Making to Empower Teacher Problem Posing and Design

Digital fabrication skills and interdisciplinary community of practice help teachers address classroom problems

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Abstract
Research on educational making and makerspaces, especially in school contexts, concerns students' experiences and learning in makerspaces. We position disciplinary classroom teachers as learners and focus on their experiences of maker skills and technologies, specifically how they identify and design solutions to problems of their own classroom practice. Across a semester-long, 60-hour course, 16 pre- and in-service teachers from 10 different disciplines identified problems of practice and iteratively designed technologies to address them. We characterize the problems they identified as well as the solutions they designed. We also illustrate how an interdisciplinary community of practice arose as an unexpected but noteworthy resource in teachers' reflections on their workshop experiences. Our findings underscore the value of opening the constructionist learning opportunities afforded by making not only to student learners but to their teachers as well.

Keywords and Phrases: Educational making, Teachers as learners, Teachers as designers

1. Introduction & Background
Educational makerspaces strive to fulfill the promises of constructionist education for every learner (e.g., Blikstein, 2013; Halverson & Sheridan, 2014). Three decades of research has focused on the transformative learning opportunities of making for students and the challenges associated with makerspaces (Martinez & Stager, 2013; Peppler et al., 2016; Blikstein et al., 2023). One recurring challenge is the mismatch between maker practices and pedagogy and the "conventional" pedagogical models in which teachers are typically experienced and trained (e.g., Kali et al., 2015; Kim, 2015). Teachers are key mediators of their students' maker learning, but they also need opportunities to experience and train in making as learners and facilitators in order to bridge this mismatch.

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At the same time, there is a growing body of work exploring teaching as a profession of *designing learning experiences*, underscoring the need to equip teachers with the skills and perspectives to effectively design and modify curricula to suit their learners' evolving needs (e.g., Brown & Edelson, 2003; Henriksen & Richardson, 2017; Kirschner, 2015). Digital fabrication spaces are particularly promising in this regard as they offer the capacity to develop tools that both address local problems and are of sufficient quality to be directly used in classrooms. Engaging in design activities can also foster development of perspectives, attitudes, and knowledge productive for maker education. Despite this potential, digital fabrication remains largely underutilized as a space for teacher learning. Some of this work comes from mathematics teaching, where the design of mathematical manipulatives (e.g., 3D printed geometry models, conic sections, tile and tower models of fractions) prompted both content and pedagogical learning among participating pre- and in-service teachers (e.g., Akuom & Greenstein, 2022; Harron et al., 2022). Designing manipulatives also led participating teachers to reflect on the roles of physical artifacts in guiding thinking and learning (Greenstein & Olmanson, 2018).

Building on this small body of work, we explore the use of makerspaces as design studios in teacher preparation programs, where teachers learn digital fabrication skills and leverage their teaching expertise to identify and address authentic challenges of practice. A core hypothesis of this work is that equipping teachers with the skills to produce functional prototypes relevant to their practice will yield directly applicable physical pedagogical objects and enhance teachers' confidence and willingness to integrate maker practices into their classrooms.

This study covers a small part of this research effort, focusing on the work and experiences of 16 pre-service teachers engaged in a 60-hour course in which they identify a challenge in their classroom practice and use digital fabrication tools to develop a physical pedagogical object to address that challenge. We explore two interrelated research questions: (RQ1) *what kinds of problems of practice do teachers seek to address when learning to use digital fabrication tools, and what types of design do they create in response?* (RQ2) *What are teachers' perceptions of the workshop format, including insights, resources, and anticipated impact on their teaching practice?*

We argue that our proposed approach to teacher training can facilitate teacher learning in ways that support constructionist commitments to powerful, learner-centered learning.

2. Methods

2.1 Participants & Setting

Our 16 teacher participants ranged from pre-service educators with limited classroom experience to 15-year veteran teachers (e.g., one recertifying in a new discipline). Their teaching expertise spans 10 subjects, including special education, and covers all primary and secondary school levels. Of the 16 participants, 13 had no prior experience with digital fabrication tools and 12 had little prior programming experience.

This study is part of a two-year project funded by the Swiss government that aims to innovate teacher training through novel teaching formats and international cultural exchanges. The Swiss course ran parallel to an educational design course at a collaborating U.S. institution, an R1 university in a major metropolitan area.

The Swiss course, taught by the third author, comprised 60 hours of design and prototyping work spread over one semester and a 5-day trip to the U.S. to explore the local makerspace landscape and meet the partner institution's students. Beginning with a hands-on workshop introducing common maker tools and techniques, participants completed a guided, iterative design cycle. Teachers first identified a challenge of practice to address and worked in groups to refine their problem definition, resulting in 11 project ideas (five pairs of teachers and six working individually). After problem definition, teachers ideated and created low-tech prototypes of possible solutions to their identified problems, ultimately developing one final functional prototype. Across the process, participants received feedback from their peers, the teaching staff, and the dozen graduate students enrolled in the parallel U.S. course. Both groups of students convened in a virtual session to refine problem definitions and initial project ideas and in a 3-hour, in-person session in the U.S. for critique and feedback on their low-tech prototypes.

All students enrolled in the course consented to participate in research. The course instructor is the third author of this paper but did not review research materials until after course grades were submitted.

2.2 Data Sources & Analysis

Data sources included photographs of participants' in-progress and final designs as well as 2-5 minute demonstration videos that participants made of their designs as part of their final project. To address RQ1, we analyzed these materials to examine the identified problems of practice and design solutions. We used two multi-dimensional frameworks to code the problems and design solutions. For the identified problems, we focused on: cognitive demand via Revised Bloom's Taxonomy (Wilson, 2016); disciplinary specificity (general vs. subject-specific); and the type of knowledge (e.g., factual, conceptual, procedural, or attitudinal). To code design solutions, we adapted and extended a framework for physical objects in science (Fernandez et al., 2024) to fit to general disciplinary contexts by examining: the range of topics, learning configurations, and outcomes allowed (from single-way to pre-defined to open-ended); student decision-making (from demonstrations to scripted activity to exploratory decision-making activity); and modality of use (teacher, individual student, or student group).

At the end of the course, participants completed a 10-minute survey focused on what they learned about practices of making, themselves (as learners and teachers), teaching with physical artefacts, working with other teachers, and the role of schooling and education in general. Participants responded to the survey in either English or French, as they were most comfortable. Responses in French were passed through Google Translate and verified by the third author. In order to address RQ2, the first author conducted a thematic analysis (Braun & Clarke, 2006) of the survey responses, and the themes were finalized in conversation with the third author. The primary themes of relevance for this paper are those of identity/self-perception and an interdisciplinary community of practice.

Challenge: Help learners...	Design solution*	Discipline(s)
Memorize, connect vocabulary to physical activity	Interchangeable, magnetic cards	Physical Ed, French
Construct oral arguments	Write-on, modular tree structure	English, Religion
Experience archeological inquiry	Mystery objects to classify	History, Science
With low vision measure by guiding ruler placement	Ruler indicating proper alignment	Special Needs Math
Construct linguistic phrases or math expressions	Magnetic frames with sliding tiles	French, Math
Map between topographical lines and 3D shapes	(F) Topographical puzzle	Geography
Spatial reasoning about geometric objects	(G) Magnetic planar solids	Math
Create new fonts to learn about font design	(H) Modular font tiles	Arts & Technology
Accessibly learn creative problem-solving	(I) Sticks and stones construction kit	Arts & Technology
Explore tessellations across scales	(J) Modular, tessellating tiles	Special Needs Math
Share progress, request help without a screen	(K) Button array	Math

Table 1: Teachers' disciplines, identified challenges, and designed solutions. *See Figure 1 for images of teachers' design solutions.

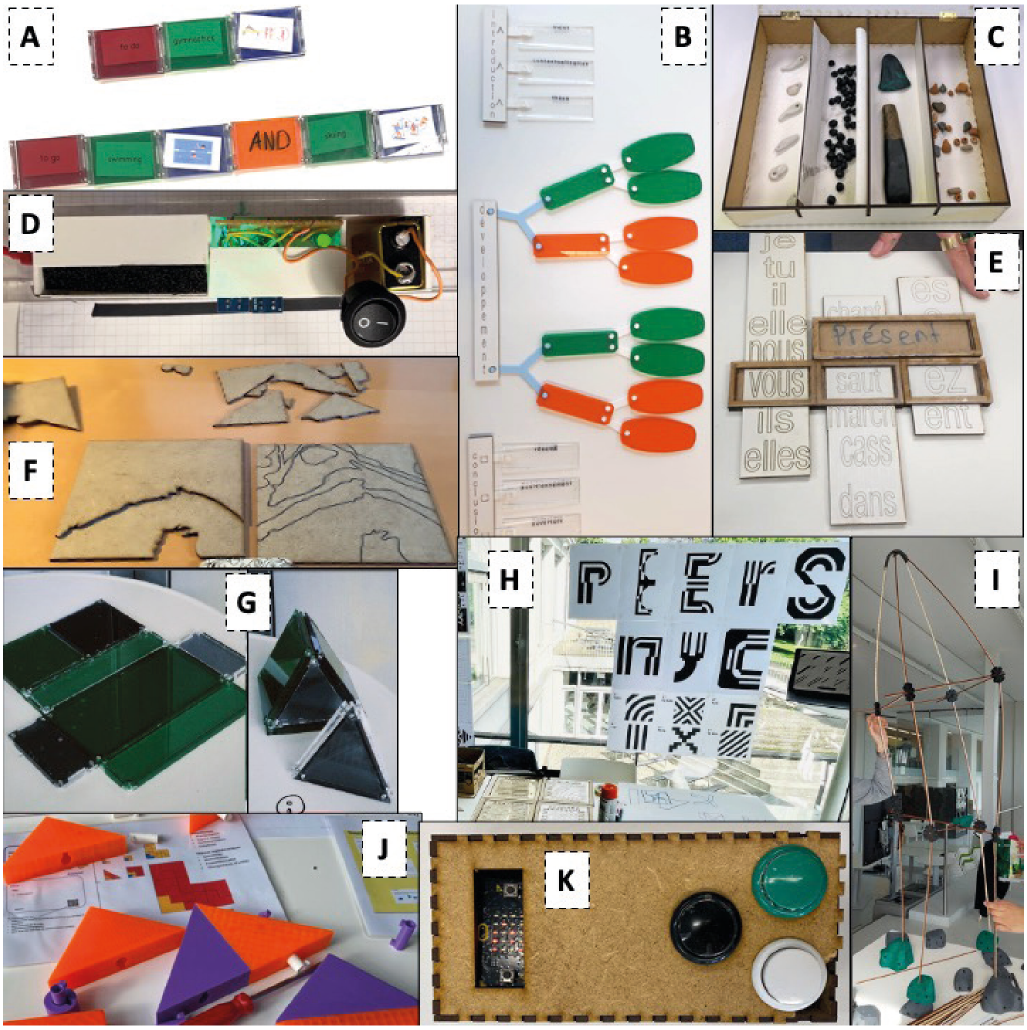

Figure 1: Teachers' design solutions. See Table 1 for further description of each design

3. Findings

We describe group-wide patterns in identified problems of practice, corresponding designs, and the workshop features participants emphasized as especially supportive of their pedagogical tool design work.

3.1 Identified Problems and Designs

The participants created a total of 11 different projects (Table 1 and Figure 1) addressing a diversity of challenges and proposed design solutions. All projects are situated in the cognitive domain related to content or practice, with the exception of (K) that focuses on a meta-cognitive goal related to help-seeking. In terms of disciplinary specificity, seven projects (A, C, D, F, G, H, J) address domain-specific issues, and four projects focus on multi-disciplinary or domain-general issues (B, E, K, I). Within the cognitive taxonomy, almost half of the projects focus on the cognitively demanding evaluation or creation processes (B, E, H, I, J), four on application (D, F, G, K), one on analysis (C), and one on memorization (A).

Figure one displays the range of design approaches and common features across designs. Eight designs consisted of pieces to be connected together (except for C, D, K), and three designs (A, B, E) consisted of 2D shapes with modifiable content that can be connected via pins or magnetic connectors. Participants tended to use laser-cut materials (six designs), one design was solely built with the 3D printer (J), and four designs used both. Two projects also used electronics (D, K), which the pre-service teachers learned to use for the first time. In terms of flexibility of materials, three of the designs can be used for different topics or disciplines (A, B, E); for example (B) can be used to support oral argumentation in any discipline. In modality of use, all designs were student-centered and, except for (D) and (K), designed to be used either individually or in groups. However, in terms of flexibility of student decision-making, five projects support exploratory decision-making (B, E, H, J, K), hence allowing also for flexibility of learning activities and outcomes, while five projects are more designed for scripted activity (A, C, E, F, G).

3.2 Interdisciplinary Community of Practice as a Valued Resource

Reflecting on the course, participants self-reported learning across a range of topics including: hands-on fabrication skills, design thinking and problem-solving, project-based learning, changes in self-perception, and broadened horizons. One notable finding—and the focus in our reporting here, in order to identify resources for this training approach—is that all participants highlighted the interdisciplinary community of practice fostered by the course context and international exchange. Without being prompted, seven participants mentioned this interdisciplinarity as a boon for their tool design process (e.g., "The chance to share diverse and varied skills and interests," "interdisciplinary links between our teaching disciplines," "I learned a lot and enjoyed collaborating with people who had very different backgrounds from mine"). When prompted overtly, every participant emphasized the value of learning with and from colleagues of different disciplines, in light of its relatively scarcity (e.g., "Super enriching and it's something that we rarely have the opportunity to do at <institution>," "Very different from what I experience at the <institution> [...] we need more courses like this").

Interestingly, only four of the groups were interdisciplinary (Table 1). Thus, even when the project team or final design was not obviously interdisciplinary, the feedback and co-working structure among the workshop's participants, who represented 10 different disciplines, made these diverse perspectives available. To this, the U.S. graduate student cohort contributed expertise in curriculum and instructional design, the design of educational technologies, and theories of learning, among others.

4. Discussion & Conclusions

In this study, we presented results from a novel teacher training course that equips educators with digital fabrication skills to create physical objects addressing self-identified problems of practice. Consistent with previous research in teacher preparation that positions teachers as designers of learning experiences (e.g., Greenstein et al., 2023; Kirschner, 2015), we demonstrate even that in a short amount of time, pre-service teachers exercise agency and creativity in responding to their students' needs through the design of new pedagogical objects.

Our work extends this existing literature by revealing the synergistic potential of engaging teachers within an interdisciplinary community of practice and supporting their use of makerspaces to develop pedagogical tools. Constructionism emphasizes the role of publicly shareable artifacts in evolving learners' thinking (Papert, 1980). In the context of teacher learning, involving an interdisciplinary community in the design process fosters cross-pollination of ideas, as reflected in a diverse array of productions that nonetheless share common design elements. Although these were the first physical objects designed by most participants—and thus of modest technological complexity—we observed considerable diversity in both the problems addressed and the solutions proposed. At the same time, similar mechanisms, such as the use of magnetic connectors or modular pieces, emerged through the shared design process as effective strategies to overcome common design challenges. We suggest that the design of pedagogical tools offers a novel professional learning context that complements traditional domain-general and discipline-specific curricula, providing an authentic setting for productive interdisciplinary work.

We acknowledge several limitations. Our pilot involved a relatively small number of participants and incorporated an international exchange component that is atypical in teacher preparation contexts. Nonetheless, our aim was to demonstrate how workshop elements beyond the exchange fostered the interdisciplinarity that participants identified as crucial to their learning. Future work, as part of our broader efforts to support teachers as makers of pedagogical resources, will seek to validate and refine these findings and examine how such training formats prepare teachers to integrate maker practices into their teaching. For instance, two pre-service teachers without prior design experience spontaneously adopted makerspace practices in their classrooms following the workshop series. We hope that, even at this early stage, our findings on teachers' experiences during the design process and the prototypes they developed in service of their own teaching offer valuable insights into the contexts and resources necessary to use makerspaces to expand opportunities for constructionist teacher learning.

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