

Teaching & learning in makerspaces: equipping teachers to become justice-oriented maker-educators

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Abstract:

Making and makerspaces are becoming increasingly popular in K-12 schools. However, professional development on making for practicing teachers is under researched. We present case studies of two teachers' sensemaking of making in a one semester graduate course on teaching and learning in makerspaces. The course was designed around three course tenets; maker as learner, as iterative, and as equitable and consequential. We utilize third generation cultural historical activity theory to analyze teachers' course work to understand their sensemaking of course tenets within their school context. We found that teachers made sense of the course content through their lens as a classroom teacher and that teachers surfaced and attempted to work through contradictions related to school routines related to high-stakes assessment and a history of stratifying youth within and across schools. These findings have implications for how we design for teacher professional learning about making and makerspaces.

Keywords: Makerspace | teacher professional learning | K-12 schools

Article:

Introduction

Making and Makerspaces are becoming increasingly popular in K-12 educational settings (Peppler & Bender, 2013) and have been put forth as an important space to support minoritized youth to develop authentic STEM identities through engaging in equitable and consequential making experiences (Calabrese Barton & Tan, 2018a). However, the integration of making into educational settings is not without critique (Martin, 2015). Some researchers have argued that the rigid nature of traditional schooling will pose challenges for the integration of making pedagogies into the classrooms (e.g. Hira et al., 2014) and can lead to a narrow view of making

as merely using particular sets of tools and technologies rather than a process of iterative design (Resnick & Rosenbaum, 2013).

The research on in-service teacher learning about making and makerspaces is an emergent field and reiterates the need to support teachers in their understanding of making, and how to integrate making within the constraints of their instructional context. While this work shows positive outcomes, such as increased confidence in using making technologies (Stevenson et al., 2019), teachers report a number of challenges with integrating making into their classrooms. These challenges include a lack of collegial support, technology issues, and a lack of time to plan and implement making in their classrooms (Stevenson et al., 2019). For example, when teachers engaged in five, one-hour sessions making professional development at a university makerspace, Paganelli et al. (2017) reported that teachers struggled with making sense of the open-ended nature of making and how to translate such experiences to the classroom even as some found the making process to be supportive of a wide range of possibilities.

The field needs further insights into how teachers make sense of making within the context of their classroom and school and provide them with professional learning resources to support their implementation of making as a process of iterative and consequential design. In this paper, we build on this emergent body of work on maker professional learning for in-service teachers with a focus on two teachers' sensemaking of making as a pedagogical practice in a semester long course organized around three core tenets of teaching and learning in makerspaces. As there is scant research on the embodied experiences of in-service teachers' learning about what making entails and how to incorporate making as integral to disciplinary-learning, focusing on two case studies is productive for mapping, in more granular detail, how the work of becoming a maker and maker-educator dialogically inform each other and unfold.

In the next section, we review literature on in-service teacher professional development of making and makerspaces to situate our course design. Next, we operationalize the three course tenets through a review of literature on making with youth. Lastly, we describe our conceptual framework for understanding how teachers make sense of the course tenets through the lens of their classroom or school context.

Background

There is little empirical research on makerspace professional development for in-service teachers. This research focuses on the outcomes of these workshops including increased confidence in using making technologies (Stevenson et al., 2019), an understanding of the importance of collaboration through making (Cohen et al., 2017; Shively et al., 2020), the types of learning activities described by teachers (Jones et al., 2020), and teachers' conceptions and misconceptions about making after a one-day workshop (Cohen et al., 2018). Collectively, these studies highlight the importance of the use of an organizing framework for teacher learning of making, the benefit of engaging teachers in making activities, and the need for sustained learning opportunities for learning about making.

In one study, in-service and pre-service teachers participated in a semester long course on making in K-12 education (Cohen et al., 2017). The teachers engaged in making projects, read

literature on making, and journaled throughout the course. In reflecting on their learning, the teachers in this course highlighted the importance of collaboration and a community of makers to support learning through making. They discussed the importance of peer-to-peer interaction and teaching within the makerspace, as well as the larger community of support that created an environment for learning through making. While this study demonstrated positive pedagogical learning on the part of the teachers, they did not explore if and how these teachers made sense of incorporating these forms of learning in their practice.

A number of the studies on teacher learning of making reinforce the challenges that teachers face in implementing making in K-12 classrooms. Teachers reported technology issues, lack of administrative and collegial support, and a lack of time for planning and implementing making in their classrooms (Stevenson et al., 2019). The research on teacher learning in makerspaces suggests that a curricular framework for making, along with embodied experiences with making support teacher learning of making as a pedagogical practice. Furthermore, this research suggests that school-based challenges make the implementation of making in their classrooms difficult. In this paper, we seek to understand how a course organized around three core tenets of making supported teachers to surface and attend to school-based challenges that made implementation of making a challenge in their context.

Three tenets of maker education

In this paper, we analyze two teachers' sensemaking of making as a pedagogical practice for their classrooms during a semester-long graduate course on making. In this course, we introduced teachers to a framework for making in K-12 education grounded in what we have defined as key three tenets: 1) maker as learner, 2) making as iterative, and 3) making as equitable and consequential (Calabrese Barton, Tan, & Greenberg, 2017; Calabrese Barton & Tan, 2018a). We explicate these tenets and literature that supports each below.

Maker as learner

Learning through making has been an important focus of the movement to bring making to K-12 classrooms (Martin, 2015). Most researchers draw historical connections between Papert's (1993) theory of constructionism and Dewey's (1938) ideas on progressive education and learning through making. Others note that making is a historical and cultural practice that is a feature of most local craft traditions (Resnick & Rosenbaum, 2013). Learning to engage with local craft and making practices happens through apprenticeship in communities of practice (Lave & Wenger, 1991). While these learning theories help us to demonstrate that learning happens through making, the integration of making in K-12 classrooms requires that we articulate learning goals and objectives that align with K-12 settings.

The *Framework for K-12 Science Education* (National Research Council, 2012) and the development of the Next Generation Science Standards (NGSS Lead States, 2013) have created a reform context that aligns making with K-12 learning goals and objectives (Quinn & Bell, 2013). For example, Bevan et al. (2014) argued that STEM-rich making, "engages learners in activities centered on the use of the scientific and technical tools, processes, and phenomena (p. 99)." As children tinker with their made objects, they need to consider how changes to the structure of

their design impacts its function, an important cross-cutting concept highlighted in NGSS (NGSS Lead States, 2013). The addition of engineering practices and disciplinary core ideas provides a context for supporting students to engage in making and design. While science education provides an arguably more seamless connection with making, there are other learning outcomes to consider when assessing students' engagement with making.

We take the stance that identity development is integral to maker education. As much as students are learning about what making could be and might entail, they are also becoming makers in the process. Our tenet maker as learner therefore foregrounds an integrated onto-epistemological (Barajas-López & Bang, 2018) development –becoming a particular kind of maker is ineluctably connected to the how, what, why, for whom of making decisions. Focusing on the onto-epistemological development of making as integrated highlights the importance of always keeping in view who students are and who students want to be, in and through making. We are therefore interested in the identity work teachers are doing in becoming makers as they engage in the activities and assignments of this course.

Making as iterative

This tenet emphasizes making as a process that involves continual reworkings as makers' design decisions are informed by incorporating community feedback, and as makers expand their suites of making expertise. Making has been described as an iterative process of design and is a “valid and valuable style of working characterized by playful, exploratory, iterative style of engaging with a problem or project.” (Resnick & Rosenbaum, 2013; p 164). The iterative nature of making requires that students have access to feedback from authentic audiences, time for revision of projects based on feedback, and learning through failure/mistakes.

The iterative process of making requires that youth have opportunities for sustained engagement in making and design (Calabrese Barton & Tan, 2018b). This sustained engagement provides youth with opportunities to plan, develop prototypes, receive authentic feedback from peers, community members, and their teachers, and make revisions to their designs. Importantly, the iterative nature of making supports maker identity work which is contingent on sustained engagement.

Making as equitable and consequential

The dominant maker movement is largely centered on white, middle class, patriarchal values. Researchers have troubled both who has access to making and who is predominantly shaping the culture of making. For example, 89% of Make magazine contributors are male and 70% of Maker Faire attendees have graduate degrees (Brahms & Crowley, 2016). As Calabrese Barton and Tan (2018a) have noted, “equity-oriented making is never separate from individual and social histories that unfold over space and time” (p. 797). Who makers are, why and for whom makers make, using what kinds of resources and with which stakeholders, and toward what ends, are important considerations if we want all students, especially those historically underserved, to have access to making (Calabrese Barton et al., 2017).

In our course we draw on the idea that making needs to be equitable and consequential (Calabrese Barton et al., 2017). This involves taking into consideration the historical, cultural and social aspects of making. The overarching goal of the course is to focus teacher learning on the process of making as a tool to support youth in creating artifacts that simultaneously support their onto-epistemological development of discipline-specific and making knowledge and practices while disrupting normative practices related to systems of power.

Conceptual framework

Teachers, like students, leverage their experiences in schooling as a resource in their learning (Putnam & Borko, 2000). Unlike students, however, teacher learning is tied to their professional practice and their livelihood and therefore, we need to consider the workplace context through which teachers are making sense of new concepts and practices about teaching and learning (Spillane et al., 2002). We utilize cultural historical activity theory (Cole, 1998; Engeström, 2001) CH/AT as a framework to understand how teachers make sense of these tenets of making within the context of their school.

CH/AT describes learning as the function of an activity system that organizes student activity to work toward community-valued objectives (Engeström, 2001). When describing the activity system, we look to identify how particular tools, community norms and distribution of labor mediate student learning toward that objective. Similarly, it is important to understand and describe the cultural and historical nature of activity. In the case of schools, we need to recognize the history of schooling in America as organized to continue and reinforce the stratification of society through assessment and tracking (Oakes, 1982) and the centering of whiteness as normative and essential.

We utilize third generation CH/AT, which requires analysis across a minimum of two interacting activity systems in order to understand the multiplicity of experiences that actors bring with them to engage in activity within a particular system (Engeström, 2001; Gutiérrez & Arzubiaga, 2012). Third generation CH/AT responds to the fact that people are negotiating multiple activity systems concurrently and relationally. Mediated activity within one activity system can surface contradictions with another interacting activity system, which presents an opportunity for new, transformative learning to occur (Engeström, 2001). This transformative learning can result in new, hybrid practices and knowledge that reflect aspects of multiple activity systems, as it can surface tensions and contradictions (Gutiérrez, 2008; Gutiérrez & Arzubiaga, 2012).

In utilizing third generation CH/AT to understand and locate opportunities for transformative learning within our making course, we look to understand how teachers' surfaced contradictions between the activity system of our course and the activity system of their school. For example, making pedagogies encourage cycles of feedback and iteration (*tools*) to support students' reflection on the effectiveness of their design. This process of iterative design can create contradictions with normative distribution of labor and norms within classroom settings. In iterative design, students would elicit and attend to feedback from authentic audiences for their design (Calabrese Barton & Tan, 2018a). Historically, students receive feedback on their schoolwork from their teachers in the form of grades (*rules*). In this way, the teachers are positioned as experts that have the authority (*distribution of labor*) to decide whether or not a

student demonstrates understanding. Therefore, as we introduce new tools like iterative design into the classroom, we must also look for contradictions within the system that surface as an opportunity for learning.

In this paper, we analyzed two teachers’ sensemaking of the three course tenets described above. Specifically, we ask: 1) How did teachers make sense of the three course tenets? 2) What tensions, if any, emerged as related to teachers concurrently negotiating their school activity system? How did they attempt to work through those tensions through course materials and assignments?

Methods

Course design

We developed case studies (Yin, 2003) of two practicing teachers in the course to understand how they made sense of making as a pedagogical practice. While the focus on only two teachers might be a limitation, in-depth case studies allow readers the opportunity “to experience vicariously unique situations and unique individuals” (Donmoyer, 1990, p. 193), so as to better grasp the complexity of teachers’ trajectory in becoming makers and maker educators, especially when there are scant insights into these processes.

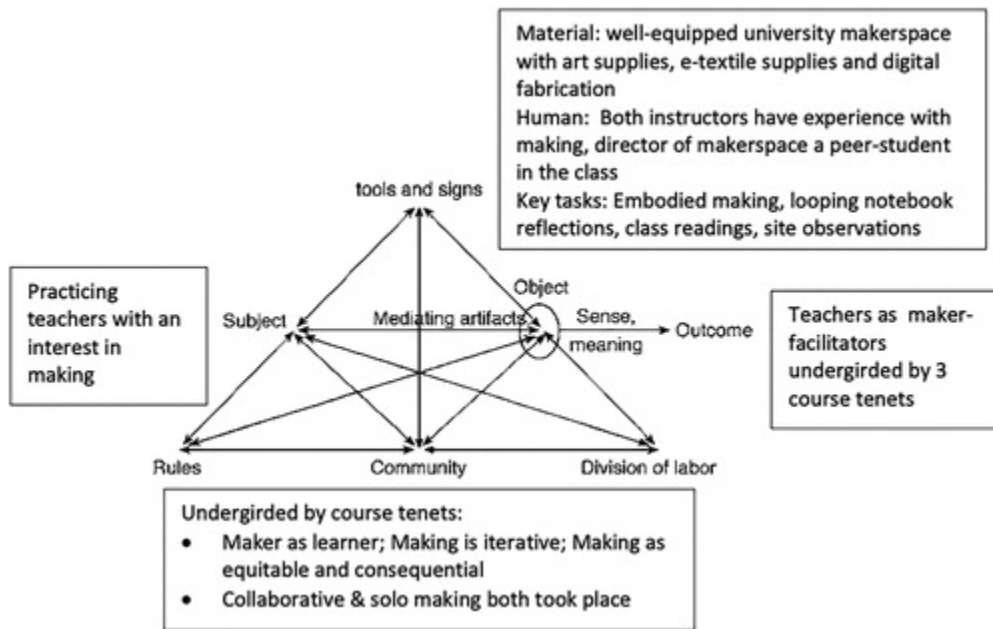


Figure 1. Activity system of the maker course undergirded by 3 tenets.

We designed the course around the three course tenets and held class in the university makerspace. We modeled making through the three course tenets through various resources and activities. Each week teachers (a) read literature on making and design in the various educational settings, (b) engaged in some form of embodied making during class that reflected ideas and practices represented in the readings, and (c) collectively worked together to apply their developing understanding of the three course tenets across these experiences through journal

writing. They also observed students and/or families engaging in making in multiple community settings. For their final project, teachers were asked to develop a plan for how they would integrate making into their professional practice. Figure 1 represents the course as an activity system organized to support the integration of making in schools. We expand on each of the core features of the course design below.

Embodied making

Each meeting, the teachers were engaged in some form of making or the design process. The making activity was designed to reflect the course tenets, as well as the theme for the week. For example, we began the course with a session on the cultural and historical nature of making. We focused on embroidery as an entry point because of the cultural and historical significance of embroidery across multiple cultures and the gendered nature of embroidery (Goggin & Tobin, 2016). The teachers read about Nyonya needlework (Cheah, 2009) and we discussed the history of needle work from early humans to current feminist movements reclamation of the art with the election of Trump and the “Me Too” Movement. We then asked each of the teachers to create an embroidery project with a saying from a social movement of importance to them. The teachers started their embroidery project in class and worked on it over multiple weeks. The teachers reflected on what they learned throughout the experience, the process of iterative making through making mistakes and getting feedback from peers, and how the experience was equitable and consequential for them.

Looping maker notebook

Each week, the teachers were asked to create an entry in their Looping Maker Notebook¹ about their experience with making that week and the readings assigned that focused on their understanding of the three course tenets. The expectation for the looping notebook was that teachers represented their developing understanding of making through a variety of media – video, blogs, creation of a personal website, drawings, animations, or journal entries. The maker notebook was looping, in that teachers could return to previous entries and expand on their understanding over the course of the semester. Teachers had a choice in how they would represent their ideas to reflect the nature of learning in informal environments that provide learners with choice in how and what they learn about (Calabrese Barton et al., 2017).

Observations of student making

Teachers also spent 3-6 hours observing youth making at one of two established after school programs that centered youth STEM activities in some form of making. Then they interpreted their site visits in a cognitive ethnography (Gutiérrez & Vossoughi, 2010) with the three course tenets, their own experiences with making in the course, and the course readings.

Final project

¹ The Looping Maker Notebook was adapted from the Looping Sketchbook assignment we learned from Professor Leila Villaverde.

For their final project, we asked teachers to design an iterative maker-learning experience for their students anchored in the three course tenets. We introduced teachers to the LAUNCH cycle (Spencer & Juliani, 2016) and asked them to organize their design of their curriculum using the steps laid out in the book. We also asked teachers to reflect on how their designed activities embodied the three course tenets.

Participants

The course was offered as an elective to students in the Masters of Education program. Students signed up for the course in consultation with their advisors. Eleven teachers participated in the course. Their teaching setting varied from pre-service to in-service, formal to informal, K-12 and higher education, and district or university classroom coaches. For the purposes of this paper, we focus on the two K-12 classroom teachers, Mary (middle grades) and Elizabeth (elementary) to highlight the particular ways that in-service teachers in K-12 formal teaching contexts made sense of and took up each of the course tenets. We chose to focus on Mary and Elizabeth as we are interested in unpacking the how/what/why/for whom in-service teachers, with their existing school-based responsibilities and expectations, take up making and maker-education as related to disciplinary teaching. Mary and Elizabeth also both teach in schools serving high percentages of minoritized students. In addition, both teachers intended to integrate making with science teaching.

Mary is a white woman teacher who has taught middle school science at the same school for the past 13 years. Caring, maternal and patient, Mary takes her job as a science teacher very seriously and sees her responsibility to teach her students such that they would become “life long learners” (final assignment) and not students who only “memorize facts.” Her science classroom is filled with a menagerie of animals including reptiles and fish. She is passionate about “doing labs” (her description of hands-on science activities) and considers herself the veteran science teacher who consistently does so at her school. Elizabeth is a young white woman with about five years of elementary school teaching experience. She is enthusiastic, eager to learn and cares deeply about issues of equity in education, once she learned about these issues as part of her master’s in education graduate degree program. A marker of Elizabeth’s excellence as a teacher is the fact that she has been chosen to be an on-site teacher educator for student-teacher interns who would be placed at her school next year. Each coauthor were co-instructors for the course and have experience with research in informal science settings with youth and/or teachers.

Data collected

We collected artifacts of participants’ sensemaking throughout the course. Data sources include weekly looping maker notebook entries from each teacher, their cognitive ethnography of students in informal making settings, and their final projects. Teacher participants were consented into the project at the beginning of class and we (the instructors) were not informed of which teachers consented into the project until the end of the semester, after grades were posted.

Analysis

We developed cases (Yin, 2003) of each of the focus teachers' sensemaking of the three course tenets within the context of their school. We each read through teachers' looping maker notebook entries, cognitive ethnographies, and final papers and coded for teacher sensemaking related to the course tenets. As we read through each entry, we wrote research memos that summarized each teachers' sensemaking of the three course tenets and key phrases from the artifact that reflected their sensemaking; noting when the teachers surfaced tensions related to what they were learning in the course and the activity system of their schools. This gave us a sense of which of the three course tenets the teachers were grappling with across each course meeting. Analysis of journal entries, cognitive ethnographies, and final projects were also informed by our classroom interactions with the teachers, as they discussed their journal entries as a core part of class. To construct teacher profiles, we drew from and looked across the above range of data to document how teachers sense-made along the three course tenets – maker as learner, making as iterative and making as equitable and consequential. Profiles were shared with teachers for feedback and member-checking.

Findings

The findings are organized according to the research questions. First, we demonstrate how the teachers made sense of the three course tenets and then describe the tensions that emerged for them through their sensemaking.

Sensemaking of three tenets

Both teachers drew on their identity as a teacher to make sense of the three course tenets (Figures 2 and 3). Mary saw a natural alignment between making, teaching middle school science, and the school robotics/STEM club. Her main impetus was to filter the course readings and activities at a practical level through a 7th grade science teacher lens. She reflected on her repertoire of “lab” activities and consistently throughout the course, wondered what would “count” as making in her science classroom, as well as in the afterschool STEM club she runs. Elizabeth also made sense of the course tenets through her identity as an elementary teacher, as well as her experiences as a maker in class. Her looping notebook entries were filled with her struggles of learning how to make, such as making mistakes learning the different embroidery stitches, re-starting stitches, wanting to quit and then reminding herself that she is a teacher of children and it behooves her to persevere and set a good example to work through challenges. Below, we draw on entries from their looping maker notebook to demonstrate how the teachers leveraged their teacher identity and experiences in making in the course to make sense of each course tenet.

Making is not for perfectionist...

As I worked on my embroidery project this week, I was extremely glad that I am not a perfectionist, because I messed up on several stitches and usually just kept going. Sometimes I tried to undo it and fix it but many times, it got better as I continued to work with it. This made me wonder how do help our students who are perfectionist work productively in a maker-space? We have already discussed and I agree that students need to be able to work on projects for extended amounts of time and after this weeks reading they need time to complete research, get input from stakeholders and the community and then more time to rework their ideas. How do we keep students moving along in this progress? or how do reign them back in when needed? Do we reign them back in?



I know that time is always going to be against me because I only have a semester for my course and my students are required to take benchmarks and a state final exam but I feel with the right experiences and exposures and using the launch cycle and projects to deliver content my students will be better prepared and hopefully more engaged in the learning process. Chapter 8 talks about "creativity is as much an attitude as it is an action". This made me think of how normally when I assign a project I will tell students to be creative but if I have not given them ways to foster this how can I expect it to happen. I want my students more than anything to love learning and care about it and not just for grades. "Purpose is not the feeling, but the why that comes from your passion." I need figure out my students passions if I want them to love and care about their learning. One way I hope to do this is by giving my students this semester a survey using the questions from page 73 and 169 to hopefully gain some

insight into their passions and then can help me plan for next year.

To help with the time issue I was trying to think of a project that could be connected to several units suggested having the students design, build and test wind mills. I think this a great idea because it connects to at least four of my units. Some questions I have: How do I take a Project Based Learning and make it a Maker experience? Is the survey a good idea? What other things can I do or test out this year to help me next year?

Figure 2. Excerpts from Mary's looping maker notebook.

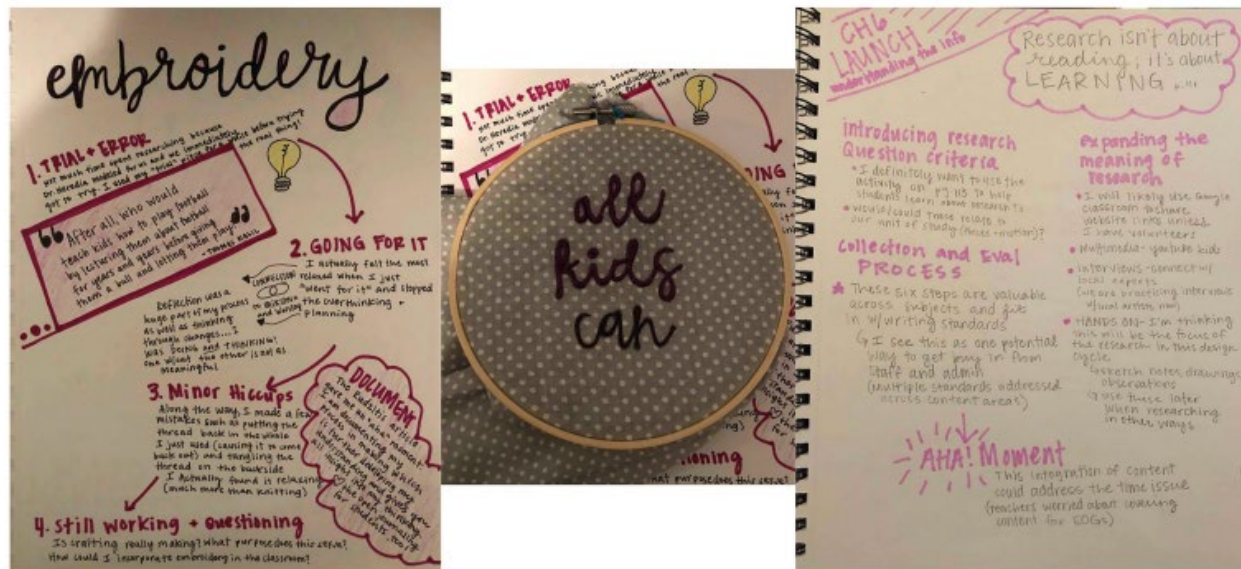


Figure 3. Excerpts from Elizabeth's looping maker notebook.

Maker as learner

Each week the teachers used their looping maker notebook to reflect on what they were learning through their making experiences in class. While Elizabeth primarily focused her onto-epistemological developments as becoming a maker, Mary focused on becoming a maker-educator.

In her sense-making through notebook reflections and class participation, Elizabeth paid attention to her own experiences making, including her lack of specific making skills and later, developing expertise with more practice (e.g., embroidery) and made connections to student learning and the importance of modeling learning through making for her students. She reflected on how she felt while making –from frustrations to feeling accomplished. Apart from her learning how to make with class-based making activities and mini-projects, this tenet was apparent in how Elizabeth engaged with the making projects that were part of class and in the issues surrounding the maker movement. In particular, she was very concerned about the patriarchal culture of making, and a reproduction of marginalizing students of color in maker learning that mirrored STEM education equity issues.

Mary operated consistently as a middle school science teacher in her sense-making of maker as learner. Her reflections and questions centered on how she might use some of the maker class activities with her middle school students and how she would facilitate as a make-educator. There was little reflection on her own identity-work in becoming a maker, rather, she very much performed and reflected from her identity as a middle school science teacher. Her considerations were significantly geared to what she could learn *about* facilitating making with youth, that she could enact in her context as a middle school science teacher. The one notebook entry where she solicited the help of her 10-year old cousin in teaching her how to code using Scratch, Mary's reflections again pointed to her positionality as a teacher –how she was glad her asking for his help “helped his confidence.” She also observed that it is important to acknowledge that the teacher need not necessarily have all the answers and that students could also be experts.

Making as iterative

Both teachers came to understand and appreciate the importance of sustained engagement and iteration in making. Through their own iterative engagement, they noted what they learned through the iterative process. Mary had more questions around how to support students' sustained engagement, whereas Elizabeth focused more on unpacking the relationships between iterative sustained engagement and equitable and consequential outcomes for students.

Connected to her own identity work in becoming a maker, Elizabeth's embodied experiences with failure and iteration, first with the embroidery project and then of the moving toy car for her final assignment appeared to solidify her conviction that iteration has to be a key feature of making. As she wrote:

Later, I dropped my vehicle in the parking deck which broke it into pieces. I would have normally been frustrated to the point of tears, but with my new identity as a maker, I saw it as an opportunity to improve my design. This time, I planned out how to make the wheels turn more effectively and settled on using old drinking straws to hot glue to the frame. This would allow my wooden axles to slide through the straw and attach the

wheels on the ends. After improving my car design, I was even more excited to share with my students how several failures led to additional learning and improvements in my vehicle. (Final assignment)

Related to her own making experiences and having to problem-solve, Elizabeth experienced the generative nature of iterative making. She was also compelled by class readings on how youth in a community making program engaged in iterative making to create prototypes that addressed salient community issues collectively identified by community members. Elizabeth tied the outcome of equitability and consequentiality of making to the youth-makers having engaged in iterative making. In her final instructional unit planning, she considered how to work in iterative making with schooling constraints, “How will I include iteration given time constraints?”

Mary, operating from her primary stance as becoming a maker-educator, worried about supporting her students through the making process. She related sustained engagement to supporting students to work on science fair projects and noted the amount of scaffolding required for sustained engagement for her students. As she continued to read and experience making in the class, she wondered how to scaffold iterative making with students. She wrote:

We have already discussed and I agree that students need to be able to work on projects for extent-end [SIC] amounts of time and after this weeks’ reading they need time to complete research, get input from stakeholders and the community and then more time to rework their ideas. How do we keep students moving along in this progress? Or how do reign them back in when needed? Do we reign them back in?” (LMN 3)

Mary consistently made connections between making as presented in the course with her experiences teaching science in schools. This knitting together of the two activity systems supported her to think through some of the challenges she had with teaching science and how there might be similar issues with making in the classroom.

Making as equitable and consequential

Both teachers reflected at length about how *White* the maker culture is and that primarily it is the middle-class white students who most have access to making experiences. When they visited an after-school maker club serving 100% youth of color, both Elizabeth & Mary described how the youth were deeply engaged with a coding program and how the youth-adult facilitator interactions seemed to be more between equals, then reflecting the typical teacher-student dynamics.

Mary’s sense-making of this final tenet fell along two lines – one on the availability and expertise of the adult facilitator, and the other on which youth were currently being served in the maker movement. She considered the importance of adult-mentor to youth ratio and suggested joining afterschool clubs with the media-specialist in the building. Even as she positioned herself as the science teacher who wanted to incorporate making into her day to day pedagogy, Mary also curiously positioned the media specialist teacher in her school, a White, male teacher, as somebody she assumed would be a natural maker-mentor to students because of his professional identity as the media-specialist. From the readings and in the community program she visited,

adult mentor to youth ratio was very low, about 1:4. As she rightly pointed out, such a ratio was difficult to maintain in a public-school program. Mary worried about how to sustain such a ratio so students could have the support they needed.

Youth demographics was a prominent discussion point in the class, begging the question who gets to be a maker. Mary reflected on how the maker movement writ large serves primarily the elite and those of the dominant culture, with youth and adults of Color marginalized. In her notebook entry, she noted how difficult it was to find pictures of youth-of-Color making. She noted that all the images she found featured White youth and White adults. Looking at her school context, she reasoned that while her robotics club almost always attracted White boys, she was hopeful that by changing it to a STEM club where she could include more making activities, more students would join. She also decided to remove a competitive aspect of the robotics club that necessitated the formation of a competitive team, so that more students could take part in STEM club.

Elizabeth consistently worked through her understanding of making as equitable and consequential in her looping notebook each week. Elizabeth wondered about how her own making project (such as working on an embroidery quote) checked the “equitable and consequential” box. She also considered access for all students in her classroom to have the opportunity to engage in maker-learning. Since she had students with learning differences who were pulled out at various times of the school day for special services, Elizabeth planned for her making activities to take place during the last block of her schedule, thereby assuring that students with specialized services would still get at least thirty minutes of making time with her. She further explored what making as equitable and consequential might entail by creating a survey to get her colleagues’ feedback on whether they would be interested in incorporating making into their classroom teaching, and the concerns they have.

Tensions between activity systems and opportunities for transformative learning

As noted above, the teachers both used their identities as teachers in their respective schools as a primary sensemaking tool of each of the course tenets. Through that process, they surfaced two key contradictions or tensions between the activity system of maker education - represented through course readings, embodied making experiences, and observations of youth in community afterschool makerspaces - and the activity system of their school (Figure 4). The two contradictions that they surfaced and attempted to work through included: 1) school routines and practices related to covering content and demonstrating student growth on state assessments and the three course tenets and 2) lack of understanding among school community members about what making is along the course’s three tenets and the benefits of integrating making into K-12 classrooms. We expand on each below.

Tension 1: school routines and practices for covering content

Both teachers recognized school routines and practices developed to demonstrate student growth on state assessments as a key factor in being able to incorporate making as reflexive of the course tenets, into their teaching. They considered possible solutions.

Mary consistently surfaced tensions related to the teacher: student ratio in makerspace settings versus her own classroom. She questioned how she would be able to support sustained engagement with making activities with her students when she was the only adult in the room:

Throughout the STEM club and even when observing the makerspace at [youth afterschool program] there was no more than five students per teacher, this allowed for all students to be heard and helped when needed. In my classroom I will have to make an intentional effort to ensure that all of my makers are taking part in the learning process and are not being overshadowed by the students that are more outspoken. This is fairly easy to do in my club, but I know that it will be more of a challenge with my regular class.

She also looked for alignment between her curricular resources (inquiry-based, hands-on science) and making activities. Mary seemed to conflate general goals of science learning with those of making completely, instead of differentiating between the similarities and differences, based on the three course tenets, and considering how particular aspects of making might integrate with particular science standards in complementary ways. For example, after we introduced the LAUNCH book (Spencer & Juliani, 2016) she was excited because she felt the text had practical advice for integrating design in the classroom. However, her remark of “still a little confused on how to do this and teach my standards at the same time,” suggests she continued to silo making and science teaching and learning.

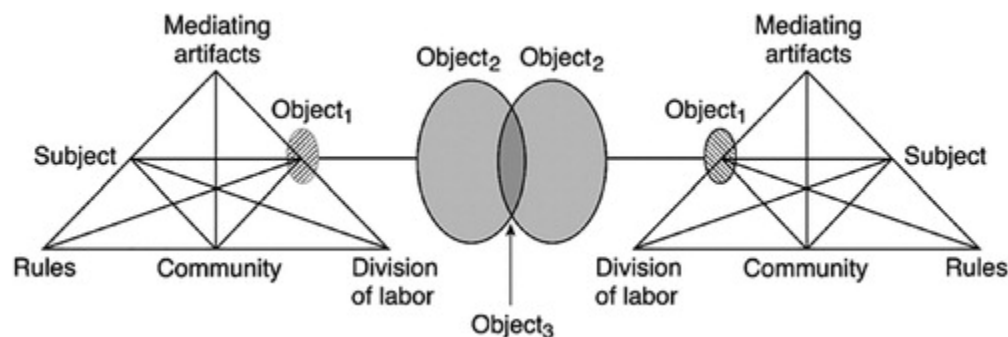


Figure 4. Two interacting systems – maker-course system + teacher’s school-based system (Engeström, 2001).

In order to address these challenges, Mary focused her final project on combining two after-school clubs, a STEM club where she is the teacher in charge, with another club under the supervision of a colleague. For Mary, keeping making out of actual school-day instructional hours would increase the chances of her school taking it up. Mary, possibly in her desire to leverage expertise, also assumed that the media specialist at her school would automatically be the best person to facilitate making at the school during the school day.

Elizabeth surfaced tensions around making and accountability contexts at her school. When reflecting on a course reading (Dougherty, 2013) Elizabeth noted, “formal education puts forth this notion that learners should be serious and always working. The emphasis on testing makes it difficult to provide sustained engagement opportunities in making.” Elizabeth wondered how the interdisciplinary approach of elementary school instruction might be leveraged to incorporate

making as a legitimate part of instructional time. “I knew that if my goal was to show other educators that incorporating making in the regular classroom, I needed my plans to operate within some of the time constraints at our school (e.g. schoolwide daily schedule).”

Elizabeth used the three tenets as a rubric to assess her instructional unit. She listed the state standards that would also be relevant for the unit, attending to the epistemic rigor of her making unit. In addition to content standards, she also considered the importance of supporting “social skills and collaboration” as she drew from classroom readings on “co-making” (Calabrese Barton & Tan, 2018a) being an essential process that fostered equitable and consequential making experiences for individual youth and the collective community. This final project was her attempt at “test driving” the idea that making could be integrated through an interdisciplinary science unit on force and motion with making as an integral part.

Tension 2: stratification within schools leads to inequitable access to making

Both teachers were compelled by how the dominant maker movement has not attended to issues of equity and consequentiality with historically minoritized youth. Both teachers quickly identified norms and constraints in their school activity system that would exacerbate such inequities. Mary reflected on how she teaches in a Title 1 school, where a majority of her students lack opportunities to visit museums with makerspaces. She also noted that the robotics club members she previously led only had White male students. This led Mary to consider turning her robotics club to a STEM club and to change the membership recruitment strategies to broaden participation. Elizabeth was concerned about her special needs students not having opportunities to engage in making in her classroom, once incorporated. These students are regularly “pulled out” for services such as for intensive literacy and math remediation. This led Elizabeth to think hard about when in the school day, she ought to incorporate making so that all students can participate.

Recognizing that they needed allies in their school activity system for incorporating making in accordance to the course tenets, both teachers created a survey for their colleagues to ascertain what their colleagues knew about making and what kinds of support they might need if making were to feature in regular instruction time. For example, Elizabeth wrote in her final project,

I addressed some of my questions about other educators I work with by using a Google Form to ask a few questions about teacher knowledge of making, challenges with time, and how their classrooms would change if time was not a concern. This data gave plenty of information for me to think about how this project would need to be presented to staff. Many concerns were with regards to covering standards before high-stakes testing as well as scheduling constraints (required literacy and math blocks, short science/social studies time, students being pulled out for various services, etc.).

Through an intentional focus on understanding the constraints related to making education in schools, the teachers worked to establish ways to integrate making that would demonstrate to teachers in their schools the power of making in education.

Discussion

In this analysis, we set out to understand how two classroom teachers made sense of making along three course tenets; maker as learner, making as iterative, and making as equitable and consequential. We found that: 1) teachers made sense of the course tenets through their lens as classroom teachers and, 2) this supported them to surface contradictions between activity systems as a site for their learning. A key difference between the two teachers was Elizabeth's concurrent sensemaking and identity-development as a maker, alongside her sensemaking through her teacher lens, while Mary was primarily focused on how to most seamlessly incorporate existing making activities into school science.

These findings have implications for the design of professional learning opportunities for K-12 classroom teachers to integrate making into their classrooms. First, professional learning opportunities should be organized around a conceptual framework through which teacher can make of sense educational making activities in ways that attend to equity. Second, teachers need early opportunities to develop solutions for tensions they surface related to making in their school context. Lastly, facilitators should include opportunities for embodied making in the course to support teacher development of maker identities. We expand on each implication below.

Organizing the course around the three course tenets of maker as learner, making as iterative, and equitable and consequential afforded the teachers opportunities to make sense of their lived experiences as teachers in classrooms and as makers in the course. Stevenson et al. (2019) similarly found that an organizing framework for making supported teachers to build confidence to incorporate making into their classrooms. Other research on science teacher professional development illustrated that professional learning models that orient teachers toward a conceptual framework for their instruction and then provided time to develop and design activities based on that framework led to greater student learning compared to teachers that were either given curriculum to use in the classroom or teachers that had autonomy to design lessons on their own (Penuel et al., 2011). We found that organizing the course around these three tenets supported teachers to surface contradictions between the activity system of the course and that of their schools and classrooms. However, the kind and degree of contradictions that teachers recognized and grappled with were different and they were related to how teachers were making sense of the three course tenets.

For Mary and Elizabeth, we observed more rigorous sensemaking in relation to making as iterative (Tenet 2) and making as equitable and consequential (Tenet 3). The teachers more readily found connections to the learning that was occurring during making and surfaced issues in their school context related to making as iterative and consequential. Many have suggested that a danger with integrating maker education into schools would result in a narrowing of making to a set of tools to learn content (e.g., Wardrip & Brahms, 2016). Our findings suggest that the support of the three course tenets that expand making beyond just a pedagogical tool to support content learning provided the teachers with resources and time to consider making as an opportunity for all students to make authentic and consequential objects through sustained iterative cycles of design.

As the teachers made sense of the three course tenets, they relied on their lived experiences as teachers in classrooms to make connections to course readings and activities. Both teachers reflected on the population of students they served, the standard course of instruction, and their work colleagues' understanding of making throughout the course. This finding reinforces the importance of attending to teachers' local context in their professional learning (Putnam & Borko, 2000). While each teacher surfaced contradictions between the two activity systems, they did not develop ideas or solutions to attend to those contradictions (transformation of their classroom activity system) until later in the course when they were designing making activities for their classrooms. This finding suggests that facilitators might surface tensions early within the professional learning activity, which would give teachers opportunities early in the semester to develop solutions, try them out, and iterate based on school community feedback as part of the course (Allen & Heredia, 2020).

As noted above, one key difference between the two teachers was Elizabeth's sensemaking of the embodied making experiences in the course. Elizabeth continually reflected on her experiences as a maker in the course and made connections from that experience to her classroom. Research on professional development in math and science regularly highlight the need for active learning experiences for teachers (Desimone, 2009; Garet et al., 2001). For Elizabeth, these active learning experiences with making provided her with an opportunity to reflect on her learning to be a maker and how that would help her to be a better maker educator. Mary on the other hand, rarely reflected on her learning through the embodied making experiences and generally spent time in her notebook entries pushing the two activity systems together looking for alignment between science education and making. In their final projects, Mary decided to focus on her afterschool club, rather than attempting a transformation of her classroom space to incorporate making. To Mary, it appeared that the classroom science activity system was incompatible with a making system. On the other hand, Elizabeth more intentionally designed a making activity for her classroom that represented a transformation of her regular classroom practice. While we cannot draw a causal relationship between Elizabeth's identity development as a maker and a more transformative learning experience, we suggest facilitators encourage more sensemaking of the embodied making experiences as teachers learn about making in K-12 education.

Conclusions

Making and maker education provide a possible context for democratizing K-12 educational spaces (Lindstrom et al., 2017). However, many have noted that the current conditions of schooling – organized around narrow sets of standards and surveillance tactics tied to high-stakes testing – are not conducive to integrating making as a process of iterative and consequential design (e.g. Hira et al., 2014). In this paper, we demonstrated how organizing a semester long course around three tenets of making supported teachers to surface contradictions between schools and makerspaces and then the time and resources to work through those contradictions as opportunities for transformation of their classroom practice.

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