Makerspaces in Teacher Education as Hubs for (Re) Designing Learning and Teaching

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Abstract

Much work on makerspaces has focused on bringing maker education directly into schools, but with limited success. Prior research shows that the challenge is not technical but cultural: constructionist learning like maker education can only flourish when schools create conditions that support new ways of teaching and learning. In this keynote, I argue that one way to build such cultural conditions is by strengthening teaching as a design practice, and that institutional makerspaces in universities of teacher education can serve as vital infrastructures for this work. I illustrate this argument through two case studies from my work: (1) teachers designing pedagogical objects for their own classrooms, which fostered their agency and collaborative reflection, and (2) the design of a novel artefact-based learning sequence by a professional team, modeled in classrooms, which expanded teachers' pedagogical imagination. Together, these strands of work show how institutional makerspaces can empower teachers as designers and inspire ambitious innovations, positioning them as hubs for cultural change in teaching.

Keywords and Phrases: Makerspaces, Teacher education, Teaching as design practice, Artefact-based learning

1. Introduction

Makerspaces are appearing in more and more schools and universities as symbols of novel educational approaches. They promise constructionist learning opportunities where students can engage with ideas through design, tinkering, and making (Blikstein, 2013; Halverson & Sheridan, 2014).

Yet their transformative potential has proven difficult to realize. Too often, makerspaces remain peripheral to everyday teaching, with limited impact on classroom culture and student learning (Godhe et al., 2019; Peppler et al., 2016). To address these challenges, teacher education has been identified as a key lever, and much work has focused on preparing teachers to integrate maker education into their classrooms (Quintana-Ordorika et al., 2024).

While such efforts are important, they may not be sufficient. As Maurer and Ingold (2021) argue, bringing maker education to a school is not a matter of a technical change of a room but of a cultural change that requires rethinking everyday practices and conditions of teaching and learning. This suggests that the question for teacher education is not only how to equip teachers to use makerspaces, but rather:

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what cultural conditions allow novel, experience-rich forms of learning – like maker education – to take root in schools, and how can teacher education help create these conditions?

In this paper, I argue that strengthening teaching as a design practice can help create such conditions. Design involves processes through which existing practices can be questioned, alternatives imagined, and new shared understandings of teaching and learning generated (diSessa & Cobb, 2004; Laurillard, 2013). I further argue that institutional makerspaces in universities of teacher education can serve as powerful infrastructures for this work. They provide spaces where teachers together design, experiment with and reflect on pedagogical tools and experiences, enabling reflection and innovation.

I illustrate this argument through two strands of ongoing work at a Swiss university of teacher education: (1) engaging teachers in the creation of physical pedagogical tools for their own classrooms, and (2) developing and modeling novel artefact-based learning experiences in collaboration with teachers. Together, these efforts position the institutional makerspace as a hub for pedagogical innovation – empowering teachers as designers and enabling the collaborative reimagining of teaching and learning, and contributing to the creation of the cultural conditions under which novel, experience-rich forms of learning can take root in schools.

2. Conceptual Background

In order to situate the argument, this section outlines the conceptual foundations that inform our work: teaching as a cultural activity, teaching as a design practice, and makerspaces as infrastructures that can support such practices.

2.1 Teaching as a Cultural Activity

Teaching is not simply the application of instructional techniques but a cultural activity. Hiebert and Stigler's (2000) comparative analysis of mathematics lessons in the United States and Japan revealed that teaching practices are shaped by cultural routines and norms that are so deeply ingrained they are often invisible to practitioners. This cultural perspective explains why educational reforms are rarely implemented as intended: teaching is sustained less by policy directives or individual choice than by cultural scripts that define what "teaching" looks like in a given context.

The Japanese practice of Lesson Study provides a compelling example of how cultural infrastructures can support ongoing professional learning. In Lesson Study, teachers collaboratively design, enact, and analyze research lessons (Fernandez & Yoshida, 2012; Stigler & Hiebert, 2009). The practice is not simply about improving a single lesson; it is a profession-wide mechanism for gradually evolving teaching through collective inquiry. Teachers co-generate knowledge through design over time, and build shared repertoires of practice. DiSessa and Cobb (2004) describe this as design functioning as a knowledge-generating activity, where the process itself produces insights that can be carried across contexts.

From this perspective, improving teaching requires more than equipping individuals with new strategies. It requires infrastructures that support the cultural evolution of practice, enabling teachers to question routines, reflect collectively, and gradually develop shared alternatives. Such infrastructures create the conditions in which novel learning experiences can take root. Change in this sense is not reform imposed from

outside, but an incremental process anchored in teachers' collective reflective practice. The challenge, however, is that such reflective practices demand sustained time and resources – elements often scarce in schools, , where professional development is typically episodic and fragmented (Darling- Hammond et al., 2017). Universities of teacher education, with their institutional capacity and mission, are particularly well placed to provide infrastructures that enable teachers to engage in these practices over time.

2.2 Teaching as a Design Practice

If teaching is understood as a cultural activity, then the question becomes: what kinds of practices enable teachers to collectively transform that culture? Lesson Study, which was mentioned in the previous section, can be seen as one such practice. While typically framed as a cultural tradition in Japanese teaching, it also exemplifies a broader view of teaching as design: teachers generate alternatives, test them, and build collective knowledge through cycles of iteration. In this sense, teaching itself can be understood as a design practice, providing structured processes through which educators question routines, imagine alternatives, and refine pedagogy over time.

Laurillard (2013) deepens this view by describing teaching as a design science. Teachers, she argues, iteratively plan, test, and improve learning activities based on evidence of student learning. Such cycles not only adapt teaching locally but also contribute to the collective knowledge base of the profession when results are shared across communities. In this sense, design practice is inherently reflective and evidence-based, creating a bridge between classroom experimentation and professional learning.

Design also generates new insights that can reshape teachers' understandings of pedagogy itself, and thus is not limited to producing artefacts or lesson plans. DiSessa and Cobb (2004) emphasize that design experiments contribute to new ways of conceptualizing learning processes. This is well illustrated in Fernández et al. (2023)'s study of how science teachers' views of hands-on science evolved from "fun activities" to opportunities for reasoning and autonomy through iterative design. Such examples illustrate how design fosters professional growth by revealing possibilities for practice that might not emerge without the act of designing itself.

Finally, design repositions teachers within their profession. Rather than being passive users of curriculum or implementers of external reforms, teachers become active designers of learning experiences, strengthening their agency and reflective capacity. Importantly, design is rarely an individual pursuit: it thrives in collaboration. Svihla et al. (2014) describe how teachers in design communities evolve from instructionist approaches toward constructionist practices, precisely because they build on each other's insights and co-develop new ideas. Thus, to speak of teaching as a design practice is to emphasize both its iterative, generative character and its communal dimension.

2.3 Makerspaces as Infrastructures for Design

If teaching is to be approached as a design practice, it requires infrastructures that make design work possible. Traditional professional development often provides little room for experimentation: teachers may be introduced to new methods, but seldom have the time, resources, or collaborative structures to iteratively design and test their

own solutions (Rodriguez-Robles et al., 2025). Without dedicated infrastructures, teaching as a design practice risks remaining an attractive idea without the material conditions for sustained realization.

Institutional makerspaces can provide such an infrastructure. Equipped with tools that allow ideas to be externalized in tangible form, they support what Halverson and Sheridan (2014) call thinking with and through materials: the act of constructing something physical forces designers to articulate, test, and refine their ideas in ways that purely discursive processes cannot. For teachers, this material engagement can open new possibilities for learning while also making visible assumptions embedded in existing practices.

Pedagogical objects designed in makerspaces can also act as boundary objects that mediate between different communities of practice (Kumpulainen et al., 2019). Such artefacts connect theory with classroom realities, while also providing shared reference points for reflection between teachers, students, and researchers. Although teaching as a design practice extends far beyond artefact creation – encompassing lessons, interactions, and learning trajectories – makerspaces are uniquely well suited for artefact-based design. They provide the environment for teachers to collaboratively prototype and refine physical tools, and to explore how objects shape learning processes. In this way, makerspaces complement collaborative practices such as Lesson Study by extending inquiry into the material domain, making teaching visible and discussable through tangible prototypes.

Taken together, these affordances suggest that institutional makerspaces can serve as powerful infrastructures for fostering teaching as a design practice. They provide teachers with the space, tools, and collaborative culture needed to design pedagogical artefacts, reflect on their role in learning, generate new professional knowledge, and cultivate a design- centered community of practice.

3. Two Case Studies of How Makerspaces Can Be Used as Hubs for Design in Teacher Education

The preceding sections outlined a conceptual argument: that teaching can be understood as a design practice through which cultural changes in teaching and learning can develop, and that institutional makerspaces can serve as infrastructures to support such practice. To illustrate this argument, we turn to two case studies that represent complementary strands of work conducted at the HEP Vaud, my Swiss university of teacher education.

In both cases, the central concern is how institutional makerspaces can be mobilized as hubs for pedagogical innovations that shape teacher learning in ways that extend beyond technical skill acquisition. Specifically, we examine how makerspace-based initiatives can influence teachers' perceptions of their pedagogical practice, their students, and their professional role, with a focus on cultivating design-oriented approaches to teaching.

The two case studies approach this concern from complementary directions. The first examines what happens when teachers themselves engage in collaborative design processes within the makerspace, developing physical artefacts to address challenges

or questions in their own classrooms. Here the focus is on the act of making as professional learning: how teachers, by designing for their own practice, reflect on pedagogy and their role as designers of learning experiences.

The second case study investigates how teachers respond when novel artefact-based learning experiences, developed in the makerspace by others, are modeled in their classrooms. Here the teachers are not the direct makers but the reflective observers, confronted with new ways of engaging students. Such experiences can act as "windows and mirrors" (Sivia & MacMath, 2016), helping teachers to imagine alternative forms of learning and reconsider their own teaching.

3.1 Case Study 1: Teachers as Makers of Pedagogical Tools

A first way in which we mobilized our institutional makerspace to support teaching as a design practice was by engaging teachers directly in the creation of pedagogical artefacts for their own classrooms. The underlying assumption is that through making, teachers not only produce concrete tools but also develop new perspectives on pedagogy, on their students, and on their professional role.

3.1.1 Context and Project Design

At HEP Vaud, a series of courses and professional development activities were established to explore the potential of makerspaces in teacher education. In total, around 30 pre- and in-service teachers participated across two editions of a semester-long course, supplemented by collaborative activities with colleagues and students at Teachers College Columbia University. The program involved approximately 60 hours of work in the makerspace, structured around the following process: (1) learning core fabrication tools such as 3D printers, laser cutters, and microcontrollers; (2) identifying problems or challenges in participants' own teaching; (3) developing initial ideas and low-tech prototypes; and (4) refining and fabricating functional prototypes. Throughout the design process, the teachers received feedback our international partners. The course was designed not primarily to equip teachers with technical skills, but to situate them in authentic design processes connected to their own practice. Participants worked in small interdisciplinary groups, sharing challenges across subject domains and reflecting on how artefacts might mediate learning differently in their classrooms.

3.1.2 Illustrative Teacher Projects

Over the course of the program, teachers developed a wide variety of projects that reflected the diversity of their subject areas and pedagogical challenges. These ranged from interactive tools to make abstract scientific processes tangible, toolkits for creative problem-solving, and puzzle-like objects that focus on mathematical concepts or that support language learning, to physical templates for conflict resolution or storyboarding tools for developing oral arguments. Some projects focused on enabling playful exploration, others on structuring complex tasks, and still others on providing students with new ways of engaging physically with ideas. This diversity illustrates how the makerspace became a site where teachers could translate their own classroom concerns into concrete design challenges.

Two examples illustrate the kinds of outcomes that emerged, shown in Figure 1. A high school biology teacher initially sought to create a tool to *illustrate* the process by which the genetic code is deciphered. Through prototyping and peer feedback, the

project evolved into an *interactive and playful* tool that allowed students to manipulate components, thereby exploring the genetic code actively rather than passively observing it (see Figure 1 left).

A second project, developed by a high school religion teacher in collaboration with a middle school language teacher, focused on preparing students for oral exams. Their idea was to help students develop oral argumentation skills by physically structuring discourse. The resulting tool allowed learners to visualize and assemble elements of an argument, turning revision into an embodied and collaborative activity (see Figure 1 right).

Both projects demonstrate how engaging with the design of objects in the makerspace prompted teachers to rethink not only the artefacts themselves but also the pedagogical assumptions underlying their teaching.

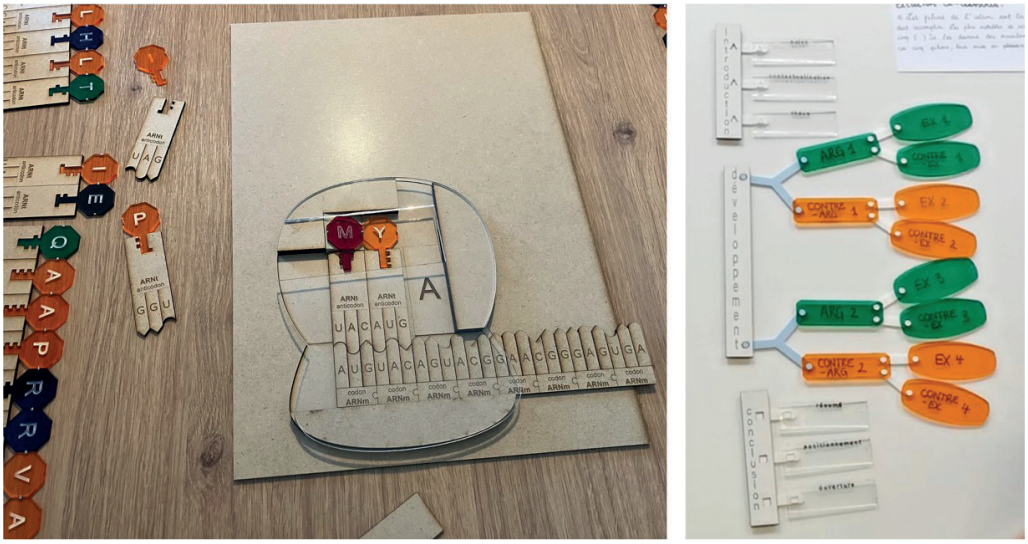

Figure 1: Two pedagogical artefacts developed by teachers in Case Study 1: (left) an interactive tool for exploring the genetic code, and (right) a modular object for supporting oral argumentation in exam preparation.

3.1.3 Teacher Reflections

At the end of the course, participants completed a short post-course survey consisting of open-ended questions about their experiences, and lasting about 10 minutes to complete. They were asked what they had learned about the practices of making, about themselves as learners and teachers, about teaching with physical artefacts, and about working with other teachers. The reflections reported here are drawn from these survey responses.

Teachers highlighted how engaging in the design process within the makerspace shaped their professional perspectives in several ways. One recurrent theme was a sense of agency and empowerment. As one middle school teacher expressed, "Designing and making an educational object has enabled me ... to see myself as a creator rather than a user of someone else's work. It's very gratifying and empowering." Others emphasized that this newfound agency was also something they believed other teachers and students should experience, describing it as a kind of professional freedom.

Another theme concerned pedagogical reflection. Several teachers reported that the process led them to reconsider the relationship between abstract concepts and concrete learning activities. One high school teacher explained, "This course made me realize how much I use abstract concepts... it helped me to decentralize myself and explore how these concepts could benefit from being made more concrete." Others noted that working with artefacts underscored the importance of interactivity and modularity, encouraging them to design for student autonomy. Still others highlighted the value of exchanging ideas across educational levels, noting that discussing objects designed for early childhood or primary classrooms helped them better understand challenges outside their own teaching context.

A further theme was the re-situation of teachers in the role of learners. One teacher observed, "I found myself in the role of the learner. I realized that I needed time, peace, and help to complete my project. As a teacher who masters his subject, it's not always easy to get down to the learner's level." This reflection illustrates how the design process not only supported professional growth but also reawakened teachers' awareness of the conditions of learning, including the vulnerability and persistence required to acquire new skills.

Teachers also voiced challenges and constraints. They mentioned the competing demands of everyday teaching, the time-intensive nature of design work, and the difficulty of mastering technical tools. While these concerns sometimes limited what teachers felt able to achieve, they also underscored the importance of institutional infrastructures that provide ongoing support, resources, and collaborative opportunities for sustained engagement in design practices.

3.1.4 Interpretation

Taken together, these findings suggest that engaging teachers in artefact-based design within institutional makerspaces can foster agency, stimulate pedagogical reflection, and renew teachers' perspectives on their role as professionals. While a single design activity rarely transforms practice on its own, it can prepare the ground for evolving conceptions of teaching and learning, particularly when repeated and embedded in supportive structures (Svihla et al., 2014). Pedagogical objects serve as boundary objects that mediate between teachers' immediate classroom concerns and broader pedagogical reflection, linking practice with professional identity. Institutional makerspaces thus provide not only the tools but also the cultural and social space for teachers to experience themselves as designers of learning.

3.2 Case Study 2: Expert-Led Design of Novel Artefact-Based Learning Sequences in Makerspaces

A second way institutional makerspaces can function as hubs for design in teacher education is by supporting the creation of novel artefact-based learning sequences that are enacted in classrooms with teachers as reflective observers. In this case study, the focus was not on teachers making artefacts themselves, but on modeling new pedagogical approaches within the familiar setting of a teacher and their students. By situating teachers as observers of their own classrooms, the makerspace served as a site where new designs could be developed, tested, and used to expand teachers' sense of what teaching in their context can look like.

3.2.1 Context and Project Design

This case study draws on a STEM education project aimed at connecting classroom science more closely to real-world STEM practices, projects and people. The project began with a collaboration with a local startup engineering a hand exoskeleton for people with paralysis. Using the university makerspace, interdisciplinary teams of researchers, engineers, and educators created a classroom-ready toolkit that allowed students to tackle simplified versions of the startup's design problems (see Figure 2): What physical structures allow one to control a paralyzed hand? What mechanisms can move the structure? How can movement be automated?

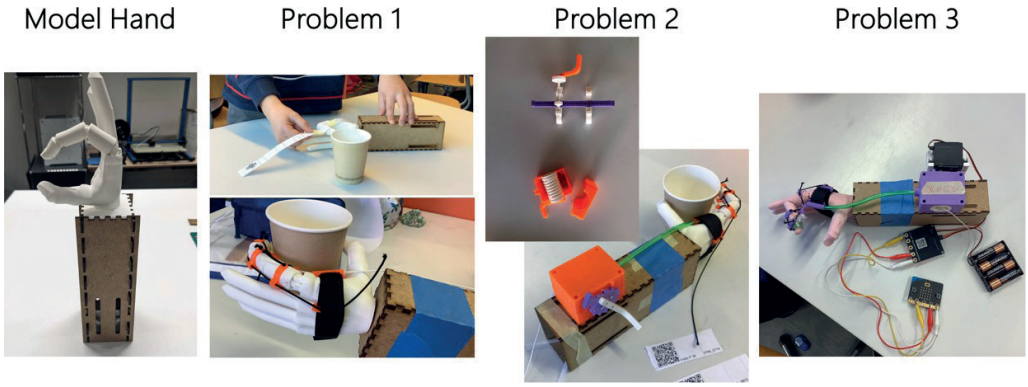

Figure 2: Toolkit developed for Case Study 2. Left: the model hand used by students. Right: the artefact-based components supporting the three design problems – structural, mechanical, and automated movement – adapted from the engineers' work on the exoskeleton.

The resulting learning sequence, designed for upper primary school, was deliberately designed to be novel, coherent, and curriculum-aligned. It integrated science and computer science standards – two domains often treated separately in the classroom, and where computer science standards in particular posed challenges for teachers. The sequence was implemented with four classroom teachers and spanned about twelve hours of instruction. Students were guided through a sequence of problems that were presented in short videos by the engineers. Using the toolkit, they then worked on these problems, experimenting with structural, mechanical, and programming challenges related to the engineers' work. In this way, the sequence not only gave students opportunities to learn disciplinary concepts, but also showed them what real STEM work looks like, who does it, and why it matters for society.

3.2.2 Teachers as Reflective Observers

During classroom implementation, the research team took the lead in teaching the sequence while the regular classroom teacher actively observed. This positioning allowed teachers to focus less on classroom management and more on how students responded to new forms of learning. Observing their own students in action, the teachers were tasked with reflecting on how the lesson design connected to the curriculum, how it differed from their usual practice, and what it revealed about their students' abilities.

3.2.3 Teacher Reflections

Teachers' reflections highlighted two main insights. First, the experience prompted them to reconsider aspects of their own practice, particularly the role of inquiry and openness in classroom tasks. One teacher observed, "I need to place greater emphasis on student questioning (and find ways to motivate them to engage in it)." Another noted how students' reactions to uncertainty challenged their usual lesson structures:

> "Some were unsettled by the absence of an immediate solution, and this confronted them with reality – which is extremely constructive. ... This fundamentally differs from ordinary lessons, where everything is more or less controlled and planned. It is much richer and more motivating for the students."

These comments suggest that observing the sequence encouraged teachers to rethink the balance between control and openness in their teaching, and to recognize the value of letting students wrestle with challenging, authentic problems.

Second, teachers reported that the project revealed dimensions of student potential that often remained hidden in more conventional lessons. For example, as one teacher reflected, "the students were more at ease than I would have expected when faced with an unfamiliar situation."

Together, these reflections underscore how the modeled sequence served as more than a curriculum innovation: it functioned as a mirror for teachers' practice, helping them identify concrete adjustments to their pedagogy while reshaping their sense of their students' capacities.

3.2.4 Interpretation

This case study highlights the potential of institutional makerspaces to model new pedagogical practices for teachers within their own classrooms. Unlike Case Study 1, where teachers designed artefacts themselves, here the makerspace enabled an interdisciplinary team to create a robust, curriculum-connected learning sequence that teachers could observe in action in their own context. Importantly, this kind of design work is not easily achievable by individual teachers: the exoskeleton kit and sequence required collaboration among three people over four design iterations to become technically reliable, pedagogically sound, and implementable.

Observing the implementation of this sequence positioned teachers in a stance of learning through modeling (Darling-Hammond et al., 2017): they were able to watch their own students engage with novel, inquiry-based tasks, free from the demands of classroom management, and focus instead on noticing what was happening. Such modeling of novel designs of learning experiences can play a powerful role in teacher learning, offering embodied examples of practice that abstract descriptions or workshops rarely convey.

At the same time, the exoskeleton project expanded teachers' pedagogical imagination (Helliwell & Ng, 2022) by showing what science teaching could look like when tied to real-world engineering problems and curriculum standards simultaneously. This kind of expansive learning (Engeström, 2014) allows teachers to see beyond their current routines, to envision possibilities they had not previously imagined, and to recalibrate their expectations of students' capacities. Teachers' reflections – on the need to prioritize questioning, tolerate open-endedness, and recognize students' ease with unfamiliar problems – underscore how modeled experiences can seed such imaginative shifts.

What Case Study 2 therefore demonstrates is not only the value of exposing teachers to new models of learning but also a possible role for universities of teacher education. Makerspaces in these institutions can serve as bases for professional design teams that develop artefact-based experiences in collaboration with schools, drawing on teachers' ideas and needs but producing designs that go beyond what teachers could feasibly construct on their own.

4. Discussion

The two case studies illustrate complementary pathways by which institutional makerspaces can contribute to cultivating teaching as a design practice. Each highlights different affordances of makerspaces for teacher education, pointing toward a broader vision of how such infrastructures can reshape the cultural activity of teaching.

Case Study 1 demonstrated how engaging teachers directly in the design of pedagogical artefacts can foster agency, stimulate reflection, and reshape teachers' professional identities. Teachers reported feeling empowered as creators, reconsidering the role of concreteness and abstraction, and rediscovering what it means to be learners themselves. These experiences exemplify how artefact-based design can move teachers one step further in their practice, positioning them as active designers rather than mere implementers of curriculum. From a cultural perspective, such engagement supports the evolution of teaching practices by embedding collaborative design and reflection into teachers' professional repertoires.

Case Study 2, by contrast, revealed the potential of institutional makerspaces for teacher trainers and researchers to develop and model innovative pedagogical practices for teachers. Here, an interdisciplinary design team developed a robust, curriculum-aligned learning sequence inspired by real-world engineering problems. By observing their own students engage with this sequence, teachers were able to reflect on aspects of pedagogy often overlooked in their practice, such as fostering questioning and tolerating open-endedness, while also recognizing students' unexpected competence with unfamiliar tasks. This case study demonstrates how teachers can learn not only by designing themselves but also by encountering designs that they could not easily create on their own. Through the approach of modeling (Darling-Hammond et al., 2017), where teachers witness embodied examples of alternative practice in their own classrooms, and through the expansion of their pedagogical imagination (Helliwell & Ng, 2022), teachers get to envision forms of teaching that go beyond their current routines or expectations.

Taken together, the two strands of work underscore the dual role institutional makerspaces can play in teacher education. They can empower teachers directly by providing spaces and tools for artefact-based design (Case Study 1), and they can serve as infrastructures for interdisciplinary teams to develop and model ambitious innovations that expand teachers' horizons (Case Study 2). Both pathways are important. The first cultivates agency and professional identity; the second broadens imagination and models what teachers cannot easily design alone. For universities of teacher education, this dual function suggests a more ambitious role: not only to prepare teachers to use makerspaces, but to become design partners for schools, capable of both fostering grassroots innovation and producing professionally designed learning sequences that align with teachers' needs.

These findings extend the conceptual background by highlighting the role of institutional makerspaces in universities of teacher education. If teaching is a cultural activity (Hiebert & Stigler, 2000) and design provides a pathway for cultural evolution in teaching (Laurillard, 2013), then institutional makerspaces offer infrastructures through which this evolution can be sustained. They provide places where teachers develop as designers of pedagogical tools, where interdisciplinary teams create robust artefact-based innovations, and also where boundaries between schools and the wider STEM world are actively negotiated. In this way, institutional makerspaces can contribute to building the cultural conditions under which constructionist, experience-rich forms of learning can take root in schools.

Looking forward, teacher education programs should integrate both pathways – teachers' direct engagement in design and their reflective observation of expert-led innovations – and research should explore how these modes interact in shaping professional cultures of teaching. For example, does exposure to modeled practices make teachers more ambitious in their own design work, or does engaging in design themselves make teachers more receptive to adopting new models? Addressing these questions will help clarify how institutional makerspaces can best contribute to the cultural evolution of teaching and to the wider adoption of constructionist learning in schools.

5. Conclusion

In this keynote, I have argued that institutional makerspaces in universities of teacher education can play a vital role as infrastructures for (re)designing teaching and learning. Rather than being peripheral spaces for occasional activities, they can become central to cultivating teaching as a design practice and to creating the cultural conditions necessary for novel learning to take root in schools.

Much of the work on maker education has pursued a more direct pathway: bringing maker tools and practices into schools and encouraging teachers to adopt them in their classrooms. While valuable, this approach often underestimates the cultural nature of teaching and the challenges of sustaining change. The cases presented here highlight a more indirect pathway. Teachers did not design tools explicitly to "do maker education," nor were they asked to transform their classrooms into makerspaces. Instead, they engaged in processes of design – either directly, in creating pedagogical objects for their own classrooms, or indirectly, in observing expert-led designs modeled with their students. This indirect pathway underscores the potential of institutional makerspaces not simply to diffuse maker practices into schools, but to serve as infrastructures where teachers' identities as designers are strengthened and new professional repertoires are generated.

By bridging research and practice, teachers and design teams, schools and the wider world of STEM, such makerspaces provide a foundation for reimagining not only what students learn, but how teachers themselves learn, design, and transform their practice.

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