Recommendations for practice include purposeful teacher reflection, scaffolded planning, strengthening connections between PBL and real-world applications, and strategies for increased student support and encouragement in the classroom.*

**Keywords:** Problem-Based Learning; Charter Schools; Case Study Analysis; Fabrication Laboratory

## Introduction

There are two general categories of methodological approaches for formal classroom instruction: student-centered and teacher-centered (Phipps et al., 2008). Student-centered teaching methods (i.e. learner-centered) focus on developing educational outcomes through involving students in their own learning process, while teacher-centered methods focus on students acquiring knowledge of concepts via direct teacher instruction (Collins & O'Brien, 2003). Student-centered methods often lead to student mastery in discipline specific content knowledge but can also contribute to the development of various professional skills (i.e. soft skills) (Mong & Ertmer, 2013; Morrison et al., 2015; Roberts et al., 2016). In agriculture education settings, student-centered teaching methods adapt well in the non-traditional environment and within each of the three components of agriculture education (Phipps et al., 2008).

To achieve learning outcomes focused on the development of professional skills, student centered methods are among the most impactful tools at a teacher's disposal (Nilson, 2016). These methods often involve more complex levels of decision making and critical thinking than traditional teacher-centered methods (Mong & Ertmer, 2013), a transferable skill valued by 21<sup>st</sup> century employers (Messum et al., 2017). While various student-centered methods can be considered effective and worthy of further investigation, I focused on problems-based learning (PBL) in this study because of its practical applicability to the development of critical thinking, decision-making, and other 21<sup>st</sup> century skills needed within interdisciplinary and agricultural education. PBL is the use of real-world application problems within an instructional sequence (Barrows, 1986). Aligning with the constructivism learning theory, which emphasizes the creation of understanding through experience (Schunk, 2012), many instructional principles within the two overlap, such as: 1) conflict is a stimulus for learning, 2) knowledge evolves through evaluation and viability, and 3)

environmental interactions and complexities are integral to knowledge development (Savery & Duffy, 1995).

PBL can be used in a variety of educational disciplines and classroom settings, and each application pulls from a specific objective associated with the process (Dahlgren et al., 1998). Objectives achieved using PBL are highly associated with critical thinking and reaching levels of creating and evaluating within Bloom's revised taxonomy (Anderson et al., 2001). While PBL has been shown to develop student interdependence, self-directed learning, effective reasoning processes, and orient students within group processing (Barrows, 1986; Savery & Duffy, 1995; Takahashi & Salto, 2018), teacher knowledge of the method is another critical point to consider for successful implementation at middle and high school levels. The adoption of PBL in the classroom focuses on facilitating students in the learning process rather than transferring or supplying knowledge (Mong & Ertmer, 2013), which requires teachers to possess specialized knowledge related to both the PBL method and the technical content.

From a pedagogical perspective, knowledge of teaching methods on behalf of the instructor can provide clarity and understanding to subject matter (Darling-Hammond, 2006). Teachers require a working knowledge of pedagogical strategies, in addition to their readily available content knowledge, to aid students in the learning process (Mong & Ertmer, 2013). Because of its highly integrated planning and execution process, the pedagogical knowledge surrounding the constructivist nature of PBL introduces some limitations to its usage for teachers. The most prohibitive limitation for this method is a teacher's willingness to adopt. Without training or proper understanding of student-centered pedagogy, teachers' decisions in the classroom can become subconscious and act opposingly to the components of PBL (Mong & Ertmer, 2013). Implementation of PBL is complex, creating the potential for teachers to engage in the method ineffectively. This can lead to a lack of motivation, independence, and freedom to explore the problems for students (Mong & Ertmer, 2013; Seng 2014; Smith et al., 2005).

Currently, most publications surrounding PBL are centered on its effectiveness and the skills it develops in students (Burriss & Garton, 2007; Mong & Ertmer, 2013; Takahashi & Salto, 2018; Wells et al., 2015), while only a few address teachers' perspectives on using PBL in the classroom (Dahlgren et al., 1998; Morrison et al., 2015; Smith et al., 2005). Due to teachers being a critical component to the adoption of this dynamic, student centered method, investigation into teachers' perspectives were warranted.

### **Purpose and Central Research Question**

This study aligns with the American Association for Agriculture Education research agenda priority four—meaningful and engaged learning in all environments (Roberts et al., 2016). The purpose of this study was to explore how teachers at a southwestern secondary private charter school (Brockson Academy) utilize the on-campus fabrication laboratory (Fab-Lab) to promote the implementation of PBL. Using a multi-case study approach, I explored teachers' perspectives on the process of implementing PBL as an instructional method in their classroom. The central research question that guided my study was: how do teachers at Brockson Academy utilize the Fab-Lab to facilitate PBL? My secondary research question was: what processes do they go through for PBL implementation?

### **Literature Review and Frameworks**

Various student-centered methods often overlap in the learning outcomes desired for students and the overall process of implementation (Nilson, 2016; Walker & Leary, 2009; Wells et

al., 2015). However, despite similarities, each student-centered method has its own purpose and suggested approaches. Three commonly utilized student-centered methods that appear similar in their outcomes are: inquiry, problem, and project-based methods. In inquiry-based learning, teachers provide students with information on a problem or experience, and students then investigate and examine the content, provoking questions for future learning experiences (Collins & O'Brien, 2003). Objectives for the inquiry-based method focus on inquiring into a question or concept and the process of understanding, often involving experimental explorations. Project-based learning associates a specific project with a tangible outcome to promote in-depth application and understanding of a central idea (Collins & O'Brien, 2003). Outcomes in project-based learning are associated with “design” and “create” objectives, where teachers and students can then evaluate their learning based on their final project. Finally, PBL also involves outcomes of a process, similar to inquiry, but focuses on the student’s ability to critically identify the problem and background knowledge needed for generating a solution (Savery & Duffy, 1995). The over-arching nature of inquiry-based learning guides the processes of problem and project-based learning. Elements of inquiry will always be identifiable in both problem and project-based scenarios; likewise, project-based learning will include elements of PBL. PBL approaches can have an associated project to accompany their solution while still engaging in content exploration and problem identification.

### **Conceptual Framework- Problems-Based Learning Process**

In its simplest form, Barrows (1986) defines PBL as the use of problems in an instructional sequence. More so, it is the identification of real-world problems combined with practical approaches to solve those problems (Barrows, 1986; Takahashi & Salto, 2018). Generally, PBL in the classroom helps to answer the “how’s” of an issue. The ways this method is used will vary depending on the instructional setting but will generally follow a process of implementation. Coupling several models (Barrows, 1986; Savery & Duffy, 1995; Smith et al., 2005), the PBL process examined in this study followed these steps:

1. Present background knowledge on a topic.
2. Provide students a problem relating to the topic.
  - a. OR Students identify a problem within the subject.
3. Students examine the content and identify the parameters of the problem within their content knowledge under teacher supervision and facilitation.
4. Students explore and investigate the possible solutions using practical logic.
5. Students and teachers reflect and analyze the solutions in terms of the previously defined parameters.
6. Students engage in a constructive debriefing relating the outcomes of the process to the original problem.

This process moves the role of the teacher into a facilitator, where the interactions between students and teachers are focused on guiding students thinking rather than relaying direct information (Dahlgren et al., 1998). Components of PBL that I examined in this study were directly concerned with the teacher’s role within this method. Each step scaffolded with the others cumulatively affects the outcome of PBL (Mong & Ertmer, 2013).

When examining PBL methods used from a teacher perspective, it is important to consider knowledge of the method itself, knowledge of the technical content, and the combination of those knowledge areas known as pedagogical content knowledge (PCK) (Darling-Hammond, 2006; Shulman, 1986). Specifically related to pedagogical knowledge, pedagogies of engagement incorporate student-centered teaching methods into classroom practices. Smith et al. (2005) described pedagogies of engagement as a continuous pattern of involvement in learning. Classified as pedagogy of engagement, PBL can bring upon several challenges to teachers with a lack of pedagogical knowledge, content knowledge, or the combination of the two in the engagement area.

As a method of engagement, PBL requires the teacher to take-on different roles within the process—planning, guiding, and debriefing (Ball et al., 2008; Mong & Ertmer, 2013). Each of these proponents are vital to the successful execution of this method. With planning being the first step in the PBL process, it ultimately is a deciding factor for the continued success of the method. Having limited knowledge of PBL as a pedagogy can also cause difficulties when transitioning into teaching with this method. The planning involved can be overwhelming to teachers previously unfamiliar with the method, potentially causing them to revert to traditional didactic teaching methods (Mong & Ertmer, 2013; Smith et al., 2005).

Seng (2014) explored teachers' views of student-centered learning and revealed that the teachers generally reported a positive attitude towards student-centered approaches. The positive associations included an appreciation for student engagement, personal responsibilities, and analytical thinking (Seng, 2014). However, specifically to PBL, the planning component was the primary reason most teachers chose to disengage from the method (Mong & Ertmer, 2013; Seng, 2014). Negative perceptions of PBL are generally associated with the lack of content emphasis; teachers felt that their knowledge as a subject expert was not fully utilized when they served as a facilitator (Dahlgren et al., 1998; Seng, 2014).

For teachers, benefits of PBL include the promotion of equal learning opportunities and higher levels of student motivation (Seng, 2014). For students, engaging in PBL introduces the social component of the learning process and provides an opportunity for independent learning (Seng, 2014). Different educational disciplines also reap diverse benefits of PBL including invoking decision-making in students and the identification of alternative explanations, all within the context of the educational discipline or across multiple disciplines (Walker & Leary, 2009), including agricultural education.

### **Theoretical Framework- Constructivism**

Constructivism, as a learning theory, states that learners create their own understanding (Savery & Duffy, 1995). Ultimately, it is an epistemology that views learning and knowledge as a working hypothesis informed from outside forces (Schunk, 2012). Interactions occurring between individuals and outside forces allows them to *construct and create* their own understandings within a given context. The definition of student-centered learning aligns almost synonymously with constructivism- involve students in their learning by creating experiences and challenging their thinking (Schunk, 2012). There is an overlap of the two concepts of student-centered teaching and constructivism. Items of commonality within the overlap include learning as process, challenging thinking, and integration of experience. This theory fits strongly with this work for two significant reasons: 1) it reinforces the ideas of PBL as a teaching method; 2) it reinforces the method as a vessel for teachers to guide students to create their own understandings.

### **Fabrication Laboratories**

Fabrication laboratories (i.e. Fab-Labs), are a network of spaces that are designed to promote innovative design and creation. Often equipped with computing and manufacturing technologies such as laser cutters, 3D printers, CAD, and other design software; Fab-Labs support engaging in technology and prototyping. These community centers, as imagined by MIT Center for Bits and Atoms, were intended to be prototype shops for entrepreneurs as a space for problem solving and community driven innovation (Stacey, 2014). Through this network however, the uses have expanded unintentionally, but with positive impact, to secondary settings.

With collaboration as a primary focus of their structure, Fab-Labs are being supported through their diverse applications in curriculum at all levels of education (Stacey, 2014), leading to their rise in high school and college campuses. They are credited for breaking a dichotomy of traditional education, combining liberal and “illiberal” arts to create greater opportunities and possibilities within education (Stacey, 2014). In education, and high schools specifically, learning labs of any kind provide variation in teaching methods to engage students in the learning process, encouraging college and career ready practices, and encouraging cross-discipline studies. Fab-Labs use constructivist principles as a framework for action and promotion of complex understanding in an educational setting (Berland et al., 2014) that directly associate with the learning theory that guides PBL.

### **Methods**

This study followed a multi-case study design, investigating individual teacher’s as a single case at Brockson Academy and their use of PBL in the Fab-Lab. I utilized a multi-case approach, which allowed insight to instruction from several angles, aligning with my central research question. With each teacher serving as a single case, I had the opportunity to explore trends across teachers using PBL in their instruction within various education disciplines (Merriam, 2009). This is an example of cross case-synthesis- replication across this multi-case studied allowed for a richer analysis (Merriam, 2009). The methodology for this study is grounded in Merriam’s (2009) case study design and approached with a constructivist lens. The constructivist lens largely implies that meaning and understanding is created through shared experiences (Creswell, 2013). By approaching this study through a constructivist lens, I aimed to identify patterns of behavior within teachers using PBL, as well as construct a meaning of its use within a context, based on those experiences of the participants (Creswell, 2013).

It is important that my position on the subject, as well as any potential biases, are disclosed (Creswell, 2013). My interest in PBL stems from my undergraduate degree focus in informal education, where I learned how to use teaching methods in different contexts. Much of the curriculum I was taught about pedagogical knowledge was how and when to use certain methods given the context it was being taught. This shaped my view of PBL and led to my research question. Furthermore, my interest in the Fab-Lab specifically came from my internship with Brockson Academy. While serving as an assistant to the lab director in the Fab-Lab, I was fascinated with the kinds of projects that teachers had designed for students—some were complex and some incredibly simple. After viewing a variety of projects in the lab, I began asking myself how these projects were meaningful to students. I was curious what teachers were doing in the planning phases and what exactly teachers wanted students to learn. Having worked within this school system poses some potential biases; however, I will remain subjective throughout this study by focusing on processes in the moment rather than prior interactions (Creswell, 2013).

### **Site Description**

For this study, the cases were situated within a southwestern private charter school. This school was selected because of its curriculum integration with an on-campus Fab-Lab and alignment with PBL as a viable method for instruction (Morrison et al., 2015). Revisiting the Fab-Lab, it is equipped with many technologies to “make almost anything” (Stacey, 2014, p. 1), providing teachers many creative opportunities to use the space for instruction and cross-discipline integration. The Brockson Academy Fab-Lab has half of the area dedicated to the design-thinking process, supported by MIT and Stanford (Pauceanu & Dempere, 2018). The space has three wall-mounted white boards, three white board table tops, and a plethora of craft materials. On the other half of the space, the digital fabrication technologies exist. This includes computers for digital

designing and modeling, as well as a laser cutter, vinyl cutter, CNC router, 3D printers, and other assembly related power tools. Furthermore, the space has a problem-oriented process on the wall that is intended to help guide students through their design. The school also employs two co-directors to oversee and guide the use of the lab by students and teachers.

### Data Sources and Collection

To aid in a quality analysis (Merriam, 2009), I triangulated the data by investigating multiple sources including: a pre-interview, observations with field notes, a post-interview, and member-checking of findings with the curriculum consultants— all data sources that are commonly used in qualitative studies. The pre-interview included questions regarding teachers' perspectives on PBL and the Fab-Lab and how they have used or planned to use either. The observations were periodic throughout the unit being taught, included observations of the teacher in the classroom, as well as in the Fab-Lab. These observations were intended to capture the teachers' preparedness for the lesson, as well as the set-up they provided the students. To guide the observations, a checklist included the steps of PBL, comments on the ways teachers responded to student questions, and general teacher facilitation. Following the observations, a semi-structured post-interview was conducted that consisted of questions guiding the teachers through the process or exploring items witnessed during the observation.

Table 1 provides a summary of the participants selected. Data collection occurred during the 2019 spring semester, lasting approximately 20 weeks, for Brockson Academy. Completion of the pre-interviews within the first third of the semester, observations during the middle third, and the post-interviews within the final third. The lab directors were interviewed before individual interviews began and were consulted throughout the remaining data collection.

**Table 1**

*A visual representation of participants selected for this study.*

Pseudonym	MS or US	Years Teaching	Sub-Discipline Taught	Lesson
Sophia	US	7	Mathematics	Redesign a non-functioning greenhouse.
Mary	US	8	Composition and Literature	Build a physical structure to reveal decision making of a literary structure.
Jennifer	MS	12	History	Design a monument or memorial to include equal access and representation.
Anne	MS	20	History	Evaluate problems experienced throughout history.
James	MS	30	Science	Create a functioning seismograph.
Rebecca	MS Director	8	Math	N/A MS Lab Director
Ben	US Director	12	Physics	N/A US Lab Director

Note: MS- Middle School grades 5-8; US- Upper School grades 9-12

### Data Analysis and Trustworthiness

The primary strategy for analysis was pattern matching, with some consideration in cross-case synthesis (Merriam, 2009). Pattern matching in these cases coded the data for words and statements associated with the process, barriers, and strengths to PBL lessons. Cross-case synthesis was used to compare the patterns identified between each case, a recommended practice for multi-

case studies, while simultaneously increasing the internal trustworthiness of the study (Merriam, 2009). All data sources were utilized in analysis (a pre-interview, observations with field notes, a post-interview, and member-checking of findings with the curriculum consultants. I used NVivo 12 as my data management software and I began with an inductive analysis to help me capture a raw view of my data outside the lens of my supporting theory and frameworks, followed by a deductive analysis that anchored the findings within the frameworks I identified. After all data analysis was complete, I totaled 216 initial codes. Coupling these methods of analysis revealed patterns of behavior across cases, ultimately revealing five overarching themes of teacher experience using PBL.

To add to the trustworthiness of the study, I utilized three data sources including interviews, observations, and lab directors- combining multiple data sources with multiple analysis methods ensured triangulation of the data. In addition, I disclosed my positionality as it pertains to this study to address researcher objectivity before entering the field. To aid in my objectivity as well as the interview process, an interview protocol has been developed to guide the structure of the pre-interviews. I engaged in member checking of my emergent findings by conducting a follow-up with participants on the findings of my research to ensure that it was representative of their experiences (Creswell, 2013). Finally, I used memoing throughout the research process and utilized rich, thick descriptions in the form of participant quotes and detailed accounts of my observations (Merriam, 2009).

### **Findings**

The participant cases followed in this study revealed various approaches for implementing PBL. In two cases, problems were anticipated, planned, and accounted for by the teacher. In the remaining three cases, teachers focused on problem-solving as it arose within a project. From the data collected and analyzed, five overall themes emerged: the differing emphasis on PBL framework components; conflicts, limitations, and constraints perceived with PBL and the Fab-Lab; teachers use of PBL and the Fab-Lab for cognitive development; the role of the environment in PBL; and the role of reflection in the PBL framework.

#### **Differing Emphasis on PBL Framework Components**

A major theme that emerged from the data was the weight attributed to each of the six steps in the PBL framework that guided this study. Omitting steps was never the case; however, teachers chose to emphasize different steps of the PBL framework. This differing emphasis on steps altered the planning process for teachers both from a content standpoint and a logistical standpoint. When teachers emphasized an importance for steps one through three (background, problem identification, and analysis), their planning was heavily content based. When teachers emphasized steps four and five (investigation and trial), they spent more time planning the logistics and mechanics of a lesson, such as how long it was going to take, what materials would be provided, and what students were expected to do. Three of the teachers spent more of their efforts on steps four and five, two of them spent their efforts on steps one through three, and all five teachers included a representation of reflection described in step six.

Jennifer, a MS history teacher, closely guided her students through the background knowledge and examination of content, present in steps one and two of the PBL framework. I observed this in her classroom as she went through the content with her students a week before their application in the Fab-Lab. Her instruction was centered around a class-wide discussion where she tied in real-life examples, including past and current events that revolved around the topic. When it came to students discovering and implementing a solution for creating something inclusive

she placed more emphasis in the need for learning of a cognitive skill. She said, “When I create problem based or inquiry-based I choose kind of one thing I want [students] to get out. One [cognitive] skill and one kind of big [content] idea ...”

In the class period I observed, the assessment goal was verbal communication. Jennifer shared that her planning for the Fab-Lab session I observed was minimal, as she graded students’ communication and critical thinking development, an item that required intense, personal observation and note-taking of her students in action. Her seventh-grade students completed a self-evaluation that rated themselves on the same items she was observing, such as “student explores multiple solutions and innovative thinking develops and expands during session,” while Jennifer compared her notes to their personal comments.

In contrast, Sophia, a US math and science teacher, weighted the background knowledge and problem identification more heavily in her planning. She would critically analyze the content she wanted her students to learn and pull from her personal experiences to deliver information in class. She believed that students needed the foundational knowledge before applying it to a project to have the necessary resources to problem-solve. Sophia shared this rationale:

Usually with the inquiry part, I’ll just stop and think about an easy way for them to experience the concept. Or maybe not easy, but a simpler way still keeping the science and the math at its most simple and coming up with a project that has simplicity built into it for them to learn about a concept.

In the case of the greenhouse design lesson I observed, Sophia shared with me her attempts at recalling issues she faced in her past career that was applicable to her students. Then, based on her personal issues and experiences, she created a lesson for her students that focused on “what [she] would have liked to have known.” Sophia put more effort and class time into her delivery of content knowledge and background so that students were prepared with enough information to problem solve on their own.

Anne and Mary, a MS history and US composition teacher respectively, spent more time planning for logistical execution, by working heavily with the Fab-Lab directors to execute their vision in the most efficient way. This was evidence of planning for steps three and four, where more work was expected of students in the classroom on the front end, to ensure efficient uses of time. Both Anne and Mary shared that the amount of time they could sacrifice from other pieces of their curriculum were reasons they planned this way. While observing their lessons, they placed a lot of their time into helping students answer questions, talking to each student individually, and facilitating an efficient use of time in the Fab-Lab.

### **Conflicts, Limitations, and Constraints Perceived with PBL and the Fab-Lab**

PBL and the use of the Fab-Lab presented the participants with several challenges that inhibited their perceived ability to impact their students. The most common challenge faced by the participants was their struggle with students’ comfortability in ambiguity. This ambiguity lied in problem-solving as well as unfamiliarity with the Fab-Lab space. When asked about student’s responses to PBL and the Fab-Lab, Mary, a US composition and literature teacher, said:

I guess it was mixed. It's interesting and [Ben] brought this up too about the level of experience with the Fab-Lab, I think makes a big difference. I noticed with the older students and maybe just age in general or critical thinking experience in general... one of the students, a senior, barely even looked at the worksheet and was just like boom, she had a plan in building this elaborate structure almost immediately. Whereas another kid, who's a freshman and who's new to the school, was kind of just really stumped.



In this quote, Mary, whose class had a mix of ninth through twelfth graders, summarized what I personally witnessed in my observations of all classes. The amount of experience with the Fab-Lab between grade levels changed the amount of problem-solving and critical thinking students engaged in outwardly, and greatly impacted students' responses to the lesson. In older grades, there was less resistance, yet students weren't always keen to jump in with a new project. Younger grades wanted to go without being told what to do, but the students didn't know how without their teacher's guidance.

James, a MS science teacher, tried to mitigate this ambiguity beforehand, by giving students very pointed tasks and expectations of how to use their time. He shared that before telling the class that they will even be using the lab, he lays out a checklist of what needs to be completed by the end of the class period, and what the learning objective is for the day. These check off items and corresponding objectives were James strength in facilitating tasks within the Fab-Lab, yet James self-identified his remaining struggle with guiding his students. He said:

I guess every year I sort of struggle with how much do I guide them? Do I push them in to a certain way of thinking rather than just saying here are some materials and look at all the materials in the lab and you need to design a device that measures earthquakes?

During my observation, James had set all the necessary materials out, and explained what each item could potentially be used for. Still, students wanted to find alternative paths, finding other materials on shelves and in drawers to create the same product. While setting expectations and gathering supplies early on generally aided James in facilitating students use of time, I could see in my observation that students had less initiative and relied on James or their peers to provide solutions to their trials that came out of the instructions or checklists he provided.

The way students responded to individual lessons varied, and it was difficult, even for teachers, to understand how connections to students could be made within a complex PBL lesson. Teachers unanimously reported that they struggled with knowing when to provide direct instruction, versus less guided facilitation during a PBL activity. During my observations, I witnessed the teachers guiding students through various questioning strategies and often referring simpler student questions to their peers. Asking questions was the default facilitation approach, followed by explanations of options based on student response.

James commented that "it takes a lot of effort and care from the teacher just to make sure that you're hitting all of the kids so that all of the kids are getting a good experience." Likewise, Anne commented that her role as a teacher was "[to create] an environment where kids get to find their own path... If you're not clear on that, if you're kind of fuzzy, then it's the blind leading the blind sort of thing." Though this concern was expressed, I saw in my observations the immense amount of support each teacher provided their students. Specifically, Mary and Jennifer's facilitation strategies stood out amongst the teachers. While Mary's students worked independently, she constantly walked around, checked in with each one, while still monitoring the room to see if additional needs were arising in the form of hands raised or eyebrows furrowing. Jennifer took a more "hands off" approach to her facilitation of PBL:

Because I allow for flexibility and because I say sure, change what you need to, sometimes [students] change things that I don't think they would necessarily need to. But you also struggle as a teacher to say do this or do that. You kind of have to let them just figure it out. I think every time I do [PBL] I learn how to do it.

Jennifer's students worked in groups but completed independent projects. Her first reaction

to any student question was “did you talk to a friend first?” followed by a series of questions, moving from vague into more specific, that would direct them towards an answer or solution. When students were not seeking her aid, she would walk the room and observe what was happening, and only intervene if students either became unsafe, or were headed down what she described as a “path of no return.”

Sophia wanted her instructions to be very vague and intentionally wrote instructions or questions with multiple outcomes. This served two purposes: 1) it ensured students were reading through the items—if they didn’t ask questions that was her indicator that students weren’t reading; 2) students would have to go through trials to solve the problem because there won’t be a clear solution on the first try. Sophia describes her interactions with her students in this ambiguity by telling them “your solution is as good as mine, figure it out,” while making herself available to answer questions in an effort to provide support and create a comfortable environment for trials of various solutions.

Mary expressed that using the lab space along with PBL was challenging for her as a teacher because it opened possibilities that both Mary and her students weren’t always sure how to achieve. She wanted her students to have every opportunity to try and test every possibility they could imagine for structures and designs that fit into her lesson prompt. Mary said, “I can talk to the kids about their ideas but then they want do that and I think well good luck because I don’t know how to do that.” In this case, the lab director’s availability becomes especially important in assisting teachers to facilitate lessons within the Fab-Lab environment. Both lab directors, Ben and Rebecca, agreed that their primary role as co-directors of the Fab-Lab is to “support teacher’s in whatever way they need.”

Another limitation expressed by teachers was their ability to create and provide their students with constructive, purposeful conflict and failure. Sophia described many tasks for her students only caused anxiety because they were uncomfortable with failure. Her higher-level math classes naturally contained difficult content that allowed students to collaborate, fail, and still be successful. “I’ll walk around and usually partners are talking to each other. When they aren’t agreeing, they get confused, and look to other groups and create like a three-way conversation.” Sophia uses this scenario to describe how she facilitates students moving from internal to external conflicts.

As far as students go, their reactions to less guidance in this problem-solving environment was either relaxed, or not—with very little middle ground. Students who were comfortable needed less guidance and were able to learn from the mistakes on their own. On the other hand, students who struggled with this experience only wanted answers and did not care to hear the reasons why solutions existed. Jennifer would thoroughly explain the process of failure and success to her students, commenting that, “I think the ability [of the teacher] to be flexible and to re-envision and talk to the kids about it being a process is really helpful.” When a student would ask “how do you want me to do this” and the teacher responded, “I don’t care, as long as [ x, y, z]”, students would begin working more persistently and with fewer questions. In all the classes I observed, student frustrations were limited when teachers explained how students would be evaluated—common pieces were a product, use of time, or depth of thought.

### **Using PBL and the Fab-Lab for Cognitive Development**

Implementing a PBL lesson allowed the teachers to cover multiple content areas and skills in a single application. The availability of the Fab-Lab promotes cross-discipline applications, where students can access and recall multiple learning experiences to solve their problems. This

gives teachers the capability of enhancing learning experiences for their students by breaking the routine of constant knowledge acquisition. Sophia describes PBL and its cross-discipline applicability, “I think in terms of learning how to think in a more elegant, complex, abstract way, you can only do that if you’re putting pieces together from different fields.”

Anne and Jennifer intentionally planned for their PBL lesson to take place later in the school year, giving students a chance to use multiple skills they had acquired thus far in various classes. This spanned from soft-skills like time management and problem solving to concrete knowledge of history topics and writing essays. When PBL offers students the opportunity to connect multiple areas, the teachers unanimously felt it was a “valuable experience”, regardless of planning or time allotment.

Mary, James, and Anne all highlighted their beliefs toward balancing hands on instruction with their direct “book learning” instruction. Rebecca, a MS math teacher and Fab-Lab Director, best summarizes this idea:

I don’t think just doing any one of those [student-centered methods] is ideal. I think you really need to make sure that there’s some direct instruction... time for students to create their own but also some in between... sometimes [as a teacher] I just have to tell you how to do things.

Sophia and Jennifer showcased their personalities through their teaching philosophies by commenting that “messy classrooms are sometimes where the best learning takes place”. They both let elements of student-guided learning emerge in their interviews when discussing how student questions often led to tangents.

The teachers’ personal teaching philosophies aligned with cognitive constructivism as a learning theory and its role in PBL. Teachers highlighted that PBL gave their students an opportunity to apply critical thinking skills. Jennifer put a special emphasis on this type of thinking with her classes; she said, “[critical] thinking is really hard in sixth and seventh grade. And depends on the kids because it develops differently.” She uses this as a reason for PBL integration in her curriculum. During an interview, Jennifer discussed “balancing concrete facts with abstract execution”; emphasizing that students had to exhibit higher levels of critical thinking to move into the abstract nature of critical thinking.

Teachers created a concrete experience through a project-oriented PBL lesson that focused on developing problem-solving skills. In some of my observations, it was likely that this was students’ first exposure to inquiry, abstract thinking, or problem solving in the classroom setting. This is where inquiry, problem based, and project-based learning intertwine. Sophia described it this way, “the learning is actually happening through the process of answering a question or addressing a problem or designing a thing.” All five projects were oriented and structured so that the completion of a product signified the identified problems were overcome.

### **The Role of the Environment in PBL**

Student collaboration in PBL was organic and occurred with or without direct elicitation from the teachers. The teachers believed that student collaboration and having multiple perspectives enriched the outcomes or solutions identified for the problem. In Sophia’s class, students were accustomed to engaging in peer collaboration before attempting to seek out a solution from the teacher. I noticed that when Jennifer refused to answer a student question or redirected them to an assignment sheet, the students would initially get frustrated and sometimes even express body language like eye-rolling, sighing, and muttering under their breath. However, after a few minutes, they reluctantly sought out advice from a peer who had moved on to the next step. What began as

an initial student frustration was replaced with rededication to the problem.

Students were also more comfortable with trials when teachers created an environment where failure would not count against them for their grades. Building a comfortable connection amongst students early in the year was Sophia's primary strategy for creating a collaborative classroom environment. Sophia described her strategy, "building that [environment] allows them [students] to shift from me telling them to do something, to owning their experiential learning." She added that she supported their efforts by making sure that they know "when [students] mess up, it's okay to repeat, I'll be here tomorrow for you to try again." Teachers maintaining that collaboration amongst students was crucial to students engaging in PBL. It seemed that the teacher themselves was guiding the collaborative, positive atmosphere, but were not always aware of the strategies they used to achieve this environment.

Students, however, were not the only ones to engage in collaborative idea-sharing or problem-solving. Mary commented that her lesson developed because of a nationwide collaboration of other humanities teachers looking to use a Fab-Lab in their respective schools. Jennifer shared her best problem-solving scenarios evolved from simple lunch conversations with Rebecca, asking themselves "how can we get students to do [blank]." In a way, Jennifer approached PBL on her own accord to answer a "how" question. Ultimately, teachers also valued collaboration with their colleagues when it related to PBL lesson development.

### **Importance of Reflection in the PBL Process**

Reflection and debriefing, the final step in the PBL framework, took many forms; it varied from verbal to written and individual to collaborative. This reflection was especially important for the MS teachers because students were often taking different approaches to a problem, while the US teachers had their students working towards a common solution. Asking about reflection with Jennifer revealed her options for class-wide reflection:

Usually we'll do a written summary, sometimes we'll do like a quick like what did you really love about it. But if it's about collaboration we don't do it verbally. I don't ask them about how their partners went verbally in a group because you know [mimicking yelling].

When reflecting on an assigned collaborative experience, students would fill out a peer-evaluation, eliminating an opportunity for disagreeing partners to argue. I was fortunate to witness Jennifer's class debrief during my observation; it was refreshing to see her approach this positively. Rather than a stereotypical "what was good, what was bad," I only heard her ask "tell me what you loved about this project" and the student responses were equally positive.

While students were encouraged to be creative and take control of their learning experiences, it created a need for teachers to identify a valuable learning moment when progress wasn't evident. For James and Sophia, that was as simple as periodically asking to students to tell them what they've done or are currently doing. Sophia would highlight certain pieces by saying "you're on the right track, but not quite there. So, let's talk about why not quite." From there she would explain where things went wrong, helping students to learn from mistakes. James would give students options for to try to direct them on the right path, saying things like "instead of [x] try [y or z]." I observed all the teachers quickly acknowledging when these learning moments were needed, addressing them, and then moving onto the next task.

Throughout the course of this study, I witnessed several accounts of adaptability from all five teachers and the two Fab-Lab directors. Having the ability to debrief and analyze the lesson as

it was occurring allowed the teachers to create the most meaningful experience for their students. With her student's reflection and debriefing, Sophia took a more personalized route, per the performance of her students. She said, "[with students] that might be like me taking really good notes and then [talking with them] and saying OK this is where you grew. It would have been great to see you push yourself more in this area." Because students are unique in their learning capabilities, teachers are not always able to plan for the process, making it important for them to react quickly in a variety of situations. Sophia summarized her constant adaptation and reflection in her classes that stood out as an example of teacher reflection for PBL instruction:

If I'm by myself, two ways. I'm debriefing in my head as the lab is happening and shifting gears pretty quickly. It's happening and I see okay that's not working... But by the time the lab was done yesterday there were a couple of things I noticed and immediately changed for the next year.

The two ways Sophia describes are her independent reflection occurring real-time within the lesson and making changes as she goes, and at the end of the lesson, making changes for future implementation. While all teachers were keen on creating time for reflection with their students, there was gap in the amount of time they made for self-reflection.

### **Discussion, Implications, and Recommendations**

The data revealed teachers in this study followed the six general steps of the PBL framework (Barrows, 1986; Savery & Duffy, 1995; Smith et al., 2005). There was variance in the weight and perceived importance of each step; however, steps were not omitted from practice or instruction. According to Walker and Leary (2009), a variance in the depth or complexity of a problem is expected in PBL and can alter the way a teacher designs their lesson; however, there is a paucity of research reflecting the importance of each individual step on instruction and the time allotment needed. The prevailing idea that emerged from the data was the effect that the perceived importance on individual steps had on the teachers' planning process for a PBL lesson. Some teachers focused on planning for content, while others emphasized planning the logistics of facilitation. In each case, the planning was thoughtful and intentional with some consideration to the remaining steps in the framework. By consciously deciding which steps to actively plan for and spend more time on with their students, teachers were better able to transition between the various roles needed in PBL lesson, such as delivering content and facilitating student collaboration. Scaffolded planning—the focus on a particular step and accounting for student responses—supports the teacher's efforts for facilitation and can minimize student's apprehensiveness to PBL and other student-centered methods (Mong & Ertmer, 2013).

For PBL to be most effective it needs to be approached as a learning process for both students and teachers (Barrows, 1986; Savery & Duffy, 1995; Takahashi & Salto, 2018). Relaying this process to students requires flexibility from the teacher to be able to switch roles from planner to facilitator between each step of the process (Mong & Ertmer, 2013). Inquiry-guided instruction and problem-solving are methods in which students may lack familiarity or experience. In these cases, teachers are not only teaching the content, but they are having to teach a new way of thinking and learning. When this new process of learning is relayed to students, it can reduce anxiety that they may feel, contributing to increased confidence to engage in the content in a more meaningful and purposeful way (Takahashi & Salto, 2018).

With PBL specifically, students' comfortability with ambiguity was a limitation that many teachers faced. Teachers reported that their students' anxieties and their ability to mitigate their lack of comfort with the unfamiliarity of problem-solving and critical thinking application is a reason they may decide against a PBL lesson or activity. Anxiety has been identified as piece of the process associated with PBL among students in prior studies, and it is not an uncommon emotion expressed (Takahashi & Salto, 2018). While the teachers took steps to make students feel

more comfortable with unfamiliarity and ambiguity, students learning to navigate this emotion is a component of PBL and constructivist learning (Schunk, 2012). The most effective way of facilitating this ambiguity, as observed, was redirecting questions to other resources that could be used to answer a question. When participants took this approach and made their students aware that it was okay to not know everything in its entirety, the students' actions became less anxious and confused and more focused on the problem at hand.

Constructivism and student-centered learning overlap with one another where cognitive conflict challenges students thinking and acts as a stimulus for learning (Schunk, 2012; Savery & Duffy, 1995). As an active piece of PBL and constructivism, intentionally creating this conflict is an effective approach for challenging students to construct an understanding of a concept or a situation (Schunk, 2012). Cognitive conflict in these cases studied existed externally through peer collaboration conflict and internally through the challenging tasks that the problems presented throughout the application. During data collection, it became clear that a comfortable and risk-free environment to fail was the most supportive way to engage students in facing this conflict (Mong & Ertmer, 2013; Smith et al., 2005).

Because project-based, PBL, and inquiry-based learning intersect and overlap, it was notable that all teachers tied their PBL to a project. Schunk (2012) discusses that constructivism in a learning environment should actively involve students with the learning materials, which could be an explanation for the project inclusion. Nonetheless, the teachers continued to focus on the processes of problem-solving throughout the entirety of the lesson (Collins & O'Brien, 2003; Savery & Duffy, 1995). This intersectionality also makes PBL a great opportunity for students to connect and apply learning from multiple disciplines and create understanding across a greater context (Mong & Ertmer, 2013; Schunk, 2012). Teachers still chose to engage with this process despite the greater time allotments and planning efforts as compared to traditional teacher-centered methods (Mong & Ertmer, 2013; Seng, 2014; Smith et al., 2005). Because this study focused on teachers and their strategies for PBL, student development over time was not tracked. However, teachers described their continued use of the Fab-Lab and PBL was a direct consideration of the opportunities provided to students for critical thinking, problem-solving, and other 21<sup>st</sup> century career skills (Dahlgren et al., 1998; Walker & Leary, 2009).

The changing external environment created an external conflict that put students in a position to retreat or approach the learning opportunity ahead of them. This is when teachers reassuring and comforting verbal support became important for students to embrace the chance to learn from the trials ahead of them, in addition to the support of student group/collaborative work. The action of verbal support and reassurance from teachers provides students motivational and emotional support necessary for constructivist learning (Schunk, 2012). Yet, the nature of the Fab-Lab supports the complexity of cross-discipline application that teachers supported (Pauceanu & Dempere, 2018). The Fab-Lab was generally described positively by teachers, but was never viewed as a direct decision-maker for the type of lesson the teacher or class would engage in. Being viewed as a collaborative space and standing resource to the school invited teachers to use it when convenient to their application and curriculum. Specifically, for the development of problem-solving skills, the Fab-Lab serves as an ideal space for student-centered engagement, as most lab settings do (Stacy, 2014; Berland et al., 2014).

When students engaged in collaborative work during PBL, it aided teachers in facilitating students' needs and was believed by the teachers to enhance the learning experience. According to Smith et al. (2005), interpersonal relationships between students and instructors is a key component to a positive, collaborative learning experience. It was evident through my observations that students relied on one another as a resource to the problems they were tasked to solve. Additionally, these collaborative interactions could be further evidence of student motivation to engage in a PBL

lesson (Morrison et al., 2015).

The final stage, and perhaps the most important for PBL, is the opportunity to debrief and reflect on a lesson (Barrows, 1986; Savery & Duffy, 1995; Nilson, 2016; Darling-Hammond, 2006). In the case of PBL, reflection should be anchored towards the learning that occurred, and the problem-solving process students experienced (Savery & Duffy, 1995). While the reflections witnessed in this study took many forms (written, verbal, etc.), reflection of the process was clearly evident and helped students to understand their role in their own learning (Dahlgren et al., 1998; Schunk, 2012), as witnessed in the observation of Mary's lesson. Nilson (2016) states that one positive attribute a teacher using PBL can have is the ability to adapt and improvise unexpected occurrences. A primary example in the case of Brockson Academy was Sophia's independent reflection and debrief as a lesson was occurring. When teachers are able to assess a situation in real-time, they are better able to adapt to their students (Mong & Ertmer, 2013; Nilson, 2016).

The amount of guidance necessary for students as they engaged in the PBL process was a struggle for the teachers in this study. The most appropriate action for teachers, recommended by the literature, is reflection after each unit or lesson that utilizes PBL or any student-centered method (Barrows, 1986; Schunk, 2012; Takahashi & Salto, 2018). This reflection should not only be on the activity itself, but the way the teacher manages the facilitation for their students. For 21<sup>st</sup> century teachers, the classroom environment evolves year to year, making it important to reflect on and understand the processes of teaching and learning to reach all students (Darling-Hammond, 2006).

Takahashi & Salto (2018) further describe stages of PBL adoption by students: anxiety, struggle, breakthrough, and transformation. As students reach each stage of this process, teachers should be comforting, supporting, and encouraging students that their experience is normal. During the breakthrough and transformation stages, cognitive constructivism will be at its peak and facilitation and guidance should prevail direct instruction (Takahashi & Salto, 2018). For teachers with a desire to integrate PBL into their classes, I recommend scaffolded planning that revolves around a greater connection of skills and content in a real-world scenario, accounting for the stages highlighted by Takahashi & Salto (2018).

Intentional planning with the laboratory directors through all stages of the lesson (not only the application) could serve as a bridge to engage more teachers in this type of learning opportunity at Brockson Academy. When planning, however, I would further recommend deciding on a main take-away or area of skill development to invest the efforts into—such as Jennifer focusing on communication, or James focusing on product functionality. This will make the lesson more purposeful for students and enhance their learning and development.

Verbal support and high energy from the teacher are primary components for a positive classroom environment. This could be as simple as independent or public praise for a job well done, or encouraging perseverance when students are ready to give up. When students feel supported, the positive energy can act contagiously for students to reciprocate the same excitement and commitment to their learning opportunities. Additionally, teachers should take moments within the lesson to connect with students, check in on progress, and adapt to emergent student needs. Each of these items are all effective strategies for engaging students to feel more comfortable with the unfamiliar method, as witnessed during data collection.

For future research, potential areas of exploration include factors that contribute to a positive and supportive environment in PBL and methods for assessing student learning, both at the process and product level. Additionally, there is still a need to investigate the specific role of each of the PBL steps and their significance, as well as student perceptions of PBL. Had time

permitted, I would add additional observation periods across multiple PBL lessons to discover trends present over prolonged implementation. While the Fab-Lab facilities used in this study are specific to Brockson Academy, this does not limit the findings to that site. A replication of the study in an agriculture education laboratory may pose new findings, yet themes of the teacher's experiences are likely transferable to that setting, as agricultural education is cross-disciplinary in nature. As I examined the process of PBL implementation by teachers, the recommendations made here for teaching practice can be replicated and transferred with respect to alternative classroom and lab settings.

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