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Craftland is Mathland: Mathematical insight and the generative role of fiber crafts in maker education

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There is tremendous excitement around makerspaces for deepening and enriching curricula across subjects, as well as engaging traditionally marginalized learners in new ways. To address the lack of translation of maker education projects to mathematics learning, we propose that educators aspire to create a "Mathland" when designing maker educational activities. Mathlands are environments envisioned by Seymour Papert where mathematics are learned alongside ways of doing mathematics in self-selected contexts, leading to an epistemology and natural language of mathematics that pervades all experiences. To imagine a Mathland where women's participation in mathematics is lifelong and lifewide, we explore traditionally female-dominated fiber crafts where long-term engagement, mathematics, and heritage intersect. As part of a longitudinal embedded multi-year ethnographic study, we conducted cohort analyses as well as grounded, iterative, and thematic coding of semi-structured interview data, augmented with crafting artifacts from 65 adult fiber crafters. Using qualitative analytical techniques, we asked: How does math occur in craft? How do crafters observe the intersection between math and craft in process? Fiber crafts were found to present a "Mathland," a lifelong context for immersive math engagement. We present crafters' math insights in the craft, as well as multiple aspects of the crafts and surrounding communities that supported the crafters in sustaining their engagement with mathematics throughout their lifetime. This study has implications for the design of inclusive and lifelong maker educational environments for mathematics learning.

KEYWORDS

maker education, crafting, fiber crafts, constructionism, mathematics education, lifelong and life wide learning

Introduction

> *Maija invited me into her lakefront home near a midwestern college town. We sat down at the kitchen table with fabric squares and measuring tape piled up at the edge of the table and half-finished quilts tossed over the side of a chair. Quilting is a large part of her life. Whether it is custom-made tools for cutting fabric shapes on the coffee table, a project in progress on the living room floor, or a ruler on top of a paper to capture the rotational angles for her next quilt, Maija's home was a craftland with quilts featured in every corner. As Maija walked me through her home, she showed me one quilt after the next, including geometric looking quilts that intricately combined triangles, squares, and hexagons of various sizes into decorative graphic designs as well as art quilts that showed picturesque themes using fabric like paint. When I asked Maija how she created her quilts, she pointed out how the quilts were composed of blocks of fabric that themselves were composed of yet smaller pieces of fabric with each including seam allowance, an edge of fabric that vanishes from sight but is necessary to sew two fabric pieces together.*
>
> *– Excerpt of mathematical engagement with quilter, Maija, age 53.*

Lifelong learning in mathematics is a predictor of several positive life outcomes including economic progress and cultural development in a rapidly changing world (Aspin and Chapman, 2001). However, with girls' interest in math and science dropping off after fourth grade (Blue and Gann, 2008; Meiksins et al., 2016), these outcomes are not known to be available to all. Women and members of underrepresented groups in STEM participate less in higher level STEM classes and in STEM careers (e.g., Boaler and Sengupta-Irving, 2012; Corbett and Hill, 2015). Women also tend to become less represented as math classes and professions as they become more advanced (Boaler and Sengupta-Irving, 2012). Researchers have explored girls' and women's participation in mathematics to understand more about the driving factors behind these gender differences. Much of this research suggests that gender differences are due to whether women perceive the cultures surrounding mathematics as welcoming, as there is a lack of evidence to suggest that women perform worse in mathematics than men (Alper, 1993; Boaler and Greeno, 2000; Boaler, 2002). Thus, it seems important to explore contexts in which women do engage in complex mathematics voluntarily and with great interest.

Within the learning sciences, researchers support learning in a domain like mathematics through focusing on increasing engagement and fluency with the concepts and practices of that domain (e.g., Rogoff, 1996; Engle and Conant, 2002; Kolodner, 2004). Through design processes, these domain practices can be introduced and integrated into formal learning environments. Introduced by Papert (1980), constructionist approaches to learning—the foundation for many Maker Education philosophies and activities—consider some of these design processes to include examining and understanding cultural contexts that are seemingly unrelated to school-based learning environments in order to think more creatively about how to make domain learning more welcome for all students. In the context of math learning, Papert proposed that educators aspire to create a "Mathland," an environment for mathematics learning in self-selected contexts, leading to an epistemology and natural language of mathematics that pervades all experience (Holbert et al., 2021).

As evidence of this expanding lens, researchers have turned their attention to crafting, a form of making, as an underexplored area for authentic STEM learning, including mathematics (Greenfield and Childs, 1977; Rogoff and Gauvain, 1984; Saxe and Gearhart, 1990; Peppler et al., 2020), computing (e.g., Essinger, 2004; Maynard et al., 2005; Kafai et al., 2014; Keune et al., 2021; Keune, 2022), and circuitry (e.g., Peppler and Glosson, 2013). In these studies, textiles, fiber, and needlework crafts are seen as viable additions to STEM tools and practices with the added potential to broaden participation in STEM fields and to improve learning outcomes for all students. We build on the premise that if we design with the socio-historical practices of underrepresented people in mathematics in mind, we can create learning opportunities in which all students achieve well (Keune et al., 2021). Yet, we do not know whether fiber crafts present a context for lifelong math learning. Thus, we ask:

1. How does math occur in craft?
   a. What are crafters' relationships with mathematics?
   b. What math insights do the crafters have, how do these insights align with math concepts?
2. What features of craft support lifetime engagement in math? What are reasons for crafting and continued engagement across the lifespan?

To answer the questions, we took a constructionist approach to the study of fiber crafts as a context of lifelong math learning and the study of learning mathematics in fiber crafts. As part of a larger critical qualitative study of traditional crafting communities across the United States, we conducted semi-structured interviews with 65 fiber crafters (augmented by analyses of textile artifacts they created), using qualitative analysis techniques to understand more about the relationship between crafting and mathematics as a place to re-envision mathematics education as a "Mathland" toward lifelong learning. We found that fiber crafts are a context for rich realization of math insight. We also show what aspects of the crafts support crafters in sustaining their engagement with mathematics throughout their lifetime. This study parametrizes math-craft relations, revealing implicit features that could sensitize designers, teachers, and researchers in (craft-based) mathematics learning to design constructionist learning environments that are intended to be life-long spaces for mathematics learning for all learners. Additionally, this study is a reminder of how critical it is to question the constraints of mainstream school curricula and pedagogies for the complex and diverse learning needs of students and for the inclusion of maker artifacts that are not yet included in formal knowledge appropriation in STEM fields.

Background

Math in everyday life

Learning within the context of extracurricular interests and hobbies is often viewed as less legitimate school-based learning (Lave, 2011), despite the fact that learning researchers have found learning outside of schools to be just as impactful (Lave and Wenger, 1991; Azevedo, 2011) or efficacious for future learning opportunity (Jenkins et al., 2006; Barron, 2010). In terms of math learning, ethnomathematicians have long asserted the ways in which math is realized in everyday life and across a range of cultural contexts (Stevens and Hall, 1998; Hall et al., 2002; Hall and Horn, 2012).

Compelling early examples of this include Saxe's (1988) study of children's engagement with mathematical practices and concepts through selling candy, emergent and materialized strategies of how people portion meal ingredients within weight watchers programs (de la Rocha, 1986), as well as strategies people engage when comparing proportional prices in grocery stores (Lave et al., 1984). Perhaps most relevant for this study is Greenfield, Maynard, and Childs' research program that explored Mexican weaving as a concept for cognitive development of representational skills (Greenfield and Childs, 1977; Childs and Greenfield, 1980; Greenfield, 2000, 2004; Greenfield et al., 2003), including how warping yarn onto a loom can become a context of spatial transformation through the assembly of resources (Maynard and Greenfield, 2003).

This prior research on everyday mathematics has demonstrated convincingly that contexts serve as significant resources for meaning-making (Lave et al., 1984; Saxe, 1989; Greeno, 1991); thus our goal is not to investigate whether crafters develop sufficiently "abstracted" understandings, but rather to discern how the context of crafting contributes to mathematical insight and how the context of craft supports the design of more inclusive learning environments.

Crafts as a context for math learning

Fiber and textile crafts have gained new attention recently, with high levels of participation in activities such as knitting in public spaces or seeing craftivism across the world (Bratich and Brush, 2011; Black, 2017; Close, 2018; Keune et al., 2022). Large online communities, including Ravelry and Etsy, are supporting whole economies related to crafts.

Research has produced evidence that there is a strong connection between mathematics and craft (e.g., Eisenberg, 2002). As mentioned above, crochet enabled a form of physically modeling hyperbolic planes that was only previously possible through cutting and taping paper (Wertheim, 2005; Taimina, 2009). This paper technique, while impressive, was tedious and a less accurate representation of an unbroken plane compared to crochet (Wertheim, 2005). Designs for an Analytical Machine that would use series of binary options to perform complex mathematical calculations quickly were inspired by Jacquard's complex looms (Essinger, 2004), and weaving has been connected to mathematical ways of thinking and doing across cultural and educational contexts (Greenfield and Childs, 1977; Saxe and Gearhart, 1990; Peppler et al., 2020). Crafts like sewing garments and costumes, knitting, crochet, and weaving have been seen as useful for active mathematics learning in out-of-school contexts.

Additionally, mathematics continues to inspire textile craft design and invention, such as the colorful tessellations seen within Jinny Beyer's famous quilting work (Beyer, 1999). Furthermore, craft activities can be designed to support math and other STEM engagement (e.g., Buechley et al., 2008; Buechley and Perner-Wilson, 2012). In one case, analyses of youth engaging with three fiber crafts shows that multiplicative proportional reasoning shows up in varying ways across the crafts (Keune and Peppler, 2020). Other work in school settings revealed the different strategies students use when making the two different types of tents, large-scale in the outdoors, and the small-scale in the classroom, such as immediate feedback from large-scale making, different math concepts required in relation to size and material (Peppler et al., 2018).

These studies suggest that fiber crafts can serve as a context for motivating people to engage with STEM ideas (Uttamchandani and Peppler, 2018; Faimon et al., 2019). For example, women tend to acknowledge the math in craft yet distance themselves from relating themselves to math in more traditional senses (Uttamchandani and Peppler, 2018). This early pilot analysis of a subset of the data presented in the current work demonstrated a conflicted stance that women had toward the math in craft. Taken together, this body of research calls for a deeper understanding of crafts as a possible lifelong form of engaging in mathematics. While other crafts that are socio-culturally less connected with practices by women could also serve as contexts for mathematics learning, we focus on fiber crafts exactly because of the gendered history of these crafts. We do so in an effort to lay the groundwork for designing high quality, lifelong additional mathematics learning contexts that are for all students. We build this decision making on recent educational research that showed that if we design learning opportunities with the socio-historical practices of underrepresented people in STEM in mind, we can create learning opportunities in which all students achieve well (Keune et al., 2021). Similar findings have also been advanced in academic leadership research that showed how subtle gender-coded advertisements can lead to lower diversity in the application pool (Dutz et al., 2022).

Constructionist alternatives: Samba schools and Mathland

To study maker activities as context for math learning, we take a constructionist approach to learning. Constructionist thought asserts that learning is best supported when learners engage in the production of artifacts that are meaningful to themselves and to those around them (Resnick, 2002). Like other theories of learning that address the socially constructed nature of knowledge creation (Case, 1996), constructionism interrogates the role that the social and broader cultural context plays into learners' choice of projects and the ways that the practices and norms of a community contribute to their meaning. From a constructionist perspective, creative production needs to resonate with the learner's culture at both the individual and social levels for engagement and learning to occur (Papert, 1980).

Papert observed that, while mathematical concepts abound in everyday experiences, the formalisms of math are often isolated to schools (Papert, 1980). As an alternative, Papert proposed that educators aspire to create a "Mathland," an environment where the learning of mathematics occurs as immersively and organically as language learning and in authentic contexts (Papert, 1980). Seeking to design an educational culture of shared values that possess constructionist principles at its core (e.g., making, designing and sharing artifacts deeply rooted in epistemic and powerful ideas), Papert studied the structure and practices of Brazilian samba schools: Community-based dancing, marching, and drumming clubs where thousands of members of a neighborhood prepare spectacular samba performances for competition in Rio de Janeiro's annual Carnival parade. While organized around dance, Samba schools were the first realization of what a "Mathland" could look like: A learning culture organized around a central idea, featuring the contributions of mixed age groups, strong affirmations of heritage, multiple points of entry, and public performance. Mathlands within the constructionist tradition are learning environments in which rich doing of mathematics happens and is articulated along the way of performing and practicing cultural practices that are deeply interconnected with mathematics.

Papert attempted to design an instance of Mathland through his development of the Logo programming environment, which was created to lead learners to mathematical insights through the process of art and design (Papert, 1980; Stager, 2020). Logo was historically recognized for its ability to design and test algorithms, generate hypotheses, pose problems, and investigate possible solutions [i.e., what Hoyles and Noss termed the process of 'mathematicizing', (1987)].

Similar Mathland ideals of immersive mathematics experiences, where experts and youth can come together to form and share mathematical habits of mind, have informed the design of tools and spaces in the decades since the concept's inception. Many of Mathland principles guided the design of the Clubhouse Network (Zagal and Bruckman, 2005; Kafai et al., 2009), an international network of afterschool centers that connect young people from underserved communities to mentors to help them create original work, develop technology skills, and foster a communal spirit of design in ways specific to the local culture. The aspiration of the Clubhouse Network is to leverage youths' interests–particularly those in popular media–toward engagement in science, technology, engineering, and mathematical ideas. The creation of the visual programming environment, Scratch, a direct descendant of Logo (Resnick et al., 2009), was designed to introduce a tool to facilitate Clubhouse Network youths' immersion in engineering and computer science concepts through interest-driven creative production (Kafai et al., 2009).

Other efforts include programs like *Turtlestitch*, a browser-based programming environment that draws on visual coding principles inspired by Scratch to turn code into embroidery (Wolz et al., 2019). In this effort, Turtlestitch physically manifests the math and design principles of Logo within the cultural histories of craft, illuminating the math-based principles inherent to embroidery as well as encouraging future exploration of mathematics-based concepts through crafting practices.

In the present study, we seek to explore traditional fiber crafts as Mathlands to better understand the multiplicity of mathematical doing with fiber crafts as well as to enrich our understanding of the conceptualization of Mathlands through the context of fiber crafts that is at once historically entangled with mathematics, such as crochet of hyperbolic planes (e.g., Taimina, 2009), yet routinely excluded from standard mathematics curriculum. This is motivated by the idea that the exploration of cultural practices that seem disconnected to the way domains are taught in school can present renewed ideas for improving educational practice (Zagal and Bruckman, 2005). Seeing Craftland as Mathland promises possibilities for extending the conceptualization of Mathland by highlighting, for instance, the importance of non-discrete mathematical engagement.

To seek these missing connections, we draw on another constructionist tenet, epistemological pluralism (Turkle and Papert, 1990), which asks to recognize and validate multiple, diverse ways of knowing and learning. Turkle and Papert (1990) called on STEM fields to accept broader and more diverse forms of engagement after noticing that women in some computational contexts rejected the ways they were asked to engage and forged their own methods and pathways. While mathematics in school may be based in epistemologies from western philosophers (e.g., Joseph, 2017), embracing epistemological pluralism makes it possible to see many ways practices and domains could connect and lead to powerful learning experiences across a lifetime.

Materials and methods

As part of a larger longitudinal multi-year critical qualitative study, we analyzed observational, photographic, and interview data of crafters to understand more about the relationship between crafting and mathematics as a place to re-envision mathematics education as a "Mathland" toward lifelong learning. Toward this end, we conducted cohort analyses as well as iterative and thematic coding of interview data to probe crafters' relationship with mathematics. While some scholars (e.g., Ericsson and Simon, 1993) speak to the limitations on veridically ascertaining the intellectual processes from people's retrospective accounts of their activities, this paper leans heavily on our positionality as critical qualitative researchers, triangulating themes from the interview data with *in situ* observations from solo and group crafting events over a multi-year span as well as artifact analyses of crafters' completed work.

Our inquiry into the connections among lifelong crafts and mathematics included conducting participant observations as researcher-learners as well as qualitative research with crafters in crafting circles. Within these environments, we as researchers were embedded in the environments as learners of the crafts from and with the crafters. The researchers acted as researcher-learners and active participant observers of the day-to-day crafting practices of the crafting circles. Learning the crafts provided opportunities to enter the cultural practices of the crafts as well as to gain first-person experience with aspects that we would later identify as deeply mathematical.

In asking participants to reflect on mathematical insights culled over a lifetime, this paper draws on established methodological traditions in both the learning sciences and STEM education in how retrospective reporting can help researchers uncover pathways to participation across a lifetime, which can lay an important foundation for later longitudinal studies that allow for concurrent reporting over a multi-decade span (e.g., Alexander et al., 2012; Allen and Eisenhart, 2017). For instance, Allen and Eisenhart (2017) employed a longitudinal ethnographic approach to research how the STEM identities of several female students are rendered in relation to local school narratives of gender, race, and ethnicity in STEM. Thompson (2014) employed narrative and conversational approaches toward understanding the socio-historical discourse that informed and propelled STEM identity work of girls who are typically underrepresented in science. Collectively, this foundational work offers an important starting point for the field's understanding of the conditions under which a lifetime of STEM insights, as well as the multiplicity of pathways and supports (e.g., financial, human, and material), can lead to later STEM outcomes that we seek to promote in our educational systems.

Participants

For the purposes of this study, we heavily draw on our semi-structured interviews (see data sources for details) with 65 crafters supplemented with observations to learn about how crafts presented opportunities for lifelong engagement with mathematics from the perspectives of people engaging with a range of crafts (see Appendix A). We recruited the crafters through online or in-person networks from within crafting communities that we engaged with. The communities were primarily located in a midwestern college town and we followed leads to other online and offline communities through snowball sampling and the recommendations of prior interviewees. All interviewees were in the United States. Of all, more than half (58%, $n=38$) were located in the midwestern, 29% ($n=19$) in the eastern, 8% ($n=5$) in the western, and 3% ($n=2$) in the southern United States. The location of the remaining 2% ($n=1$) respondent is unknown. The majority (90%; $n=59$) of participants resided in urban areas including towns, 5% ($n=3$) resided in rural areas, and 5% ($n=3$) did not provide information about their area of residence.

We did not purposefully seek out a racially, ethnically, gender, or age diverse sample. Rather, in this early work we interviewed crafters who were interested in participating in the study and wanted to talk about their experiences. Of the 65 participants, 57 crafters (88%) were White, three were Asian, four were Black, and one did not disclose their race. Of all interviewees the overwhelming majority self-identified as women (92%, $n=60$). Four (6%) interviewees identified as men and one interviewee (2%) identified as gender non-binary. However, the interviewees did range in age. By generation, 49% ($n=32$) born between 1981 and 1996 (i.e., 20–35 years old at the time of the interview), 13% ($n=8$) were born between 1965 and 1980 (i.e., 36–51 years old), 36% ($n=24$) were born between 1946 and 1964 (i.e., 52–70 years olds), and 2% ($n=1$) were born between 1928 and 1945 (i.e., 72 years old). Throughout the coding and analysis processes, we looked for shifts across these generations, but did not find substantial differences.

Overall, the crafters we interviewed were highly educated, with 80% ($n=52$) having at least a bachelor's degree. Of these, 5% ($n=3$) had a doctorate and 38% ($n=25$) a master's degree. The remaining 20% are broken down as follows: 14% ($n=9$) had some college, 3% ($n=2$) finished high school, and 3% ($n=2$) did not provide educational information. The interviewees reported a range of professions and occupations, including students, professors, artists, store owners, and seamstresses. Interviewees reported their highest level of math experiences. For 28% ($n=18$) of the crafters, high school math was their highest level of experience and for 45% ($n=29$) college level math, including calculus (25%, $n=16$). Of all, 27% ($n=18$) did not provide information about their highest academic math experiences. Based on the educational level of the interviewees, their professional engagement, and their reports about the highest level of academic math experiences, we assume that the interviewed crafts had prior experience with math.

On average, the crafters pursued three crafts, showing that the sample of people we interviewed and observed had experience across crafts and could comment on their engagement with mathematics through crafting across a range of craft contexts. The crafts included knitting, crocheting, quilting, garment making/cosplay, weaving, spinning, needlework, and macrame. The most frequent crafts the interviewees engaged with were knitting (60%, $n=39$), sewing (54%, $n=35$), and crocheting (43%, $n=28$). On average, most of the crafters started crafting in their teens and learned from their parents, grandparents, great aunt, friends, wife, nanny, and teachers. It was most common for the crafters to learn from a mother (31%, $n=20$), self (25%, $n=16$), or a grandmother

(16%, $n = 10$). This means that the crafters we interviewed and observed were enculturated into crafting most typically through their families, especially female family members. Additionally, it suggests that crafters typically started to learn crafting at an early age. On average the interviewees started at 16 years. Those that taught themselves reported resources such as classes at libraries and craft shops and the internet. Twelve participants (18%) did not report who taught them to craft.

Data sources

The data sources for this study consisted of semi-structured interviews with 65 adult crafters as well as 397 project pictures of the work by a subset of crafters, which were augmented by our observations throughout over 5 years of critical qualitative research. The semi-structured interviews were the body of data that most dominantly served the analysis for this study (Appendix B). The photographs contributed to general sensemaking and contextual understanding.

A total of five researchers embedded themselves in crafting circles, each specializing in one craft, including, sewing and cosplay, weaving, crocheting, knitting, and quilting. The qualitative data were documented by taking field notes of our observations alongside notes in a reflective journal that documented our own engagement in mathematics through crafting, including milestones, projects, and mathematical insights, as well as observations of ongoing activities, online research, craft-material practices, and projects that crafters produced. These field notes and observations included a rich body of understanding of the crafts. The first-hand craft experiences, through learning and researching, made it possible to appreciate and analyze the mathematical engagement of the crafters, thus, presenting a wealth of backdrop experiences we implicitly and explicitly drew on while analyzing the data sources that dominantly informed this study, interviews and photographs of artifacts created by crafters. For the observations of the crafters' series of projects and practice photographs captured the kind of engagement that crafters highlighted as mathematical as we engaged with them in in-depth conversations and interviews.

We conducted semi-structured interviews with the fiber crafters in person at their homes, studios, and in public spaces, over the phone, or with video conferencing tools. The interviews were on average 59 min long (minimum 19 min and maximum 166 min). Three interviewees wrote their responses to the interview questions. These are, thus, not included in the average calculation. The researchers who conducted the critical qualitative research also conducted the interviews, including the second to fourth author of this manuscript who all specialized in particular crafts as part of their involvement in the larger research project. The interviews were audio or video recorded and later transcribed verbatim. The semi-structured interview protocol included three thematic areas: (1) Demographics, (2) connections between math and crafts, and (3) learning crafts.

First, demographics related questions included questions about the participants' age, their highest level of formal education, their occupations, the kind of crafts they were practicing, their length of experience with crafts, and whom they learned from. Although we interviewed each crafter for a specific craft, it was not always possible for the crafters to respond to questions based on one craft alone as most had experiences with several crafts. Formal education and occupation related questions provided information about the crafters' experience and relationship with mathematics within formal settings, such as school or their profession. Second, questions that asked crafters about the connections between math and crafts asked interviewees to elaborate on their experience of mathematics within craft practices. Here, we focused on getting crafters to articulate any mathematics concepts they connected with their craft and, where possible, to elaborate how they considered and experienced these connections arising within their craft practices. Lastly, questions related to learning the crafts asked interviewees to explain their reasons for crafting and continued craft engagement as well as how they knew that they were getting good at their craft and the kind of learning and teaching processes that worked well for them.

To augment the interviews, we captured 397 photographs of the crafters' projects by 32% ($n = 21$) of the interviewed crafters. We captured the projects as part of volunteer studio tours during which crafters' presented their projects to us either in photographic or physical form. Some crafters did not feel comfortable having their projects photographed because they had prior experience of people copying and publishing craft inventions that were not their own or had recently contributed their work to book projects or competitions and were not sure whether they were permitted to share images of their work with us. Throughout the study the photographs served to strengthen our contextual understanding of the crafters and their engagement with material mathematics processes. To show the breadth and depth of the mathematics used in crafts for the purposes of this paper, we selected quilt examples that represent concepts from elementary, middle, and high school level education standards as set out in the common core and that display simple to complex mathematical reasoning involving multiple math concepts.

Analytical techniques

We conducted our analyses using a qualitative methodological approach for interviews following Carspecken's (1996) recommendations of semi-structured interview protocols for critical ethnography. We began by taking two separate passes at the data to first get a sense of larger trends across demographic information and then to better understand interviewees' ideas about mathematics and learning around the crafts.

The first pass at the data included an analysis of the cohort of interviewees to organize the characteristics of the individual interviewees and the cohort. From the interviews, we gathered demographic information, including length of the interviews, age and generation, gender, occupation, educational level, and highest math course taken, years of craft experience, and who taught them their craft. When possible, the author who conducted an interview did the cohort analysis of those interviews, because the interviewer had contextual understanding about the person that other researchers could not have.

The second pass through the data involved segment analysis, which involved dividing the interview transcripts into larger themes and cycles of iterative thematic analysis based on the interviewer and interviewee co-constructed knowledge production during the interviews (Carspecken, 1996). We first explored the data in ways that separated pieces of the interviews from the participants and the researchers who conducted the interviews. This surfaced emerging themes related to math in the crafts, yet also decontextualized the crafters' lived narratives. Thus, we returned to the texts of the interview transcripts and created thematic summaries for each interview in relation to both emergent themes: (1) Math in the crafts and (2) learning culture at play in the crafts. We wrote the thematic summaries around relevant quotes that stood out from the interviews to stay connected to the interviewees' language. These summaries became the basis for subsequent analyses related to the themes and research questions. The following sections provide additional analytical detail mapped onto the sub-research research questions related to how math occurs in craft as well as what features of craft support lifetime engagement in math.

Analysis for math in the craft

To analyze the data to answer research question 1 about math in the crafts, we looked at four areas: (1) crafters' relationships with mathematics, (2) math insights crafters gain in the craft and their alignment with academic math concepts, (3) the breadth and depth of the mathematics involved in the creation of finished craft products, and (4) active interplay between math and craft. Throughout this article, we use the term *mathematical insight* to mean verbalized mathematical ideas or engagement that the crafters shared. We use the term *mathematical concept* to mean a named or recognized topic or domain within mathematics, generally drawing from the Common Core Mathematics Standards.

First, to analyze the crafters' relationships with mathematics in response to research question 1a, we explored the emergent tensions between how crafters spoke about math in an academic or formal sense and math as is related to use in crafting. We assigned each interviewee a category of "positive," "negative," or "other" for both academic math and craft math based on the summaries of each interview around math in the craft. The authors met and discussed each categorization and came to 100% agreement on these codes.

Second, to answer research question 1b, we looked closely at the math insights the crafters articulated in connection to their crafts. Throughout the interview, we asked questions such as "Do you see any connection between your craft(s) and math?" Responses to this question and other spontaneous talk throughout the interviews allowed us to pull out recognized formal math concepts both by name (e.g., "There is a lot of geometry") and by description (e.g., "Basic arithmetic stuff.") and connect them to the insights the crafters mentioned. Together, and reaching 100% agreement among the authors, we translated these insights into math domains and topics as outlined by the Common Core Standards for Mathematics (National Governors Association Center for Best Practices, 2010). We calculated how many concepts were aligned overall and how many times each concept was mentioned.

Additionally, we analyzed artifacts to better understand the math insights and its breaths and depth in crafts, including a mathematical analysis of the quilt pattern by examining the photographs for representation of the mathematical insights. First, the artifact analysis included asking the crafters to highlight mathematical patterning within the crafts. Second, we deepend the artifact analysis in the studio by examining the photographs for mathematical concepts by augmenting them with graphic overlays. These graphic overlays present the patterns required to complete the projects. In addition to the concepts that the crafters pointed to, we also analyzed mathematical insight beyond what was articulated by the crafters. For instance, where the photographs showed interlocking tessellations, crafters did not call upon this in their description of their math insight. Yet, they produced intricate shapes and elegantly applied the principles of translation, rotation, and mirroring while working on the structure of their pieces, including in the seam lines, sewing order, and assembly. Therefore, adding our mathematical analysis to the participants' mathematical insights enables us to show their mathematical insight beyond what was being articulated. We used quilts to show the analysis because they clearly display patterns that can be reproduced in print.

Analysis of craft as lifetime engagement in math

To analyze the data around craft to see voluntary lifetime engagement in mathematics, we looked at why crafters continue to craft. We also explored the reasons why interviewees started to craft and what led them to continue to craft over time. During the interview, we asked the question "If I would say 'I make or create things because …' how would you complete the sentence?" Responses to this question and other spontaneous talk throughout the interviews presented several reasons for crafting described by the interviewees. We counted the various reasons mentioned and calculated how many times each reason was mentioned. The authors reached 100% agreement on these codes.

Findings

How does math occur in craft?

This section presents findings to better understand whether and how fiber crafts can serve as a context for mathematical insights. First, we present crafters' relationships with mathematics: generally, crafters express overwhelmingly positive relationships with the mathematics they engage in their craft, even though only half describe having a positive relationship with their academic math experiences. Second, we report mathematical insights that crafters cite and perform in connection with their crafts and how those align with the Common Core State Standards. In the process, we illuminate the breadth and depth of mathematics concepts demonstrated in crafting projects in order to observe the manifestation of the intersections between fiber crafts and mathematical insights. Lastly, we show how mathematical concepts intersect and overlap within crafting practice, demonstrating the complexity of mathematical expression and calculation that transpires within the creation of fiber craft designs, examining specifically the ways in which crafting can shape mathematical insight and vice versa.

This section of the findings presents evidence that math occurs in craft and that both can be aligned. Due to the tight connections between craft and math reported by crafters, a compelling context for modeling lifelong and lifewide Mathland emerges. Beyond the alignment between craft and math toward possible broadening participation strategies, we also seek to show that there may be differences between academic math and craft approaches that highlight potential starting points for re-shaping current approaches in math education.

What are crafters' relationships with mathematics?

Through emergent coding of interview data, we identified tensions that presented crafters' relationship and experiences with academic math as well as the kind of math performed through crafting practices, which we call "craft math" (Supplementary Table S1). While 1 (2%) interviewee reported a negative relationship to craft math and 8 (12%) stated both positive and negative relationships with craft math, most crafters we interviewed (86%, $n=56$) reported a positive relationship to craft math. This means that the crafters had a nearly universally positive relationship with math within the craft, recognizing math as part of their craft and enjoying engaging with it.

However, this clear relationship was not mirrored in how crafters spoke about their relationship to academic math. Crafters reported a range of relationships to academic mathematics. Of those crafters who reported a positive relationship to craft math, 40% ($n=26$) also mentioned positive relationships to academic math while 34% ($n=22$) crafters expressed negative relationships to academic math. Additionally, 12% of crafters who had positive relationships to math within crafts had positive as well as negative experiences with academic mathematics and 8% ($n=5$) of crafters had positive and negative relationships with craft math as well as academic math. The range of backgrounds and relationships to academic math means that crafters do not universally consider themselves proficient in academic math although they recognize math as an important part of their craft.

While we identified a nearly even split between crafters with positive and negative relationships to academic math, we also identified that these prior experiences did not seem to change crafters' relationships to craft math. Two typologies thus became worthy of further analysis, namely, 1) crafters who have positive relationships to both academic and craft math and 2) crafters who have positive relationships to craft math but negative relationships to academic math. To better understand these typologies, we present qualitative analyses from example case studies.

Positive craft math and positive academic math

The crafters in this group (40%, $n=26$) mentioned positive relationships to academic math. These crafters said that they felt good about their mathematics experiences in school settings and drew connections between academic and craft math. For example, Gina, a 59-year-old woman spoke about intersections of academic and craft math in her weaving:

> I actually did very well in math, and I feel like that's part of why it was so, it was comfortable for me to learn weaving, because you calculate (…) you weigh a piece of yarn, and you have a yard of yarn that you measure off.

Gina's comfort and her positive disposition toward academic math directly impacted her engagement with weaving. Weaving requires understanding of complex tools and accurate measurements. Gina was also at ease with craft math as she explained how math is relevant in her craft:

> Whether it's a blanket or an art work (…), you need math to calculate the yardage and the waste of the yarn that's going to be on the loom tied on, that's going to be cut off with fringe (…) when you're done.

Her engagement of math in crafts resulted in the performance of math with physical consequences. Crafters' understanding of academic math alleviated possible challenges they could experience through craft, such as cutting yarn too short and risking the loss of material. This is important because yarn can be valuable; some crafters made the yarn themselves from their own livestock (e.g., sheep), bought expensive yarn, selected the yarn with care, or used yarn that was in limited supply.

Positive craft math and negative academic math

Crafters in this group (34%, $n=22$) had a negative relationship to academic math. These crafters expressed concern about the current mathematical pedagogy but spoke with enthusiasm about the relevance of mathematical ideas in craft. For example, Jasmin, a 64-year-old weaver noted:

> I'm actually hopeless at math. I actually can't even do algebra, but I love the math that's involved in weaving, and whenever (…) we used to give tours, and we used to get a lot of students (…) ask them the math questions.

Jasmin connected both academic math ("algebra") and craft math by contrasting them in terms of her relationships to them. She considered her academic math skills beyond repair. By contrast, she connected positive emotions with the math that she used in crafts. Jasmin owned a weaving-related retail and a design business. The tours she mentioned in the excerpt above refer to her workshop and design portfolio. Although her expressed relationships to academic math are negative, she engaged in mathematical discussions when they were relevant to her work. For Jasmin, academic math was disconnected from outside-of-school experiences:

> I don't think I ever learned math in a real-world way. (…) I remember those questions if you're driving so many miles and how much gas, what do you use to get to XYZ place, and it didn't mean anything to me. I didn't care, you know. Here [with weaving], I care, so I pay attention to the math.

Together, these cases present how varied experiences in academic math do not preclude crafters from recognizing, performing, and enjoying math in craft. In the case of Jasmin, crafts present a context for making math applicable and relevant to personal interests and experiences, as a way to enter, apply, or extend academic math.

A key finding is that the interviewed crafters appraised their own mathematical competency by separating math into multiple parts–treating academic math as a higher form of mathematical competency and craft math being a lower form–and positioning themselves relative to each (Uttamchandani and Peppler, 2018). Constructing two kinds of math functions to allow speakers to position themselves in variable ways about math. It is possible that this in turn allows speakers to a) account for their self-appraisal as less capable in higher-level math or b) position themselves as especially competent since they are capable at both types of math. In so doing, speakers may tacitly or implicitly resist simplistic identities as "math people" or "not math people." These findings have deep implications for the study of mathematical self-appraisal. Rather than simply treating people as "math people" or as having a stable-low or stable-high mathematical self-appraisal, these cases reveal that there is much deeper complexity in how and why speakers construct a representation of mathematics as a subject and their own abilities therein.

Furthermore, Jasmin's dismissal of academic math, deeming it devoid of real-world contexts that interested her, also works both ways: by academic settings not recognizing contexts like crafting as a form of mathematical engagement, it communicates to her that her interests are of little interest to the field of mathematics. By contrast, had Jasmin's school experiences positioned the kind of basic arithmetic that powerfully can be used to accomplish textile crafting as not necessarily being of a lower level than more abstract kinds of math (Papert, 1980), it is possible that she would have felt invited to position herself as legitimate participant in deeper mathematical practices.

What math insights do crafters have, and how these align with math concepts

From the findings above, we observe that crafters recognize crafting as mathematical practice. In this section we show what kinds of connections they form by presenting the crafters' mathematical insights that the crafters articulated through interviews and artifacts. To better understand the range and conditions under which crafters forge these mathematical connections, we explore the math concepts that crafters recognized in the crafts (research question 1b) and develop an emergent alignment between fiber crafts and mathematics domains that are typically taught in K-12 contexts and beyond. In the process, we illuminate how crafts present themselves as arenas for a range of mathematical engagement and establish starting points for how we can make translations to educational practice.

During the interviews with crafters, we asked questions such as "Do you see any connection between your craft(s) and math?" Of the interviewees, 95% ($n=62$) responded to this question (the others acknowledged connections to math but did not elaborate with examples even after probing). Crafters responded to this question in myriad ways and mentioned various mathematics concepts and ideas throughout other portions of the interview as well. We elicited the crafters' math insights and aligned these with recognized math concepts as outlined by the Common Core Standards for Mathematics (National Governors Association Center for Best Practices, 2010); (Supplementary Table S2).

In their responses, crafters mentioned a range of insights, with many claiming alignment with more than one relevant math concept in the process of crafting. Geometry, which involves reasoning with shapes and their attributes, including calculations of area, surface area, and volume (National Governors Association Center for Best Practices, 2010), was described most frequently by 40% ($n=26$) of the interviewees (see Supplementary Table S2, row 1). For instance, one of the interviewees, Mimi (53 years old), spoke of how she applied the *Pythagorean theorem* ($a^2+b^2=c^2$ CCSS.MATH.CONTENT.8.G.B.7) toward the triangular constructions in a quilt she made. The Pythagorean theorem was used in this case to calculate the length of the hypotenuse of each triangle in a Missouri Star design, including each variation of the triangles in the design. Supplementary Figure S1 shows a photograph of a part of a quilt with a variation of a Missouri Star design (top left) and an illustration of the original design by Mimi to graphically present the fabric pieces (i.e., triangles and squares) needed for the quilt alongside the pythagorean theorem at play within the design (top right).

To create a Missouri Star design, quilters need to cut units of triangles and squares out of fabric and piece them together into a star block, applying the Pythagorean theorem to calculate the length of each of the sides of the triangles in relation to the star block as well as the size of the whole quilt. The Missouri Star design and its variations provide a visual representation of typically invisible yet important underlying aspects of the theorem (see Supplementary Figure S1, bottom).

Quilt designs such as the Missouri Star require a non-discrete engagement with mathematics as they call on the quilter to engage with a multitude of mathematical concepts at once. Admittedly, in this process, crafters simultaneously engage in other domains such as artistic decisions (e.g., color and pattern), economic decisions (e.g., financial costs, availability of materials, and time), among others that layer on top of the mathematical patterning and execution. For the purposes of this paper, we focus on the mathematical engagement in the crafts. For example, to create the Missouri Star design, quilters conceive of the whole square block simultaneously as four intermediate-sized squares that each consist of four small squares and eight individual straight-edge triangle units that together produce the complete star block (see Supplementary Figure S2). The division of the grid into smaller subsets of triangles relates to the use of fractions and a creative way to engage with *multiple parts that make up a whole* (CCSS.MATH.CONTENT.3.G.A.2). When considering the production process of a quilt that first requires planning a pattern, then cutting apart fabric to produce the individual pieces that make up a block, and then putting together the pieces into the larger image, *spatial visualization* and *spatial reasoning* skills are required (CCSS.MATH.CONTENT.HSG.GMD.B.4).

The domain of Number, Operations, and Fractions was mentioned second-most frequently (35%, $n = 23$), along with Ratios and Proportional Relationships (35%, $n = 23$; Supplementary Table S2 rows 2 and 3). For instance, Kate (35 years old) said that she uses "Multiplication, division, you know… basic arithmetic stuff" when working out how big her weaving projects should be and how much material she needs to create the desired size. In relation to Number, Operations, and Fractions, she described the process of preparing to make placemats:

> So, say I'm making four placemats, and they each need to be 15 inches long (…) plus 10 inches of warp (…) So, if I add that together, I need 25 inches per [placemat], and if I'm making four placemats, then I need 100 inches worth of warp.

This simple example for illustrative purposes demonstrates how these calculations can grow much larger and more complicated when working with more complex projects and numbers. Within the Common Core Standards, Number, Operations, and Fractions includes using place value understanding and properties of operations to add and subtract and fluently multiply multi-digit whole numbers (National Governors Association Center for Best Practices, 2010). For another example, in the quilt seen in Supplementary Figure S3, a variation of a New York Beauty pattern, the quilter needs to make multiple calculations and understand various numbers in relation to one another. The starburst in the middle of each circular shape is made up of 20 thin triangles. Alternatively, the outer rim of the circle is composed of 32 triangles when whole; the focal circle in the image here is partially covered by another circle and only displays 24 triangles. At a most basic level, the quilter needs to determine how many of each triangle are needed for each repetition of the circle motif, determine how many circles can fit within the full size of the quilt, and multiply the number of triangles by the number of circles ($20\times =$ number of total thin triangles; $32\times =$ number of total wide triangles; $\times =$ number of circles in the full quilt; CCSS.MATH.CONTENT.4.NBT.B.4). This does not yet consider the size of each of the individual shapes, or the seam allowance needed to achieve the desired outcome. The amount of fabric needed must be determined through additional layers of multiplication with fractions (e.g., $[60 + ½] \times [60 + ½]$; CCSS.MATH.CONTENT.4.NF.B.3.C).

Thus, the crafter here needs to perform multiple operations with whole numbers and fractions to determine the desired final size of the quilt, the number of circles, thin triangles, and wide triangles to cut, how much fabric is needed to produce the desired number of shapes, and how much fabric is needed to provide the background base color. Number, Operations, and Fractions as a mathematics standard first appears in the early years (CCSS.MATH.CONTENT.K.OA.A.1; CCSS.MATH.CONTENT.3.NF.A.1). In crafting practice, it becomes necessary to hold many numbers and fractions in play at a time, and to perform operations across multiple levels (CCSS.MATH.CONTENT.5.NF.B.7) to arrive at a desired result. This example, as well as the previous example of the Missouri Star quilt, each demonstrate one of the standards in Supplementary Table S2 at play in the craft. It is also important to note that this is one approach to these explanations, and that multiple layers of concepts and standards are present in each crafting project. Later in this section, we describe another example from a lens that looks across multiple standards in the table to demonstrate both the breadth and depth of concepts in crafting.

Overall, the group of crafters who showed a positive relationship to academic math mentioned more math insights (67 concepts mentioned) than the negative academic math group (44 concepts mentioned). This difference was fairly small and a t-test comparison showed no significant differences between these groups. Moreover, we looked at each domain listed in Supplementary Table S1 and explored whether there were differences in how often each domain was mentioned by crafters in the positive academic math and negative academic math groups. CHI-square tests showed that there were no significant differences between groups for any of the math domains. This suggests that having more or less positive relationships with academic math does not impact the crafters' ability to recognize, name, and describe mathematics in crafting. An important note, however, is that our population for this study consists mostly of highly educated and economically advantaged crafters. Future work should continue to explore these trends with more populations, such as people who craft out of necessity rather than hobby (e.g., for employment or entrepreneurship).

What features of craft support lifetime engagement in math?

Beyond the alignment between craft and math toward possible broadening participation strategies, the first section of the findings presented evidence of how crafters move between craft and math.

In this section of the findings, we deepen our analysis of the aspects of crafting to support the design of interventions that cater to sustained engagement. It is important for the learning sciences to investigate how craft can be a context for learning math and, in doing so, support rich and sustained engagement. Toward this end, this section unpacks the culture of crafting that is hospitable to mathematical thinking over a long time.

What are reasons for crafting and continued engagement across the lifespan?

During the interviews, we gathered characteristics of the crafts and the culture of crafting that may help to motivate and foster long-term engagement. All of the crafters, we identified 17 emergent reasons across the participants. The top five were: creative expression (28%, $n=18$), cognitive challenge (23%, $n=15$), gift giving (23%, $n=15$), calming (20%, $n=13$), and heritage (18%, $n=12$).

Many crafters ($n=18$) told us that they keep crafting because it gives them an outlet to be creative and to express themselves. For example, Jennifer (55 years old) said, "I like working with my hands and being creative, and for me (…) my work is not all that creative, so I need a creative outlet." Crafting can provide lessons for educational spaces to support learners in engaging in creative expression and problem-solving as academic settings may not traditionally provide such room. Other crafters ($n=15$) said that they continue to craft because it provides them with a cognitive challenge. For example, Kimberly (23 years old) said, "Because I loved to fix mistakes. It's my favorite thing ever. It's like a mystery. I have to figure out why it happened and then fix it." Some crafters ($n=13$) also said that crafting has a calming effect, which prompts them to continue crafting. For example, Sun (24 years old) told us that, "I like crocheting by myself because the activity of crocheting is very de-stressing, it's very stress relieving." The personal nature of this materialized form of mathematics participation may run counter to the ways some learners experience math in academic and classroom settings, which is often remembered for its high-stakes and depersonalized nature. In its place, laying a foundation for mathematics engagement that infuses interest-driven and creative expression creates more room for learners to enjoy the act of risk taking and voluntarily solving challenging problems. If the problems to be solved are of interest to the learners, they may enjoy the challenge more.

The sociocultural nature of crafting--with its ties to communal participation and intergenerational practice--shaped several interviewee responses. For instance, some crafters ($n=15$) said that they continue to craft to give handmade gifts. Jenna (61 years old) said, "I'm not even sure why I started again. I do not even remember starting. I had made a quilt for my brother-in-law." In a similar vein, some crafters ($n=13$) expressed that crafting helps them connect to their family histories and their heritage. For example, Jay (73 years old) said, "I feel sometimes when I knit (…) a connection through history with women, a historical time (…) that I can follow through today." Together, these reasons suggest that there is a communal nature to the culture of crafting that supports some crafters to continue practicing over sustained periods of time. These interviews reposition mathematics as a lived sociocultural practice, one in which textiles tacitly communicate mathematical insights between family members and across generations through the teaching of, and immersion in, craft. Indeed, the interaction between domain-specific and social processes lies at the heart of Papert's (1980) envisioning of a Mathland for learning. In contrast to the decontextualized formalisms of traditional classrooms, a Mathland-inspired approach to math education would integrate activities that are more communal and product-oriented. This could involve using math principles to create gifts to take home, or bringing artifacts from home to school to recreate and explore the mathematics principles and ideas within.

Other reasons for sustained crafting included contributing to zero-waste and self-sufficiency ($n=7$; Elsa [32 years old]: "I also like the self-sufficiency that comes through knowing that I can create items that are useful to me and others), exploring a range of fibers and materials ($n=6$; Mandy [60 years old]: "My raw materials, they are just so gorgeous. And making them into things that I get to wear, even more fun."), feeling pride and a sense of completion ($n=5$; Conny [52 years old]: It takes me to my happy place. It's like that sense of accomplishment."), addressing grief, illness, or trauma ($n=3$; Jana [34 years old]: "So I have a seizure disorder and crocheting was something that I learned to keep my hands busy. It prevents seizures, which is neat."), and earning income ($n=3$; Lisa [58 years old]: "I really have a lot [of projects at home], so in general, I really wanna be making things to sell just so I'm earning a little income."). These reasons are deeply personal and touch multiple areas of the crafters' lives. This suggests that offering a range of experiences and opportunities in mathematics may be necessary for welcoming more learners into authentic, sustained participation in math.

In sum, crafters offer several reasons for their sustained engagement in mathematics through crafting; many of these reasons seem to be tied to a communal approach that is grounded in the production of specific and purposeful projects that build on the personal enjoyment of learners. As data for this study were not collected through a survey, these reasons were emergent, meaning that the percentages presented here are not necessarily representative. However, these reasons can still provide some design principles that could guide the design of interventions that seek to support longer-term engagement with mathematics.

Discussion

Prior studies, remind us that complex mathematical problem solving can be present in various forms across multiple contexts, including basketball and candy purchases, which do not necessarily translate into classroom mathematical contexts in terms of performance also due to the interest and passion related aspects associated with the practices (e.g., Nasir and Hand, 2008). What has less been considered is how these contexts in and of themselves present forms of mathematical patterning that is not only a source of preparation for more canonical math, but a way to make and know math in its own right. Within this paper, we are presenting crafts as such a math doing and knowing context that is deeply materialized and provides opportunities for non-discrete deep dives into depth and breaths of mathematics throughout lifelong practices. Craft as a mathland presents craft as a mathematical tangible manipulative that grows and develops alongside the crafter, one that opens new depths and supports the possibility of continued learning of new and more complex patterns that are new and more complex in terms of the mathematics employed.

Taken together, the findings of this study provide insight into cultures of mathematics, both related to and separate from crafting. Through the possibility of engaging with mathematics through craft throughout a lifetime, crafting presents a Mathland in which formalisms and concrete, product-oriented, personally meaningful activities come together. Just as Papert (1980) wrote about gears of his childhood, fiber crafts may engage other children in a lifelong relationship with mathematics. One key aspect, directly connected to the findings, is that crafters' relationship with academic math did not impact their ability to identify, perform, or enjoy math in a range of ways within the wider sociocultural context of crafting. The participants reported engaging with mathematical concepts through their craft, and they considered math to be an important aspect of their craft practice. Multiple crafts are settings to forefront mathematical reasoning across materials and levels of complexity.

Further, crafting represents the ideals of Mathland. Stretched across a lifetime, crafts can connect to family and cultural heritage, provide multiple points of entry, and public engagement in various social constellations. The crafting processes described by the interviewees closely align with models of good scientific inquiry, where the learners actively participated in acquiring and co-constructing domain-related knowledge developed in conversation with crafting materials and traditions. This seems to stand in opposition to math in schools, which may have a reputation for not allowing co-construction of knowledge; several crafters reported finding academic math burdensome.

Beyond that, our study shows that crafts also push our understanding of what a Mathland can and should be, providing insights into how to extend Mathlands that encourage life-long (i.e., throughout one's life) and life-wide (i.e., across different aspects of one's life) engagement. These aspects relate to: mathematics as patterning, mathematics as non-discrete, developmentally appropriate mathematics, pluralistic ways of engaging with math, physical life-wide dimension, interests paired with mathematics.

Crafters engage in the production of *mathematics as patterning*, the production and doing of units that are pieced together into a larger whole. This means that crafters produce and reproduce measuring units rather than using ready-made units. For example, units can be crocheted together such that the repeating units together form an overall symmetrical pattern. Symmetry can deliberately be altered to infuse aesthetic variations reflecting the crafter's own creativity, producing endless possibilities using the combinatorics of craft parameters to tessellate such patterns.

Crafts as a mathland shows *math as non-discrete* and something that is related to the real and physical world that people inhabited. Here, multiple mathematical explanations and underlying patterns of worldly phenomena are being produced and re-produced alongside each other rather than being treated as separately. Crafts as mathland suggests that mathlands are supportive of non-discrete engagement rather than teasing apart individual concepts and treating them separately.

While it can be confusing and challenging for learners to learn everything all at once, crafts as a Mathland includes a developmental component: crafters can choose how deep and how broad they engage with math by choosing more or less complex projects and patterns in their productions. Extrapolated into Mathland this means that Mathlands need to be capable of providing learner-selected ways to deepen and widen their engagement opposed to a lock-step progression directed, for example, by a curriculum. In short, Mathlands should support *developmentally appropriate* engagement with the domain.

Crafts expand what math can be and is by focusing on patterning as an alternative way of doing, exploring, and, at its best for instance with the example of crocheted hyperbolic planes, advancing mathematics. Such *pluralistic ways of engaging with math* extends what we know of math circles in which learners engage alongside expert mathematicians to learn their professional ways of doing. Crafts suggests that Mathlands should present legitimate forms of math that are different from doing math as we know it.

Unlike Logo–an original constructionist Mathland in which learners engage math through the creation of artistic expressions with a computer–crafting is a physical engagement with mathematics. Crafts can be worn on the body and placed on furniture, whereas creations with other constructionist environments remain as part of the on-screen engagement. The dimensionality of the fabric makes it possible to increase the breadths of the mathematical engagement, even supporting dimensional reasoning through playful engagement. Typically, and as reported by our participants, crafts are done for reasons other than doing mathematics. Crafts are sprawling from the crafters' crafting circle into other aspects and corners of the crafters life and beyond (e.g., through gifting). Lifelong engagement of crafts, thus, adds a *physical life-wide dimension* to what we can conceptualize as Mathland.

Whereas Scratch, another flagship computer-based constructionist environment that was purposefully designed to background mathematics in favor of interest-driven engagement (Peppler and Kafai, 2007; Stager, 2020), crafts combine interest-driven aspects (e.g., knitting a pokemon-themed sweater) with deep mathematical engagement, highlighting *interests paired with mathematics* as an important aspect of what makes up lifelong and life-wide Mathlands.

This study posits that a craftland is Mathland embedded in one's heritage, history, and various cultures around them. Crafters plan their learning around big ideas rather than focusing on skills in isolation. They are encouraged to do reflective thinking as they use different ways to develop their projects and share their emotional connections and warmth with pieces they make for their loved ones. They fondly weave their loved ones' preferences into their pieces as they develop their designs. Overall, the crafters' description of their own craft conceptualization, design and creation processes has underlying STEAM-related learning even when they academically appeared to be less interested in math. Experienced crafters in this study felt comfortable with the measurement, density, weight, yarn tension, thickness, and shrinkage of the wide range of fabric and yarns. They discussed that once they got the embodied pattern of a stitch or a block in quilting they could advance it for making new patterns and designs, deepening and appropriating their math learning. Furthermore, crafting advances a variety of culturally responsive pedagogies foregrounded in different social and philosophical thoughts. Several crafters talk about their cognitive and affective experiences as they describe their love for crafting and their openness for following processes that lead to more elegant mathematical thinking, both in explicit and implicit ways. It calms their minds and helps them create things in a non-threatening environment where making mistakes is expected to advance their skills. Their description of the processes sounds like a different mathematical language where they are excited to take up challenging tasks, feel proud of their projects, and engage in lifelong and lifewide learning. The examples in this study resonate with Papert (1980) concept of mathematics – "The mathematics must be continuous with well-established personal knowledge from which it can inherit a sense of warmth and value as well as 'cognitive' competence."

The results of this study pose questions for future research, which could explore crafting in other communities and settings in order to design principles for the investigation of varied learning environments by analyzing the affordances of tools for creating personally meaningful objects, authentic activities, reflexive practices, and adaptive capacities. This work may pave the way to enhance design principles in collaboration with community partners to promote sustainable interventions to produce life-long and life-wide study of mathematics (Banks et al., 2007). This work also poses questions for the design of makerspaces and maker education environments more broadly. What would it look like to turn a makerspace into a Craftland? While some maker education focuses heavily on digital technology and high-end fabrication tools, fiber craft is an original context for making, with both a long history and a depth and breadth of disciplinary possibilities. Especially as much maker education focuses on making's utility for STEM and STEAM learning, the above principles of craft as a mathland have great potential as a design framework for makerspaces and maker education programs. Similar to the digital maker technologies often found in maker-centered learning environments, crafts can require practice to achieve proficiency, and this process can take a lifetime. The present findings point to the need for designing mathematical entry activities with fiber crafts as well as mathematical fiber crafts tracks that make it possible for students to engage with crafts in mathematical ways across school grade levels and beyond.

Because most participants in this study were highly educated and belonged to an economically advantaged social class, future work should investigate crafters at the intersections of issues of class, race, gender, and sexual orientation and those who craft for living. In the future, examination of how craft shapes math and how math shapes craft can be expanded to see whether they produce construct validity. For example, future work should assess how representative the results of the interview questions produced in this study are in a more varied population. Moreover, future research should explore in more depth contexts where crafting is a necessity or tradition rather than a hobby. For example, Blikstein (2021) examines international perspectives on the implicit cultural nature of making, urging us to consider the context, culture, and history when determining the emancipatory potential of maker activities. Furthermore, Kim et al. (2019) have elucidated how a strong understanding of local culture can be leveraged to forge maker pathways into STEM trajectories. Additional work could provide further information about how crafting and math co-occur *in situ* and would work toward amplifying and re-valuing complex work performed in everyday life by members of underrepresented groups. Finally, we recognize that math in everyday settings may seem less complex to some than math in formal settings. This perceived lack of sophistication and complexity may be read as a natural limit to the possibilities of craft and math. However, we argue that the ways math manifests in everyday settings has immense utility and more meaning to those who play, explore, create, and design in Craftlands.

Implications

This section elucidates some implications of this study for the design of Mathlands. First, teachers and teacher educators can continue to go beyond assessing proficiency in math through content-based standards to encourage improved procedural fluency, strategic competence, adaptive reasoning, and productive disposition (National Research Council, 2001). These strands of mathematics proficiency are already recommended, and work should continue to forefront them, alongside the math practice standards, in math classrooms. Continuing to integrate manipulatives and craft-based activities into mathematics education could also allow learners and educators to explore multiple modes of learning and create interdisciplinary environments that ask students to analyze the norms, beliefs, and values that inform the design of the manipulatives and crafts more deeply. This study shows promise for using relationships with participants to translate lifetime engagement in self-selected crafting activity into workshops and then applying them to formal classroom settings to understand how people engage with the concepts as they construct their interests, bridging the gap between self-selected and mandatory education. Finally, it would open spaces to educate people in the historical, cultural, and social biases concerning crafting that consign this highly technical art to the realm of domesticity and restrict it from prestige, status, and power due to its association with women. It is perhaps worth mentioning again that new innovations in physically modeling hyperbolic space came about when a woman mathematician discovered it could be done with crochet (Wertheim, 2005; Taimina, 2009). Thus, highlighting the rigor of craft and making space for it in classrooms could lead to new discoveries, new ways of understanding mathematics, and new ideas of what math is and can be at its core.

Second, when embedded in constructionist approaches to learning, these Mathlands would support the investigation of different cultural contexts that are not credited with their due importance in current school learning environments. Recentering and revaluing such communities and contexts would require creative work around both the objects of learning in classrooms and assessing students' learning. Building on the cultural, historical, and intellectual implications of crafting, educators could begin to support learners in understanding mathematics in ways that foreground what is personally relevant to the learners rather than defaulting to ritualistic performance of operations. Therefore, this study recommends that supportive math spaces be designed and integrated using these domain practices to work toward opening a diversity of math experiences for learners.

In the larger sociocultural context, this study presents compelling evidence for positive approaches to increase women's participation in STEM fields, which entails drawing upon Papert's constructionism, Lave's everyday math, and ethnographic studies of both craft and math *in situ* to create and identify tools, materials, and activities for use in both formal and informal practice of mathematics.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Indiana University and the University of California, Irvine Institutional Review Boards (IRB). The patients/participants provided their written informed consent to participate in this study.

Author contributions

Field work was driven by AK, NT, and PS. Analysis and writing was driven in collaboration by all authors.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.1029175/full#supplementary-material

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