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EDITORIAL

Trends, tensions, and futures of maker education research: a 2025 vision for STEM+ disciplinary and transdisciplinary spaces for learning through making

Andri Ioannou[1] · **Brian E. Gravel**[2]

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Abstract

This special issue aims to sketch the present state of maker learning research, reveal possible tensions, and present future possibilities to articulate principles for learning through design in the era of maker education. The special issue was announced in 2022 in ETR&D, a leading academic journal in educational technology. Of the 50 submissions to the special issue, eighteen (18) were accepted for publication. The editors favored a robust inclusion of papers to help define the contours of the field at present. Four clusters of topics are identified in this collection of papers: (i) STEM+ disciplinary and transdisciplinary learning spaces; (ii) Digital technologies in making, opportunities and challenges; (iii) Assessment practices and frameworks; (iv) Representation, inclusion, and tensions around maker-centered initiatives and reforms. The editors of the special issue believe that these clusters reflect the current state-of-the-art in the field as well as significant questions to guide near future research. Reflecting on these papers but also the overall editorial process, the editors identified several opportunities and provide suggestions on how the field might expand moving forward.

Keywords Maker education · Makerspaces · Learning through design · STEM+ · Educational technology · Special issue

Introduction to the special issue

As the maker movement and learning through design are increasingly adopted in K-20 classrooms and public (informal) makerspaces, students have more opportunities to generate unique, personally meaningful projects and artifacts, using digital technologies,

✉ Andri Ioannou
andri.i.ioannou@cut.ac.cy

Brian E. Gravel
brian.gravel@tufts.edu

1 Cyprus University of Technology (Cyprus Interaction Lab) & CYENS Center of Excellence, Limassol & Nicosia, Cyprus

2 Tufts University, Medford, MA, USA

crafting and art traditions, and elements of computing and engineering. As a form of educational practice, making is not new; yet it is newly important in educational conversations across contexts and with diverse orientations. One such context concerns the technological advancements currently enabling making practices beyond fabrication and affording the design of educational technologies for learning in makerspaces. Another context concerns makerspaces as sites where issues of equity and power in STEM are both stabilized and disrupted, with possibilities for democratizing learning (Blikstein, 2013). Now with more than 20 years of research in the field (e.g., Lin et al., 2020; Papavlasopoulou et al., 2017; Schad & Jones, 2020) we know that maker education can promote STEM-related learning outcomes, support expansive forms of collaboration, deepen empathy, and enable complex coordination of people, materials, and purposes, which are proving increasingly important across varied work and learning spaces. Altogether, maker education seems to bring to the forefront an integrated and holistic approach to learning with benefits across domains and orientations. Yet, despite the considerable work in the field, quickly accumulated during the last two decades, significant questions remain unanswered. The promise of the maker movement exists in tension with many aspects of the educational landscape and more research is needed that illuminates both the challenges and opportunities for maker education.

It remains a challenge understanding how to support learners to develop as makers, what people are learning in makerspaces, how these spaces humanize learning, and how to best assess shifts in practice and learning in these open-ended environments. The special issue project was motivated to address this challenge. It aimed to synthesize current knowledge on learning through making, including the design and evaluation of learning in maker contexts, as well as the exploration of tensions and possibilities to articulate principles for learning through design in the era of maker education. The project started in late 2021 when the special issue proposal was accepted in ETR&D, a leading academic journal in educational technology. In early 2022, the co-editors pushed an open call for papers. The special issue was scheduled to be published by the end of 2023. As editors, we favored a robust inclusion of papers to help define the contours of the field at present. Four clusters of topics have been identified in this collection of papers: (i) STEM + disciplinary and transdisciplinary learning spaces; (ii) Digital technologies in making, opportunities and challenges; (iii) Assessment practices and frameworks; (iv) Representation, inclusion, and tensions around maker-centered initiatives and reforms. Overall, the variety of research methods and research contexts in our collection of manuscripts allows the reader of this special issue to gain a comprehensive insight into the current state-of-the-art in maker education. The collection of manuscripts provides insights on what might be the next steps in research and practice of maker education, based on today's findings from empirical research across contexts and with diverse orientations.

Theoretical foundations of maker education

Theoretically, one distinct orientation towards making builds on Constructionism. Papert's theory of Constructionism asserts that people construct knowledge when they design, build, and share their own meaningful artifacts (Morado, 2021; Papert, 1991). That is why researchers subscribing to the *maker culture* and *maker movement* place emphasis on studying learning and skill development via making, tinkering, coding, and play (Gravel et al., 2022; Honey, 2013; Martinez & Stager, 2013; Timotheou &

Ioannou, 2019a, 2019b). These orientations embrace digital fabrication, technology, and computing aiming to integrate the tools, practices, and mindsets of maker learning into curricular enactments, typically to promote STEM or STEAM practices (e.g., Gravel & Puckett, 2023; Timotheou & Ioannou, 2021a, 2021b). Another orientation focuses on the relational and historical aspects of making (Barajas-López & Bang, 2018) and offers critical insights into how forms, structures, and systems support maker learning. For example, examinations of crafting, heritage, and cultural practices as social learning activities offer insights into how making can address issues of equity and power, particularly within dominant cultures (Vossoughi et al., 2016). Research builds from these different orientations, while also existing at intersections of culture, technology and computing, and social transformations (Calabrese-Barton & Tan, 2018; Gravel et al., 2021; Searle et al., 2020).

The theoretical foundations of maker education and work within and across different domains and orientations invite important questions such as *for whom* and *towards what ends* (Philip et al., 2018) and what is it that students are learning in makerspaces? (Petrich et al., 2013; Vuorikari et al., 2019). As this movement grows, so too do examples of where making continues to privilege and advantage those from dominant locations (Vossoughi et al., 2016). Critical interrogations of technological structures, tendencies, and practices (Eglash, 2004) are necessary in addressing questions of equity and possibility in making. At the same time, research on learning designs (e.g., Wasson & Kirschner, 2020) and design-based research (e.g., McKenney & Reeves, 2014) meshing pedagogy and STE(A)M practice in maker contexts are becoming of great interest. Drawing on this opportunity for dialogue, we aimed for this special issue to become a venue for discourse around empirical investigations. We sought to include manuscripts that compile contemporary and emerging research approaches in this burgeoning area and contribute to the growing empirical literature on learning through design, pedagogy and practice, maker technology, and maker education.

Clusters of contributions motivating new questions

The initial call for paper proposals resulted in 50 submissions. All submissions underwent a rigorous anonymous peer review process, with over 30 field specialists from around the world agreeing to provide expert reviews. After at least two rounds of revisions and extensive work by the authors and reviewers to ensure high quality contributions, we allowed the more robust submissions to be processed for publication. Of the 50 submissions, eighteen (18) were finally included in the special issue. The special issue was designed to offer a sketch of the present state of design and maker education research thus we favored a robust inclusion of papers to help define the contours of the field at present. The works included seem to form four general clusters of topics. Often, the manuscripts delve into issues that span across these clusters of topics, although they are summarized under one cluster based on the editors' perceived dominant focus. Collectively, the papers represent a synthesis of international perspectives underpinning alignments that need to be in place for maker learning and impact to occur. Meanwhile the variety of research methods and research contexts in this collection allows the reader to gain a comprehensive insight into the current state-of-the-art in maker education.

Cluster I: STEM+ disciplinary and transdisciplinary learning spaces

While educational reforms continue focusing on the necessity of educating young students to be more confident, interested, and capable in the STEM disciplines (Science, Technology, Engineering, Mathematics), an increasing number of studies acknowledge the different types of skills that maker education endorses as well as the historical arc of making that requires expanding our considerations of disciplinarity. The editors of the special issue recognize these trends as "*STEM+*" research. An obvious example is the push to integrate the arts (A), framing STEAM as an integrative and expanded curricular practice. Yet, all too often, STEAM is a license to using the arts in service of STEM, which fails to realize the important *mutual relationship* between the arts and STEM that STEAM might aspire to achieve (Halverson, & Sawyer, 2022). Creative assemblies of these intersections advance efforts to reimagine the relationships between and among humans, materials, and the natural world (Barajas–López & Bang, 2018; Peppler et al., 2023). This cluster touches on STEM+ learning spaces, identifying disciplinary learning in making, as well as transdisciplinary environments where the practices of different domains *meet and coexist* (Sengupta et al., 2019).

The first three papers in this cluster offer findings from enacting making in transdisciplinary environments. The work of Naomi Thompson (Thompson, 2023) examines the question of how student-created artifacts showcase learning in a making intervention designed to engage youth with mathematical practices inherent in weaving. The cases presented in this work exhibit a range of sophistications related to instantiations of mathematics relevant to weaving. The study builds toward a broader way to recognize and validate engagement with mathematical ideas through making. Next, Daryl Axelrod and Jennifer Kahn (Axelrod & Kahn, 2023) examine multimodal composing and maker education working with predominantly Hispanic, low-SES, urban high-school students on making digital comics based on literary novels. The authors discuss implications for expanding maker education into formal non-STEM disciplinary spaces and the importance of grounding learning designs in students' preferred repertoires of practice and ways of being and knowing. Furthermore, Cassia Fernandez, Tatiana Hochgreb-Haegele, Adelmo Eloy, and Paulo Blikstein (Fernandez et al., 2023) present an analytical framework which encompasses the material dimension of learning in the design of science lesson and aims to guide educators on developing materials for hands-on science learning. The authors investigate the connections between the design of materials and students' epistemic agency, whilst toolkits and activities designed for science education are presented.

The next two papers in this cluster offer work in disciplinary environments. First, Pi-Sui Hsu, Eric Monsu Lee, and Thomas Smith (Hsu et al., 2023) examine the relationships between youth's engineering identity and productive struggle, that is constructing correct new knowledge and reconstructing prior knowledge. The authors focus on processes of identity negotiation during making, which afford students the opportunity to leverage making tools (e.g., 3D printers) and apply engineering knowledge and practices to solve engineering issues. The authors report that the boys and girls who were engaged in the process of productive struggle showed changes in their identity with engineering. Next, Richard Lee Davis, Bertrand Schneider, Leah Rosenbaum, and Paulo Blikstein (Davis et al., 2023) focus on measuring changes in high-school seniors' problem-solving skills after working in year-long digital-fabrication course with a focus on problem-solving with mechanistic systems. They found that high-school students' participation in a maker course, working through multiple cycles of the engineering design process, was associated with better performance on hands-on mechanistic problem tasks and an "expert approach" in problem solving.

The papers in this cluster lead us to wonder about the relationships between disciplinarity, materiality, and making: *How do contemporary descriptions and frameworks of disciplinary engagement and practice support and validate maker-centered pedagogies? In what ways do existing disciplinary definitions inhibit the possibility for maker education to illuminate new forms of multimaterial and transdisciplinary practice?*

Cluster II: digital technologies in making, opportunities and challenges

Making activities may use both digital and analog technologies alike. In the digital space, maker-oriented technologies can be 3D printers, laser cutters, (educational) robots, and inexpensive smart interfaces that allow the students to create systems with sensors, actuators, and connectivity. On the other hand, carpentry and woodworking activities or weaving activities make use of analog maker tools. Papers in this cluster emphasize the use of digital technologies in making, providing examples of integration and use, along with opportunities and challenges involved.

The first two papers in this cluster provide examples of technology integration and use. First, Alex Fegely, Cory Gleasman, and Tammi Kolski (Fegely et al., 2023) consider educational robotics as motivational tools for computer science learning. They document preservice teachers' gains in motivational persistence and retention of programming concepts after working on hands-on maker activities with educational robotics. Next, Matthew Caratachea and Monty Jones (Caratachea & Monty Jones, 2023) describe teachers overcoming challenges in using immersive VR devices to design student-centered maker learning experiences that addressed K12 science content. This study offers a model for teacher practice with immersive VR and examples of curriculum and learning activities.

The next two papers in this cluster focus on the opportunities but also challenges involved in technology integration and use. First, Li Cheng, Pavlo Antonenko, and Albert Ritzhaupt (Cheng et al., 2023), examined teachers' beliefs in relation to their 3D printing integration levels in science classrooms. They found no correlation between teachers' beliefs and their 3D printing integration levels based on analysis of survey data and lesson plans. Teachers reported several challenges they encountered in their 3D printing integration, from logistical and technical challenges to more pedagogical ones such as how to effectively integrate 3D printing in the curriculum. Next, Soo Hyeon Kim and Amber Simpson (Kim & Simpson, 2023) consider home environments as a context for the development of engineering discourse and practices. They examine how parents' use of epistemic supports differs between engineering design tasks with technology and engineering design tasks without technology, within the different phases in the engineering design process. The authors present findings related to opportunities and tensions through the use of technology that co-emerge during troubleshooting and epistemic uncertainty around STEM concepts.

The papers in this cluster punctuate a need for maker education research to conceptualize activity as situated within specific kinds of projects and contexts: *How might learning benefit from conceptualizing specific technologies or ways of thinking (e.g., computational thinking) as tools or practices enacted within specific making contexts (e.g., parents' work with children compared with teachers' work in classrooms)? How might future research on* *educators' learning and development as makers also be situated within systems that are co-constituted through interactions of tools, people, ideas, practices, and goals?*

Cluster III: assessment practices and frameworks

Prior studies have already highlighted several challenges concerning assessment in makerspaces, lack of assessment practice, and deficiency of assessment frameworks for maker education. For instance, a survey by Peppler et al. (2017) reported that makerspace practitioners experience several barriers in their assessment practices which include but are not limited to the lack of access to dedicated technology for documentation, lack of youth motivations to capture making, and documentation taking time away from and interrupting the flow of making. The papers in this cluster address the need for assessment tools as well as frameworks for teaching and assessment in maker education.

The first two papers in this cluster focus on providing dedicated tools for documentation. First, Ourania Miliou, Maria Adamou, Aekaterini Mavri, and Andri Ioannou (Miliou et al., 2023), present details on the use of a digital tool for self-assessment and reflection in maker contexts, with a focus on the students' use of 21st century skills. Despite the reported challenges in adopting the self-assessment and reflection tool in their making practice, the study reports positive findings concerning students' increased awareness of their development of 21st-century skills during making. Next, Vishesh Kumar, Peter Wardrip, and Rebecca Millerjohn (Kumar et al., 2023) focus on the design of assessment tools for educators in a public library makerspace. These tools support the recording of observations of learning events by maker educators in a drop-in library makerspace. The authors discuss how the design process, which reveals design tensions, interacts with the educators' values and interests.

The next two papers in this cluster prioritize the lack of assessment frameworks in maker education. The work of Kailea Saplan, Sam Abramovich, and Peter Wardrip (Saplan et al., 2023) aims to help maker educators and facilitators articulate the types of assessments they need and design assessments for maker learning in library makerspaces and other out-of-school spaces. The authors offer a framework which outlines key properties of one's definition of success in making. A yet another assessment framework for maker learning is offered by Xun Ge, Kyungwon Koh, and Ling Hu (Ge et al., 2023). This framework incorporates the lens of expertise development, that is, evaluating students over a span of developmental processes rather than on a fixed time frame. The work also presents useful rubrics that the authors developed to evaluate students' inquiry questions and the overall quality of the maker projects in their work.

Last in this cluster comes the work by Dishita Turakhia, David Ludgin, Stefanie Mueller, Kayla DesPortes (Turakhia et al., 2023), which synthesizes the perspectives of experienced maker educators from makerspaces with varied organizational formats, indirectly contributing to the discussion of assessment practice and frameworks. The work presents findings on competencies that maker educators prioritize, challenges they face at the student-level, teacher-level, and institutional level, and teaching strategies they use to accomplish learning goal, such as scaffolding, collaboration, and relationship building.

The papers in this cluster act on the evident lack of assessment practice in maker contexts to support maker educators in assessing and documenting outcomes of maker learning: *How might we fulfill the expectation of capturing learning and skills development in these dynamic learning spaces? How might the heterogeneity of makerspaces and goals be translated into assessment practices? How might digital technologies support assessment* *and the capturing of learning and skills development in situ? Can these assessment tools be content agnostic and context agnostic?*

Cluster IV: representation, inclusion, and tensions around maker-centered initiatives and reforms.

Makerspaces have been lauded as a panacea for closing digital inequities, supporting broadening participation of underrepresented demographic groups in STEM fields. The ubiquitous nature of these spaces suggests that they could situate learning in authentic problems that consider the participants' lives, histories, identities, interests, and needs. The scope of papers in the pillar, rather, communicates that this promise has yet to be fulfilled (see also Ryoo & Calabrese Barton, 2018; Vossoughi et al., 2016).

The first couple of papers in this cluster bring up issues of power in maker education contexts. First, Megan Goeke and David DeLiema (Goeke & DeLiema, 2023) into "agency" as a core pedagogical goal of the maker education movement. The authors documented heterogenous professional visions of agency used within the maker education field, raising questions about how to mitigate inequitable power dynamics in makerspaces. Next, Ofer Chen, Fabio Campos, and Yoav Bergner (Chen et al., 2023) examine an instance of school reform by interviewing the principal and seven faculty members in a high school after the first year of implementing making-centered curricula. Among other findings, the authors report that such reforms require far from trivial adaptations to educators' skills, instructional approaches, and pedagogical beliefs. Notably, the process of implementing change involves navigating complex dynamics and power relations and should attend to potential student and educator marginalization.

The next two papers in this cluster focus on initiatives acting on equity matters. First, Adam Maltese, Kelli Paul, Barbara Yarza, and Lauren Penney (Maltese et al., 2023) present a coding club they implemented for girls from marginalized groups. The authors share details on their choices that had a positive impact and seem to be promising pathways in broadening participation, for example, their rearrangement of focus to centering on problem-solving and design and to using problems that are tied to participants' lives. Next, in acknowledging issues of inequity and dominance in makerspaces, Lynn Nichols, Rachel Gorsky, and Kimberly Corum (Nichols et al. 2023) offer a theoretical framework that centers on knowledge of technological and inclusive practices in makerspaces, as well as a conceptual framework which outlines the process of creating and sustaining an inclusive makerspace. The authors aim for these frameworks to guide the establishment of inclusive makerspaces.

The papers in this cluster offer important cautions regarding the promises and complexities of making, the ways school-based implementations are shaped (e.g., Gravel & Puckett, 2023), and the central importance of critical perspectives in research on making in larger institutionalized educational contexts. As makerspaces continue to be built in formal and informal educational spaces, and as more maker-based curricula are developed, the persistent tension between the promise of this movement and the realities of the institutional and organizational settings within which they are situated (e.g., schools, museums, STEM cultures, communities) must be carefully considered, both practically and in terms of new research. These papers lead us to question notions of inclusion: *How might stronger attention be placed on theory and approaches that specifically address issues of power toward furthering the vision of making as a way to dismantle oppressive educational structures?*

General reflections and opportunities moving forward

The editors believe that the four clusters framing the collection of papers in this special issue reflect the current state-of-the-art as well as the significant questions remaining to be answered in future research. The articles included have theoretical grounding and methodological rigor, present empirical findings, and document good examples of studying maker learning. Reflecting on the collection of papers in this special issue, but also the overall editorial process from start to end, we identified several opportunities for how the field might expand moving forward.

Define and clarify maker education and goals in context

There is deep complexity around maker education and goals. This special issue offers confident perceptions of these phenomena, but its clear these accounts and perspectives differ (see similar concerns by Hoadley, 2017, in the CSCL context). From the submissions made to this special issue, it is apparent that different authors have different understandings of maker education and its place on the education map. Furthermore, the collection of papers suggests heterogeneity in makerspaces and their intended outcomes, which is also constantly changing as the learners set their own learning goals and define/re-define their own projects in these spaces. The diversity in approaches is welcomed, from using making as an opportunity to integrate and talk about technology, to using making as a pathway to broadening participation, intellectual freedom, and democracy. Yet, it is important that all contributions are understood *in context* with clarity regarding the authors' views on maker education and its goals. In other words, how the constructs are defined, theorized, and situated is necessary to include if conclusions are to be extracted from new contributions. For example, how *coding* is conceived as a making activity in specific contexts is connected to what it supports learners in achieving e.g., engage students in STEM disciplinary learning spaces, and how *inclusion and democracy* are realized through making is an inseparable part of any findings from specific contexts. The present breadth of perspectives suggests that an integrated approach to maker education would benefit the community and future research. In contrast, the lack of such an integrated approach hinders the potential of maker education, arguably constraining conversations to isolated discussions around how to integrate and talk about technology, how to develop curricula in a STEM+ era, how to work with power inequalities, and what outcomes to expect, among others. What constitutes maker education and goals must be well articulated and understood before further progress in the field can be made.

Consider an ecological lens on maker education

From a few papers across clusters, it appears that an overly technocentric approach i.e., a simplistic focus on technology, along with the many reported challenges faced by those who aim to integrate technology in their maker practice, may lead to a decrease in students' and teachers' interest in making (e.g., in this issue, see Chen et al., 2023) which is not surprising considering the prior work in the broader field of learning (e.g., Falloon et al., 2020). We are not suggesting that digital technologies (e.g., robotics, 3D printing, digital fabrication) are unimportant in making and maker education, but rather that the goals must be clarified with an ecological lens in mind. That is, we would suggest that a technocentric approach with an agenda to promote the use of technology per se (digital or analog), should be de-stressed as the primary focus in future research. Rather, the relationship between technology use and making should be understood through an ecological lens, understanding technologies as tools that mediate the development of cultural practices, skills, forms of computation, and social organizations (see Tucker-Raymond & Gravel, 2019). What should be stressed in practice and future research is the deliberate and intentional integration of specific tools and materials into the overall context of maker activities. Research should emphasize maker pedagogy, such as design-based learning or project-based learning, where technological tools, either digital or analog, come to support the thinking processes. That said, although the possibilities of the technology must be well known to students and educators alike, their actionable use (e.g., operating a 3D printing) can be done with the support of a maker technician specialized in the use of these tools (digital or analog). This will ensure that the teachers' capacity in the actionable use of these tools does not inhibit their integration towards the desired goals. The ecological view of maker education encourages future research building on understandings of activity as collective and distributed among the people, tools, and materials in the space.

Furthermore on the idea of an ecological view of maker education, teachers should not be expected to design maker-oriented learning experiences without support. Ample time working with maker-oriented technologies (digital or analog) and some technical proficiencies are necessary before teachers can incorporate them in their lessons or even consider them in their learning designs (e.g., in this issue, see Turakhia et al., 2023). Certainly, educators can benefit from maker-centered professional development and direct teaching of skills (e.g., programming) needed in a maker-centered curriculum (e.g., in this issue, see Fegely et al., 2023). Yet, the design of a maker-oriented learning experience could be a collective effort between educators, as experts in curriculum and pedagogy, and technologist or technicians, who specialize in maker technology (digital or analog), not to exclude policy makers and other decision makers in education. Furthermore, we must admit that there is a large community of maker-practitioners in makerspaces and fablabs (i.e., informal education) who do not necessarily publish or document their work and learning designs, although recently active in some research communities (see the Young Makers program https://www.constructionismconf.org/). An ecological approach supports reimagining maker educational systems as co-constituted through interactions among and between the participants, the tools and materials, and the particular contexts of the educational environment. Such an approach would bring important value and insights to the maker education research.

Reinforce assessment to inform policy making

Assessment is a pressing issue in maker contexts, linked to policy and reform especially in relation to preparing the workforce of the 21st century. While the number of makerspaces around the globe and in K-12 institutions continues to grow (perhaps thousands already), the systematic documentation of the benefits in terms of learnings, attitudes, and disposition must become explicit, if we are to hope for a true reform of education. And because makerspaces, whether found in formal or informal education contexts, are inherently different in terms of learning opportunities, process, and challenges, new forms of assessments and tools are needed to support the documentation of learning outcomes (in this issue, see Miliou et al., 2023). As Saplan et al. (2023) argue in this special issue, a traditional, one-size-fits-all assessment tool or practice of assessment is unlikely to fulfill the expectation of capturing learning and skill development in these dynamic learning spaces. Linked to the previous suggestion for an ecological lens on maker education, technocentric makerspaces (i.e., an agenda to promote use of technology and computing skills) tend to have very different goals than makerspaces aiming to promote equity, inclusion, and democracy or even, makerspaces aiming to promote STEM+disciplinary and transdisciplinary learning. This heterogeneity in intended outcomes makes assessment difficult and once again makes *the context* an inseparable part of any findings. Notably, despite the heterogeneity, in almost every paper in this special issue, we found evidence of learning from failure and the value of fostering resilience towards failure through making (while we use failure for brevity here, note Vossoughi et al. (2016) discussing the powered nature of how notions of failure operate in specific communities). Whether this was discussed directly by the authors (e.g., in this issue, see Ge et al., 2023; Turakhia et al., 2023) or remained silent behind other relevant findings and discussions, as editors of this special issue, we would like to draw attention to the importance of this competency that can be developed in maker contexts. In the ever-changing world we live in, embracing iteration and reflection, and creating spaces for the learners to tinker, experiment, and take risks are of paramount importance. Documenting, through assessment, how maker education can nourish such outcomes can bring hope for a true reform of education.

Re-examine claims and redefine goals on equity and democracy

Makerspaces are often discussed as spaces to address issues of equity and power in STEM, with possibilities for democratizing learning (Blikstein, 2013). Papers included in this special issue claim that equity is not guaranteed and call for further articulations and critical theorization of maker education to advance this professed vision for maker education. Increasingly, reports of hegemonic structures controlling makerspaces highlight the fragility of maker education as a space for addressing equity. It is simply not enough to build these spaces and hope dominance will be rejected at the proverbial doors. In-line with the recommendation to clarify goals in context and consider an ecological lens, future research on making and maker education needs continued critical grounding and expansive methodological approaches that attend to the "simultaneity of stories-so-far" (Massey, 2005, p. 130) within these spaces. Makerspaces are not simply built and turned on; they are living social constructions, the dynamics of which require more study if we are to realize the potential they hold for equity, intellectual freedom, and democratized learning. One specific sight of considerable dissonance is the transition from K12 environments into more formalized university-level STEM learning contexts. It is becoming common that K12 students experience making in ways that are grounded, humanizing, and inspiring (Calabrese Barton & Tan, 2018; Gravel et al., 2022), only to discover those possibilities all but vanish in the higher-education spaces (with some notable exceptions: see Andrews et al., 2021; also https://csed.engin.umich.edu/c-sed-lab/#). Another emerging space where redefined goals and attention to equity is required lies in the rise of artificial intelligence (AI) as a tool and structure within maker education conversations. The warnings of overly technocentric approaches feel particularly important in light of society's apparent willingness to "give oneself over" to large language models and AI. The AI discussion punctuates the importance of critical theory in future research, and a realization that maintaining spaces that center equity requires deliberate and intentional practice. The future of maker education research, thus, should attend to power dynamics within spaces, but also longer timescales of how spaces are made and remade, and how experiences are shaped along the arcs of participation in maker activities.

Conclusion

Researchers have long recognized the potential of maker education to support learning. This special issue makes some progress in addressing the many and various benefits that maker education seems to nourish, from the development of specific skills to participation and democracy. Collectively, the papers in this special issue represent a synthesis of international perspectives. The four emerging clusters of work seem to reflect the current state-of-the-art in the field as well as the significant questions remaining to be answered in future research. The breadth of perspectives suggests that an integrated approach to maker education would benefit the community and future research. STEM+ disciplinary and transdisciplinary spaces for learning through making are becoming a reality. Bringing maker education research findings into policy and reform should be a prioritized goal as research in the field continues to mature.

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Andri Ioannou is an Associate Professor at the Cyprus University of Technology. Andri has a Ph.D. in Educational Technology from the University of Connecticut (USA) and a BSc in Computer Science from the University of Cyprus. Via her research at the Cyprus Interaction Research Lab (https://www.cyprusinteractionlab.com/) and EdMedia of the CYENS Center of Excellence (https://edmedia.cyens.org.cy/), Andri's work has contributed to key areas of educational technology with emphasis on the design and evaluation of technology-enhanced learning environments, learning design for the promotion of 21st century skills, and technology integration in education.

Brian E. Gravel is an Associate Professor of STEM Education at Tufts University and Director of Elementary STEM Education. Brian has his Ph.D. in STEM Education, and a B.S. and M.S. in Mechanical Engineering from Tufts University. Brian's work is grounded in community partnerships, using co-design practices to build humanizing approaches that share stories of learners' brilliance when engaging in different forms of STEM learning. His research focuses on learning with representations, materials, and processes in making spaces and with expressive computational technologies. Major threads include makerspaces in schools, designing culturally sustaining learning ecologies, and the study of transdisciplinary practices in computational STEM activities.