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What shapes implementation of a school-based makerspace? Teachers as multilevel actors in STEM reforms

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Abstract

Background We investigate the factors that shape teachers' implementation of a school STEM reform—the creation of a high-school makerspace. Educational reformers have increasing interest in making and makerspaces in schools. Prior research shows how factors shape reform at the classroom, school (organizational), and institutional levels, as well as across levels. However, most research on teachers tends to focus on classroom-level effects, which may not capture the full complexity of how they navigate multilevel reforms. We consider teachers' decision-making from an ecological perspective to investigate what shapes their implementation efforts, using observational and interview data collected over 2 years in a large comprehensive high school.

Results We find teachers' efforts are shaped by four "distances"—or spaces teachers traversed, physically and conceptually—related to skillsets and distributed expertise, physical space, disciplinary learning, and structural factors. The distances operate as a constellation of factors—independently identifiable, co-operatively manifesting—to shape implementation. We position teacher deliberations and decision-making as portals into the forms of organizational and institutional supports offered in multilevel reforms.

Conclusions The paper contributes insights into makerspace implementation in schools, adding to the emerging literature on how making can transform STEM learning experiences for students. We conclude that teachers' decision-making around multilevel implementations can inform our understanding of how makerspaces are implemented and their impact on students' experiences, as well as how seeing teachers as multilevel actors can offer new insights into reform dynamics writ large. We offer implications for makerspaces in schools, as well as methodological and theoretical considerations for how organizations and institutions can better support teachers as agents of STEM reform.

Keywords STEM, Makerspaces, Teacher learning, Reform implementation

Introduction

For nearly a decade, educators have increasing interest in "making" and "makerspaces" in schools. Making is an activity involving design and construction of artifacts, ranging from weaving to programming microcomputers, in ways meaningful to the learner (Halverson & Sheridan, 2014). Makerspaces are places where students can engage in these hands-on making experiences (Hatch, 2013). Pedagogical approaches used in making and makerspaces can support students' agency; inquiry with materials; approaches to design and problem solving; design self-efficacy; science, technology, engineering, and mathematics (STEM) literacy practices; and engagement in different and more equitable forms of STEM learning (Andrews et al., 2021; Bevan et al., 2015; Calabrese Barton & Tan, 2018; Martin et al., 2018; Puckett & Gravel, 2020; Sheridan et al., 2014; Tucker-Raymond & Gravel,

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2019). Schools are increasingly implementing making as a STEM reform effort (Martin, 2015), yet there are still relatively few studies that explore how schools adopt maker education in K-12 settings (e.g., Hansen et al., 2019; Kim & Sinatra, 2018; Rouse & Gillespie Rouse, 2022; Stornaiuolo & Nichols, 2018; Vongkulluksn et al., 2018). Making in schools requires careful consideration of how teachers navigate new activities and spaces and how schools as institutions shape their implementation.

Bringing making to schools has largely been driven by educators and researchers interested in reforming STEM learning pathways for K-12 students (Kim et al., 2019). Maker pedagogies, maker technologies, and makerspaces offer promise for supporting interest-driven, individualized STEM educational experiences aimed at enhancing opportunities for students to make meaning through inquiry, design, and investigation (Halverson & Peppler, 2018; Martin, 2015). There has been some increase in studies of making and makerspaces in K-12 schools in recent years, with important focus on pedagogical interventions, technologies, and outcomes of different forms of making (Rouse & Gillespie Rouse, 2022), but research has not focused on factors shaping teachers' implementation of maker activities in schools. In this paper, we add to this literature by describing the implementation of a makerspace—a physical space in the school building—as a STEM reform, where new configurations of people, tools and materials, and activities can support STEM learning (Hira & Hynes, 2018).

There is extensive research on how STEM reforms involving inquiry, design, and investigations (National Academies of Sciences, Engineering, and Medicine, 2019) are implemented in schools, with one prominent example being the *Next Generation Science Standards* (NGSS Lead States, 2013). Research on NGSS illustrates how factors operating across classroom, school, and larger institutional levels shape implementation. At the classroom level, teachers' content knowledge and disciplinary practices, agency, and sensemaking shape implementation and pedagogy (Allen & Penuel, 2015; Severance et al., 2016). At the school level, successful implementation is shaped by professional development (PD) communities that shift teachers' beliefs and pedagogical knowledge related to new approaches (Reiser et al., 2017). School leadership also plays a pivotal role in fostering conditions conducive to teachers learning new ways of teaching science and engineering (McNeill et al., 2018). At the institutional level, policy guides like the NGSS appendix defining *Science and Engineering Practices* shape how relationships between disciplinary activity, like science and engineering, are constructed in schools (Moore et al., 2015). Teachers' implementation of such reforms is associated with PD that often fails to coordinate standards, instructional needs, and professional needs (Cassidy, 2018). Successful STEM reforms rely on complex alignments of factors across levels of the educational environment, including classrooms, school-level organizations, and larger institutions (Bybee, 2014; Coburn et al., 2016). Prior research on STEM reforms like NGSS addresses alignments (Fulmer et al., 2018), but overlooks teachers as crucial actors, whose experience, training, certification, and teaching demands stretch across multiple levels of reform.

At the classroom level, teacher agency appears in decision-making about how students are arranged, organized, and what they are asked to do (e.g., Roschelle et al., 2013). At the organizational level, teachers act to translate standards into pedagogy (Ball & Cohen, 1999). At the institutional level, they interact with broader policy contexts, through certification demands and professionalization, shaping collaboration and how messages are communicated (e.g., at conferences; Mockler, 2012). Thus, it is important to recognize teachers' roles within the multilevel system in considering how institutional and organizational factors shape STEM reform implementation, including bringing making and makerspaces to schools.

In this article, we examine teachers' positions within schools and across institutional levels to describe how multilevel dynamics shape making in schools. Examining the introduction of a makerspace and integration of maker pedagogy at a large urban public high school, we draw upon over 1000 observation hours of PD and teaching, and 69 interviews with administrators, teachers, and students over the course of 2 years, focusing primarily on 11 teachers most intensively involved in the PD. Overall, we identify and describe four "distances" shaping teachers' use of a newly introduced makerspace and maker pedagogies. These include what we call *skilled distances* between the practices and expertise required in making (e.g., woodworking skills) and teachers' developing comforts with these skills (operating across classroom and organizational levels), *physical distances* between classrooms and makerspaces (operating across the classroom and organizational levels), *disciplinary distances* between practices of a teacher's subject area and work in the makerspace (classroom and institutional levels), and *structural distances* between school-level curriculum and policy mandates and new maker activities and learning arrangements (institutional, organizational, and classroom levels). The distances are specific to the STEM makerspace implementation studied here, however, structural distances relate to broader reform dynamics; some distances are more easily traversed, while others are greater and more complex, creating challenges and opportunities for teachers as they work to implement reforms.

The paper offers two major contributions. First, we contribute to a persistent gap in past research on makerspaces—which has largely focused on informal learning contexts (see Peppler et al., 2016a)—by identifying and describing dynamics shaping their implementation in schools. This work adds to recent research on maker interventions, technologies, and outcomes (Rouse & Gillespie Rouse, 2022) by offering a perspective on how makerspaces are taken up in a particular school context. Second, we uniquely theorize teachers as multilevel actors to examine how their roles at multiple levels reveal dynamics across classroom, organization, and broader institutional levels that shape STEM reform efforts. Both contributions have implications beyond our specific case. The first lays groundwork for the ongoing implementation and study of makerspaces in schools as STEM reforms. The second draws attention to the importance of understanding relationships between such pressures as what a teacher is required to master based on certification processes, the content focus of state mandates, and the skill and pedagogical demands of new reform efforts. Our study suggests changes at organizational and institutional levels are needed for successful makerspace implementations. We offer recommendations for addressing challenges and how this research can inform the implementation of current and future maker reform efforts.

Makerspaces as school STEM reforms

The Maker Movement in education has been met with excitement (Dougherty, 2012), imagined possibilities (Martin, 2015), and cautions (Vossoughi et al., 2016). Maker education research builds on a history of reforms promoting technology-mediated project-based learning (Blumenfeld et al., 2000), where issues of pedagogy and assessment (Barron et al., 1998) were the primary focus of the research community. Makerspaces offer renewed ways of critically examining how technology-rich STEM spaces are occupied (Kim et al., 2019), how knowledge and work is understood and distributed (Tucker-Raymond et al., 2020), and how learning arrangements are reimagined (Vossoughi et al., 2020). Martin's (2015) compelling case for why schools should integrate making has been affirmed with research showing how making provides opportunities for STEM learning (Tucker-Raymond & Gravel, 2019), for shifting power dynamics around knowledge, authority, and skill (Vossoughi et al., 2021), and for building communities that support transforming educational practice through making (Peppler et al., 2016a).

Making is often associated closely with STEM, yet as an activity, it offers ways of focusing less on specific disciplinary practices and more on the transdisciplinary possibilities (Marín-Marín et al., 2021)—where "multiple disciplines meet and coexist" (Sengupta et al., 2019, p. 3). Many educators embrace notions of STEAM (where the "A" is added for arts) as a form of transdisciplinary activity, involving aspects of the arts in making (Halverson & Sheridan, 2014). Teaching STEM in integrated ways supports learning that is situated within "real-world" contexts that make STEM disciplinary practices more relevant to learners (Honey et al., 2014; Takeuchi et al, 2020). This vision of making as a STEM reform effort that also promotes work at the intersections of traditional school disciplines offers generative opportunities for learners to weave together approaches that drive meaningful inquiry and creation.

Popularized as an organizing construct in 2005 with the introduction of MAKE magazine, makerspaces first appeared in libraries and community centers (Blikstein, 2018). These informal educational environments produced exciting descriptions of learning that was creative, hands-on, interest-driven, and engaging for young people and adults alike (see Peppler et al., 2016b). As the relationships between making and learning were articulated (Vossoughi & Bevan, 2014), schools began to wonder how makerspaces might work to deepen and transform STEM learning pathways (Kim et al., 2019). The promise of this movement for education was articulated by Martin (2015), as national conferences (FabLearn; https://fablearn.org), and organizations (MakerEd: https://makered.org) emerged to support growing numbers of teachers, administrators, and researchers interested in making in K-12 contexts. At the same time, important critiques of the movement emerged around issues of power (Vossoughi et al., 2016) and gender (Chachra, 2015; Norris, 2014). While many schools have built makerspaces or implemented maker pedagogies (Godhe et al., 2019), questions remain about how makerspaces are taken up by teachers in school communities, how teachers learn to teach in these spaces, and what shapes their success in transforming STEM learning opportunities (Rouse & Gillespie Rouse, 2022).

To bring making to their classrooms, teachers must navigate elements of space, leadership, and curricular and professional development (Wardrip & Brahms, 2016). Researchers have named the transformative possibilities of makerspaces in schools and described what learning through making looks like, including opportunities for interest-driven and situated learning through design and constructing artifacts (Peppler et al., 2016b). A recent review of studies on making in schools notes a range of outcomes for maker education, going beyond content learning outcomes, and the need for more attention to teacher learning and equity-oriented approaches

(Rouse & Gillespie Rouse, 2022). Yet, there is some disagreement in the literature regarding how well makerspace interventions align with schooling ideologies (Godhe et al., 2019). Stornaiuolo and Nichols (2020) introduce key tensions for bringing makerspaces to schools, including "how infrastructures at the school and district level support the functioning of makerspaces and how makerspaces are organized internally and within the school" (p. 123–124). Thus, new research on the integration of makerspaces into schools—as a STEM reform—and how teachers embrace making into their teaching amidst the multitude of pressures that shape practice can contribute to the movement to bring making to schools.

Multilevel implementation pressures

Historically, research on reform implementation in education has focused on one level at a time: the reform (e.g., Elmore, 1979) or the teachers (e.g., Cohen, 1990; Hill, 2001). Like implementation research, studies of teacher learning in reform contexts often adopt single-level perspectives (Rigby et al., 2016) focused on classroom practices, leaving a persistent gap in understanding multilevel dynamics and how teachers navigate them. As we have noted, the integration of a makerspace in a school has implications for teachers' actions across the levels of the system—it affects classroom decisions and opportunities, it is entangled with school-level and district policies ranging from schedules to course requirements, and it surfaces issues of alignment between existing institutional demands and reformed pedagogies that center inquiry, design, and new visions of disciplinary practice (Godhe et al., 2019). We draw from research on factors shaping multilevel reform, like the NGSS (Pruitt, 2014), to motivate our study. This research informs our analysis of skills, physical spaces, disciplinary learning, and structural demands, which are categories that structure our findings.

Reforms often demand new skill development and learning arrangements, asking teachers to develop disciplinary knowledge, pedagogical skills, knowledge of students, and skill operating within systems (Ball et al., 2008; Darling-Hammond, 1996; Friedrichsen & Barnett, 2018). Yet, effectiveness is often measured using student achievement data (Chestnutt et al., 2019), which focuses implementation on compliance and fidelity (Ingersoll & Collins, 2017). This constrains teachers' curricular and pedagogical autonomy (Smith, 1991) and limits how they can develop new skills and pedagogies as professionals. Integrating making and makerspaces in schools resembles other technology integration reforms (Ertmer et al., 2012), where both willingness and PD affect implementation (Becker, 2000; Smith et al., 2007). Teachers integrating maker pedagogy must develop new practices, including distributing classroom expertise (Brown et al., 1993), adopting new roles as co-learners with their students (Gravel et al., 2022), and developing new skills like programming, digital design, and fabrication (Sheridan et al., 2014). This prior research motivated our study by punctuating the need for opportunities where teachers' can develop their own making practices (Rouse & Gillespie Rouse, 2022), such as professional development or district-level supports for teacher learning, as well as exploring new ways to structure knowledge, expertise, and authority in their classrooms.

Research on how implementations travel across a school examines how teachers' relative positions—in terms of physical location—effect implementation. Frank et al. (2011) examined diffusion processes within schools, suggesting spaces teachers occupy in schools, and how they engage with reform ideas, influence implementation. Propinquity between teachers, or relative distances between classrooms within a school building, also shape responses to new instructional practices. When teachers' classrooms are closer to each other, conversations around how to implement new reforms increase (Spillane et al., 2017). Based on this, we would expect the physical location of a makerspace will impact the forms of implementation that take hold.

Reform efforts like NGSS have had significant influence on disciplinary practices in K-12 teaching and learning. The emphasis on science and engineering practices in NGSS asks teachers to shift their relationships to the disciplines they teach (Duschl & Bybee, 2014). Opportunities to reexamine disciplinary practices can support teacher's adoption of new approaches (Ball et al., 2008), and can support moves toward collective agency with students (Haverly et al., 2018; Stroupe, 2014). Thus, there are advantages to asking teachers to question what and how they teach as part of the reform process.

At the institutional level, curriculum frameworks and testing pressures ask teachers to focus largely on content. Yet, NGSS emphasizes "core disciplinary concepts" in relation to "disciplinary practices" in the classroom (NGSS Lead States, 2013). Teachers must confront competing pressures about what constitutes disciplinary practices, and how they are understood within a "school" context (Reiser et al., 2017). These competing pressures exist across levels (e.g., teacher certification exams promote content-driven perspectives), and teachers are left navigating inconsistent messages while having to translate these messages into classroom practice (Allen & Penuel, 2015). Furthermore, accountability systems that position teachers as didacts and content managers (Pellegrino et al., 2014) are often at odds with messages promoting students' inquiry and agency in STEM (Miller et al., 2018). Teachers implementing makerspace activities must navigate and coordinate the substance of the new approaches and their own histories and relationships to disciplinary learning (Spillane et al., 2002).

Finally, cutting across all levels of the system are structural considerations that deeply influence how reforms are implemented. Many studies address organizational level dynamics—school buildings and districts—by considering instructional leadership and administration (Rigby, 2016; Spillane & Callahan, 2000). For example, with NGSS, principals' roles as school leaders require them to develop fluency with shifting pedagogical commitments (McNeill et al., 2018). However, teachers, too, must develop this fluency (Manz & Suárez, 2018) with how school-level policies affect decisions they can make in their classrooms. Institutions provide "raw material and guidelines" (Hallett & Ventresca, 2006, p. 13)—for example, the curriculum standards, pedagogical ideologies, and policies regarding specific populations (e.g., students with identified and labeled disabilities, or students labeled as "English language learners" by district, state, and federal entities)—that shape and constrain the decisions teachers make regarding their practice. Structural factors affect all levels of the educational system, and in the case of makerspaces as a multilevel reform, teachers' responses to navigating these pressures may provide insights into how those structures shape implementation.

Taken together, this prior research informs our interest in exploring how teachers negotiate multiple levels of reform, including skills demanded by new pedagogies, disciplinary boundaries, issues of physical space, and structural constraints. Our focus is on how makerspaces are implemented by teachers in the context of a school, and we look to theoretical perspectives on teacher decision-making to guide our analysis of how they navigate multilevel reforms.

Theoretical lens: agency as portal in multilevel reform

Rather than positioning teachers as passive targets of reform efforts (Mehta, 2013; Russell & Bray, 2013) we take an institutional perspective, joining a growing body of research examining teachers' roles as agentic "policy actors" to understand STEM reform efforts (Heineke et al., 2015). Viewing teachers as actors in a complex and dynamic system allows us to analyze their experiences as responses to elements of the reform in the institutional context. The roles teachers perform, decisions they make, and their descriptions of the pressures shaping their response to reforms illuminate how the structuring environment—i.e., the teachers' working conditions, shaped by district and institutional dynamics (Kraft et al., 2016)—shapes implementation. Whenever something new is introduced to a school context, the pressures operating within and across levels combine to structure the responses actors can enact. To understand what shapes the implementation of a school makerspace we look to teachers' decisions as evidence of how that structuring environment supports, or constrains, implementation. We draw from ecological models of teacher agency to understand how teachers navigate and coordinate factors spanning multiple levels of the system in which they participate, including their own relationships to prior experiences, new possibilities, and what is perceived as achievable within their local school context (Wallace & Priestly, 2017).

Priestly et al.'s (2015a) ecological models of teacher agency offer theoretical grounding for understanding how teachers' decisions and actions reflect larger dynamics of reform implementation that operate across the levels of a system. Teacher agency is historically undertheorized (Vongalis-Macrow, 2007), and ecological models of teacher agency offer considerable potential for understanding how teachers engage with policy (Priestly et al., 2015b). Emirbayer and Mische (1998) proposed an architecture for theorizing agency: not as a quality of individuals, but as temporally and relationally emergent within specific contexts, "there are no concrete agents, but only actors who engage agentically with their structuring environments" (p. 1004). This model proposes that agency is emergent in specific structuring environments. It is *relational* in that it emerges from interactions with the environment (Priestly et al., 2015b). Teachers' professional practice evolves within specific school contexts, organized by their relationships with policies of the building, district, and within larger institutional dynamics, like state standards and professional licensure requirements. When teachers engage agentically, such as implementing a new pedagogical approach or shifting classroom structures, their actions constitute interactions with those structures in the environment. The introduction of a makerspace to a school community alters the existing context, and an ecological model positions teacher agency as reflecting the conditions within which they practice. Ecological models are *temporal* in that they "build on past achievements, understandings, and patterns of action" (Priestly et al., 2015b, p. 24). When teachers act agentically, we see not only their response to the conditions, but ways in which their histories and knowledge of the dynamics of the structuring environment inform what actions appear possible. These histories constitute teacher practice at the classroom level, at the school governance and administrative levels, and in institutional settings like professional learning and licensure work.

From an empirical perspective, ecological models offer a definition of agency that shifts focus toward observing what actors do, the decisions they make, and the actions they take with respect to the reform context (Biesta & Tedder, 2007). The focus in this paper is not on agency as a construct, rather on using an ecological perspective to transform teacher decisions into portals that reveal their relationships to factors in their professional context. We position teachers' responses to situational dynamics within reform efforts as reflections of how the structuring environment is supportive or restrictive of implementation. We define the structuring environment as the particular school, as an organization, situated within larger district and institutional (e.g., statewide or federal systems) dynamics. Teachers' deliberations and decisions are, thus, evidence of factors and logics that shape reform within the structuring environment. The tensions teachers experience and describe in attempting to implement something new can provide insights into the ways different aspects of a school—at the classroom, organizational, and larger institutional levels—work toward or against their efforts. Thus, our study is an opportunity to explore the dynamics of multilevel reform through the lens of the actors navigating implementations.

This paper explores how teachers' institutional and organizational locations, defined as their relative position within schools and to disciplinary activity, shape school-based implementation of makerspaces by addressing the following research questions:

- What factors shape teacher implementation of a makerspace in a comprehensive high school?
- In what ways do teachers navigate those factors within the structuring environment?

Methodology

This study draws from a multi-year effort to introduce a makerspace in a large comprehensive high school, complete with PD activities, experimental course designs, and opportunities for youth to engage in summer making programs. The makerspace, which we call The Workshop, occupies a dormant woodshop in the basement of the large school. The Workshop is located in Brownsville High School,[1] with a student enrollment of ~ 1850 students. Brownsville is racially, ethnically, and linguistically diverse, with students speaking more than 50 languages. The Workshop opened in Fall 2014, as a design-based research project (Brown, 1992) examining ways a makerspace influences teachers' and students' ideas about learning. The effort emphasized engineering-inquiry and STEM-rich maker pedagogy through after-school and in-school programming.

Design of makerspace implementation

The installation of the makerspace was an opportunity to form research–practice relationships in ways shown to sustain the shifts in practice that reforms intend (Bryk & Gomez, 2008; Donovan & Snow, 2017). Acknowledging teachers' roles across levels suggests working *with*, teachers, rather than observing them from the outside (Shotter, 2006), could provide novel insights into STEM reform efforts (Penuel & Fishman, 2012). The research team forged the partnership with Brownsville in The Workshop through four primary activities: a week-long summer PD, after-school "open studios" making with support and guidance from researchers leading the efforts, group meetings to discuss evolving makerspace activity, and co-planning and facilitation of classroom units.

Maker pedagogy integrates different technologies, digital and analog, that support processes of design and fabrication. Integrating different technologies into pedagogy is most effective when situated within disciplinary inquiry (Campbell et al., 2014; Mishra & Koehler, 2006). Effective technology-related PD includes opportunities for teachers to engage in technology-mediated learning themselves, to reflect on that learning alongside data of students engaging in similar activities, and finally the modification of curricular activities to fit their particular pedagogical contexts (Gerard et al., 2011). PD for teachers in The Workshop was designed to focus on engineering inquiry (Hmelo-Silver, 2006; Kolodner, 2002) and reflective practices in design (Wendell et al., 2017). This involved the exploration, framing, and addressing of issues and problems using materials and design processes focused on iteration and revision (Peppler et al., 2016b; Tucker-Raymond & Gravel, 2019). The first author designed the PD, with consultation from members of the research team, drawing from Gerard et al.'s (2011) principles for effective technology-related PD. In the year prior to the PD, the research team spent significant time in the makerspace supporting youth in after-school open-ended making. Teachers and administrators expressed the need for professional development opportunities as interest in the new makerspace grew. We drew from these experiences in considering how to support teachers to implement these approaches in their classroom practice.

All teachers were invited to join the summer PD, and it was the first engagement with The Workshop for all those who attended. Teachers were positioned as learners and makers: they framed and solved problems related to their classrooms, or issues they saw in The Workshop itself, as means for engaging in making and engineering

[1] Pseudonym.

Table 1 Participating teachers [pseudonyms], subject areas, experience, disciplines

Name	Discipline/subject area	Years of experience	Undergrad Major	Makerspace implementation project
Murph	Automotive, Tech Ed	24	Automotive Technology	Designing and making pneumatic mechanisms
Jill	Special Education, English	5	Elementary Ed, History	
Katie	ELL*, English/ Humanities	4	English Literature	
Julia	Physics, Engineering	5	Physics	Demonstrating physics concepts by building physical objects like seesaws and pendula
Erin	English	10	ELA Education	Designing a public art installation expressing the themes from the novel Frankenstein
Matt	Mathematics	5	Mathematics Education	Exploring functions using tools/tech in the makerspace; introduced sine wave robot to students
Marilyn	ELL, Science	10	Women's Ministries	
Charlie	Chemistry	8	Chemistry	Environmental protectors for massing scales for chemistry experiments
Donna	Visual Art	30	Fine Arts	
Alex	Mathematics	8	American Studies, Mathematics	
Cara	Mathematics	2	Mathematics	

* "ELL" refers to "English language learners", a designation used by state and district regulations, and a term used with the school to refer to both teachers and students from specific populations. We acknowledge this term conflicts with asset-oriented approaches, and agree with calls to remove it from our ways of referring to emergent bilingual and multilingual students (see González-Howard & Suárez, 2021)

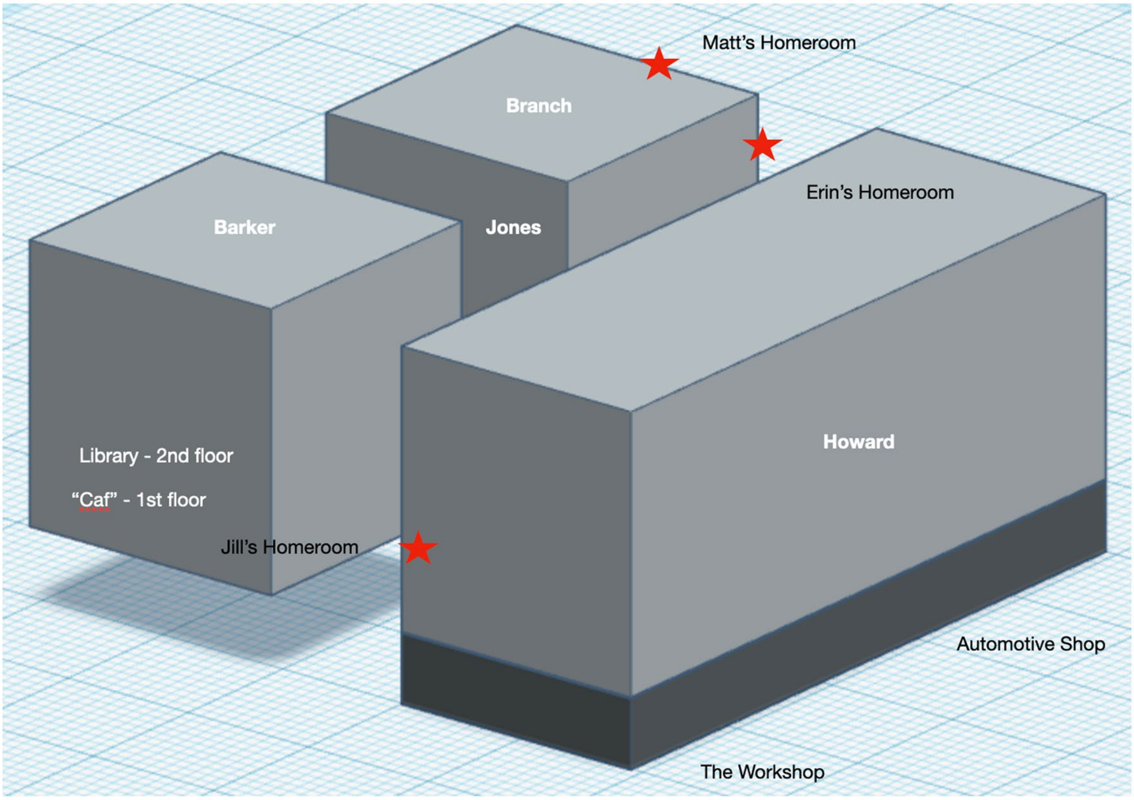
inquiry. For example, one group designed the "ultimate teacher table", a portable charging hub with a wireless document camera to keep power flowing while enacting lessons anywhere in The Workshop. The research team complimented these projects with specific skills sessions focused on coding, robotics, soldering, wood working, and digital design and fabrication. Teachers also reviewed video data of students working in the makerspace to look for patterns in their engagement and interest. The PD culminated with teachers designing lessons—some adapting activities from the workshop—to bring their students to the makerspace, and the formulation of committees to contribute to future governance of the makerspace.

Over the school year, teachers continued their development through paid time spent in the makerspace working on projects of personal interest (e.g., e-textiles) and alongside students when interests converged (e.g., building an electric go-cart) after school hours. Of the 11 PD teachers (see Table 1), six attended the after-school "open studios" sessions once a week for the school year (Murph, Jill, Julia, Erin, Matt, and Marilyn[2]), and five implemented curricular activities with their students in the makerspace (Murph, Erin, Matt, Charlie, and Julia). Teachers who chose to implement a lesson or unit in the makerspace received support from the research team for designing, planning, and assembling materials and scaffolds for students. In many cases, the research team also assisted implementation of units, offering help and just-in-time support for teachers and students. Teachers participated in three focus group meetings throughout the school year to share and reflect on their experiences in the makerspace.

Participants

Teacher participants were recruited through informal drop-in sessions and individual conversations with the research team. Teachers chose to participate based on interest in making and inquiry, and they were compensated for their time. Table 1 describes the teachers, their disciplinary focus, experience, and the projects they implemented. The participating teachers represented a diverse range of expertise, experience, and disciplinary perspectives, which allowed for the PD to reinforce the potential of transdisciplinary activities. As teachers shared their experiences engaging in different forms of technology-enhanced inquiry in their own practice (e.g., engineering projects in the auto shop, art and technology projects in ELA), they could imagine new possibilities for how making might enhance their curriculum. Where most maker education initiatives are STEM focused, because of the range of subject area teachers, the composition of the participants from Brownsville High School allowed us to examine transdisciplinary opportunities—akin to STEAM—and expand understanding of how makerspaces influence *where* STEM happens in the school and curriculum.

[2] All teacher names are pseudonyms.



Four "Houses" of Brownsville High School

All buildings are connected by bridges at every floor. Branch occupies the 4th floor of the northeast building, Jones occupies floor 1-3. Howard occupies the entire building to the south. Barker occupies the building to the northwest.

Fig. 1 Schematic representation of Brownsville High School's four buildings, showing the relative position of key locations in the school

The school and the makerspace

Brownsville High School is a 460,000 sq. ft. complex comprising three connected buildings. Administratively, the school is separated into four "houses" (Barker, Jones, Branch, and Howard), each with a principal and counselors. Students are assigned homerooms in one house for all 4 years. Students' days are organized based on grade level and house, each determining where classes meet and where students spend most class time in their school day. The library and cafeteria are located in one building, requiring some students to traverse significant distances throughout the day (see Fig. 1).

The Workshop, while the center of engineering inquiry and making at Brownsville High, is located in the basement of the southeast building, called Howard House. Built in the 1970s, Howard's original configuration included an automotive shop (with 6 garage bays) and a 3500 sq. ft. woodshop on the ground level (adjacent the locker rooms located beneath the gymnasium), a welding and metal shop located on the first floor, and art studios and home economics spaces located above the vocational spaces. The Workshop is located in the old woodshop, adjacent to the auto shop. At the time of data collection, the space was still new, with no dedicated staff, and a very nascent culture. The makerspace was introduced by the research team in collaboration with the school principal as a place to promote inquiry, design, and making, but with an emphasis on co-designing with teachers and students based on interests and practices that emerged as popular and engaging. Activities in the space focused primarily on framing and solving community-centered problems, playful explorations of new tools and materials, and repairing bikes and electronics. Students' and teachers' interests were at the center of engineering inquiry in The Workshop. It operated as a shared space organized by the committee of teachers, in consultation with the research team. Brownsville High is an under-resourced school, particularly with respect to adding staff positions. While studies of makerspaces in schools across the country point to the importance of dedicated staff (Kim et al., 2019), that is not currently possible for many schools like Brownsville. The makerspace housed old wood working tools from its prior life, but otherwise remained relatively low-tech. There were limited digital

Table 2 Data sources by teacher

Name	Observations by setting		Interviews
	Classroom	Makerspace	
Murph	2	42	3
Jill	2	8	3
Katie	2	12	3
Julia	2	8	3
Erin	3	14	4
Matt	4	21	3
Marilyn	2	8	2
Charlie	2	2	2
Donna	2	1	2
Alex	2	2	2
Cara	2	2	2

Observations do not include the week-long PD

technologies (e.g., one single 3D printer, a few robotics kits), but ample hand tools and crafting materials.

Data collection

We collected primarily qualitative data including ethnographic fieldnotes (Emerson et al., 2011), observations in the makerspace and in classrooms, video and audio recordings of events, such as whole-group meetings, and interviews. We interviewed each of the 11 participating teachers during the summer PD, in fall, and in spring. We developed an interview protocol to understand teachers' relationships to technology reforms, the PD and ongoing professional learning, their participation in makerspace programs (e.g., after-school sessions, workshops with students), and persistent challenges they saw in continuing to develop makerspace activity. The authors conducted and transcribed all interviews.

Observations took place in the makerspace and in classrooms. We observed each teacher's classroom activity in fall and spring. We observed teachers who implemented lessons within the makerspace or implemented maker pedagogy in classrooms. A protocol guided the translation of observations into fieldnotes, to capture data about participation, activities, and conversations; the authors and trained research assistants conducted all observations and at times multiple observers generated multiple field notes of the same observation session. In addition, video and audio recordings were made to examine curricular enactments both in the makerspace and in classrooms, which were used to inform an interaction analysis (e.g., Gravel & Svihla, 2021). Table 2 outlines the data sources by specific teacher.

In keeping with our theoretical lens of examining different levels and dynamics of the school as a structuring environment, we collected data not just in the space itself, but from across the school—in classrooms, following students as they moved through different spaces, interviews with counselors and administrators—to gain a more complete picture of teachers' experiences, their decisions, and pressures that shaped reform implementation. In total, over 2 years we conducted over 1000 observation hours in the makerspace and in classrooms, compiling 355 fieldnotes and 396 video recordings, and 69 interviews with administrators, teachers, and students.

Analysis

The analytic processes were iterative, beginning with three focal teachers who were involved earlier in the research: Murph, Erin, and Matt. Their persistent presence and classroom implementations drew our attention to how teachers were finding ways to use the makerspace in their teaching. We reviewed data for these key informants (Miles et al., 2014), including fieldnotes where their activities were reported, interviews with each of them, and transcripts of group meetings where they shared about their work. Summaries of their activities were transformed into analytic memos (Charmaz & Belgrave, 2007) focused on themes across the key informants' decision-making, including: perceptions of the makerspace (e.g., new possibilities for maker activities), relationships to transdisciplinarity (i.e., how teachers tangled with making relative to their content areas), pedagogy (e.g., concerns about knowing technology in order to teach it), and accountability tensions (e.g., constraints of standardized testing).

The initial themes grounded analysis of the larger dataset of observations, interviews, and meetings of all 11 PD teachers. We used a multilevel coding process (Saldaña, 2015) to focus our attention on ways of describing teachers' deliberations and decision-making. We first coded statements based on the initial themes and how teachers were discussing them, relative to the classrooms, issues within the school, or larger institutional factors like accountability measures. We used an open coding approach to characterize the tensions teachers expressed relative to the initial themes. For example, issues related to disciplines surfaced in the ways that teachers talked about what they were "supposed" to teach, which we coded as "math curriculum", or what mathematics was "supposed" to look like in schools relative to what they imagined for the makerspace, which we coded as "math pedagogy". This refined set of codes, corresponding to the initial themes, was further explored using video to confirm evidence in fieldnotes and statements in interviews and meetings about activities the teachers conducted with their students.

Table 3 Summary of distances findings: teachers addressing each distance and levels of operation

Distance	# of teachers addressing distance (out of 11)	Levels of operation	Characteristics of distance shaping reform implementation
Skilled	9	Classroom, Organizational	Learning constraints of new tools/materials; new configurations of skill and authority
Physical	11	Classroom, Organizational	Generative tensions fostering intentional planning; limiting engagements
Disciplinary	7	Classroom, Institutional	Perceptions of disciplinary learning; new forms of practice; and translating practice to pedagogy
Structural	11	Classroom, Organizational, Institutional	Curricular accountability; policies regarding specific students; safety and management considerations

The large corpus of video data was used primarily to hone the initial and refined themes, even though close analysis of the video was not a focus of the present analysis. For example, we report on an English teacher who implemented a STEM-rich makerspace unit, and video proved central to understanding how that teacher negotiated different pressures within the context of instruction in order to enact the unit in the makerspace (Gravel & Svihla, 2021). A second cycle of coding was used to sharpen our focus towards navigating the physical spaces of the school, developing skills relative to teaching in the makerspace, concerns with disciplinary expectations and demands, and larger structural concerns around accountability, safety, and professional responsibility—what we refer to as "distances" in this paper.

We report the outcomes of this analysis as factors that operated across more than one level of the system—classroom, organization, institution—and how they shaped implementation, which we identify as four "distances". The identification of these specific, yet in many cases also overlapping, distances came from the expanded analysis of all 11 PD teachers' participation. We use specific segments of the data that are representative of the dimensions of each "distance", where it operated, and how overall the distances describe the structuring environment.

Trustworthiness of our process and findings comes through thick descriptions (Creswell & Miller, 2000), triangulation and member checking (Curtin & Fossey, 2007; Merriam, 1998), and the multidisciplinary research team. Building member checking into the existing implementation efforts increased the trustworthiness by buffering against "traps" that can skew the outcomes of these checks (Carlson, 2010), and primarily took place within our common and consistent meetings with teachers. Triangulation involved comparing emerging themes with evidence from video data, a process enhanced by the multidisciplinary nature of the research team. Our research team included sociologists, learning scientists, engineers, and developmental technology specialists. The authors are collaborators with expertise in maker education (Tucker-Raymond & Gravel, 2019), school-based technology reforms (Puckett, 2022; Puckett & Gravel, 2020), and learning in design (Gravel & Svihla, 2021). The range of expertise in designing and studying learning in making (Gravel) coupled with sociological perspectives on organizational and institutional dynamics (Puckett) allowed us to view, analyze, and construct claims through a multidimensional perspective, lending credibility and trustworthiness to our inquiry (Guba, 1981). The engineers and developmental technology specialists worked largely as research assistants but offered essential support to students and teachers in their efforts.

The research team worked alongside teachers and students as co-learners, co-makers, and observant participants (Erickson, 2006). At times, the researchers supported teachers and students by sharing techniques or approaches, but also took great care not to serve as "experts", to remain consistent with trying to co-design the space together. Our approach was intended to build trust and a collective commitment to understand how a makerspace might impact the possible learning pathways for students at Brownsville. Our findings are a selection of illustrative excerpts from the overall data corpus organized to address the research questions by using teachers' experiences and decision-making to understand what shaped implementation with the multilevel reform context.

Results

We identify four *distances*: skilled, physical, disciplinary, and structural. These distances describe spaces teachers traveled, physically and conceptually, in their makerspace implementation efforts. We explore how these distances characterize classroom, organizational, and institutional influences on teachers' engagements. The findings are organized beginning with skilled distances and moving out to structural distances, based on the levels where each operated. An overview of where the distances operated and how many teachers addressed them (Table 3), is elaborated with specific evidence of how teachers navigated each distance.

Skilled distances

Skilled distances, or distances related to skills and distribution of expertise required to implement makerspace activities, related closely to classroom practice. Technology-rich pedagogies like making require specific knowledge and practices regarding the technologies themselves, the ways tools are used in disciplinary activity, and how to teach with these technologies (Mishra & Koehler, 2006). Skilled distances are influenced by two primary dimensions: (1) opportunities to learn about new tools, materials, and skills for making, and (2) configurations of skills and authority. These pressures operate primarily at individual and organizational levels, relating closely to teachers' classroom practice and organizational structures that shape skill and expertise configurations (e.g., the pressure teachers feel to know how to do everything; Giroux, 2018).

The majority of teachers expressed apprehension about skills required to teach in the makerspace. Katie, an "ELL" English and humanities teacher, highlighted the distances between making as an activity and what is required to enable it in class:

> *...I also need to know how to actually operate this thing because legally when I have a class of 30 kids… I don't want to be this person, but I'm like, "Okay, so how do we do the 3D printer." Teach me…then once I develop that confidence then I will be free to make the less-structured project-based assignments.*

Katie reflected on the tension of wanting to support learning in the "project-based" contexts of making, and not wanting "*to be this person*", which we interpret as resisting pressures to feel as though she has to know how to do everything in a makerspace. She felt pressure to know how to use tools if she was to teach a full classroom. Donna, a visual arts teacher, framed it this way, *"I need to know how do it myself before I come down here with my students."* A number of teachers' comments focused on similar concerns:

> *"This [The Workshop] is a big space, if you're teaching in a makerspace, there's a big level of mastery."—Erin*
>
> *"And, it's not easy to teach a class here, bringing my class, everyone just wanted to jump on the saws. It's tough, takes a special person."—Julia*

Overall, 9 of 11 teachers expressed concerns regarding the skills needed to bring large classes The Workshop.

Anticipating these concerns, we compensated teachers for spending time learning in the makerspace. We posited that this protected time might support teachers to develop skill and comfort with new tools and ways of learning (e.g., engineering inquiry), opening space for teachers to imagine how their students might learning in these ways. Marilyn, an "ELL" science teacher, reflected:

> *... the confidence that I have gained in the makerspace just over the last month has been exponential, so I think the more confident that I am down there and different options that you can do in the space, because really, the options are endless, but just kind of getting used to, or more confident with e-textiles or 3D printing or whatever else people are working on, I think it's going to make it easier for me to brainstorm what can I actually do with my class down there?*

Marilyn and five other teachers regularly attended after-school open studios. They engaged in a range of projects: robotics, e-textiles, paper crafting, building an electric go-kart, making cosplay costumes (Observations, Fall 2015). Dedicated time and space for teachers to engage as makers themselves, exploring interest-driven projects, supported navigating distances between their own comforts and what they thought it took to bring classrooms of students to the makerspace. While Marilyn was "getting used to, or more confident" with making, she hinted it was not necessary to become an expert or gain "mastery". Engaging as a maker herself shaped Marilyn's sense of the possibilities, which would contribute to her implementation.

Increased knowledge and confidence in The Workshop constituted only one dimension of skilled distances, however. Teachers' own developing appreciation of curricular possibilities of the makerspace surfaced challenges regarding how to arrange a classroom to work across that range. Katie wanted to engage her students in more "project-based assignments", but was reluctant to bring students to The Workshop without knowing how to use tools. Mastery over all tools in a makerspace is neither realistic nor a goal. Participation and collaboration structures that support learning new processes *through* making are important aspects of these skilled distances, including the distribution of skills and authority.

Teachers bridged this skill distance by reconfiguring classroom roles with regard to expertise. De-centralized pedagogical approaches where the teacher facilitated different projects, and students served as guides and experts in various ways led to successful implementation. Six of the 11 teachers explored this distributed structure for skills and expertise both in classroom implementations and in after-school workshops. Erin, an English teacher, implemented a 6-week making unit with her English students in the makerspace, where they distilled themes from *Frankenstein* by Mary Shelley inspiring the design and construction of an interactive public art piece. Students designed, planned, and built a large public art installation. It was not the goal of this project for each student to gain the same knowledge and skills; the project required a distribution of roles, tasks, and expertise.

> *I ask Erin about what she thinks [of students' work]. "They are doing everything. Literally I'm just helping with questions." She says that they come in, know what to do, and get to work, and talk to Sarah [the student project manager] if they need to know something. Each person has a job for the day (or maybe more than a day?), and they seem to have a sense of what needs to get done. I asked about the two boys working on code [in Arduino], and Erin said that Tuyen [student teaching assistant] had helped them by building some code they could tinker with, rather than needing to write the entire thing from scratch. Tuyen had explained the code to Erin earlier that day, Erin tells me. "Tuyen is a genius." Tuyen's help made determining the colors, sounds, and length of tones easy. "She did an array. I'd never heard of that before!" Erin says Tuyen basically made it so that their diagrams, the wiring plans, could be translated directly into the code for the Arduinos that control each panel. (Observation, Spring 2016)*

Erin's class broke a large task into different components, and students focused their learning on developing specific expertise for the components they chose (Gravel & Svihla, 2021). This structure was devised in planning conversations among Erin and the researchers. The class was further supported another student, Tuyen, who worked with Erin to assist programming tasks for the Arduino-controlled art installation. Erin also named one student, Sarah, the "project manager". She noticed this student was *"very disengaged from that whole process … I feel she didn't think that she was someone who had the clout to participate."* Erin asked if she could be project manager, organizing tasks, materials, and timelines. The student accepted, and Erin said, *"She was like the woman of the class."* Her classmates went to her for help with questions. She received progress reports from each group and coordinated multiple ongoing tasks. The decentralized role Erin took in this project, namely the distribution of tasks and decisions, are evidence of how, in one case, teachers navigated skilled distances to support maker implementation.

Material and technical support was crucial in Erin's efforts to span skilled distances. While this was resource intensive, it points toward important supports that should be present to encourage teaching in a makerspace. Time to develop skills as learners themselves contributed to gains in teacher confidence in their abilities to teach in the makerspace. Beyond skill development, concerted efforts to reconfigure relationships to knowledge and responsibility contributed to successful implementation.

Physical distances

Our findings confirm physical space influences forms of professional work in educational organizations (Spillane et al., 2017). However, navigating a large school building presented both challenges and generative tensions, in some cases leading teachers to be intentional and organized. We locate these pressures within the classroom and organizational levels of the system, as they relate most closely to teachers' assigned classroom locations and movement patterns within the larger school building. Figure 1 includes a representation of Brownsville HS.

The distances from The Workshop to other locations in the school building influenced teachers' engagements with the space; this first emerged after the summer PD:

> *"[Researcher's name] talks about the after-school space and if there are teachers who want to be here to facilitate; he says he can be here, too. Murph … he's already here (next door in the auto shop) so he can be in the makerspace." (Observation, Fall 2016).*

In this note, [Researcher] talked with teachers about facilitating students' access to the space in after-school hours, but all the PD teachers commented about the makerspaces' location, in the basement of one of the four school buildings; it is not centrally located, nor would students or staff find themselves walking by it on their way to any other location. For Murph, traveling to the makerspace was easy—he was already next door—and he came to The Workshop regularly after school. He frequently brought classes to the makerspace as well. His training in vocational education supported his physical presence, as he referenced teaching engineering design in his courses and feeling comfort with making (PD Interview, Fall 2015). Other teachers, whose homerooms were not adjacent to the makerspace, had differing engagement levels.

Jill, a special education teacher who worked two floors up and a building away, expressed her challenges in this same discussion: *"I think it's hard to get to. I mean, I'm on the other side of the building but I think the drawback for some students is they think it's a long walk."* Jill acknowledged the distance for her and her students, nearly 5 min of walking and climbing stairs. Students whose classes met in the makerspace were routinely late to other classes because of the distance from other classrooms, and Brownsville's bell schedule (at the time) allowed zero minutes for passing. Jill introduced another perspective on movement in the school depending on where homerooms were located:

> *...they tend to stick in the neighborhood like the Barker house is right here and the Howard house is right there and those classes shift. They are right among each other and then the science classes just happen to be on this side so those students just go up a flight or two flights and their science classes are up there. As freshmen, they're mostly within a certain area. The other side of the building, Jones and Branch, they've got to hike from that side of the building, over here for science, they've got to hike down to the caf[eteria], I mean, people whose classroom distance is far ... you know what I mean? That's why I don't think it's such a far walk from the makerspace because they're doing it all day.*

Jill argued students and teachers used to covering longer distances as part of their usual movement may not find a long trip to the makerspace so different. Homerooms located closer to major gathering spaces (e.g., the "caf", see Fig. 1) required students to travel shorter distances, while other homerooms required students to travel farther. While physical distance seemed to keep Jill away from the makerspace, she acknowledged for others, longer distances are typical.

In contrast, physical distance also generated tensions that fostered intentionality. Erin's classroom was clustered with other English classrooms at the intersection of Branch and Jones, she had a "hike" to get to the makerspace; nearly 5 min of walking and climbing four flights of stairs. Regarding this distance she said:

> *...[it's] just important that I'm super intentional about when I was going, and that for those days, there was a clear protocol about what going there meant. Like, every long block, we meet up there instead of meeting in class, materials needed to be brought down, etcetera. I've always been far away from things.*

For Erin, physical distance imposed a need to be intentional about schedule, preparation, and readiness for specific needs of teaching in the makerspace. The distance generated an important tension: having to traverse the school to get there, Erin thought about *why* she was bringing her class to the makerspace and whether they needed to be physically present in that space to do the work she planned. While proximity alone does not predict implementation, it contributed in a few ways: proximity supported Murph's frequent engagement, distance challenged Jill's engagement, and distance catalyzed intentional deliberations about teaching in the makerspace when Erin brought her English students there.

Negotiating physical distances, and considering proximities in decisions about pedagogy, demonstrate how the makerspace's location relative to other activities and spaces influenced implementation. The organization's decision to cluster English classes a great distance from the vocational spaces influenced Erin's work; the auto shop's location next to the makerspace influenced Murph's work. Physical distances also interacted with other organizational factors (e.g., scheduling) and disciplinary distances, evident in Murph and Erin's stories.

Disciplinary distances

Maker pedagogy, which emphasizes engineering inquiry and design, often differs from pedagogies teachers use in subject-area classrooms (Songer et al., 2002). *Disciplinary distances* are constituted by teachers' perceptions of making relative to the disciplinary activity they teach. We locate these distances at the classroom and institutional levels, as they relate to how teachers develop their classroom pedagogy relative to the ways larger disciplines structure and constrain notions of learning and practice (Bang et al., 2012). This distance was mentioned explicitly by 7 of the 11 teachers, primarily by those teaching math and English. Disciplinary distances have perception, practice, and pedagogical dimensions, each shaping implementation.

The emergence of the "maker movement" and characterizations that center entities like MAKE Magazine (Dougherty, 2012), have contributed to a general perception that makerspaces are STEM spaces (Tucker-Raymond & Gravel, 2019; Vossoughi et al., 2016). As such, STEM teachers tended to have different orientations to the disciplinary practices and goals of work in these makerspaces than humanities teachers. For example, Charlie, a chemistry teacher, framed makerspace activities primarily as opportunities to engage his chemistry students in making instruments for experimentation; Julia and Murph saw ways to teaching engineering design in the space; and Erin saw making as a new form of expression in English. Perceptions of makerspaces and visions of how to use it with students were complicated by teachers' relationships to disciplinary inquiry and related pedagogical commitments and pressures.

Erin found ways to incorporate a makerspace project while fulfilling her obligations for disciplinary activity, which required significant planning, much like traversing the physical distance of Brownsville. Spending 6 weeks designing and building a piece of public art meant having to justify where English was happening in her teaching:

> *Erin: A lot of English happened before we got down*

Fig. 2 Frankenstein interactive art installation consisting of three large panels adorned with boxes that emit light and sound when the user places their hand on them

> *here. It was lots of planning, lots of reflection, lots of …*
> *Brian: Going back to the text, looking?*
> *Erin: Going back to the text, yeah. Some English stopped when we came down here, but I was okay with that because we had done lots of it. I like front-loaded a lot of things. They did a lot of essays in a short amount of time to balance my own departmental expectations. I did take some latitude as far as … They did research, but they did not write a research paper, but they did it, research, in this space.*

Erin acknowledged common elements of English (e.g., "essays") were needed to balance her professional obligations with her experimentation in the makerspace. In planning and framing the problem, students read the novel, explored themes through writing, and constructed interpretations through discussion; ELA set the foundations for making their interactive public art installation (Fig. 2). She explored new ways of conceptualizing disciplinary practices—like "research"—for work in the makerspace, asking students to research materials, electronics components, and computer code. Seeing new ways of defining English practices suggests this disciplinary distance generated productive tensions for teachers' pedagogical implementations.

Surprisingly, the math teachers (Cara, Matt, and Alex) expressed more doubt and listed more challenges to integrating makerspace elements in their current teaching than teachers from other disciplinary traditions. Making often entails a great deal of math (e.g., in coding, in weaving patterns) and it is often associated with STEM, so this finding was unexpected. Cara noted, *"I'm a math teacher, but there's pressure from admin and MCAS, that they have specific things they need to learn."* Math teachers have the most prescribed scope and sequence within the school curriculum (Handal & Herrington, 2003), reflected in Cara's question raised during one of the after-school meetings, *"With all the topics already in Algebra 1, what could we get rid of? They need all that for Algebra 2."* All 3 of the math teachers expressed interest in exploring making within their classroom but expressed doubts about how this integration might work. Perceptions of classroom mathematics demands conflicted with how teachers imagined incorporating making.

Making is a transdisciplinary and multimodal activity (Tucker-Raymond & Gravel, 2019), yet teachers faced challenges identifying connections to their disciplinary pedagogy. Matt, a math teacher, saw connections between making and mathematics, *"I know that they're there."* In after-school sessions, Matt spent hours building a robot that drew sine waves with different periods and amplitudes; engaging as a learner himself to explore connections between making and mathematics. A former math major, building a robot that drew sine curves sparked the curiosity about mathematics he experienced in school himself. He explored relationships like a circle's radius and a sine curve's amplitude by tinkering with his robot; making and mathematics mutually supported his curiosity. He saw possibilities for this in his classroom teaching:

> *"That was something that would mathematically be interesting and applicable to students in class. You could see how the radius dilates the function that would graph vertically. We could talk about how the radius of the circle affects the amplitude of the resulting graph."*

Yet, Matt admitted he was uncertain about how to construct those same relationships, between making and mathematics, when it came to curriculum and pedagogy.

> *"I think the major thing that I am struggling with or looking for, or needing more support on, is making those connections … I don't necessarily see those connections as easily. I know that they're there, I just don't necessarily know how to scope into that."*

Connecting one's background with the tools, materials, and ways of thinking about disciplinary learning requires traversing multidimensional distances involving the nature of school mathematics and associated pedagogical commitments. The possibilities for making in a classroom were shaped by institutionalized perceptions of disciplinary practice and learning. Matt brought his students to the makerspace for a lesson on mathematical functions, where students identified different "inputs", "outputs", and "functions" of tools like hammers and thermometers. The lesson focused on tools as metaphors for mathematical functions, yet students engaged in very little of the exploration and tinkering Matt experienced during his robot project. Disciplinary distances influenced how Matt worked in the makerspace and his curricular implementation. His own relationships to disciplinary learning supported his work in the makerspace, yet the structural distance of mathematics teaching shaped his students' experiences. Matt's experiences were a characteristic example of mathematics teachers and their challenges navigating this distance.

Structural distances

The final distance shaping teachers' implementations was structural, or the ways policies structured expectations and demands on teachers that were often at odds with working in the makerspace. Structural factors affect all levels that teachers navigate, including classroom expectations, pedagogical orientations, and professional standards for teachers' skills and knowledge. All 11 of the PD teachers discussed structural distances. Our focus for structural distances is on policies enacted through institutional logics in the school organization. Makerspaces generally, and specifically the ways The Workshop invited exploration and creativity, are in tension with the very constrained, focused, and narrow visions of curriculum and pedagogy in most K-12 schools (Godhe et al., 2019). We share the experiences of teachers to illuminate the structural issues that affected makerspace implementation, while maintaining that the responsibility to address challenges lies with the organizations and institutions that produce them. The structural distances we found relate to curriculum and accountability, policies regarding specific students (e.g., "ELL"), and policies relating to safety and management in the makerspace.

During PD, teachers consistently cited structural distances as factors influencing their use of the makerspace. At the end of the PD, Katie (a designated "ELL" humanities teacher) planned to collaborate with an "ELL" science teacher, Marilyn, on a makerspace project. They wanted students to answer the question, *"How will I create a physical sign, symbol, or other visual that communicates my 'inner message' and connects with my text about this subject?"* This transdisciplinary project involved blending textual explorations of ideas like racism or inequality and making different expressions of an "inner message" about the topic. This lesson design cleverly navigated disciplinary distances by positioning design and material fabrication as tools for expressing meaning and literary themes. However, in terms of implementation, Katie said:

> *"It would have been rolled out during this unit but basically what's happening is I know that we have high-stakes exams coming up and I feel like such a [expletive] teacher saying this, but right now I just need to make sure my kids are writing a five-paragraph essay."*

Katie's response highlights pervasive and immediate pressure of accountability systems and "high-stakes" standardized tests. Katie elaborated:

> *"... there are so many tests. There's the PARC pilot, now the PARC's been abandoned, thank god. That test was a hot mess. ESL students have to take a standardized test called the Access. We have been told it's going to take fewer days, but that's three, four, five, the first time we administered that was two weeks of school. That's insane. They're taking this test, it's crazy. There's AP exams, there's the MCAS, there's the SAT, ACT, there's midterms, there's finals. I think if you add up all the days that kids spend taking an exam of some kind it's about 15% of the entire year which is nuts. It's out of control."*

Like in all public schools, Brownsville students are frequently tested, and that testing is tightly coupled with the curricular scope and sequence. Curricular policies mandate what content is taught. Cara, a mathematics teacher, confirmed this, "*but there's pressure from admin and MCAS, that [students] have specific things they need to learn.*" Testing and content constrain pedagogical possibilities to the point where teachers feel unsupported in attempting new implementations, regardless of excitement about potential benefits. While makerspaces as STEM reforms are intended to transform learning pathways, curricular policy and testing demands highly influenced whether, how, and when teachers considered implementing makerspace projects. In fact, of the five classroom implementations in The Workshop, two teachers opted to implement after subject-area testing was completed (Physics and English).

Katie's perspective on testing illuminates a second dimension to structural distances, which are policy requirements for students from specific groups like those labeled as "ELL" or students with disabilities. Making offers opportunities for expanding the ways students can participate and learn, creating opportunities for students to thrive and excel in ways different from traditional classrooms. Yet, we heard teachers express that flexible time was limited and dominated by activities mandated by "ELL" and special education policies:

> *"I have IEP meetings, I'm trying to write the IEP, I'm trying to develop support tools or find support tools or provide extra help or get in touch with parents. I*

have an array of activities." - Jill, special education teacher
"...just doesn't seem to be enough time in the day to get that done or add in a project with all of the other expectations from the department." - Marilyn, "ELL" science teacher

Teachers of students labeled in these ways are often not given adequate time or resources to fulfill their responsibilities, let alone explore new innovations and approaches that could be especially beneficial for their students. Their commitment to their students forces them to decide whether to support mandated activities or explore new possibilities. Brownsville is a school where more than 50 languages are spoken by enrolled students, and structural demands on "ELL" teachers are significant. Katie was unable to attend after-school sessions because of a conflict with her responsibilities to students labeled as "ELL"; many such students were required to attend an after-school enrichment program in order to participate in other activities (such as a college preparation program). Students asked Katie to lead the after-school enrichment group:

"I was like, 'All right. We'll have a meeting but listen guys if no one shows up we're not going to do it,' and then 40 kids showed up. I was like, 'Okay, I need to do this.' I basically said, "You know what? This is going to be my commitment. The Workshop isn't."

Katie, who professed a deep commitment to her students' needs and success, was forced to choose between work in the makerspace she was excited about and supporting her students in a mandated activity. Being forced to make such a decision reflects how structural distances influenced and shaped Katie's participation, who ultimately never implemented maker activities with her students; it proved challenging for Jill and Marilyn as well, who spent time in the makerspace themselves, but never brought their students there.

The third dimension of structural distances relates to safety and management in the makerspace. Every teacher we met, including those outside the eleven summer PD teachers, expressed some concern about navigating safety issues with tools (e.g., wood working tools), managing materials, the time to set up and organize materials, and accountability for lost, broken, or stolen items.

"...going down to The Workshop is like, to me just to be totally honest, it's like taking my class down, having 30 kids, we're working with the wood shop and what if something happens?"—Katie

The shared concern of bringing 30 students to *"the wood shop"* reveals how teachers must navigate safety and liability if they teach in technology-rich environments like makerspaces. While issues of organizing materials and arranging the space certainly relate to teachers' pedagogical skills, their comments often specifically referenced liability. Concerns over bringing large classes to the makerspace were fueled by pressures to maintain "control" and safety, both having structural or institutional origins (Noguera, 2003), evidenced by earlier comments about "legal" responsibilities. Yet, teachers wanted to engage with The Workshop, like Marilyn and Katie's planned unit on "Inner Message". Julia also articulated this tension in an interview during the summer PD, seeing the opportunities relative to the contingencies:

"There's just so much stuff and so much space. There's a lot of opportunities there. And that's a challenge because you have to manage all that stuff, the safety, the organization. The maintenance is daunting."

Challenges navigating distances related to safety, management, and liability were pervasive and consistent, illustrating structural pressures originating at the organizational and institutional levels.

All teachers communicated, at various times, that they saw potential benefits in inquiry-based approaches possible in the makerspace. Institutional structures created distance between these possibilities and having to navigate the constraints of their jobs. We found structural distances related closely to curriculum issues, work with students designated as "ELL", and safety and management. Taken together, it seems reasonable these distances would be insurmountable, which was the case for Katie, Marilyn, and Jill—all "ELL" or special education teachers—who admitted they never brought their students to The Workshop or explored maker pedagogy in their classrooms.

Discussion

This paper makes two major contributions. First, it addresses a gap in research on school-based makerspaces by identifying and describing dynamics shaping implementation (Stornaiuolo & Nichols, 2020). Our findings support relevant conclusions for those wanting to implement makerspaces in K-12 schools: distances between current practices and the demands of reform shape teachers' implementations, and these distances operate as a constellation of pressures that cannot be isolated when understanding makerspace integration in schools. Skilled, physical, disciplinary, and structural distances must be jointly considered in multilevel reform efforts, contextualized within organizational and institutional pressures. A second contribution proposes theorizing teachers as *multilevel actors* whose experiences reveal reform dynamics and suggest paths for improved implementation of makerspaces moving forward. We discuss the first contribution in terms of mapping the notion of distances and multilevel makerspace reforms, followed by an articulation of what teachers' experiences reveal about the tensions and possibilities of makerspaces.

We describe four distances that reflect the ways teachers discussed their responses to installation of a makerspace at Brownsville High School. It is important to remember that the teachers in this study were volunteers who expressed interest in bringing making into their practice, yet not all teachers ultimately decided to do this. Rather than conceiving of the four distances we identify as hurdles or impediments to implementation, we frame them as factors shaping and influencing these efforts. For example, teachers' efforts to develop their own skills and comforts in the makerspace increased their confidence with new forms of learning (as with Marilyn). Yet, translating personal discovery into new pedagogical approaches remained challenging (as with Matt), influenced by both factors at the classroom and institutional levels. Dedicated time, with support, contributed to teachers developing skills with new materials and tools (as with Erin), yet efforts to incorporate making in classrooms was shaped by other structural, disciplinary, and physical distances (Matt, Marilyn, and Donna). The distances we report reflect the experiences of teachers in our study and how these distances jointly operate across different levels of the system to shape implementation.

The distances operated as a constellation of pressures—independently identifiable and co-operatively manifesting—that shape implementation. The nature of this dynamic can be further discussed by examining particular tensions that teachers reported and how they reflect the work required by teachers to navigate reforms that span levels of the educational system. Erin's experiences reflect tensions at the intersection of skilled, disciplinary, and physical distances. The disciplinary distances Erin experienced encouraged her to reconcile and clarify her goals for bringing making into an English course. Physical distances encouraged intentionality around planning, which contributed to a reconfiguration of roles and skill distributions in her classroom implementation of the Frankenstein project. The tensions exist at the intersections of distances, when competing pressures interact, reflecting the dynamics of the structuring environment. They are relationally emergent, in that they are produced through interactions with the environment, including professional learning opportunities but also the organizational logics shaping teacher practice at Brownsville. For example, the PD and "open-studios" supported teachers in developing skills for making themselves, and for thinking pedagogically about making. At the same time, demands for specific populations (e.g., students with IEPs) and concerns about safety had noticeable impact on teachers' decisions about implementation. The distances are also temporally emergent as each teacher's prior experiences and achievements (e.g., developing skills) interacted with the possible pathways for implementation. The mutually informing nature of the distances—expressed as tensions emerging from teachers' experiences—position teacher deliberations and decision-making as portals into the forms of organizational and institutional supports offered in multilevel reforms.

Bringing making to schools constitutes a STEM reform, offering opportunities for teachers to implement new approaches in their classrooms. Distances offer us a means of understanding what contributed to teachers' decisions to implement—such as the protected time and space to engage as makers themselves. They also contribute to how we understand why other teachers chose not to implement makerspace activities in their own teaching. Compounding pressures from organizational and institutional factors impacted the decisions teachers made. These decisions about implementation are portals into aspects of the organizational and institutional environment—i.e., the structuring environment—that support different forms of agentic actions.

Distances provide opportunities to expand how we understand teachers' decisions as more than classroom-level issues. Prior work conceptualizing teachers' roles in STEM reforms as classroom level issues—in terms of pedagogy and learning outcomes—reduces the complexities reported by teachers through the decisions they made about using the makerspace. Matt experienced tensions in decisions about his classroom teaching, which operated at the intersection of skilled, disciplinary, and structural distances. His personal curiosity drove exploration of disciplinary learning with technology, advancing his own skills regarding learning mathematics through making. The time and space he had after school supported him in exercising this curiosity. We could argue that he experienced a kind of pedagogy himself that would transform his mathematics teaching—building robots to construct mathematical functions. In fact, the research team was somewhat surprised by his expressed struggle seeing a path forward for bringing this kind of inquiry into his mathematics classroom.

Notions of school disciplinary learning and curricular constraints, operating at the structural level, combined to limit the scope of implementation opportunities for Matt. His concerns did not appear driven by explicit curricular demands, rather more subtle pressures he felt about what needed to happen in his mathematics teaching. Thus, the construct of distances illuminates places where teachers interested in implementing reforms must navigate nuanced pressures that exist *across* levels of the complex educational system. Matt developed new skills for shifting pedagogies at the classroom level—using robotics technologies to explore mathematical functions; he admitted he learned by doing this himself. Yet, the ways he experienced the disciplinary needs for high school mathematics were shaped by structural factors at the institutional level—e.g., the curriculum frameworks—which constrained the possible pathways he saw for those same shifts in classroom practice. Matt's implementation of a makerspace activity consisted of introducing the metaphor of inputs and outputs for functions using tools in the makerspace. While students responded to this positively, the generative potential of his own constructive work with the sine-drawing robot did not appear in his classroom teaching.

The findings we present are specific to a makerspace implementation, and the ways teachers navigated skilled, physical, and disciplinary distances are tightly connected to the goals of bringing making to school (Martin, 2015). Makerspaces engender new distributions of skills and knowledge, evidenced in Erin's implementation. They are new physical spaces in a school building, which offer opportunities for collaborations and interactions focused on inquiry, design, and creative construction. They also invite a melding of disciplinary practices that foster rich forms of personally meaningful learning. The skilled, physical, and disciplinary distances directly correspond to the kinds of learning pathways makerspaces offer, which make them desirable STEM reforms (Kim et al., 2019). Structural distances, however, expose particular places where organizational and institutional policies and practices may impact a broader scope of reforms. We concede that structural distances are broader, and perhaps more amorphous than the other three; that is the nature of structures that organize entire systems (Foucault, 1979). For teachers, structural demands are often felt through specific policies enacted at the school level. Tight control over curricular targets and pacing deeply impacted multiple teachers' implementations.

Yet as we note, there are also more nuanced structural issues such as those Matt described, where his makerspace mathematics project did not appear to fit with how he understood mathematics should be taught in his classroom. The ecological framing of this study suggests factors operate as a constellation to produce dynamics where isolating singular factors affecting implementation becomes quite difficult. Additionally, institutional logics position teachers as isolated disciplinary practitioners enacting approaches for particular students, not as intellectuals who can make informed decisions about practice or learn alongside their students. Thus, structural distances appear pervasive and global, and often limit the expansive possibilities of reforms directed at increasing student-centered inquiry like makerspaces. While teachers developed their own skills and were excited to explore new pedagogies, constraints operating through structural distances created considerable impediments to implementation. Taken together, these institutional and organizational factors deserve further research and scrutiny.

Our second contribution is positioning teachers as multilevel actors, whose experiences navigating classroom, school, and institutional pressures offer new insights into how the structuring environment supports or stifles reform. Positioning teachers as *multilevel actors* builds on prior work seeking to examine the dynamics of reform across levels of a system (Coburn, 2001, 2004). We define multilevel actors as individuals with specific knowledge of an organizational space who confront and navigate reform pressures within and across individual (e.g., classrooms), organizational (e.g., school), and institutional (e.g., policy) levels of the reform context. Teachers have unique knowledge of the "lived logics" (Woulfin, 2016) of their structuring environments (i.e., their particular schools). As such, their experiences with reform surface this unique, situated knowledge as a resource in navigating multilevel pressures. Thus, we can frame their experiences as portals into how the structuring environment is supporting or stifling implementation.

Teachers' experiences are more than reflections of their individual journeys, but also windows into how they understand the policies and practices of the school in supporting new kinds of pedagogy. In this way, the distances are an initial sketch of a new ways of understanding makerspace implementation dynamics that account for the pressures that operate at and across levels. The implementation decisions we observe are reflections of teacher agency in practice—i.e., decision-making—connecting teachers personal experiences with the larger organizational and institutional logics that set the conditions of the structuring environment. At the same time, we can understand teachers' decisions *not* to implement makerspace reforms as another kind of agentic action, whereby teachers have weighed the pressures and chosen paths that work for their professional histories and status. Ecological models of agency reframe teacher actions as evidence of supportive environments, with implications for how organizations and institutions could further encourage reform implementation.

The study's limitations are also worth addressing. This study took place in one school, where 11 of 115 teachers at the school voluntarily participated. This presents a significantly different case from reforms where all teachers in entire districts are required to adopt new instructional approaches. Significant prior research on implementation focuses on larger, institutional mandates that relegate teachers to the role of passive targets in reform efforts (Mehta, 2013; Russell & Bray, 2013). The limitations of a study focused on a small number of teachers who volunteered raise questions about the applicability of the findings to other multilevel reforms. In particular, it seems skilled, disciplinary, and physical distances have specific relationships to makerspace implementations, based on the data reported. Structural distances may have more general impacts in shaping reforms that break from dominant modes of instruction and assessment.

At the same time, these limitations motivate future study of multilevel STEM reform, and continued exploration of makerspaces in schools. The relatively smaller number of participants created the opportunities for this study, as the research team was able to develop and sustain close relationships with the participating teachers. The early adopters of this nascent makerspace were invited to co-construct the culture, atmosphere, and image of The Workshop for the rest of the school. As more teachers became interested and aware of what could happen in the makerspace, teachers were positioned as leaders who could support colleagues interested in exploring making in their own pedagogy. In the subsequent years following data collection, growth in teacher and student interest in the space blossomed (Gravel & Svihla, 2021). Descriptions of that growth are beyond the scope of this study, but they signal an important need for future study of how teachers are considered essential and valued actors in makerspace implementations.

Conclusions and implications

The constellation of distances that shape implementation of the makerspace at Brownsville reveal the complex multilevel dynamics of this STEM reform effort. As continued attention is paid to reforming approaches to disciplinary inquiry and pedagogy (e.g., Duschl & Bybee, 2014), this/ paper offers insights into how communities develop and sustain new practices, like the integration of a makerspace. This includes reconceptualizing where STEM happens in a high school, blurring historically tight disciplinary boundaries to recognize that students in an English class can engage in STEM practices in a makerspace in ways not initially considered in efforts like NGSS. Makerspaces, thus, offer opportunities for future study of how STEM reforms unfold in complex systems like a comprehensive high school. While the promise of making to transform STEM learning pathways is noted, researchers and reformers must partner with teachers to understand how these practices and spaces serve to deepen students' learning opportunities. Teachers, skilled in negotiating the constellation of pressures, provide insights into how communities might shift practices, but also how organizational and institutional factors impede or encourage reform implementation.

As research continues to examine and substantiate the learning potential of making (e.g., Greenberg et al., 2020; Rouse & Gillespie Rouse, 2022), our paper has implications for creating and sustaining makerspaces in schools. First, the forms and frequency of professional supports offered to teachers, including opportunities to reframe how knowledge and skills are located and distributed in instructional designs, require careful reconsideration. We illustrated the relationships between teachers building their own skills in making and their decisions to implement. Sustained engagement in these learning activities, with accompanying forms of support promoted both the exploration and implementation of maker-based learning. Thus, teachers need space to assume roles as learners themselves as they reexamine their own relationships to the different pressures we describe. Additionally, innovative professional learning opportunities that bring together multiple stakeholders—teachers, students, administrators, researchers—might further advance the integration of STEM-rich making in schools. Secondly, our paper has implications for the physical placement of makerspaces within school buildings. If makerspaces are to be central drivers of STEM/STEAM pedagogical innovations, there are benefits to their location also being central. Propinquity can support both traversing the physical space as well as increased sharing of reform ideas and pedagogies (Spillane et al., 2017). Distances from classrooms to these collaborative spaces can spawn intentional curricular development, thus placement should be measured against how the space will be used in classroom activity. However, the onus cannot reside with teachers in discussions of maker education reform, rather, the most salient implications from our study point the critical role of policymakers and administrators.

From a structural perspective, school policies both help and hinder integration efforts, and audits of how existing policies affect makerspace integration could improve implementation. Specifically, policies that disenfranchise students carrying particular labels, denying them access to transformative experiences, must be revised. Making encourages expansive ways of learning that could have specific benefits for students labeled with dis/abilities or as multilingual. Making offers opportunities to center culturally sustaining practice, thus policies that narrow participation in these spaces counteract this potential. Moreover, as teachers explore the learning possibilities in making, they must be given time and curricular flexibility to nurture new pedagogies. Expanding notions of disciplinary and transdisciplinary learning through STEM-rich making—as in Erin's *Frankenstein* example—require organizational and institutional attention;

teachers are eager to embrace new approaches, but pressures beyond their control are limiting.

The distances that shape implementation of makerspaces in schools offer guidance on how teachers and administrators might further support these moves toward student-centered, inquiry learning in STEM. As continued attention is directed toward meaningful disciplinary learning in classrooms, acknowledging the unique and powerful role that teachers assume as multilevel actors will provide further insights into how schools can embrace innovation.

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BEG is the PI on the project, leading the design, data collection, analysis, and writing; CP was a major contributor to theoretical and analytical developments for the manuscript, and participated in data collection activities. Both authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

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The authors declare that they have no competing interests.

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References

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education, 66*(2), 136–149.
Andrews, M. E., Borrego, M., & Boklage, A. (2021). Self-efficacy and belonging: The impact of a university makerspace. *International Journal of STEM Education, 8*, 24. https://doi.org/10.1186/s40594-021-00285-0
Ball, D. L., & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. *Teaching as the Learning Profession: Handbook of Policy and Practice, 1*, 3–22.
Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389–407.
Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development, 55*(5–6), 302–318.
Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the Learning Sciences, 7*(3–4), 271–311.
Becker, H. J. (2000). 'Findings from the Teaching, Learning, and Computing Survey: Is Larry Cuban Right?' *Education Policy Analysis Archives, 8*(51), 2–32.
Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education, 99*(1), 98–120.
Biesta, G., & Tedder, M. (2007). Agency and learning in the lifecourse: Towards an ecological perspective. *Studies in the Education of Adults, 39*(2), 132–149.
Blikstein, P. (2018). Maker movement in education: History and prospects. In M. De Vries (Ed.), *Handbook of technology education* (pp. 419–437). Springer.
Blumenfeld, P., Fishman, B. J., Krajcik, J., Marx, R. W., & Soloway, E. (2000). Creating usable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educational Psychologist, 35*(3), 149–164.
Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178.
Brown, A., Ash, D., Rutherford, M., Nakagawa, K., Gordon, A., & Campione, I. C. (1993). Distributed expertise in the classroom. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 188–228). Cambridge University Press.
Bryk, A. S., & Gomez, L. M. (2008). Ruminations on reinventing an R&D capacity for educational improvement. American Enterprise Institute Conference on the Future of Educational Entrepreneurship, Washington, DC.
Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education, 25*(2), 211–221.
Calabrese Barton, A., & Tan, E. (2018). *STEM-rich maker learning: Designing for equity with youth of color*. Teachers College Press.
Campbell, T., Longhurst, M. L., Wang, S.-K., Hsu, H.-Y., & Coster, D. C. (2014). Technologies and reform-based science instruction: The examination of a professional development model focused on supporting science teaching and learning. *Journal of Science Education and Technology, 24*(5), 562–579. https://doi.org/10.1007/s10956-015-9548-6
Carlson, J. A. (2010). Avoiding traps in member checking. *Qualitative Report, 15*(5), 1102–1113.
Cassidy, M. P. (2018). The impact of incoherent professional learning on standards-based reform. In S. J. Zepeda (Ed.), *Making learning job-embedded: Cases from the field of instructional leadership* (pp. 55-73). Rowman & Littlefield.
Chachra, D. (2015). Why I am not a maker. *The Atlantic, 23*, 2015.
Charmaz, K., & Belgrave, L. L. (2007). Grounded theory. *The Blackwell Encyclopedia of Sociology*. https://doi.org/10.1002/9781405165518.wbeosg070.pub2
Chesnutt, K., Gail Jones, M., Corin, E. N., Hite, R., Childers, G., Perez, M. P., Cayton, E., & Ennes, M. (2019). Crosscutting concepts and achievement: Is a sense of size and scale related to achievement in science and mathematics? *Journal of Research in Science Teaching, 56*(3), 302–321.
Coburn, C. E. (2001). Collective sensemaking about reading: How teachers mediate reading policy in their professional communities. *Educational Evaluation and Policy Analysis, 23*(2), 145–170.
Coburn, C. E. (2004). Beyond decoupling: Rethinking the relationship between the institutional environment and the classroom. *Sociology of Education, 77*(3), 211–244.
Coburn, C. E., Hill, H. C., & Spillane, J. P. (2016). Alignment and accountability in policy design and implementation: The Common Core State Standards and implementation research. *Educational Researcher, 45*(4), 243–251.
Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. *Oublier. Educational Evaluation and Policy Analysis, 12*(3), 311–329.
Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory into Practice, 39*(3), 124–130.
Curtin, M., & Fossey, E. (2007). Appraising the trustworthiness of qualitative studies: Guidelines for occupational therapists. *Australian Occupational Therapy Journal, 54*, 88–94.
Darling-Hammond, L. (1996). The quiet revolution: Rethinking teacher development. *Educational Leadership, 53*(6), 4–10.
Donovan, M. S., & Snow, C. (2017). Sustaining research-practice partnerships. In B. Bevan & W. R. Penuel (Eds.), *Connecting research and practice for educational improvement Ethical and equitable approaches* (pp. 33-55). Taylor & Francis.
Dougherty, D. (2012). The maker movement. *Innovations: Technology, Governance, Globalization, 7*(3), 11–14.
Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-014-0012-6

Elmore, R. F. (1979). Backward mapping: Implementation research and policy decisions. *Political Science Quarterly, 94*(4), 601–616.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (2011). *Writing ethnographic fieldnotes*. University of Chicago Press.

Emirbayer, M., & Mische, A. (1998). What is agency? *American Journal of Sociology, 103*(4), 962–1023.

Erickson, F. (2006). Studying side by side: Collaborative action ethnography in educational research. In G. D. Spindler (Ed.), *Innovations in educational ethnography: Theory, methods and results* (pp. 235–258). Routledge.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*(2), 423–435.

Foucault, M. (1979). *Discipline and punish: The birth of the prison*. Vintage Books.

Frank, K. A., Zhao, Y., Penuel, W. R., Ellefson, N., & Porter, S. (2011). Focus, fiddle, and friends: Experiences that transform knowledge for the implementation of innovations. *Sociology of Education, 84*(2), 137–156.

Friedrichsen, P. J., & Barnett, E. (2018). Negotiating the meaning of Next Generation Science Standards in a secondary biology teacher professional learning community. *Journal of Research in Science Teaching, 55*(7), 999–1025.

Fulmer, G. W., Tanas, J., & Weiss, K. A. (2018). The challenges of alignment for the Next Generation Science Standards. *Journal of Research in Science Teaching, 55*(7), 1076–1100.

Gerard, L. F., Varma, K., Corliss, S. B., & Linn, M. C. (2011). Professional development for technology-enhanced inquiry science. *Review of Educational Research, 81*(3), 408–448.

Giroux, H. A. (2018). Teachers as transformative intellectuals. *Thinking about schools* (pp. 183–189). Routledge.

Godhe, A.-L., Lilja, P., & Selwyn, N. (2019). Making sense of making: Critical issues in the integration of maker education into schools. *Technology, Pedagogy and Education, 28*(3), 317–328. https://doi.org/10.1080/1475939X.2019.1610040

González-Howard, M., & Suárez, E. (2021). Retiring the term English language learners: Moving toward linguistic justice through asset-oriented framing. *Journal of Research in Science Teaching, 58*(5), 749–752.

Gravel, B. E., Olivares, M. C., & Tucker-Raymond, E. (2022). Re-making education in STEM classrooms with computational making. In C. Mouza, A. Ottenbreit-Leftwich, & A. Yadav (Eds.), *Professional development for in-service teachers: Research and practices in computing education* (pp. 143–170). Information Age Press.

Gravel, B. E., & Svihla, V. (2021). Fostering heterogeneous engineering through whole-class design work. *Journal of the Learning Sciences, 30*(2), 279–329. https://doi.org/10.1080/10508406.2020.1843465

Greenberg, D., Calabrese Barton, A., Tan, E., & Archer, L. (2020). Redefining entrepreneurialism in the maker movement: A critical youth approach. *Journal of the Learning Sciences, 29*(4–5), 471–510.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology, 29*(2), 75–91.

Hallett, T., & Ventresca, M. J. (2006). Inhabited institutions: Social interactions and organizational forms in Gouldner's Patterns of Industrial Bureaucracy. *Theory and Society, 35*(2), 213–236.

Halverson, E., & Peppler, K. (2018). The maker movement and learning. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International Handbook of the Learning Sciences* (pp. 258–294). Routledge.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review, 84*(4), 495–504.

Handal, B., & Herrington, A. (2003). Mathematics teachers' beliefs and curriculum reform. *Mathematics Education Research Journal, 15*(1), 59–69.

Hansen, A. K., McBeath, J. K., & Harlow, D. B. (2019). No bones about it: How digital fabrication changes student perceptions of their role in the classroom. *Journal of Pre-College Engineering Education Research J-PEER, 9*(1), 6.

Hatch, M. (2013). *The maker movement manifesto*. McGraw Hill Professional.

Haverly, C., Calabrese Barton, A., Schwarz, C. V., & Braaten, M. (2020). "Making Space": How novice teachers create opportunities for equitable sense-making in elementary science. *Journal of Teacher Education, 71*(1), 63–79.

Heineke, A. J., Ryan, A. M., & Tocci, C. (2015). Teaching, learning, and leading: Preparing teachers as educational policy actors. *Journal of Teacher Education, 66*(4), 382–394.

Hill, H. C. (2001). Policy is not enough: Language and the interpretation of state standards. *American Educational Research Journal, 38*(2), 289–318.

Hira, A., & Hynes, M. M. (2018). People, means, and activities: A conceptual framework for realizing the educational potential of makerspaces. *Education Research International*. https://doi.org/10.1155/2018/6923617

Hmelo-Silver, C. E. (2006). Design principles for scaffolding technology-based inquiry. In A. M. O'Donnell, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative learning, reasoning, and technology* (pp. 147–170). Taylor & Francis.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Ingersoll, R. M., & Collins, G. J. (2017). Accountability and control in American schools. *Journal of Curriculum Studies, 49*(1), 75–95.

Kim, A. Y., & Sinatra, G. M. (2018). Science identity development: An interactionist approach. *International Journal of STEM Education, 5*, 51. https://doi.org/10.1186/s40594-018-0149-9

Kim, Y. E., Edouard, K., Alderfer, K., & Smith, B. K. (2019). *Making culture: A national study of education makerspaces*. Drexel University ExCITe Center.

Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(30), 9–40.

Kraft, M. A., Marinell, W. H., & Shen-Wei Yee, D. (2016). School organizational contexts, teacher turnover, and student achievement: Evidence from panel data. *American Educational Research Journal, 53*(5), 1411–1449.

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education, 102*(4), 771–795.

Marín-Marín, J. A., Moreno-Guerrero, A. J., Dúo-Terrón, P., & Bemonte, J. (2021). STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education, 8*, 41. https://doi.org/10.1186/s40594-021-00296-x

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research J-PEER, 5*(1), 30–39.

Martin, L., Dixon, C., & Betser, S. (2018). Iterative design toward equity: Youth repertoires of practice in a high school maker space. *Equity & Excellence in Education, 51*(1), 36–47.

McNeill, K. L., Lowenhaupt, R. J., & Katsh-Singer, R. (2018). Instructional leadership in the era of the NGSS: Principals' understandings of science practices. *Science Education, 102*(3), 452–473.

Mehta, J. (2013). How paradigms create politics: The transformation of American educational policy, 1980–2001. *American Educational Research Journal, 50*(2), 285–324.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative Data Analysis: A Methods Sourcebook*. Sage.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053–1075.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

Mockler, N. (2012). Teacher professional learning in a neoliberal age: audit, professionalism and identity. *Australian Journal of Teacher Education, 38*(10), 35–47.

Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of engineering in K-12 state science standards. *Journal of Research in Science Teaching, 52*(3), 296–318.

National Academies of Sciences, Engineering, and Medicine. (2019). *Science and engineering for grades 6–12: Investigation and design at the center*. National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States*. The National Academies Press.

Noguera, P. A. (2003). Schools, prisons, and social implications of punishment: Rethinking disciplinary practices. *Theory into Practice, 42*, 341–350.

Norris, A. (2014). Make-her-spaces as hybrid places: Designing and resisting self constructions in urban classrooms. *Equity & Excellence in Education, 47*(1), 63–77.

Pellegrino, J. W., Wilson, M. R., Koenig, J. A., & Beatty, A. S. (2014). *Developing assessments for the next generation science standards*. National Academies Press.

Penuel, W. R., & Fishman, B. J. (2012). Large-scale science education intervention research we can use. *Journal of Research in Science Teaching, 49*(3), 281–304.
Peppler, K., Halverson, E., & Kafai, Y. B. (Eds.). (2016a). *Makeology: Makerspaces as learning environments* (Vol. 1). Routledge.
Peppler, K., Halverson, E., & Kafai, Y. B. (Eds.). (2016b). *Makers as learners.* (Vol. 2). Routledge.
Priestley, M., Biesta, G. J. J., & Robinson, S. (2015a). Teacher agency: What is it and why does it matter? In R. Kneyber & J. Evers (Eds.), *Flip the System: Changing education from the bottom up* (pp. 134–148). Routledge.
Priestley, M., Biesta, G., & Robinson, S. (2015b). *Teacher agency: An ecological approach*. Bloomsbury Publishing.
Pruitt, S. L. (2014). The next generation science standards: The features and challenges. *Journal of Science Teacher Education, 25*(2), 145–156.
Puckett, C. (2022). Digital Adaptability: A new measure for digital inequality research. *Social Science Computer Review, 40*(3), 641–662.
Puckett, C., & Gravel, B. (2020). Institutional ambiguity and de facto tracking in STEM. *Teachers College Record, 122*(8), 1–38. https://doi.org/10.1177/016146812012200811
Reiser, B. J., Michaels, S., Moon, J., Bell, T., Dyer, E., Edwards, K. D., McGill, T. A., Novak, M., & Park, A. (2017). Scaling up three-dimensional science learning through teacher-led study groups across a state. *Journal of Teacher Education, 68*(3), 280–298.
Rigby, J. G. (2016). Principals' conceptions of instructional leadership and their informal social networks: An exploration of the mechanisms of the mesolevel. *American Journal of Education, 122*(3), 433–464.
Rigby, J. G., Woulfin, S. L., & März, V. (2016). Understanding how structure and agency influence education policy implementation and organizational change. *American Journal of Education, 122*(3), 295–302.
Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Classroom orchestration: Synthesis. *Computers & Education, 69*, 523–526.
Rouse, R., & Gillespie Rouse, A. (2022). Taking the maker movement to school: A systematic review of preK-12 school-based makerspace research. *Educational Research Review, 35*, 100413. https://doi.org/10.1016/j.edurev.2021.100413
Russell, J. L., & Bray, L. E. (2013). Crafting coherence from complex policy messages: Educators' perceptions of special education and standards-based accountability policies. *Education Policy Analysis Archives, 21*, 12.
Saldaña, J. (2015). *The coding manual for qualitative researchers*. Sage.
Sengupta, P., Shanahan, M. C., & Kim, B. (2019). Reimagining STEM education: Critical, transdisciplinary, and embodied approaches. In P. Sengupta, M. C. Shanahan, & B. Kim (Eds.), *Critical, transdisciplinary and embodied approaches in STEM education* (pp. 3–19). Springer.
Severance, S., Penuel, W. R., Sumner, T., & Leary, H. (2016). Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences, 25*(4), 531–564.
Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531.
Shotter, J. (2006). Understanding process from within: An argument for 'withness'-thinking. *Organization Studies, 27*(4), 585–604.
Smith, M. L. (1991). Put to the test: The effects of external testing on teachers. *Educational Researcher, 20*(5), 8–11.
Smith, T. M., Desimone, L. M., Zeidner, T. L., Dunn, A. C., Bhatt, M., & Rumyantseva, N. L. (2007). Inquiry-oriented instruction in science: Who teaches that way? *Educational Evaluation and Policy Analysis, 29*, 169–199.
Songer, N. B., Lee, H. S., & Kam, R. (2002). Technology-rich inquiry science in urban classrooms: What are the barriers to inquiry pedagogy? *Journal of Research in Science Teaching, 39*(2), 128–150.
Spillane, J. P., & Callahan, K. A. (2000). Implementing state standards for science education: What district policy makers make of the hoopla. *Journal of Research in Science Teaching, 37*(5), 401–425.
Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research, 72*(3), 387–431.
Spillane, J. P., Shirrell, M., & Sweet, T. M. (2017). The elephant in the schoolhouse: The role of propinquity in school staff interactions about teaching. *Sociology of Education, 90*(2), 149–171.
Stornaiuolo, A., & Nichols, T. P. (2018). Making publics: mobilizing audiences in high school makerspaces. *Teachers College Record, 120*(8), 1-38.
Stornaiuolo, A., & Nichols, T. P. (2020). Makerspaces in K-12 schools. In J. March, C. McLean, & J. Rowsell (Eds.), *Maker literacies and maker identities in the digital age: Learning and playing through modes and media* (pp. 117–132). Routledge.
Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487–516.
Takeuchi, M. A., Sengupta, P., Shanahan, M. C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: A critical review. *Studies in Science Education, 56*(2), 213–253.
Tucker-Raymond, E., & Gravel, B. E. (2019). *STEM literacies in makerspaces: Implications for learning, teaching, and research*. Routledge.
Tucker-Raymond, E., Gravel, B., & Pierce, E. (2020). 80/20: Making identities in making spaces. In J. A. Gammel, S. Motulsky, & A. Rutstein-Riley (Eds.), *I am what I become: Constructing an identity as a lifelong learner* (pp. 201–220). Information Age Publishing.
Vongalis-Macrow, A. (2007). I, Teacher: Re-territorialization of teachers' multi-faceted agency in globalized education. *British Journal of Sociology of Education, 28*(4), 425–439.
Vongkulluksn, V. W., Matewos, A. M., Sinatra, G. M., & Marsh, J. A. (2018). Motivational factors in makerspaces: A mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions. *International Journal of STEM Education, 5*, 43. https://doi.org/10.1186/s40594-018-0129-0
Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on out of School Time STEM, 67*, 1–55.
Vossoughi, S., Davis, N. R., Jackson, A., Echevarria, R., Muñoz, A., & Escudé, M. (2021). Beyond the binary of adult versus child centered learning: pedagogies of joint activity in the context of making. *Cognition and Instruction, 39*, 1–29.
Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review, 86*(2), 206–232.
Vossoughi, S., Jackson, A., Chen, S., Roldan, W., & Escudé, M. (2020). Embodied pathways and ethical trails: Studying learning in and through relational histories. *Journal of the Learning Sciences, 29*(2), 183–223.
Wallace, C. S., & Priestley, M. R. (2017). Secondary science teachers as curriculum makers: Mapping and designing Scotland's new Curriculum for Excellence. *Journal of Research in Science Teaching, 54*(3), 324–349.
Wardrip, P. S., & Brahms, L. (2016). Taking making to school: A model for integrating making into classrooms. In K. Peppler, E. Halverson, & Y. B. Kafai (Eds.), *Makeology Makerspaces as learning environments* (Vol. 1, pp. 97–106). Routledge.
Wendell, K. B., Wright, C. G., & Paugh, P. (2017). Reflective decision-making in elementary students' engineering design. *Journal of Engineering Education, 106*(3), 356–397.
Woulfin, S. L. (2016). Duet or duel? A portrait of two logics of reading instruction in an urban school district. *American Journal of Education, 122*(3), 337–365.

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