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FabLab Teacher Efficacy: A Framework for Designing Effective Professional Development for FabLab Teachers and Facilitators

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ABSTRACT

FabLabs foster 21st-century skills, yet their integration into K-12 classrooms remains limited. This study aimed to design and validate a FabLab Teacher Self-Efficacy Instrument, and then pilot it in a FabLab-centered professional development program. A 45-item Likert survey was used to measure teacher confidence across planning, instruction, and assessment. Teachers reported the highest efficacy in planning ($M = 3.78$), followed by instruction ($M = 3.64$), and the lowest in assessment ($M = 3.19$). Qualitative findings revealed barriers, including a restrictive school culture and limited instructional time. Participants emphasized the importance of hands-on training, collaboration, and sustained support to build both pedagogical and technical confidence for meaningful FabLab integration.

Keywords: FabLab, Pedagogical Knowledge, Self-efficacy, STEM.

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INTRODUCTION

Federal and local governments have increased investments to prepare students for a technology-driven workplace and to meet the workforce needs of 21st-century industry (American Federation of Scientists, 2024; National Academies of Sciences, Engineering, and Medicine [NASEM], 2024; NASEM, 2022; Reider, Knesti, & Malyn-Smith, 2016). FabLabs have been promoted as highly productive educational contexts that help K–12 students develop the knowledge and skills demanded by 21st-century work environments (Gershenfeld, 2012; Richard & Giri, 2019; Milara et al., 2017) and cultivate positive attitudes toward STEM careers. They are also presented as one of the fastest ways to meet manufacturing workforce needs and address technician shortages. Beyond closing skills gaps for entry-level roles that do not require a college degree, FabLabs in K–12 settings have been advanced as a means to increase student motivation for learning STEM concepts. Despite their growing role in preparing the future STEM workforce, the pedagogical foundations of FabLabs have received limited attention from the STEM education research community. This study addresses that gap by (1) developing and validating a self-efficacy instrument tailored to FabLab teaching and (2) using the instrument to measure the effects of a professional development program on K–12 teachers' self-efficacy for FabLab pedagogy.

The development of such an instrument is timely given the growing interest in integrating FabLabs into K–12 curricula and the potential benefits for students. A systematic review found that design and prototyping activities in FabLabs increase college students' motivation, creativity, problem-solving, and collaboration (Sumroo, Casakin, & Georgiev, 2022). Other studies report gains in self-confidence and more positive attitudes toward STEM careers following FabLab participation (Taheri, Robbins, & Maalej, 2020). Despite these documented benefits, FabLabs have been slow to penetrate K–12 classrooms due to substantial infrastructure costs, a limited pool of qualified teachers who can facilitate FabLab-based learning (Author et al., 2023), steep technological learning curves, and constrained access to professional development, as many schools do not prioritize FabLabs. Consequently, most FabLab learning occurs in informal settings or in higher-education engineering and design programs (Sumroo et al., 2022). Yet, despite their popularity elsewhere and industry's urgent workforce needs, comparatively little attention has been paid to (1) the quality of FabLab activities (with respect to content and pedagogical affordances), (2) the pedagogical efficacy of FabLab teachers and informal facilitators (Lassiter et al., 2013), and (3) the barriers to integrating FabLab activities into K–12 classrooms. Addressing these gaps will require intentional investment in high-quality FabLab resources,

research on factors that support or impede teacher adoption, and identification and removal of implementation barriers. In this study, we present the design and validation of a FabLab teaching self-efficacy instrument and report results from a pilot study using the instrument to measure the impact of a professional development program on K–12 FabLab educators’ self-efficacy.

LITERATURE REVIEW

Several studies have examined teachers’ knowledge and skills within the FabLab context. Saari, Pöllänen, and Vartiainen (2019) investigated the pedagogical development of FabLab facilitators through an analysis of collaborative design processes between facilitators and educators in Finland. They argued that while FabLabs are often introduced for their technological affordances, their educational value depends on intentional pedagogical design. Using a qualitative case study, the researchers identified key strategies facilitators employ to support student learning, including task structuring, feedback mechanisms, and reflective practice. They emphasized the importance of viewing facilitators not merely as technical experts but as educators who must cultivate adaptive, student-centered pedagogical frameworks. This study contributes to the growing recognition that effective FabLab implementation requires both technical fluency and an understanding of constructivist, inquiry-based teaching principles.

In a subsequent study, Saari, Pöllänen, and Vartiainen (2020) focused specifically on scaffolding strategies used by technology-oriented FabLab facilitators to support novice learners. Through classroom observations and facilitator interviews, they identified a range of instructional techniques—such as questioning, demonstration, and stepwise feedback—that facilitators use to scaffold students’ engagement with digital fabrication tools. The findings reveal that facilitators often struggle to balance autonomy with sufficient guidance. This study highlights the complex pedagogical demands placed on FabLab facilitators and calls for targeted professional development in instructional design and learning theory. More recently, these authors conducted a systematic review of studies published between 2020 and 2023 on maker education, including FabLabs, with particular attention to teacher development. Their review identifies a shift in research focus—from student engagement with tools to the professional learning ecosystems necessary for effective maker pedagogy.

A study by Alimisis, Kynigos, and Kynigos (2019) conducted across several European schools also underscores the importance of teachers’ pedagogical knowledge. Their findings indicate that when

teachers are confident in using design-based and project-based pedagogies, FabLab-based learning has a positive influence on student motivation. Successful implementations were characterized by teachers' participation in structured professional development that included curriculum co-design, hands-on engagement with tools, and opportunities for reflective practice. Similarly, Smith and Johnson (2020) found that teacher capacity—both technical and pedagogical—is the foundation of meaningful FabLab integration. They further emphasized that when teachers adopt a design-thinking mindset, student engagement and learning outcomes improve significantly.

Collectively, these studies highlight the central role of FabLab teachers' and facilitators' pedagogical knowledge in effective implementation. This underscores the need for interventions that equip educators with the knowledge and skills necessary to facilitate student learning in FabLab environments. However, to support teachers in developing these competencies, it is first essential to create instruments capable of accurately measuring teachers' knowledge and skills related to FabLab instruction. Such instruments are critical for evaluating the impact of professional development programs on teachers' pedagogical growth. Bandura's (1997) self-efficacy theory offers a useful framework for this purpose (Tschannen-Moran & Hoy, 2021). This theory has guided the development of self-efficacy instruments across various educational domains (Bekiroglu & Aydeniz, 2013; Aydeniz & Ozdilek, 2016; Unfried et al., 2022; Toma, 2024; Yang, Wu, & Li, 2023). Accordingly, Bandura's framework informed the development of the instrument presented in this study.

THEORETICAL FRAMEWORK

The theoretical foundation of this study is grounded in Bandura's (1997) self-efficacy theory, which defines self-efficacy as an individual's belief in their ability to successfully perform specific tasks under given conditions. In education, self-efficacy influences not only what teachers choose to do but also the effort they invest and their persistence when faced with challenges (Bandura, 1997, 2002). Over the past two decades, research has underscored the central role of self-efficacy in teacher effectiveness, demonstrating its impact on pedagogical decision-making, classroom resilience, and student engagement (Klassen & Tze, 2014; Zee & Koomen, 2016).

According to Bandura (1997), four sources shape self-efficacy: mastery experiences, vicarious experiences, verbal persuasion, and physiological or affective states. Of these, mastery experiences—successfully performing teaching-related tasks—are the most influential.

Teachers tend to gain confidence when engaged in authentic tasks that mirror real classroom challenges (Authors, 2016; Morris et al., 2017; Swackhamer et al., 2009). Vicarious experiences, such as observing peers or mentors effectively teach, also strengthen self-efficacy by showing teachers that success is attainable (Lindqvist et al., 2019). However, unstructured or negative observations can have the opposite effect, underscoring the importance of guided reflection and scaffolded observation protocols to ensure positive outcomes (Hadar & Brody, 2016).

Verbal persuasion (feedback from instructors, mentors, or peers) can further enhance teachers' confidence, particularly when feedback is specific, constructive, and grounded in observable practice. While verbal persuasion is generally less influential than mastery experiences, timely and supportive feedback remains essential for professional growth (Poulou, 2007; Tschannen-Moran & Hoy, 2007). This is especially true in innovation-centered teaching environments like FabLabs, where iterative design, experimentation, and uncertainty are inherent. Finally, teachers' physiological and emotional states such as stress, anxiety, or excitement also affect self-efficacy. Of note, elevated stress or negative emotions can undermine confidence, particularly in high-stakes or unfamiliar contexts (Pajares & Schunk, 2001).

In sum, teacher self-efficacy is multidimensional and sensitive to well-designed learning experiences. Professional development that incorporates authentic, supported, and reflective teaching practice can strengthen educators' confidence and competence to implement innovation-driven pedagogies like FabLabs in K–12 classrooms. The goal of this study was not merely to measure the effects of professional development on teachers' self-efficacy, but rather (1) to validate a survey instrument that can serve as a reliable tool for assessing FabLab educators' self-efficacy in facilitating student learning, and (2) to identify barriers to integrating FabLab activities into the K–12 curriculum.

RESEARCH METHODS

This study employed a mixed-methods design, incorporating both quantitative and qualitative data. Participants completed a Likert-scale survey along with open-ended questions that explored their professional development needs and perceived barriers to implementing FabLab activities in K–12 classrooms.

Participants

The study was conducted within a professional development program designed to equip K–12 teachers with the knowledge, skills, and tools

necessary to effectively integrate FabLabs into their curricula. Participants were teachers who attended a three-day FabLab-focused professional development workshop.

In terms of gender distribution, 62.5% of participants self-identified as female and 37.5% as male. Regarding teaching experience, 6.25% had 3–5 years, 12.5% had more than 5 years, 18.75% had more than 10 years, and 62.5% had more than 15 years of classroom experience. With respect to FabLab teaching experience, 18.75% of participants had taught in a FabLab for one year, 43.75% for 1–3 years, 18.75% for 3–7 years, and 18.75% for more than seven years. Table 1 summarizes the types of schools where participants were employed (responses were provided by 16 participants).

Table 1: The Demographics of the Schools that Participated.

#	School type	Elementary n	Middle n	High School n	Total
1	Urban	25.00% 4	43.75% 7	31.25% 5	16
2	Suburban	25.00% 4	43.75% 7	31.25% 5	16
3	Rural	25.00% 4	43.75% 7	31.25% 5	16

Data Sources, Collection, and Analysis

Data were collected using a 45-item Likert-scale survey that included two open-ended questions focused on teachers’ self-efficacy for teaching through FabLabs. The survey comprised nine items related to teachers’ planning efficacy, 23 items related to teaching efficacy, and eight items related to assessment efficacy.

The initial questionnaire was developed by the authors and reviewed by a group of teachers participating in the professional development program. The first author, a professor of STEM education with extensive experience designing and validating self-efficacy instruments, and the second author, a professional development leader and recognized thought leader in the FabLab field, collaboratively designed the instrument. Teachers were asked to provide feedback on the clarity of the questions (to ensure reliability) and on the alignment of survey items with the intended efficacy categories (to ensure construct validity).

Additional feedback was gathered from two of the first author’s graduate students—one a lecturer in the College of Engineering and the other a practicing teacher—as well as from three FabLab experts. Two of these teachers were graduates of the FabLab Institute with at least two years of FabLab teaching experience, and the third was a professor in the College of Design who had overseen a FabLab for more than five years.

Based on this feedback, the questionnaire was revised to improve clarity, accuracy, and alignment with the study's goals.

The final questionnaire (Appendix A) included three sections: (1) self-efficacy for planning FabLab instruction, (2) self-efficacy for facilitating student learning during FabLab teaching, and (3) self-efficacy for assessing students' FabLab-related competencies. It also contained open-ended questions designed to capture teachers' professional development needs, perceived barriers to implementation, and the supports and resources they deemed necessary for effective FabLab integration. The questionnaire was administered online to FabLab Institute graduates and other teachers who had taught in FabLabs within the partner districts. Although 45 teachers began the survey, 18 participants completed it in full.

Survey data were analyzed using descriptive statistics, with mean scores calculated for each item and category. Responses to the open-ended questions were analyzed thematically to identify patterns and trends in teachers' perspectives. Thematic codes and interpretations were refined through multiple rounds of team discussion to enhance validity. While correlational analyses could have yielded additional insights into factors influencing teachers' success with FabLab instruction, the study's sample size did not meet the threshold required for such analyses (Bonett & Wright, 2000; Fraenkel & Wallen, 2023; P.I., 2017; Smith & Wells, 2006).

RESULTS

The purpose of this study was to measure FabLab teachers' pedagogical self-efficacy across three domains: planning, facilitating instruction, and assessment. This section first presents the descriptive quantitative results, followed by a thematic analysis of teachers' responses to the open-ended questions.

FabLab Planning Efficacy

Findings from the self-reported efficacy data indicate that teachers felt generally confident in their ability to plan FabLab lessons. The planning domain was measured using nine Likert-scale items. Across these items, the average score for the planning category was 3.72 on a five-point scale, with a standard deviation of 0.37. The individual item scores ranged from 3.11 to 4.24. Teachers rated themselves highest ($M = 4.24$) on the item related to "designing lessons to support student learning of STEM content in FabLab settings effectively." The lowest-rated item ($M = 3.11$) was "developing assessments (rubrics and other assessment mechanisms) to

measure FabLab-specific learning outcomes effectively.” A summary of the full results is provided in Table 2.

Table 2: Summary of FabLab Planning Efficacy

Statement	Min	Max	M	SD	Variance	Count
1. Effectively supporting my students' learning of STEM content through experiences I provide in the FabLab.	3.00	5.00	4.24	0.61	0.37	21
2. Evaluating quality of external (online or elsewhere) FabLab activities from pedagogical affordability perspective.	2.00	5.00	3.71	1.08	1.16	21
3. Designing FabLab lessons to optimize my students' cognitive engagement with the material.	2.00	5.00	3.81	0.85	0.73	21
4. Designing FabLab lessons that promote student creativity.	3.00	5.00	4.24	0.53	0.28	21
5. Designing FabLab activities that challenge my students to evaluate pros and cons of different design processes.	2.00	5.00	3.29	0.82	0.68	21
6. Designing activities that empower my students to effectively use formal design processes (like design thinking, continuous improvement, and/or engineering design cycle) in their projects.	3.00	5.00	4.10	0.68	0.47	21
7. Designing intellectually rigorous learning activities, where students question and challenge one another's ideas, designs and/or products.	1.00	5.00	3.48	1.14	1.30	21
8. Designing learning activities that encourage students to generate conjectures, alternative solution strategies, ways of interpreting evidence, or models.	2.00	5.00	3.43	1.00	1.01	21
9. Developing assessments (Rubrics and other assessment mechanisms)	2.00	5.00	3.11	0.85	0.73	19

to effectively measure FabLab specific learning outcomes.

Note. M = Mean, SD = Standard Deviation, Min =Minimum, Max =Maximum.

FabLab Teaching Efficacy

The average score for the teaching component across all items in this category was 3.64, with individual scores ranging from 2.94 to 4.37. Teachers rated themselves lowest ($M = 2.94$) on the item “Guiding students to program digital systems (such as Micro:Bits or Arduinos) to achieve a specific design goal,” and highest ($M = 4.37$) on the item “Creating a classroom culture where students feel safe to take risks in their approach to problem solving.” A summary of the full results for this category is provided in Table 3.

Table 3: Summary of FabLab Teaching Efficacy

Statement	Min	Maxi	M	SD	Variance	Count
10. Helping my students develop meaningful goals for their projects.	2.00	5.00	3.84	0.87	0.76	19
11. Guiding my students to use diverse problem solving strategies.	2.00	5.00	3.47	0.88	0.78	19
12. Establishing a classroom culture where students use formal problem solving strategies (e.g., design thinking) in their solutions to the problems.	3.00	5.00	4.16	0.67	0.45	19
13. Giving students adequate time for brainstorming or idea creation for their projects.	2.00	5.00	3.89	0.85	0.73	19
14. Creating a classroom culture where students feel safe to take risks in their approach to problem solving.	3.00	5.00	4.37	0.67	0.44	19
15. Supporting students to effectively collaborate as they engage in problem solving.	3.00	5.00	3.95	0.69	0.47	19

16. Implementing class norms and procedures to ensure that all students make meaningful contributions to the design of targeted solutions.	2.00	5.00	3.79	0.61	0.38	19
17. Establishing norms and procedures for students to effectively communicate their ideas with one another.	2.00	5.00	3.68	0.73	0.53	19
18. Ensuring that students use technologically appropriate language to make contributions to the design discussions.	1.00	5.00	3.37	1.13	1.29	19
19. Guiding students to understand the importance of listening to others' ideas.	2.00	5.00	3.89	0.85	0.73	19
20. Guiding students to use a variety of communication tools and techniques to effectively present their design product or process to relevant audiences.	2.00	5.00	3.68	0.73	0.53	19
21. Establishing norms of collaboration so students can engage in productive discourse within and among student groups.	2.00	5.00	3.74	0.96	0.93	19
22. Guiding students to engage in productive arguments regarding their rationale for various design decisions.	1.00	5.00	3.21	1.20	1.43	19
23. Guiding students to integrate knowledge across different disciplines to come up with creative solutions to the problem they attempt to solve.	2.00	5.00	3.37	0.93	0.86	19
24. Guiding students to identify, collect and analyze appropriate information for their projects.	2.00	5.00	3.74	0.85	0.72	19
25. Developing norms and protocols to ensure that all students assume individual	1.00	5.00	3.33	1.05	1.11	18

responsibility for making valuable contributions to the group projects.							
26. Developing instructional protocols to ensure that students attend to, critique, and contribute to each other's ideas.	1.00	5.00	3.22	0.97	0.95	18	
27. Giving students sufficient time to understand the design challenge goals and /or the constraints.	2.00	5.00	3.89	0.87	0.77	18	
28. Effectively noticing individual students' struggles and providing appropriate scaffolding so they can successfully complete their projects.	2.00	5.00	3.83	0.76	0.58	18	
29. Guiding students to use appropriate modeling software to design a system or a system component.	1.00	5.00	3.67	1.15	1.33	18	
30. Guiding students to program digital systems (like microbits or Arduinos) to achieve a specific design goal.	1.00	5.00	2.94	1.35	1.83	18	
31. Guiding students to use CAD or CAM software to program computer controlled tools like 3D printers, CNC routers, and/or laser cutters to accomplish a design or fabrication task.	1.00	5.00	3.72	1.37	1.87	18	
32. Guiding students to create 3D objects from CNC router and/or laser cutter designs.	1.00	5.00	3.67	1.00	1.00	18	

Note. *M* = Mean, *SD* = Standard Deviation, *Min*=Minimum, *Max*=Maximum.

These results indicate that the FabLab teachers felt confident in their abilities to facilitate student learning in FabLabs. This relatively high confidence may stem from their confidence in their general pedagogical skills. This self-reported confidence needs to be validated through classroom observations.

FabLab Assessment Efficacy

The average score across all items in the assessment domain was 3.26, with individual scores ranging from 3.00 to 3.50. Standard deviation values for each item are provided in Table 4. Teachers rated themselves highest ($M = 3.50$) on the item “developing assessments to measure students’ proficiency in technical skills” and lowest ($M = 3.00$) on the item “developing assessments to effectively measure students’ creativity skills.”

Table 4: Assessment Efficacy for FabLabs

Statement	Min	Max	M	SD	Variance	Count
33. Using various formative assessment strategies to increase the quality of students’ reflection over their problem solving approach, process or product.	1.00	5.00	3.28	1.04	1.09	18
34. Ensuring that students show an adequate understanding of properties of different materials used in the fabrication of real world products.	2.00	4.00	3.33	0.67	0.44	18
35. Ensuring that students show their conceptual understanding of key scientific concepts involved in the design of their fabrication products.	2.00	4.00	3.11	0.74	0.54	18
36. Ensuring that students show understanding of the design aspects of the machinery used in the fabrication of real world products.	2.00	5.00	3.33	0.88	0.78	18
37. Developing assessments to effectively measure students’ creativity skills	1.00	5.00	3.00	1.05	1.11	18
38. Developing assessments to effectively measure students’ collaboration skills	1.00	5.00	3.28	1.10	1.20	18
39. Developing assessments to effectively measure students’ critical thinking skills	1.00	5.00	3.28	1.04	1.09	18

40. Developing assessments to measure students' proficiency in technical skills.	2.00	5.00	3.50	0.90	0.81	18
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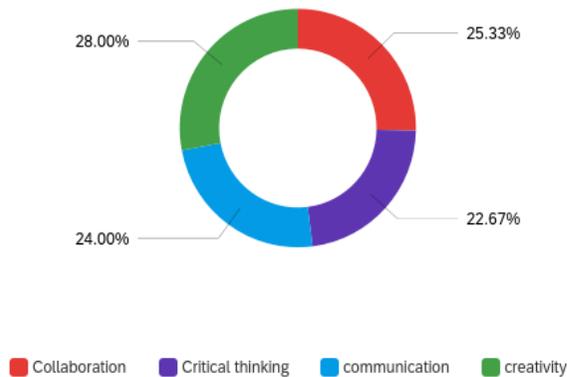
Note. M = Mean, SD = Standard Deviation, Min =Minimum, Max =Maximum.

Professional Skills

Participants were asked about their self-efficacy in teaching professional skills such as collaboration and communication as well. All teachers reported feeling confident in fostering students' collaboration, critical thinking, communication, and creativity within the context of FabLab learning. Teachers' responses are summarized in Figure 1.

Figure 1

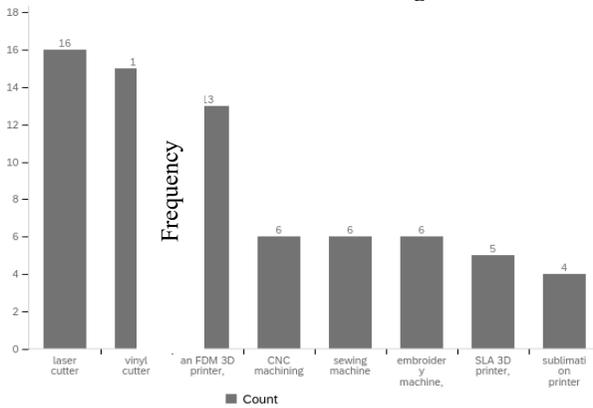
Teacher Efficacy for Promotion of Professional Skills



Technical Knowledge Efficacy

We asked teachers to rate their confidence in maintaining the following machines that are commonly found in FabLabs to measure their technical knowledge. Figure 2 summarizes teachers' responses to the questions related to their technical knowledge.

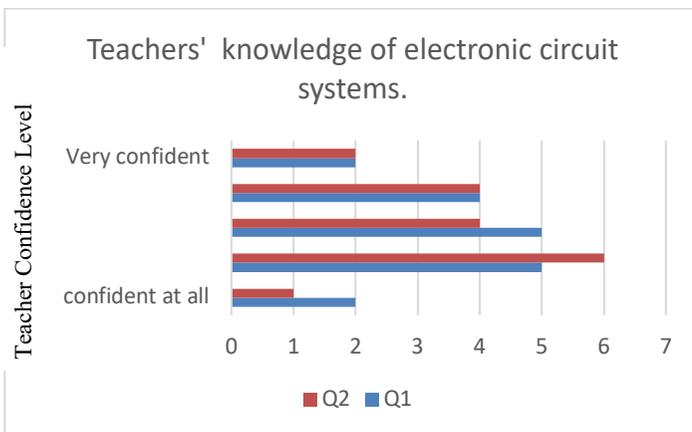
Figure
Teachers' Confidence in Their Technical Knowledge



Note. Summary of teachers' confidence in their technical knowledge reported in frequencies.

We also asked the participants to indicate their confidence in teaching the fundamentals of circuit design in electronic systems. This question is relevant as most FabLab educators are required to have a foundational understanding of basic circuitry and electronics associated with micro-computing. Without such knowledge, teachers may not be able to effectively guide student learning. Teachers' responses to this question are summarized in Figure 3.

Figure 3
Teachers' Technical Knowledge



Note. Q1=understand the fundamentals of the circuit design of electronic systems. Q2= apply this understanding to other relevant problems.

School Culture and Student Populations Served

When asked about barriers, teachers consistently referenced challenges rooted in school culture, one teacher noted:

The barriers I have encountered seem to mainly fall under the umbrella of school culture. Due to high and chronic teacher absences, we are frequently splitting and/or covering classes, which diverts time and energy away from teaching and learning. Another issue that falls under this category is students shying away from or being highly resistant to activities that challenge them to use creative problem-solving skills and complex problem-solving involving technology. Students are not asked to use creative problem solving consistently across the curriculum, and therefore struggle in this area because they are not given enough opportunities to practice and grow this skill.

Another teacher elaborated on the difficulty of helping students engage in sustained, higher-order thinking tasks:

From a computational standpoint, I feel confident in my ability to get students to a place where they know how to use a variety of equipment and software at a basic level. However, where I struggle is getting students to conceptualize complex problems from a three-dimensional perspective. I am challenged with how to support students in maintaining the stamina to stick with a complex design problem long enough to address the more nuanced and complicated parts of the process. In my opinion, removing these barriers extends far beyond addressing issues inside our school building and requires large-scale changes in social welfare, wages, policy, and mutual aid.

Time for Planning FabLab Instruction

Several participants highlighted insufficient time for lesson planning as a major challenge. One teacher shared:

Time limitations are the biggest issue for our school. If there were more opportunities for classroom teachers to integrate these types of technology, students would gain greater skills.

Another expanded on this concern:

Time and expectations can sometimes be a barrier. As FabLab teachers, we are usually given more and more responsibilities until our workload is almost unbearable. Not only are we maintaining and updating machinery and teaching students how to use and maintain those machines, but we are usually tasked with anything IT or engineering related. Not to mention PBL design and implementation, and the normal tasks of any educator. All of this is without any sort of extra compensation. The skill level and certification levels that most FabLab teachers are working at make us some of the most highly trained teachers in the country, and we should be compensated for it. It is also important to remember that only trained individuals can 'sub' for a FabLab teacher for safety reasons. So if we need to take a day off, the lab is closed for that day. This is a tremendous amount of pressure to put on a teacher with no support system in place.

Dedicated Time for FabLab Instruction in the Curriculum

A recurring theme among teachers was the limited instructional time allocated for FabLab activities. One teacher explained:

Outside of an introduction to engineering & technology course, it is difficult for all students to find the time to access and use tools in a fabrication lab and learn necessary skills for that tool (i.e.: CAD/CAM). – (T1)

Another teacher added:

I think the biggest barriers are instructional time and alignment with state standards, access to long-term skill development for students, monitoring students' understanding and gradual release of student access to technology, and upkeep of the technology. – (T2)

Professional Development Needs

Teachers reported varying professional development needs, with the most common being time to deepen their technical and pedagogical knowledge through hands-on experience and collaboration. One teacher explained:

The depth of knowledge that you are asking about is a challenge to convey because, unless you really geek out on this stuff, it requires quite a bit of additional time and experience. Time on

machines, time with a knowledgeable technician. I know the goal is for students to live and learn through experience, and as much as the machines and software decrease the technical skill required (compared to traditional Industrial Arts), learning alongside a technician teacher accelerates the experience. The biggest barrier I've been facing recently is that the teachers who assign tasks have not tried the project beforehand, so they've no concept of the skills that need to be in place before sending students into the lab. As a lab specialist, I have not been rigid in following any "anticipatory set" procedure (aside from the General Safety Quiz) as a means to decrease barriers to entry and encourage people to participate in the lab.

Other professional learning interests included collaboration with colleagues for co-planning lessons, networking for shared resources, and strategies for scaffolding student engagement in design projects.

Preference for Modality of Professional Development

While most participants did not express a strong preference for professional development modality, nearly all agreed that in-person, hands-on learning opportunities were most effective. One teacher stated:

PD's should be in-person. Also, there should be events where FabLab personnel and school admin can meet with local industry and university personnel to develop relationships for further support and direction.

Another teacher added:

As for preferred modality, I think given that most of us should have the equipment, it would just depend on how many need basic support vs. intermediate. I think if a teacher is very new to the technology, they may need in person to be able to see first-hand out to run the equipment and troubleshooting techniques. Each session being an hour would be great with some hands-on design on the teachers part would be great.

A consistent theme across responses was the desire for a community of practice—spaces where teachers, industry professionals, and higher education partners could share expertise, experiences, and resources. Teachers also agreed that in-person professional development is particularly valuable for new FabLab educators.

DISCUSSION

FabLabs have gained prominence as effective contexts for teaching K–12 students essential 21st-century skills such as creativity, critical thinking, leadership, entrepreneurship, communication, and problem-solving (Li & Todd, 2019; Iivari, Kinnula, Juustila, & Kuure, 2017). As a result, FabLabs have been integrated into both formal and informal learning environments for several years. Despite this increasing presence, limited attention has been devoted to the professional development of FabLab facilitators—whether they operate within classrooms or informal learning spaces.

This study pursued three objectives: (1) to develop, validate, and test a measurement instrument for FabLab teachers' and facilitators' self-efficacy; (2) to identify FabLab teachers' professional development needs; and (3) to examine barriers to effective FabLab integration in school-based STEM learning. The FabLab self-efficacy survey was developed and validated using an expert panel method. Because of the small sample size and the diverse contexts in which participating teachers worked, this approach proved the most feasible for validation in K–12 settings.

Findings indicate that, on average, FabLab teachers felt reasonably confident in their ability to plan, facilitate, and assess student learning when supported through professional development. The mean scores were 3.78 for planning, 3.64 for instruction, and 3.19 for assessment on a five-point scale. However, even after intensive professional development and ongoing support, teachers did not express strong confidence in their pedagogical skills related to FabLab instruction. Participants also identified multiple barriers to effective FabLab integration, including school leadership, school culture, curricular alignment, and insufficient time and space for co-planning.

These findings carry significant implications for pre-service teacher preparation, curriculum design, and the long-term sustainability of FabLab-based learning. First, although many K–12 students now experience FabLab learning opportunities, most teacher education programs still neglect to prepare pre-service teachers with the pedagogical knowledge required for FabLab integration. One strategy to address this gap is fostering partnerships between colleges of education and engineering schools that operate FabLabs, allowing pre-service teachers to co-develop and implement FabLab learning experiences for K–12 students. Such collaborations can strengthen both motivation and pedagogical competence.

Second, FabLab integration in schools often occurs voluntarily, typically led by highly motivated teachers who receive minimal

institutional support. These teachers frequently implement FabLab activities as extracurricular or enrichment programs without compensation or collaborative planning time. This volunteer-based model is unsustainable. When these teachers leave, programs often dissolve due to a lack of continuity or institutional ownership. Sustainable STEM initiatives like FabLabs require both institutional competencies and people competencies. As MacAuslan (2018) emphasizes, sustainability depends on committed stakeholders (leaders, teachers, and families), supportive organizational structures (curriculum, policy, and processes), dedicated instructional resources (such as lab spaces), skilled and motivated teachers, and systems of accountability and recognition for results. Without these factors, FabLab integration in K–12 settings will remain fragile.

Finally, while teachers rated themselves relatively high in planning and instructional domains, their lower confidence in assessment points to a critical need for professional development focused on evaluating student learning in FabLab environments. The higher self-efficacy scores for planning and teaching may reflect teachers' general pedagogical confidence rather than FabLab-specific expertise. In contrast, the lower scores in assessment may indicate limited knowledge of evaluating technical and creative competencies unique to FabLab learning. These findings suggest the need for further investigation into the sources of teachers' self-efficacy in planning, facilitating, and assessing FabLab learning. To deepen understanding, we plan to conduct follow-up semi-structured interviews with participating teachers.

The issues raised by participants also prompt an important question: What should professional development for FabLab educators look like?

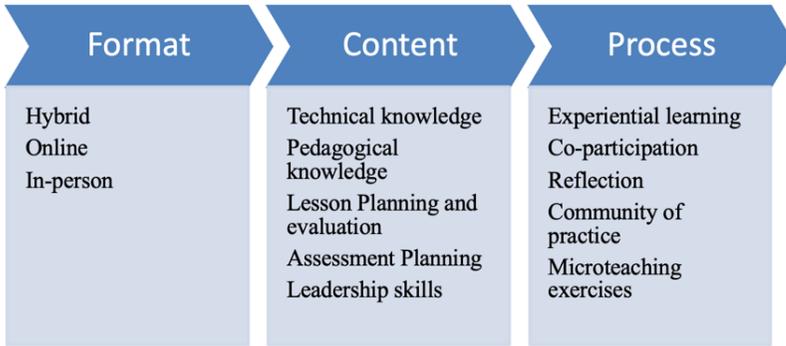
A Professional Development Program for FabLab Teachers

We propose a professional development framework to guide the design and implementation of such programs. Effective FabLab professional learning requires a multipronged approach—addressing content, pedagogy, modality, and leadership. Given the open-ended, problem-oriented nature of FabLab learning, professional development should center on problem-based learning, emphasizing creativity and problem-solving rather than solely conceptual understanding. The proposed framework is summarized in Figure 4.

Figure 4

FabLab Educator Professional Development Model

FabLab Educator Professional Development Framework



Modality

PD for FabLab educators can occur through different modalities depending on teachers' needs and learning preferences. New teachers benefit most from in-person PD, as it allows them to gain hands-on experience with design and fabrication tools and build confidence in operating the technology used in their classrooms. This experiential approach also fosters collaboration and trust among participants, creating a foundation for future peer problem-solving and support. More experienced teachers, however, may prefer online PD formats that allow for greater flexibility and focus on advanced topics such as refining pedagogy, integrating new instructional resources, or improving assessment practices.

Content

FabLab content presents a new instructional domain for many traditional teachers. Educators must not only learn to use fabrication technologies such as 3D printers but also understand the pedagogical approaches that help students leverage these tools for innovation. Additionally, teachers need strategies to assess students' learning outcomes effectively. Therefore, PD aimed at enhancing FabLab educators' efficacy should target three areas: technological efficacy, pedagogical efficacy, and

assessment efficacy. Finally, because launching and sustaining a successful FabLab requires vision and coordination, leadership development should also be an explicit component of FabLab PD.

Process

The process through which teachers learn is equally as important as PD content and modality. Consistent with existing literature on effective professional learning, teachers develop most effectively when they learn within a community, engage in experiential and collaborative lesson design, and reflect on their own practice. Teachers build self-efficacy when they test their knowledge through microteaching experiences and receive feedback in supportive environments.

While the proposed framework can serve as a general guide, FabLabs differ in purpose, context, and focus. Depending on educators' needs, PD may emphasize different components of the model. For example, since FabLabs are often led by a single motivated teacher, that individual's technical expertise often shapes the lab's instructional focus—whether electronics, digital fabrication, textiles, or laser cutting. Regardless of technical content, scaffolding remains a critical pedagogical skill that enables teachers to effectively guide students' learning.

To scaffold effectively, teachers must engage in experiential learning themselves, developing awareness of students' prior knowledge, observing learning challenges in real time (Alonzo, Berry, & Nilsson, 2019), and responding with appropriate pedagogical adjustments (Author, 2016; Russ, 2018). Noticing and addressing critical moments during students' productive struggle (Myhill & Warren, 2005) is a key skill for FabLab teachers, particularly when supporting novice learners (Pitkänen, Iwata, & Laru, 2020). Developing such skills and self-efficacy requires authentic, hands-on learning opportunities that are best achieved through in-person PD that includes microteaching and peer feedback.

Given teachers' limited time for collaboration, an online community of practice can further enhance professional learning by allowing educators to share best practices, troubleshoot challenges, and exchange resources. Such communities extend the benefits of in-person PD and promote sustained pedagogical growth.

LIMITATIONS

Like any research, this study is subject to several limitations. First, the FabLab teaching community is relatively small and geographically dispersed, encompassing educators at both the elementary and secondary levels who implement FabLab activities through diverse instructional formats—ranging from regular classes to after-school programs.

Consequently, the findings should be interpreted cautiously and may not generalize to all FabLab educators. Second, correlational analyses could have provided deeper insight into the factors influencing teachers' successes and challenges; however, the sample size did not meet the statistical requirements for such analyses (Bonett & Wright, 2000; Fraenkel & Wallen, 2023). Finally, while this study represents an initial validation of the FabLab self-efficacy instrument, further research is needed. We plan to continue administering the instrument to additional FabLab educators to increase the sample size and conduct further validation analyses in future studies.

REFERENCES

- Bekiroglu, F. & Aydeniz, M. (2013). Enhancing pre-service physics teachers' perceived self-efficacy of argumentation-based pedagogy through modelling and mastery experiences. *EURASIA Journal of Math Science and Technology Education*, 9 (3), 233-245.
- Aydeniz, M., Ozdilek, Z. (2016). Assessing and enhancing pre-service science teachers' self-efficacy to teach science through argumentation: Challenges and possible solutions. *International Journal of Science and Mathematics Education*, 14, 1255–1273. <https://doi.org/10.1007/s10763-015-9649-y>
- American Federation of Scientists (2024). *K-12 STEM education for the future workforce: A wish list for the next five year plan*. Retrieved Online from <https://fas.org/publication/>
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. WH Freeman.
- Bandura. (2006). Guide for constructing self-efficacy scales. In F. Pajares & T. Urda (Eds.), *Self-efficacy beliefs of Adolescents* (Vol. 5, pp. 307–337). Information Age Publishing.
- Bonett, D. G. & Wright, T. A. (2000). Sample size requirements for estimating Pearson, Kendall and Spearman correlations. *Psychometrics*, 65, 23-28.
- Fraenkel, J.R., & Wallen, N. E. (2023). *ISE: How to design and evaluate research in education, Eleventh Edition*. In McGraw-Hill Higher Education.
- Garcez, A., Silva, R., & Franco, M. (2022). The hard skills bases in digital academic entrepreneurship in relation to digital transformation. *Social Science*, 11, 192. <https://doi.org/10.3390/socsci11050192>
- Hadar, L. L., & Brody, D. L. (2016). The interaction between group processes and personal professional trajectories in a teacher education professional development community. *Journal of Teacher Education*, 67(5), 398–411.

- Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K.S. (2016). Educating the reflective educator, in: *Proceedings of the 6th Annual Conference on Creativity and Fabrication in Education – FabLearn*, 16, 26–33, <http://dx.doi.org/10.1145/3003397.3003401>
- Klassen, R. M., & Tze, V. M. C. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. *Educational Research Review*, 12, 59–76.
- Lassiter, S., Mcennis, C., Morrison, J., King, H., Skarzynski, B., & Waldman-Brown, A. (2013). *Training and inspiring educators in digital fabrication: A professional development framework*. In: Proceedings of Fab 9 Research Stream, 1-4.
- Li, X. & Todd, R.J. (2019). Makerspace opportunities and desired outcomes: Voices from young people. *The Library Quarterly*, 89(4), 316-332.
- Lindqvist, H., Weurlander, M., Wernerson, A., & Thornberg, R. (2019). Influencing self-efficacy in higher education. *Teaching in Higher Education*, 24(3), 381–396.
- Livari, N., Kinnula, M., Juustila, T., & Kuure, L. (2017). Multiple voices in the maker movement. *Association for Information Systems. ECIS 2017 Proceedings*. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1122&context=cis2017_rp
- MacAuslan, I. (2018). What factors affect the sustainability of educational programs? *Oxford Policy Management*, Retrieved from, <https://www.opml.co.uk/insights/what-factors-affect-sustainability-education-programmes>
- Morris, D. B., Usher, E. L., & Chen, J. A. (2017). Reconceptualizing the sources of teaching self-efficacy: A critical review of emerging literature. *Educational Psychology Review*, 29, 795–833.
- Myhill, D., & Warren, P. (2005). Scaffolds or straitjackets? Critical moments in classroom discourse. *Educational Review*, 57(1), 55-69.
- National Academies of Sciences, Engineering, and Medicine; Policy and Global Affairs; Government-University-Industry Research Roundtable, & Whitacre, P. (Eds.). (2024). *Supporting K-12 STEM education to create the foundations for innovation: Proceedings of a Workshop—in Brief*. National Academies Press (US).
- National Academies of Sciences, Engineering, and Medicine; Policy and Global Affairs; Government-University-Industry Research Roundtable, & Whitacre, P. (Eds.). (2022). *Addressing supply chain and manufacturing challenges and opportunities: Proceedings of a Workshop Series—in Brief*. National Academies Press (US).
- Norouzi, B., Kinnula, M., & Iivari, (2021). Digital fabrication and making with children: Scrutinizing adult actors' strategies and

- challenges in mediating young people's activities. *International Journal of Child-Computer Interaction*, 21, 100267.
- Park, S., Oliver, J. S.(2008) Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38, 261–284. <https://doi.org/10.1007/s11165-007-9049-6>.
- Pitkänen, K., Iwata, M., & Laru, J. (2020). Exploring technology-oriented Fab Lab facilitators' role as educators in K-12 education: Focus on scaffolding novice students' learning in digital fabrication activities. *International Journal of Child-Computer Interaction*, 26, 1-11.
- P.I., L. (2017). Minimum sample size method based on survey scales. *International Journal of Research & Methodology in Social Science*, 3(3), 44 -52.
- Poulou, M. (2007). Personal teaching efficacy and its sources: Student teachers' perceptions. *Educational Psychology*, 27(2), 191–218.
- Rayna, T., Striukova, L. (2021). Fostering skills for the 21st century. *Technological Forecasting and Social Change*, 164, 1-15.
- Reider, D., Knestis, K. & Malyn-Smith, J.(2016). Workforce education models for K-12 STEM education programs: Reflections on, and implications for, the NSF ITEST Program. *Journal of Science Education and Technology*, 25, 847–858: <https://doi.org/10.1007/s10956-016-9632-6>
- Russ, R. S. (2018). Characterizing teacher attention to student thinking: A role for epistemological messages. *Journal of Research in Science Teaching*, 55(1), 94- 120.
- Sherin, M. G., & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education*, 13(3), 475-491.
- Smith R.C., Iversen O.S., Hjorth M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction*, 5, 20-28.
- Smith, Z. R., & Wells , C. S. (2006). Central limit theorem and sample size. *Paper presented at the annual meeting of the Northeastern Educational Research Association*, Kerhonkson, New York, October 18-20.
- Toma, R.B., Yáñez-Pérez, I., & Meneses-Villagrà, J.Á.(2024). Measuring self-efficacy beliefs in teaching inquiry-based science and the nature of scientific inquiry. *Science and Education*. <https://doi.org/10.1007/s11191-024-00553-9>
- Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education*,

17(7), 783–805.

- Unfried, A., Rachmatullah, A., Alexander, A., & Wiebe, E. (2002). An alternative to STEBI-A: validation of the T-STEM science scale. *International Journal of STEM Education*, 9, 24, <https://doi.org/10.1186/s40594-022-00339-x>
- Yang, W., Wu, R., & Li, J. (2023). Development and validation of the STEM Teaching self-efficacy scale (STSS) for early childhood teachers. *Current Psychology*, 42, 7275–7283 (2023). <https://doi.org/10.1007/s12144-021-02074-y>
- Zee, M., & Koomen, H. M. Y. (2016). Teacher self-efficacy and its effects on classroom processes, student academic adjustment, and teacher well-being: A synthesis of 40 years of research. *Review of Educational Research*, 86(4), 981–1015.
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Appendix A.

FABLAB TEACHER SELF-EFFICACY SCALE

PART A. Planning Efficacy

Please indicate how confident you feel about achieving the following teaching activities. (1=not confident at all, 5=Very confident)

Statement

1. Effectively supporting my students' learning of STEM content through experiences I provide in the FabLab.
2. Evaluating quality of external (online or elsewhere) FabLab activities from pedagogical affordability perspective.
3. Designing FabLab lessons to optimize my students' cognitive engagement with the material.
4. Designing FabLab lessons that promote student creativity.
5. Designing FabLab activities that challenge my students to evaluate pros and cons of different design processes.
6. Designing activities that empower my students to effectively use formal design processes (like design thinking, continuous improvement, and/or engineering design cycle) in their projects.
7. Designing intellectually rigorous learning activities, where students question and challenge one another's ideas, designs and/or products.
8. Designing learning activities that encourage students to generate conjectures, alternative solution strategies, ways of interpreting evidence, or models.
9. Developing assessments (Rubrics and other assessment mechanisms) to effectively measure FabLab specific learning outcomes.

PART B. Teaching Efficacy

Please indicate how confident you feel about achieving the following teaching activities. (1=not confident at all, 5=Very confident)

10. Helping my students develop meaningful goals for their projects.
11. Guiding my students to use diverse problem solving strategies.
12. Establishing a classroom culture where students use formal problem solving strategies (e.g., design thinking) in their solutions to the problems.

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13. Giving students adequate time for brainstorming or idea creation for their projects.
 14. Creating a classroom culture where students feel safe to take risks in their approach to problem solving.
 15. Supporting students to effectively collaborate as they engage in problem solving.
 16. Implementing class norms and procedures to ensure that all students make meaningful contributions to the design of targeted solutions.
 17. Establishing norms and procedures for students to effectively communicate their ideas with one another.
 18. Ensuring that students use technologically appropriate language to make contributions to the design discussions.
 19. Guiding students to understand the importance of listening to others' ideas.
 20. Guiding students to use a variety of communication tools and techniques to effectively present their design product or process to relevant audiences.
 21. Establishing norms of collaboration so students can engage in productive discourse within and among student groups.
 22. Guiding students to engage in productive arguments regarding their rationale for various design decisions.
 23. Guiding students to integrate knowledge across different disciplines to come up with creative solutions to the problem they attempt to solve.
 24. Guiding students to identify, collect and analyze appropriate information for their projects.
 25. Developing norms and protocols to ensure that all students assume individual responsibility for making valuable contributions to the group projects.
 26. Developing instructional protocols to ensure that students attend to, critique, and contribute to each other's ideas.
 27. Giving students sufficient time to understand the design challenge goals and /or the constraints.
 28. Effectively noticing individual students' struggles and providing appropriate scaffolding so they can successfully complete their projects.
 29. Guiding students to use appropriate modeling software to design a system or a system component.

30. Guiding students to program digital systems (like microbits or Arduinos) to achieve a specific design goal.

31. Guiding students to use CAD or CAM software to program computer controlled tools like 3D printers, CNC routers, and/or laser cutters to accomplish a design or fabrication task.

32. Guiding students to create 3D objects from CNC router and/or laser cutter designs.

PART C. Assessment Efficacy

Please indicate how confident you feel about achieving the following teaching activities. (1=not confident at all, 5=Very confident)

33. Using various formative assessment strategies to increase the quality of students' reflection over their problem solving approach, process or product.

34. Ensuring that students show an adequate understanding of properties of different materials used in the fabrication of real world products.

35. Ensuring that students show their conceptual understanding of key scientific concepts involved in the design of their fabrication products.

36. Ensuring that students show understanding of the design aspects of the machinery used in the fabrication of real world products.

37. Developing assessments to effectively measure students' creativity skills

38. Developing assessments to effectively measure students' collaboration skills

39. Developing assessments to effectively measure students' critical thinking skills

40. Developing assessments to measure students' proficiency in technical skills.

PART D. Technical Efficacy

1. I feel confident in troubleshooting and maintaining the following: Please select the options you feel confident about.

- an FDM 3D printer,
- SLA 3D printer,
- CNC Machining
- laser cutter
- sewing machine
- embroidery machine,
- sublimation printer
- vinyl cutter

2. How confident do you feel about the following? Helping students to:

(1=not confident at all, 5=Very confident)

1. understand the fundamentals of the circuit design of electronic systems

2. apply this understanding to other relevant problems.

PART E. Efficacy to Promote Students' Acquisition of Professional Skills

I feel confident in my knowledge and skills to design learning experiences for my students to develop the following 4C skills. Please mark the option(s) that you feel confident teaching.

- Collaboration
- Critical thinking
- communication
- creativity

PART F. Open-Ended Questions

1. What are the barriers to effective FabLab implementation at your school/context? How can these barriers be removed?-Text Box
2. What would you like to see in a professional development program designed for FabLab instructors/facilitators? Please elaborate on (content, duration, modality (in-person or online) of PD, follow-up, support activities, and resources)-Text Box

PART G. Demographic Questions

1. What is your gender?

- Male
- Female
- Non-binary/third gender
- Prefer not to say

2. Years of teaching experience

- 1-3
- 3-5
- 5+
- 10+
- 15+

3. Years of experience teaching FabLab activities?

- 1
- 1-3
- 3-7
- 7+

4. Please select the type of school you are currently teaching at

	Elementary School	Middle School	High School	Community college
Urban	<input type="radio"/>			<input type="radio"/>
Suburban	<input type="radio"/>			<input type="radio"/>
Rural	<input type="radio"/>			<input type="radio"/>