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Digital Fabrication Laboratories: Problem-Based Learning for Special Education Needs Student Psychology

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Abstract
Purpose: The aim of this study is to examine light on PBL in an unconventional, high-tech FabLab setting.
Theoretical Framework: The design indicate two middle schools that implement problem-based learning (PBL) in their makerspaces are the focus of this study. Students from each school worked together to solve problems they came up with.
Methodology: The methodology indicate of student-student interactions are divided into three broad categories: setting specifications with teammates, engaging in personal discovery, and communicating findings.
Findings: The resultof these studies show that teachers at the FabLabs employ PBL and an unstructured problem scenario to help students learn about design and engineering (fabrication laboratory).
Implications: Demonstration utilizing tangible objects, explaining the failure of the prototype, and handling behavioral concerns are all instances in this study.
Value: This study was focusing directly to the subject of design and engineering (fabrication laboratory).

Keywords*:* Engineering Education, Problem-Based Learning, Digital Fabrication Laboratory, Special Education

1. Introduction

A change toward inductive pedagogy in engineering education has occurred not only at the university level, but also at the K–12 level, in the 21st century. K–12 STEM education has been shown to need engineering and design instruction as a result of the most recent NGSS release for K–12 science education. Engineering and design students in middle school can benefit greatly from the use of problem-based learning (PBL). a method to teaching and learning that stresses the use of real-world situations and open-ended challenges (Livstrom, et al., 2019). Experiential learning has been around since the early 20th century, when Burch, et al., (2019) and others emphasized the value of PBL. As defined by Russo & Minas (2020), inductive pedagogical approaches "promote the problem-solving talents and attitudes that most instructors would state they wish for [their students]" (Ahern, et al., 2019). For the purpose of this study, PBL in middle school digital fabrication labs, a nontraditional learning environment rich in technology, will be examined. Clarification: The FabLabs in the middle schools examined in this study were not registered with the Fab Foundation, but their design was inspired by those seen in other institutions that fall under the same brand. In addition, those in charge of the middle school FabLabs were FabLearn Fellows.

Making its way into K–12 education is a relatively new occurrence. The Fabrication Laboratory, or FabLab, is a rapidly evolving type of makerspace. Digital fabrication and prototype technologies such as laser cutters and vinyl cutters, CNC routers, and 3D printers were pioneered by MIT professor Neil Gershenfeld (Kantaros, et al., 2022). Creating a real product from a computer design is the simplest definition of digital manufacturing (Smith, et al., 2020). It will be possible to "create tangible goods on demand, wherever and whenever you need them," says Gershenfeld (Bettiol, et al., 2020)

Makerspaces in schools have grown in popularity among K–12 educators in the last five years. More precisely, FabLabs have been set up at a number of universities, which have access to a greater number of high-tech digital fabrication gear and specially educated faculty members. In this non-traditional learning environment, many instructors rely on PBL as a guide for developing and delivering curricula.

PBL has been around for a while, but using it in a FabLab, where students have access to cutting-edge equipment, is a relatively new development. The extent to which FabLabs can create strong problem-solving and engineering skills is yet speculative and undefined. How students engage in this high-tech setting, and how teachers and students interact in these places under PBL, are some of the questions this presents. Middle school engineering education is the topic of this study, which looks at how PBL works in a FabLab context using two schools' case studies. To better understand the role of FabLabs in schools as PBL learning settings and how PBL in FabLabs affects student and teacher collaboration, we conducted this study.

In a study conducted by Chan & Blikstein (2018) on Exploring Problem-Based Learning (PBL) for High School Design and Engineering Education in a Digital Fabrication Lab, it was found that students in each school where the study was conducted were able to tackle various challenges in a self-directed and group manner. According to him, through the PBL approach, students are able to explore and interact with each other in defining problem specifications and findings. The interaction between teachers and students also takes place where the teacher can be overcome as a facilitator rather than an instructor in addition to managing student behaviour. The study conducted using the case study approach aims to investigate two FabLabs (Fabrication Laboratories) in secondary schools in engineering education using the PBL approach. Two secondary schools equipped with FabLabs were selected as study sites and observed for eight weeks. The sample of the study consisted of two teachers and 15 to 25 students aged about 11 to 13 years and from the same socio-economic background. Three main themes were used in the analysis of students' engagement in the FabLab, namely 1) specification setting with friends in the group, 2) personal exploration, and 3) communication related to discovery. The results of the observation are positive when there is collaboration and communication between students about their findings and views on sharing ideas. This is the most important key to the idea of constructivist learning as explained by scholars such as Vygotsky and Papert. The conclusion from this study shows that Digital Fabrication needs to be aligned with appropriate curriculum and pedagogy so that teacher-student interaction can foster and contribute to a fabrication-oriented and technology-intensive learning environment. So the following research questions are a natural outgrowth of this:

A PBL method used the FabLab environment and digital fabrication technologies to influence how students cooperated. It is interesting to see how the different FabLab learning spaces with PBL approaches affected teacher-student interaction.

2. Literature Review

Both Constructivism and Constructionism are examples of this type of thinking

Xiao, et al., (2022) all emphasized the importance of experiential education in holistic learning. "Culturally meaningful curriculum construction" was proposed by Dewey as a way to relate education to the actual world by using local culture as a source of inspiration for "generative themes" (Christian, et al., 2021) for curriculum design. There are many similarities between the reasons for using digital technologies in education and those for developing artificial intelligence.

Constructionism, which Griffin (2019) developed based on Piaget and Vygotsky's constructivism theories, asserts that students' creation, production, and public sharing of artifacts greatly enhances the formation of knowledge. By drawing from the culture around them, a kid can develop "intellectual architecture of his/her own design" (Temple, 2021). Then, the youngster is able to build "hierarchies of knowledge" and strengthen their intellectual abilities as a result (Hall, 2020).

On the basis of Papert's theory of constructionism and with the help of other researchers in this field of study, Papavlasopoulou et al. (2019) describe four fundamental factors to constructing a constructionist learning environment: designing, personalizing, sharing, and reflecting. Iterative thinking and design activities are valued in constructionist approaches for designing because they encourage students to think creatively, critically, and analytically (Tham, 2021). Using DiSessa's computer literacy construct, Berland argues that constructionism is a "foundation for action" that teaches people how to express themselves through computing (Dohn, et al., 2022).

Computational involvement is a concept coined by Reynolds-Cuéllar et al. (2020) to describe how constructionists connect with real-world, social, and community-based viewpoints in the design process itself. Because of the maker movement's emphasis on constructionism, several schools have begun establishing FabLabs.

Designing for personalization in a constructionist perspective requires attention to several levels, such as the cognitive and affective characteristics of the learner. There are bricoleur and planner approaches to maker-oriented activities, according to Hagerman et al. (2022). Situated learning and communities of practice, as well as Vygotsky's Zone Of Proximal Development, can help expand individual cognition by incorporating the expertise and abilities of others in the process of enhancing one's own capacities (Silalahi, et al., 2019). Lastly, there is a focus on metacognition, which is directly linked to the importance of learner agency in constructionism (Holmes, 2019).

Inquiry-Based Education

Students are the focus of PBL, which is a popular way of teaching in schools and universities around the country. Using their current knowledge, students in PBL actively create new information, which is drawn from foundational educational theories like Piaget's and Papert's constructivism and constructionism (Simanjuntak, et al., 2021). As a result, PBL encourages students to strengthen their creative thinking, problem-solving, and communication skills (Liu, 2021).

Medical educators realized in the 1980s that the process of patient diagnosis requires a team effort that relies on inductive reasoning and expert knowledge from doctors in a wide range of disciplines. PBL was born out of this realization (Tinning, 2022). Medical schools have been utilizing this method of instruction for years, but it was only in the 1980s and 1990s that other academic institutions began using it, including K-12 schools (dos Santos, et al., 2020). From the many definitions of PBL that have been presented over the past two decades, Gu, et al. (2020) presents three crucial characteristics that clearly define PBL:

Tutoring as an aid to education and development

Self-directed and self-regulated learning are the learners' duties.

The motivating force behind unstructured instructional challenges. Savery further reminds us that PBL is difficult because it involves substantial scaffolding to help kids acquire problem-solving, self-regulation, and collaborative skills (Chan & Blikstein, 2018).

In PBL, students create their own learning goals by responding to questions posed by a problem scenario. A PBL learning cycle typically has four phases: problem presentation, investigation, solution, and process evaluation (Wijnia, et al., 2019). For most students, the problem scenario they are working on is completely new to them If there is any new information, they will share it with their coworkers so they can come up with an action plan to tackle the problem. PBL doesn't just focus on problem solving; it also uses ill-structured problems to help students learn. It's possible to think of PBL as a teaching strategy for small groups because of its emphasis on cooperative learning and the development of higher-order problem-solving skills (Singh & Thurman, 2019).

FabLabs

Since scholars have comparable but differing conceptions of the term "creating," Freeman et al (2020) state unequivocally that no single definition exists. When it comes to embracing a maker mindset, Martin emphasizes the importance of attributes like playfulness, growth-oriented, failure-positive, and collaborative (2015, p. 36). As previously stated, these traits are also consistent with PBL's three key features. Research on DIY communities conducted in 2018 by Ensign & Leupold found that the rise of social computing and other collaboration and sharing technologies has led to an increased interest in DIY culture and a broader adoption of DIY techniques over the past few decades. A new breed of makerspaces has emerged, catering primarily to professionals and older members of society. Second industrial revolution in the 21st century is referred to as "Democratization of Manufacturing" by Fiaidhi and Mohammed (2018). Personalized digital fabrication equipment like 3D printers and laser cutters are now much more widely available due to lower production costs and an increase in demand, according to the author of the paper.

FabLab modules such as 2D and 3D printing, PCB assembly, and basic programming were introduced in two-day after-school seminars taught by Norouzi , et al. (2021). The outcomes were largely favourable. To teach children about the role of technology in their daily lives, additional study is needed. Their analysis shows a lack of studies on digital manufacturing in middle schools. Brulé & Bailly (2021) present another academic perspective on the possibilities of digital fabrication as an instructional technology and attitudes toward employing digital fabrication to teach STEM courses (rather than vocational education). There is a fundamental distinction in how digital manufacturing activities are viewed in artifacts. Hartikainen et al. (2021) propose integrating digital fabrication into the school curriculum to help pupils study more actively.

3. Material and Methodology

FabLabs at two middle schools were studied as part of a case study using the PBL method of teaching engineering to middle school pupils.

As part of the first research site, students in sixth and seventh grade were given an opportunity to design and build prototypes to solve physical problems or inconveniences in their classroom's furniture, under the guidance and supervision of the school's director of the Fabrication Lab (the head teacher). Students in fifth and sixth grades were supervised by their science teacher through an eight-week project in which they researched the lives of renowned women of the twentieth century and created a tangible museum exhibit for their peers. The FabLab in this private school was used for this project.

Choosing a location

This study focused on two middle school campuses equipped with an active FabLab. Both locations have FabLab "classrooms" with one to two teachers and 15 to 25 students. Teachers and students from the design and engineering classes at each of the participating middle schools are included in the study. As many as a few of their pupils were in the lower grades of sixth grade. Most of the students were between the ages of 11 and 13, and they all hailed from similar but not identical socioeconomic situations.

In both institutions, FabLab classes were part of the daily schedule for pupils. The FabLab lesson was taught by a dedicated teacher/director at the first school site, and it was kept apart from regular math and science sessions. For this location, the second school's FabLab instructor was called "science teacher," "makerspace coordinator," and "science project work." This lab was utilized by both middle school educators. A laser cutter, a 3D printer, and a variety of hand tools and craft supplies were available in both FabLabs. Both areas had tables and chairs that could easily be relocated.

Gathering of Data

To begin, most of the observations in the classroom were passive. While working on their projects in groups in the classroom, students were observed closely as to how they collaborated with one another. The teacher-student relationship was also observed in a variety of ways. Field notes and photographs were used to document classroom activities, and an observation checklist (Appendix 1) was produced in advance. Making sense of how lessons in makerspaces are set up and run was made easier thanks to these observations in the classroom. The makerspace at the private school was the focus of the second case study, which featured three sessions from the charter school. Nine sessions were observed over a period of eight weeks.

Semi-structured interviews were conducted with each FabLab teacher to learn about their FabLab's PBL and STEM integration practices. There were no more than one hour-long interviews. Appendix 2 contains the questions from the interview protocol. FabLab teachers were interviewed in order to acquire a better understanding of how they came up with the curricula for their classes and how they incorporated PBL into the FabLab.

Analyzed Information

For a qualitative inquiry like this one, all of the photographs and field notes taken during interviews were analyzed for data. Observations and interviews revealed recurring themes, which were then organized into categories. Because this was an individual honors thesis, no interrater reliability was done. There was an emphasis on student collaboration on a particular challenge or task of the day, as well as examples of teacher interaction with students and the tools they utilized or explored during that communication, among other things. It was determined that digital fabrication tools and the maker-space atmosphere contributed to the PBL teaching approach.

4. Results and Discussion

Interaction Amongst Students

For the purpose of assessing the involvement of middle school kids in their school's FabLab, three themes emerged from classroom observations: Involving colleagues in defining requirements, Self-discovery, Information exchange on new discoveries.

Students from the two schools were at various stages since the observations were done over an eight-week period at the same time but on different schedules. There was a big difference between the charter school (the first school site) and the private school (the second site) when it came to prototype development. Next, examples of student interaction and PBL assignments will be presented to illustrate these themes.

Collaboration in the Definition of Specifications Aaron1 and his friends, all sixth-graders from the charter school in the first case study, sketched their prototype in 3D using the 123D Design program before using the laser cutter to build a genuine prototype for testing. Because of this, Aaron was unsure if the rendering software's scale was accurate. To find out, he went out and bought a 12-inch ruler and took measurements of the actual size of his prototype. For the sake of accuracy, he returned to his laptop to double-check the measurements he had taken in real life with those he had made earlier in the day. Software and real-world scaling were found to be incompatible. Aaron gave 12-inch rulers to his teammates and instructed them to measure in the actual world to prove to themselves that the software's scaling needs to be changed (Figure 1). Problem inquiry is the phase in which an example like this would be used in PBL.

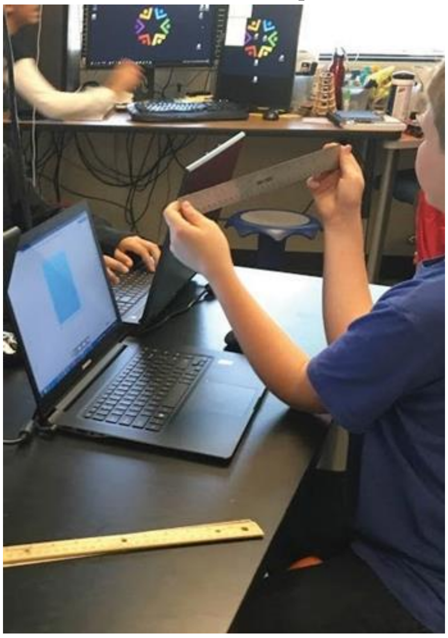

Figure 1. Christian has a conversation with his peers sitting across from him at the table about scalability (not shown here). Source: Prepared by the authors (2022]3)

Exploration of the Self. Christian**,** a sixth-grader, was using the 123D Design software to create a complex product. Instead of using basic forms like rectangles and circles to extrude cuboids and cylinders, he created a more complex 3D shape by creating discrete 2D layers and stacking them on top of one another. The hinges were also a part of it. Toggle and rotate his virtually completed object, Blake employed the software's included x, y, and z axes. Using the software's scaling options, he checked to see if the sides and layers fit together. It was a more complex and advanced design compared to the ones created utilizing simple extrusion from 2D to 3D using the rendering program. Figure 2 shows a picture of Blake's design. The problem investigation phase of PBL would include this scenario.

Discoveries are communicated to the public. Both Welly and Shaina are in the sixth grade and have been friends since they were in first grade. Their headphone hanging prototype was quickly made from cardboard using a laser cutter and rendering software (refer to Figure 3). They experimented with holding the prototype at various lengths from the table's edge. The prototype was then put to the test by being hung on genuine headphones to see how well it held up. There was no doubt in their minds that this variable—the distance the prototype was held at from the table on which it was placed—affected the stability of the headphones. Besides the headphones' weight and size, other factors that influenced their experiment were their strength when holding the prototype down and the quantity of glue they utilized. After a few failed attempts with heavy headphones, students realized that cardboard could not handle the weight and began using lightweight headphones instead. It was determined that Welly and Shaina would use extra hot glue to bind the cardboard layers to make their prototype stronger and more stable. However, they did not get any further than discussing the concepts of balancing, free body forces, and some potential mathematical and physical equations that could aid in the improvement of their prototype during the observation session. Figure 3 shows a prototype of Welly and Shaina's headphone hanger. PBL's problem-solving phase would include this case, and the process assessment phase might also apply.

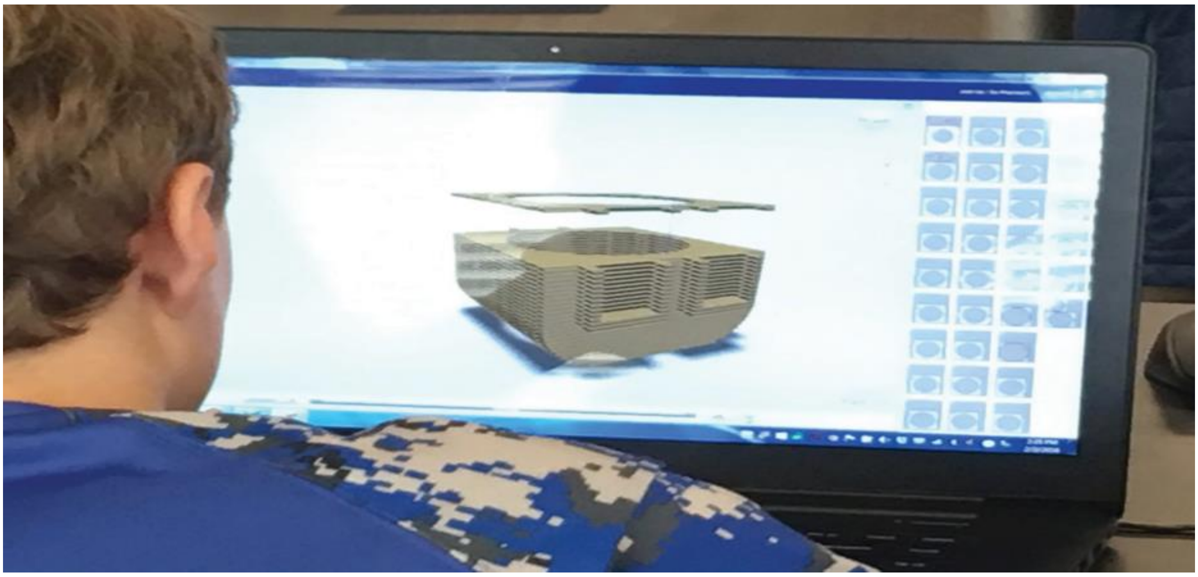

Figure 2. An example of Griffin’s 123D Design software creation. Source: Prepared by the authors (2023)

Defining a set of requirements. When Lewis and Lyca compare sizes started working on their museum show, they were in the very early stages of planning. While visiting museums and seeing massive exhibits, they learned that they were unclear of the appropriate size for their own. Because of this, they were unsure of the actual measurements of their display board. However, they needed to know the length and width of the board's dimensions in order to acquire an accurate estimate. It was so determined that they would measure the size of their board by rolling out a measuring tape, unrolling it, and placing it on a wall of their makerspace classroom. Although they both used the word "big" to describe their views, it was discovered that they had very different beliefs about the concept of size. Both students were able to communicate their ideas for the size of their board in numerical terms by using a measuring tape. Figure 4 shows an illustration of Ethan and Fiona using a measuring tape to discuss the dimensions of exhibit boards PBL's problem presentation and investigation phases would apply to this situation.

Figure 3. Headphone hanger prototypes are tested by Welly and Shaina. Source: Prepared by the authors (2023)

Figure 4. With the use of a measuring tape, Lewis and Lyca compare sizes. Source: Prepared by the authors (2023)

Exploring one's own identity. As part of a team comprising Hannah and Ian, Greg was assigned the duty of researching 20th-century female role models from around the world. We were just getting started with the semester, and the teacher had only just given us the poorly constructed question. It was determined that the three of them would initially work independently on their own, searching the Internet for material about historical women they were familiar with and studying others they had never heard of before beginning their research. Although the teacher provided some direction as to which websites the students should peruse, they rarely turned to other sources of information (such as library books) in their quest for data. While this particular group appeared to be laser-focused on the subject at hand and capable of working independently, other student groups who attempted to work independently veered off course. Problem presentation is the phase in which this example would be included in PBL.

Exchanging ideas regarding new discoveries. It was after they spent some time researching historical ladies that Thomas, Iya and Lester had a discussion about their findings and who they found most interesting. In addition to certain well-known female figures, the trio was fascinated by other lesser-known female figures. Due to the lack of consensus, they spent more time debating which female figure they should display to their peers. Their exhibit concept began to take shape after they agreed on a historical character. As a starting point, the teacher asked the students whether they remembered any interactive features from their past visits to museums that included historical individuals. This was a wonderful question that helped students recognize that many of the history museums they had previously visited didn't have a lot of interactive features or displays in a static poster format. Their exhibit idea began to take shape as they brainstormed and searched online for possible interactive features and ways to best bring out traits of the female figure they wanted to show. They were not disappointed. A problem presentation and investigation phase of PBL could apply to this situation.

FabLab students and teachers interact in this part while they work on their team projects. As an example of student-teacher interaction, consider the following three scenarios:

The use of real-world objects to demonstrate a concept. While working together on a design using 123D Design, Janet, Katy, and Laura realized that they needed to make some changes. Their research focused on developing a revolving element that could be mounted on a wall. A rotating component was an issue for them because they didn't know how to implement it. They requested their teacher for guidance on how to make a revolving shape in the software with the help of their teacher. Classroom paper towel dispenser was opened to demonstrate pupils how a cylindrical component in the dispenser revolved to help them better grasp mechanical rotational systems. The second question the students had for their teacher was: Is it more effective to paste the prototype to the wall or to drill holes in it so that it may be hooked to the wall? As they toured the makerspace, their teacher pointed out which items were nailed to the wall, hooked into it, or were attached to something else, like a shelf or a window. For the prototype, the teacher instructed the students to do a series of measurements, calculations, and experiments to determine which method worked the best. The students were able to identify how their prototype may benefit from these examples.

Discussing the failure of the prototype. After showing his instructor a prototype that had "failed," Matt, a fifth-grader, explained to his teacher that the project was a failure. To clarify further, he noted that cutting forms through his material (cardboard or foam core) using a little X-Acto knife was challenging because his shapes turned out jagged and did not match the specifications he had planned. When the teacher asked him what he would do if he could use a laser cutter for this task, he replied, "If only [he] could."

Responding to Behavioral Issues. Only Nate had been given the task of decorating the makerspace classroom walls by the school's science teacher. He was using CorelDraw (a rendering software) to create simple objects like rectangles that would subsequently be laser-cut. CorelDraw's scaling feature let Nate measure and accurately scale his 2D and 3D models for laser cutting. Despite the fact that he was working quietly on his laptop, he appeared to be fully immersed in the assignment that his teacher had assigned to him. There were no other pupils working on this assignment; it was exclusively assigned to Nate. Their team members were also working on their projects, creating shared Google Drive folders, and contemplating team names. To help Nate get used to working in a group, the teacher assigned him a solo task in the FabLab using rendering software and high-tech tools so that she could gradually introduce him to group work and hope that his antagonistic behavior difficulties would not prevent him from participating.

There are a variety of influences on PBL in a FabLab environment from the observations made at the two middle school FabLabs studied.

Savery (2015, p. 15) identified three key qualities of PBL that both schools' FabLabs failed to meet: teachers' attempts to be facilitators rather than instructors, students' attempts to take charge of their own learning, and the creation of poorly-structured challenges for class sessions.

When it comes to the maker mentality, there is a strong expectation that students (peers) and potentially students and teachers will collaborate as much as feasible. It appears that teachers' use of FabLabs and other makerspaces can be informed by computational engagement with community-based viewpoints, as stated by Herro et al. (2021) as the guiding principle for their work (Walker & Kafai, 2021). Because students were actively encouraged to collaborate, the bulk of examples show students working in teams, apart from Nate, who chose to work alone with FabLab tools (despite still sticking to the PBL concept). It's possible that a PBL-driven FabLab doesn't always need to emphasize the maker attitude of playfulness and collaboration. Even though Nate's interaction with the teacher was unique, she managed to assist him through an unstructured challenge using PBL methods.

According to our research, the FabLab's Project-Based Learning model encourages student engagement by encouraging students to take ownership over their projects and ask thoughtful and relevant questions of their teachers (their facilitator, in this case). Constructionist learning, as articulated by authors such as Voon, et al., relies on students communicating with one another about their findings and/or insights as a crucial means of exchanging true ideas (2020). There isn't enough evidence to say that the FabLab's digital fabrication tools improved student communication, even if they prompted some discoveries and/or insights and were linked to their sharing of authentic ideas inside the FabLab context. A lot of research is needed in this area.

Limitations

There was a lack of debate and research on subjects like arts education, community development, cooperation and participation in this study because the FabLab environments studied focused on STEM. Students in higher-income communities may have different approaches to teaching FabLab classes than students in lower-income communities because this study only included two middle schools in California, the United States.

There was also a limited schedule for the research project, lasting only 9 months from the invention of the research question to its end, including 3 months dedicated to site visits, weekly FabLab observations, and interviews with teachers. Extending this study's duration by more than a year and increasing the number and diversity of study locations would allow for additional examples of interactions to be documented. Additionally, video recordings of the students' interactions with their peers and tools should be incorporated into the qualitative research process in order to provide more accurate descriptions and quotations.

Prospective Investigations

This study opens the door to a more quantitative examination of PBL in FabLabs. Qualitative observations and interviews played a large role in this investigation. There's always the possibility of employing learning analytics in FabLabs to get a better handle on how PBL actually works. When it comes to STEM test results, kids who engage in problem-based FabLab activities tend to fare better than those who don't. This holds true for children at all levels of academic attainment (not only at middle school).

Other evaluations could be done as well. FabLab seminars or workshops on digital fabrication, for example, might be used to gauge middle school students' attitudes and comprehension of the term "engineering" in the near term. There is a lot of need for further investigation on educational inequalities in the FabLab context. Are students from low- and middle-income backgrounds better served by having access to a FabLab at their school? In the FabLab, how might the conduct of higher- and lower-income pupils be different? Using digital manufacturing in conjunction with STEM subjects taught in traditional schools would students, no matter their background, achieve the same understanding?

There is a need for future study to look at how students, instructors, and school administrators acquire "maker" identities as a result of engaging in FabLab activities beyond the realm of digital fabrication and STEM education. A more in-depth look at how people develop their identities in relation to and through making would be fascinating.

5. Conclusion

It may be a brief study compared to other, larger-scale, longer-term research undertakings. Students and teachers interact differently while using PBL in a non-traditional, technology-rich learning setting. Many countries of the world are experiencing a boom in the maker movement, and educational technology is one of the fastest-growing segments of that movement. However, this enormous potential must be moderated by adequate curricula, appropriate teaching methods, and constant monitoring of students' learning outcomes. To illustrate how students interact with a PBL approach, examples of student interaction have been documented. Future research might focus on FabLabs and other non-traditional learning environments to explore certain PBL phases in greater detail. " This study could also compare PBL and other inductive teaching methods for engineering education within FabLabs. More research should be done into how teacher-student interactions might help students learn in an edtech and maker-friendly classroom.

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