Prospective Teachers' Design Decisions, Rationales, and Resources: Re/claiming Teacher Agency Through Mathematical Making

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Abstract

Positioning teachers as designers of their own curricular resources invites opportunities for their explorations of innovation at the intersection of content, pedagogy, and design. As researchers accepting greater responsibility for the preparation of teachers for work in diverse contexts, our work explores structures of teacher preparation that cultivate the imagination of more humanistic forms of mathematics teaching and learning by supporting such explorations. This paper reports on an investigation into the nature of prospective teachers' design activity as they were tasked with the Making of mathematical manipulatives. We share findings from the analysis of this activity that convey the diversity of design decisions, rationales, and mediating resources that it entailed. The implications of these findings for teacher preparation are considered.

Key Words: Mathematics Education, Teacher Preparation, Making, Educational Responsibility, and Technology

Objectives

Positioning teachers as implementers of curricular materials designed by others is convenient, but it comes with a potential to collapse the space of possibilities for how teaching and learning might occur. Increased access to digital design and fabrication technologies generates new opportunities that challenge this presumption and disrupt the consequent denial of agency that it entails. Thus, a framing of teachers as *designers* (e.g., Maher, 1987; Svihla et al., 2015) is an orientation that may now be embraced more fully than ever.

We connect with this body of literature that frames teachers as designers of learning experiences, while conceiving of design more broadly to include the "intentional activity of transforming ideas and knowledge" (Carvalho et al., 2019, p. 79) into "tangible, meaningful artifacts" (Koehler & Mishra, 2005, p. 135). Our purpose in doing so is to present a novel Making experience within mathematics teacher preparation that we hypothesized would inform their curricular and pedagogical thinking and cultivate images of themselves as agents of curricular and pedagogical reform (Leander & Osborne, 2008; Priestley et al., 2012). *Making* in this sense is conceived as the creative production of artifacts via activities that include designing, building, and innovating with tools and materials to solve practical problems (Halverson & Sheridan, 2014). Thus, the experience tasks prospective mathematics teachers (PMTs) with digitally designing (using Tinkercad; Autodesk Inc., 2016), 3D printing, and evaluating original manipulatives that are responsive (Authors, under review) to the mathematical, pedagogical, and curricular (Dewey, 1990; Pinar et al., 1995) needs and interests of actual learners.

While there is a considerable body of research on *students'* mathematical Making (e.g., Bower et al., 2020; Valente & Blikstein, 2019), research is only beginning to uncover the benefits that *teachers* experience in Making contexts (Authors, 2017, 2018, 2019, under review). And research has yet to explore the design decisions teachers make through their design activity. Thus, this paper reports on research that aims to address this gap by seeking to answer the following question*: As prospective mathematics teachers Make new manipulatives for mathematics teaching and learning, what is the nature of the resources and rationales they bring to their design decisions and how do these intersect to mediate their decision making?* We are addressing this question through the analysis of five PMTs' design activities.

Theoretical Framework

We organized our theoretical framing around the learning theories of constructivism and constructionism. These theories recognize that knowledge is actively constructed by a learner, with constructionism adding the dimension that the knowledge be constructed through the process of making a shareable object (Harel & Papert, 1991) within a collaborative social context. Then, Pratt and Noss's design case study (2010) offers a proof of concept that a *Learning by Design* approach (Koehler & Mishra, 2005; Koehler et al., 2004) could provide a venue for characterizing the interplay between a designer's knowledge, experiences, intentions, and other resources as they are invoked during the iterative design of the shareable object.

A learning by design approach to advancing teacher knowledge involves participants in the activity of *designing* – or the purposeful imagining, planning, and intending that interacts with Making – by calling on them to "actively engage in inquiry, research and design" so that they can make "tangible, meaningful artifacts" that represent "the end products of the learning process" (Koehler & Mishra, 2005, p. 135). In our case, the learning process is the range of course objectives (including the development of an inquiry pedagogy) of a specialized mathematics content course for future elementary teachers; the end products are manipulatives that these prospective teachers will share with children with the intention of promoting their mathematical learning. As PMTs design these manipulatives, it is their intention (Malafouris, 2013) to provide them with particular affordances (Gibson, 1977) for utilization schemes (Verillon & Rabardel, 1995) that they hypothesize will enable the child to abstract, through their sensorimotor engagement (Kamii & Housman, 2000; Piaget, 1970), the perceptual elements that are the basis of the target concepts. As this process invites occasions for their active inquiry, PMTs must make a host of design decisions for a variety of reasons; they draw on a range of conceptual, social, and material resources to mediate them.

In order to characterize and organize the resources that mediate participants' design decisions, we appeal to Schön's (1992) notion of "knowing in action" (p. 2). Within a design setting, Schön considers knowledge to be in action as "the designer sees what is 'there'…, draws in relation to it, and sees what he/she has drawn, thereby informing further designing" (p. 5). This process of seeing-drawing-seeing is what Schön means by the phrase 'designing as a reflective conversation with materials.' It's this kind of conversation that is critical to Papert's (1980) constructionism, where conversations with artifacts are seen as essential for motivating and facilitating the construction of new knowledge (Ackermann, n.d.). It's also one that permits an analysis of these conversations to move beyond "static, explicit and objective" (Scheiner et al., 2019, p. 161) perspectives on knowledge to recognize the dynamic, blended, and transformative (Scheiner, 2015) nature of knowing. We therefore locate this learning by design approach to the invention of manipulatives at the "interplay between theory and practice, between constraints and tradeoffs, between designer and materials, and between designer and audience" (Mishra & Koehler, 2006, p. 1035).

Methods

This study is part of a larger project that aims to test and refine the hypothesis that a pedagogically genuine, open-ended, and iterative design experience centered on the Making of a mathematical manipulative would be formative for the development of PMTs' inquiry-oriented pedagogy. The larger project took place across two semesters of a graduate-level specialized mathematics course for PMTs at a mid-sized university in the northeastern United States. Forty students comprised thirty-four groups. For the study reported here, we took an exploratory case study approach (Yin, 2009) to understanding PMTs' design activity by taking the three elements of each of their design decisions as the unit of analysis: the decision itself, a rationale for making the decision, and the resources that mediated the decision making (see Figure 1). The manipulative's design, transcripts of video-recorded in-class design sessions, and three written project components formed the data corpus.

We took a grounded theory (Corbin & Strauss, 2008) approach to analyzing the data. We began by individually analyzing the components of one design case and generating codes that characterize the design decisions and their mediating resources as they were revealed in the PMTs' written work and in the transcripts. Next, we collaborated to reach consensus on the codes that had been developed and to clarify their definitions. Analysis involved the constant comparison of data to ensure coherence was maintained across codes and cases. Finally, as a reliability check on our analytic scheme, three additional researchers on the project individually analyzed the same design case, and then we convened to refine the coding process. At this point in our analysis, we have organized design decisions in terms of the designers' intentions: the intended user, the target concepts, and their imagined usage schemes. The analysis is ongoing and new codes are being introduced and shared between the two researchers.

Results

We chose five design cases from among the thirty-four projects for analysis as they revealed the greatest number of design decisions. Here we present a selection of decisions made by "Moira" and "Anyango" that speak to their intentions for the design of their manipulatives and that illuminate the diversity of decisions, rationales, and resources evoked by the design experience.

Both Moira and Anyango chose the child they had worked with in problem-solving interviews earlier in the course as their intended user of a tool. Moira explained: "After seeing the student I tutor have issues with solving fraction problems, I decided to create a tool that I believe will help him understand fractions." Anyango shared that "The student I am working with said she enjoys fractions… so I want to continue with her interest by learning and playing with a manipulative to gain a deeper understanding." Both Moira and Anyango decided to create a fraction tool, but they provided different rationales for that decision. Moira hoped to help her child make better sense of fractions; Anyango learned that her child enjoyed working with fractions and hoped to extend her current thinking about them.

Moira's design (Figure 2, left) is a tool for fraction comparison. It consists of "a series of rings that rest on a cylinder... The notches help divide the rings equally up into pieces to represent parts of a whole. Each ring represents a different number of parts, like sixths and eighths." Anyango also designed a tool for fraction comparison (Figure 2, right), yet her design is markedly different from Moira's. Anyango describes her tool as "a 3D version of fraction strips. Each strip was made to be a rectangular/square piece that slides into individual pegs… [the] blocks stack vertically... to indicate height as value and amount." While the mathematics of fractions and the technological knowledge required to design equal partitions interact to mediate both Moira and Anyango's design decisions, fraction concepts are embedded differently in their designs. For Moira, fraction values are represented as arc lengths of the partitions of a continuous ring; for Anyango, they are represented as discrete fractions of the height of a referent whole. As another point of contrast, Moira's imagined utilization scheme involves aligning notches so that "the rings are able to be compared, showing how many fifths are in one half," for example. Central to Anyango's scheme is that "all the fractions [can be] mounted on one platform… so that the student could begin to grasp how all the smaller parts can equate and compare to the whole."

Decisions about the role that color plays mediated design decisions for Moira, Anyango, and other PMTs, as well. Anyango explains that in her design, "The colors didn't matter much." Giving each fraction block its own color would have been "aesthetically pleasing, but it did not affect how the manipulative worked." Moira makes the same design decision, but with a different rationale mediated by different resources. She explains that all of her "rings have the same color," because if each ring had a unique color, it might "take away reasoning from children. If a student believes that a yellow ring represents 1/6ths, they will immediately reach for yellow the second that they hear sixths." By giving the rings the same color and leaving them "unmarked," Moira ensures that children will construct their own meanings in relation to each of the rings, thereby giving her tool the promise that it can "be used in multiple ways." Thus, epistemological knowledge mediates a decision that seems to reflect Moira's commitment to an inquiry pedagogy that affords multiple means of engagement from which teachers can formatively assess their students' thinking.

Conclusion and Significance

A host of new possibilities are afforded to teachers at the intersection of digital design and fabrication technologies, student-centered design practices, and inquiry orientations to mathematical learning. As researchers accepting greater responsibility for the preparation of teachers for work in diverse contexts, this work explores what teacher preparation might look like that cultivates the imagination of more humanistic forms of mathematics teaching and learning. In particular, we hypothesized that a pedagogically genuine design experience would be formative for the development of an inquiry-oriented pedagogy that is legitimately responsive to the particular needs and interests of actual learners. The quantity and variety of design decisions made by the prospective teachers speaks to the agency that the open-ended and iterative design experience afforded them, and the scope of resources that were evoked and brought to bear upon these decisions permits the re/positioning of (prospective) teachers as teachers with expertise. Consequently, whereas teachers are too often responsible for implementing curricular materials that they neither designed nor approved, this work has demonstrated that similar design experiences have the potential to disrupt such alienating activity by providing prospective teachers with realized visions of themselves re/claiming the authority afforded to teachers as agents of curricular and pedagogical reform.

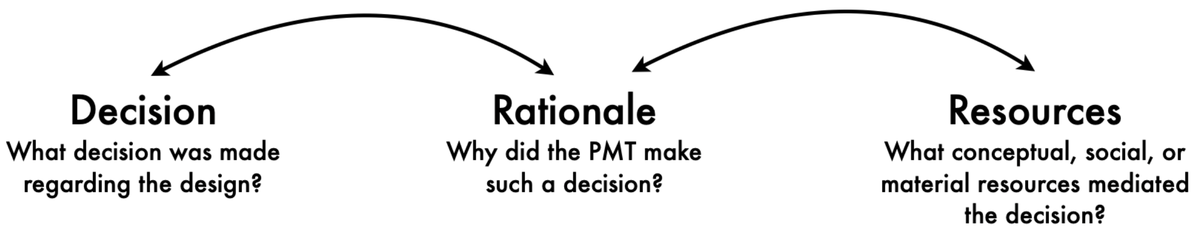

Figure 1. The 3 elements of a design decision.

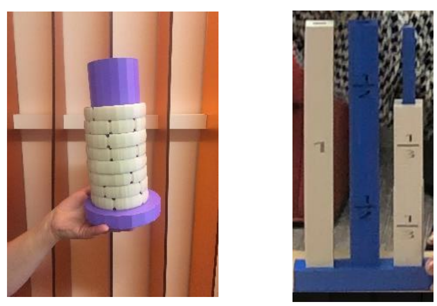

Figure 2. Moira’s fraction tool (left) and Anyango’s fraction tool (right).

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