Before the COVID-19 pandemic, some teacher education programs started maker education initiatives to integrate the tools, practices, and mindset of the maker movement into their curricula. These efforts came to a grinding halt at the beginning of the pandemic due to the sudden transition to emergency remote teaching (ERT). Post-ERT, educators have been exploring strategies for students to recover from the interruptions of their learning gains and maker education seems to be on the backburner compared to other priorities. However, maker education is still meaningful post-pandemic because it promotes creativity, collaboration, problem-solving, and resilience using hands-on projects. Envisioning teacher education programs in 2025, all teacher educators will have developed the competencies necessary to apply and implement the practices of maker education within their subject areas. Furthermore, all preservice and in-service teachers should have the literacy, fluency, and toolsets to engage with maker education, as well as develop a maker mindset. In other words, maker education should be infused into every aspect of teacher education. Detailed vision and suggestions for implementation are discussed.
INTRODUCTION

In the years leading up to the COVID-19 pandemic, teacher education programs began introducing maker education initiatives that leveraged the tools, practices, and mindsets of the maker movement (Rodriguez et al., 2018; Schad & Jones, 2020). According to a 2017 national survey, about 50% of the 123 participating teacher education programs offered maker education preparation to their undergraduate and graduate students, to various extents (Cohen, 2017). Fourteen undergraduate programs had an entire course on teaching and learning with maker technologies and principles, while 19 graduate programs provided such a course. Seven graduate programs had an entire course on researching the maker movement. Moreover, many participating programs indicated their intent to include more maker education preparation. While it is hard to tell whether making in education was steadily gaining prominence in teacher preparation programs before the pandemic, it is evident that maker education had a sudden cessation or became stagnant due to the COVID-19 pandemic, causing a gap in preparing preservice and in-service teachers to learn about maker principles and technologies.

The pause of maker education initiatives is not highlighted during the pandemic mainly due to the heavy emphasis on the transition to emergency remote teaching (ERT) at the beginning of the pandemic (Ferri et al., 2020) and then the strong need to address interruptions in student learning gains (Khan & Ahmed, 2021). During ERT, teachers and teacher educators were forced to teach their courses virtually, relying on learning management systems and videoconferencing tools (la Velle et al., 2020). Meanwhile, they had to provide technical support to their students and parents (Greenhow et al., 2020). Thus, coping with ERT became the priority for all educators. Furthermore, tools, resources, materials, and spaces for maker education initiatives became inaccessible to most educators. After ERT, educators have been finding strategies to address gaps in students’ learning gains (Engzell et al., 2021). As a result, most educators lack the time, energy, and resources to restart their maker education initiatives. However, this does not mean that maker education should remain on the backburner post-pandemic.

Envisioning teacher education programs in 2025, one key goal should be to advance maker education by building on the legacy of the maker movement (Halverson & Sheridan, 2014). In other words, by 2025, all preservice and in-service teachers should have a foundation in the tools, practices, and mindsets associated with the maker movement. To fulfill this goal, both low and high-tech maker education preparation should be-
come a critical part of the teacher education programs. Teacher educators should prepare all teachers to implement making as an instructional strategy by designing and offering curricula that foster teachers’ curiosity, providing them the opportunities to play, experiment, and create, encouraging them to test theories, and promoting productive failures and community building through hands-on and digital making projects. All participants in the teacher education programs should gain self-empowerment, cultivate a failure-positive attitude, nurture creativity, and develop the habits of a lifelong learner through maker education. In addition, preservice and in-service teachers should also implement maker education in their instructional practices. Overall, by 2025, the infusion of maker-centered tools, practices, and mindsets should be ubiquitous in teacher preparation programs.

VISION

By 2025, our vision is that all teacher educators and candidates will have developed the competencies necessary to apply maker education within their content areas. Inherently, making and the associated tools, practices, and mindsets are a crucial part of teacher education programs since they compel educators to move beyond the traditional classroom and embrace learning environments that are active, collaborative, and student-centered. Making in 2025 thrives in spaces where students can reconfigure furniture, brainstorm on whiteboards, and share their laptop screens on larger displays (Talbert & Mor-avi, 2019). Furthermore, these spaces need to have easy access to power for laptops and tools, flat tables where students can spread out materials, and ample storage for consumable resources and incomplete projects. In order to model how making takes place in the classroom, teacher educators will need to look beyond the conventional integration of technology, pedagogy, and content knowledge by placing a greater emphasis on the role of the learning context (Mishra, 2019). Based on the experience gained from the pandemic, these learning contexts should also include collaborative online spaces where all students can fully contribute and participate whether they are in person or learning and making remotely.

While maker education is often associated with the physical creation of personally meaningful artifacts, digital making provides opportunities to overcome many of the issues related to the cost of consumable materials. By 2025, most schools will have fully transitioned to 1:1 environments, where all students will have access to a laptop computer. As such, teachers can leverage online technologies, which provide a space for students to design,
create, share, and remix projects with peers through computer-supported collaborative learning. Teacher education programs should infuse digital making by helping teacher candidates look beyond conventional online artifacts, such as Google documents, spreadsheets, and blogs, to see how students can express their knowledge through 3D models, collaborative coding, and interactive digital art. New technologies, such as artificial intelligence and virtual reality, can help teachers push beyond the boundaries of their classroom walls to enable students to create virtual galleries of work that can be shared and exhibited with the world.

By 2025, all K-12 students will be required to take at least one computer science (CS) class to graduate high school. CS will act like literacy and math, a foundational knowledge base for students to explore and express ideas across domains (Weintrop et al., 2020). Therefore, all teacher education programs must introduce future educators to CS regardless of their specialization. Making and CS, however, complement each other from the perspective of creative coding (Blikstein, 2018). Both CS and maker education promote constructionist strategies, especially learning by doing. Marrying making with human-computer interaction through physical programming and robotics projects utilizes the best of both worlds. In practice, teachers at all grade levels can use programming languages such as Scratch to support students as makers and coders through digital storytelling. Teacher education programs can start with Scratch as an approach to help teachers become more familiar with coding, and then help them transition to physical computing using a platform such as Makecode and user-friendly microcontrollers including the micro:bit, Circuit Playground Express, and Raspberry Pi. Once teachers learn how to blink an LED, control a servo motor, and read sensor values, they have the potential to introduce students to creative computing projects such as making robotic pets, interactive board games, and self-driving cars. In this way, making can support the mission of broadening participation in CS, while also providing teachers and students with a creative pathway that acknowledges and affirms their identities and interests.

As teacher education programs introduce making to their students, it is crucial that there is an ongoing narrative about issues related to the digital divide and equity in schools (Reimer & Hill, 2022). Purchasing 3D printers and laser-cutters can further the divide between the haves and have-nots and potentially lead to inequitable learning outcomes. Teacher educators should discuss how to support digital equity by making tools accessible and choosing platforms that support students both in-person and online. Furthermore, with the unknown impact of the pandemic on students’ social-emotional learning (Edgar & Morrison, 2021), teachers should infuse making as
a therapeutic approach to help address student mental health issues and to build resilience through productive failure.

Teacher education programs, however, are only one piece of the puzzle needed to establish making as a sustainable practice in education. In order for maker education to thrive, schools and their social structures should be designed with a *students as creators, not consumers* philosophy which accounts for the time, people, and money needed to support hands-on learning. This includes rethinking school schedules to accommodate lengthier projects, supporting teachers by encouraging them to struggle alongside their students, and allocating the financial and human resources needed to staff makerspaces, maintain equipment, and restock consumables. Teacher education programs can work to model this mindset through preservice courses and professional development sessions for in-service teachers, administrators, and other educational stakeholders. Ultimately, these sessions should aim to disrupt the traditional model of schooling while also creating a shared vision of cultural transformation that supports and values making in K-12 education.

Although it is of utmost importance to infuse maker education in every aspect of teacher preparation programs, there are numerous factors that need to be considered to enable the achievement of this goal. First, resources, such as funding, physical space, time, people, materials, and technology, are indispensable factors to consider for the sustainability of maker education. Post-pandemic, teacher education programs may face financial issues, such as deficits, reduced grant opportunities, and decreases in budgets, making it difficult to fund the purchase of new maker tools, technologies, and consumable materials. Furthermore, changes in the physical campus structures due to transition to new learning models, limited time in the curricula, and a lack of staff for equipment maintenance further complicate the post-pandemic landscape.

Second, culture and mindset are salient variables. Culture in the teacher education programs and K-12 schools greatly affects stakeholders’ buy-in to maker education (Bullock & Sator, 2015). Beliefs that maker education is not a standardized practice and can only thrive in informal learning spaces and after-school programs will hinder the infusion. This mindset also causes a lack of interest from teacher educators, which results in the shortage of skilled teacher educators who draw from the maker paradigm.

Last but not the least, other education initiatives might also be notable elements. For example, the offering of online education has been on the rise in higher education. Though online learning might be personalized and flexible, it poses certain challenges to maker education, which requires physical
spaces, resources, personnel, and face-to-face instructional time. Another example is the fast-moving initiative of integrating computer science education into all K-12 schools, which overlaps with maker education, albeit with different beliefs, mindsets, and goals. However, the above-mentioned components should not deter the goal of **maker education infusion** in every aspect of teacher preparation programs.

**IMPLEMENTATION**

To reiterate, our vision is that by 2025, the **infusion** of maker-centered tools, practices, and mindsets for teacher educators, preservice, and in-service teachers should be ubiquitous in teacher preparation programs. This goal is both powerful and challenging. However, implementing applicable strategies in optimal and effective ways will make it not only feasible but also influential. Therefore, we propose specific suggestions for teacher preparation programs and implications for future research.

First and foremost, teacher educators need to have the maker mindset and competencies. It cannot be stressed enough how important it is for teacher educators to offer maker education preparation that is rooted in the maker paradigm of constructionism (Harel & Papert, 1991), and builds on the legacy of the maker movement (Papavlasopoulou et al., 2017). Besides, teacher educators need to have the knowledge, skills, and abilities to utilize maker principles and technologies and then design meaningful and authentic making projects for their students. More empirical studies on how to cultivate teacher educators’ maker mindset and competencies, including design-based research and longitudinal studies, are greatly needed.

Teacher education programs need to provide comprehensive and ongoing quality professional learning opportunities for teacher educators, preservice, and in-service teachers on maker principles and technologies. Professional development needs to be targeted. They should consist of workshops and activities that can be turn-key for the classroom, along with proper alignments with grade-level standards to elicit buy-ins. Teacher education programs also need fully designed curricula that have readily available lesson plans to support the active implementation of maker projects and activities in K-12 settings.

Another strategy to promote maker education preparation is to have more exposure to maker projects and curricula. For example, hosting physical or digital maker faires will showcase artifacts and real-world applications of the making projects, as well as the outcomes of the service-learning
projects generated by teacher educators, preservice and in-service teachers, and K-12 students and teachers (Harlow & Hansen, 2018). Both professional development and additional exposure might have the ability to cultivate participants’ maker mindsets and competencies. Research on to what extent various strategies impact the cultivation is needed.

At the program level, administrators should identify the right faculty who have the mindset, competencies, and experiences to lead maker education preparation. Research in this area is also needed, which could provide structures and guidelines on the details of the mindset, competencies, and experiences needed for maker teacher educators like those pointed out in the Teacher Education Technology Competencies (Foulger et al., 2017). Furthermore, it is helpful to establish mutually-beneficial partnerships with local communities and school districts and collaborate with teachers who are already implementing maker education. Pairing K-12 maker education mentors with teacher educators and students will be highly productive and fruitful. Empirical studies focusing on the effects of school-university partnerships on maker education fill a literature gap.

Post-pandemic, we should consider the advantages and disadvantages of offering maker education in different learning modalities. Teacher educators should know how to facilitate both face-to-face and virtual making sessions while starting the conversations with students on how to promote maker-centered learning in different modalities to ensure equity (Harron & Jin, 2022). Research on virtual making and equity issues in maker education will add considerable value to the field.

Proactively seeking funding and resources is critical to fulfilling the vision. The leadership teams could first highlight the importance of maker education and map it onto strategic plans. Then, administrators could prioritize funding for maker education and designate it as an indispensable part of the technology fund each year to maintain existing equipment and purchase technologies and consumables. Leadership teams could look into the physical spaces and find room for establishing model maker classrooms, maker labs, makerspaces, and media centers (Cohen, 2017) and support all stakeholders to be creators, rather than consumers of knowledge. Other creative solutions include teaching and collaborating with local classrooms, libraries, museums, and makerspaces, designing mobile makerspaces, and working with other programs and colleges. In general, resources including funding, physical space, materials, and technology, as well as human resources, are vital components. Research on innovation and leadership strategies is needed to document such endeavors.

Lastly, teacher education programs should explore opportunities in seemingly competitive initiatives and/or programs. In recent years, comput-
er science education has become a critical part of K-12 education, which continuously broadens participation (Dunton et al., 2022). However, making projects, especially those using high-tech tools, also help students learn computational thinking concepts and practice coding skills during the design thinking processes and hands-on making (Timotheou & Ioannou, 2019). Maker education and computer science education should not be exclusive to each other. Instead, there are opportunities to better utilize the assets of each in K-12 teaching and learning (Kjällander et al., 2018). For example, creative computing and interactive art projects employ both making and CS (Payne et al., 2021; Yang & Zhang, 2016). Students can create high-tech artworks using maker materials, technologies, e-textiles, paper circuits, and single-board microcontrollers. Students can also present and showcase their artifacts in events such as Maker Fashion Show, Maker Music Performances, and Maker Interactive Art Gallery. We need teacher educators and partners who have the maker mindset and competencies to lead such efforts in collaboration with those advocating CSforALL. Meanwhile, research in this area is relatively scarce. Future research on how creative computing projects affect students’ maker mindset, competencies, computational thinking, and coding skills is much needed.

References


