11 RECLAIMING TRADITIONALLY FEMININE PRACTICES AND MATERIALS FOR STEM LEARNING THROUGH THE MODERN MAKER MOVEMENT

Kylie Peppler, Anna Keune,
and Naomi Thompson

Making, an educational reform movement that celebrates hands-on creative practices and technological inventiveness, is expanding in K-16 settings (Peppler, Halverson, & Kafai, 2016). The practice of making is conceptually inclusive of a range of tools and materials. From creating cardboard castles to laser cutting nature-inspired models, making provides youth the space to design personally meaningful artifacts. In our view, this aligns with constructionist approaches to learning (Papert, 1980) and promises a particularly impactful entry point for traditionally underrepresented youth to science, technology, engineering, and mathematics (STEM) fields.

Despite these promises, critiques have been raised from inside the maker educational movement that making is all too often associated with high-technology practices, including robotics, which may traditionally be more appealing to male audiences (Buechley, 2013). Although other material practices, such as fiber crafts, are also featured at world Maker Faires, flagship events showcase the state-of-the-art projects, while other practices are often relegated to the sidelines. Today, textile crafts have seen a resurgence of interest both within the maker movement and beyond, prompting us to re-examine the connections between crafting, mathematics, and computing. History demonstrates repeated patterns of innovation that have stemmed from traditionally feminine practices and materials. One prominent example arcs back to the history of computing, which is rooted in weaving, crocheting, and other textile crafts. Central to this examination is the role of embodied forms of learning, inherent in this view of constructionist theory in the form of body syntonicity.

This chapter examines contemporary cases of traditionally feminine crafts through the lens of constructionist theory to uncover how embodied forms of learning can disrupt—and ultimately benefit—STEM learning through the integration of new materials and practices. The data presented here draw heavily on our interventionist work in school and out-of-school settings with middle-school-aged youth to test how and to what extent fiber crafts can be used in to teach and learn STEM concepts. These interventions included the exploration of computational aspects of sewing (i.e., fabric manipulation or fabric origami) and rigid heddle loom weaving and mathematical aspects of handloom weaving. We analyzed youth engagement with fiber crafts in relation to emergent mathematical and computational concepts and further examined their body movements in relation to the computational and mathematical concepts we identified in their crafting. Collectively, this work offers a way to reclaim historically marginalized practices in ways that disrupt stagnant practices and spur innovation in STEM fields.

OBJECTS-TO-THINK-WITH, EPISTEMOLOGICAL PLURALISM, AND BODY SYNTONICITY

Papert (1980) theorized materials as "objects-to-think-with" that allow learners to discover formal systems as they explore inherent properties of materials while designing personally meaningful projects. Objects-to-think-with have two leading characteristics: They support epistemological pluralism and body syntonicity (Papert, 1980; Turkle & Papert, 1992).

Epistemological pluralism honors the existence of multiple productive approaches to engaging with a given subject and asserts that it is important to legitimize undervalued ways of engagement to diversify the learning culture of a particular domain (Turkle & Papert, 1992). Concerned with cognitive styles in the context of computing, Turkle and Papert observed people's practices and sense-making processes in relation to computational concepts. They found that expressive and relationship-forming engagement with computational materials was a legitimate approach to learning about computational concepts that, if devalued, led people to turn away from computing. Furthermore, they identified that technological innovations of computational materials made expressive approaches to computing possible. Thus, introducing new materials may change who engages with a subject and how.

Body syntonicity suggests that learning emerges as learners draw on experiences of imagining their own bodies in place of or in relation to the object they are manipulating. Papert (1980) developed the idea of body syntonicity in the context of computation when children manipulated digital representations and robotic materials by applying computational instructions. Certain computational materials supported children to imagine themselves as a computational representation that they were manipulating. Thus, the way in which materials are designed can support or obstruct learners to draw on their bodily understanding.

Together, the notions of body syntonicity and epistemological pluralism present a conceptual starting point for strategically designing STEM learning contexts that broaden participation by considering how materials shape the learning process for diverse learners. However, it remains unclear how exactly certain materials that are historically connected with underrepresented groups may support formal engagement in STEM in ways that can be equally recognized.

MATERIAL FEMINISMS

The learning theory of material feminisms extends this prior understanding to consider the body as one of many objects that shape a learner's understanding. At its core, material feminism takes into consideration that the actual physical body of the learner plays an active role in the shaping of possible experiences (Alaimo & Hekman, 2008). This extends the idea of body syntonicity. Papert argued that body syntonicity relates to the learners' imagination of the body in place of the objects they manipulate. The material feminist tradition recenters the actual body as source that opens up opportunities to learn. Although the body plays a role across feminist approaches, the focus on the physical body extends postmodern feminism that has focused on the discursive role of materials and their production through discourse (Alaimo & Hekman, 2008). Rather than considering the role of the body as a product of material-discursive practices and representations thereof, Barad (2003) suggests that the physiology of the body is also a force of production and to understand what it produces, the relationship among the material-discursive and its production must be illuminated.

Related to STEM learning, de Freitas and Sinclair (2013) have taken up Barad's materialist approaches for understanding the "materiality in/of mathematics" to advance the understanding of how the material nature of mathematics can radically shift the way mathematics is taught and learned. Instead of considering a learner's body as something that needs to be supplied with fixed, abstract concepts, de Freitas and Sinclair found that mathematical concepts, the materials of learning, as well as the learners doing mathematics, emerge in context as they physically come together. This view of seeing what else mathematics may become, in terms of continually developing concepts and practices, invites creativity and inventiveness into learning settings in ways that foster the kinds of learning that constructionist scholars aim to support.

The idea of how the personal, disciplinary, and material have come together over time—and the cultural assumptions that may have formed around their interaction—lead us to take a historical look at patterned trends of materials of STEM innovations and material-discursive notions of these materials in society (e.g., who uses what) to reveal which materials represent an ontological cut within disciplines. Material traces of exclusion can reveal possibilities for reintroducing historically relevant materials and the ways of knowing and producing they support. This presents possibilities for a renewed look at how we theorize, capture, and design constructionist learning environments that help broaden how legitimate participation in disciplinary learning happens.

STEM AND TEXTILES

Despite recent efforts of educational reform movements to foster inclusive STEM cultures, most STEM fields remain predominantly masculine domains with an incorrigible gender gap, especially in the United States (Sax et al., 2017). The underrepresentation of women is particularly problematic as diverse workplace environments have been linked to national economic security and productivity (Sax et al., 2017). While there continues to be a significant discrepancy in women's representation in STEM careers, researchers have observed that there is generally no gender difference in girls' and boys' mathematical achievement (Hyde, Lindberg, Linn, Ellis, & Williams, 2008). Still, there has been a steady decline in women's representation in the STEM workforce and higher education (Landivar, 2013). Nuanced studies of girls' and women's mathematical participation suggests that these differences stem from perceptions of the discipline of mathematics and the extent to which the cultures surrounding mathematics are welcoming to women (Alper, 1993). Mathematics as taught is frequently removed from the contexts in which the ideas make sense; leveraging design is useful as a pedagogical tool; allowing students to experience the mathematical ideas they are working with as an "object-to-think-with" (Papert, 1980) is likely to change the very nature of what they understand about mathematics.

A noteworthy "object-to-think-with" in STEM is electronic textiles (Buechley, 2006), which consistently present a cogent context and notable exception for introducing youth—especially girls—to circuitry learning (Buchholz, Shively, Peppler, & Wohlwend, 2014; Kafai, Fields, & Searle, 2014). Throughout history, fiber crafts have held an intimate relationship with technology innovation (Plant, 1995). For example, the earliest computers that women operated through punch cards for storing and accessing information were based on the Jacquard loom, which used punch cards to program fabric patterns (e.g., Plant, 1995). Such pivotal fiber craft-based innovations in STEM fields are not outliers. In mathematics, Taimina and Handerson (2005) proofed the possibilities to model smooth hyperbolic planes using crochet techniques, which had previously been considered impossible to construct. Using these models in teaching can support learning of mathematics (Taimina & Henderson, 2005). Fiber crafts offer opportunities for profound engagement in complex STEM concepts. However, despite this intimate relationship, we know little about how fiber crafts could be a context for STEM learning and for diversifying participation in STEM.

CONTEXT

Although part of a larger initiative related to fiber crafts and STEM learning, the data presented here draw heavily on our interventionist work in school and out-of-school settings. We facilitated interventions in school and out-of-school settings with middle-school-aged youth to test how and to what extent fiber crafts can be used in teaching and learning STEM concepts. These interventions included a week-long fiber crafts camp at the Indiana University School of Education's maker space to explore computational aspects of sewing (i.e., fabric manipulation or fabric origami) and rigid heddle loom weaving, as well as mathematical aspects of handloom weaving. We also conducted extended fiber crafts courses at a Midwestern public school to study the inherent computational concepts, practices, and products of heddle loom weaving and fabric manipulation. Across school and out-of-school settings, each session lasted between sixty and ninety minutes and was joined by eight to ten middle-school-aged youth.

During the interventions, we videorecorded youth crafting and conducted five- to ten-minute–long semi-structured interviews with the youth as they worked on personally meaningful projects. The interviews asked youth to explain their design process and any surprises they encountered while crafting. The interviews were also videorecorded using mobile cameras to capture the embodied meaning making of the youth around the construction of the fiber artifacts. Last, we captured project dimensionality and complexity through videorecordings of youth projects to support a detailed view of materialized STEM concepts.

We analyzed the youth engagement with the fiber crafts in relation to emergent mathematical and computational concepts by iteratively coding the video based on the K12CS framework for computer science education (e.g., functions and loops) and the Common Core (CC) state standards for mathematical proficiency (e.g., algebraic reasoning). Then, we coded the interviews for markers of artifact formation and how youth described their body movements in relation to the computational and mathematical concepts we identified in their crafting. As case studies, we selected three youth who performed the craft activities in ways that made the facilitated craft technique and pattern recognizable in their artifact. As most youth accomplished that, the youth we selected serve as typical examples of the movements of tools and materials that brought about deep engagement with STEM learning.

ALGEBRAIC REASONING: WEAVING PATTERNS

Two CC math practice standards that span across grades ask students to seek out structures and to express patterns. Both practices are visible as one young weaver, Kade, attempted to incorporate a recursive sequence pattern into his weaving design. Just over halfway through a weaving introduction workshop, participants were handed paper with blank one-inch-by-one-inch grid squares to help them continue to design their weaving patterns. A facilitator—one of the authors of this chapter—sat down with Kade to help him see how his grid paper could be used. Looking at the few rows he had already woven, the facilitator began reading his project, "Sort of looks like, like over over over, under under, over over over over, under under under." Together, Kade (K) and the facilitator (F) started to translate the weaving into a number pattern and to continue it forward. The weaver had a vision that the facilitator couldn't see at first:

K: *Three, two, four, three*

F: *Three*

F: *Two // K: Five (overlapping speech)*

K: *Four*

F: *Ohh*

K: *And then six. And then that's supposed to be five.*

F: *Ok cool.*

K: *And then it would go on to seven, six, and eight, seven, and nine, eight, and then ten, nine. I don't know.*

F: *Oh, I see what you're doing.*

Kade was developing a recursive sequence (3, 2, 4, 3, 5, 4, 6, 5, 7, 6, 8, 7, 9, 8, 10, 9) that could be described as following the pattern: "minus one, plus two." Mathematical proficiency, as described by CC standards 7 & 8 includes "discern[ing] a pattern or structure" and "notice[ing] if calculations are repeated" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Not only does the work with pattern and sequence in this episode align with these descriptions of proficiency but also this weaver went a step further than noticing and discerning by inventing a structure with repeated calculations. Thinking about patterns in this way may also have implications for more advanced and pure mathematics. He was not asked or instructed to invent such a sequence but was prompted to do so by the weaving activity itself. Additionally, the grid planning sheet (figure 11.1) helped him imagine the sequence further and to determine how his plan would play out in the physical world with the weaving materials.

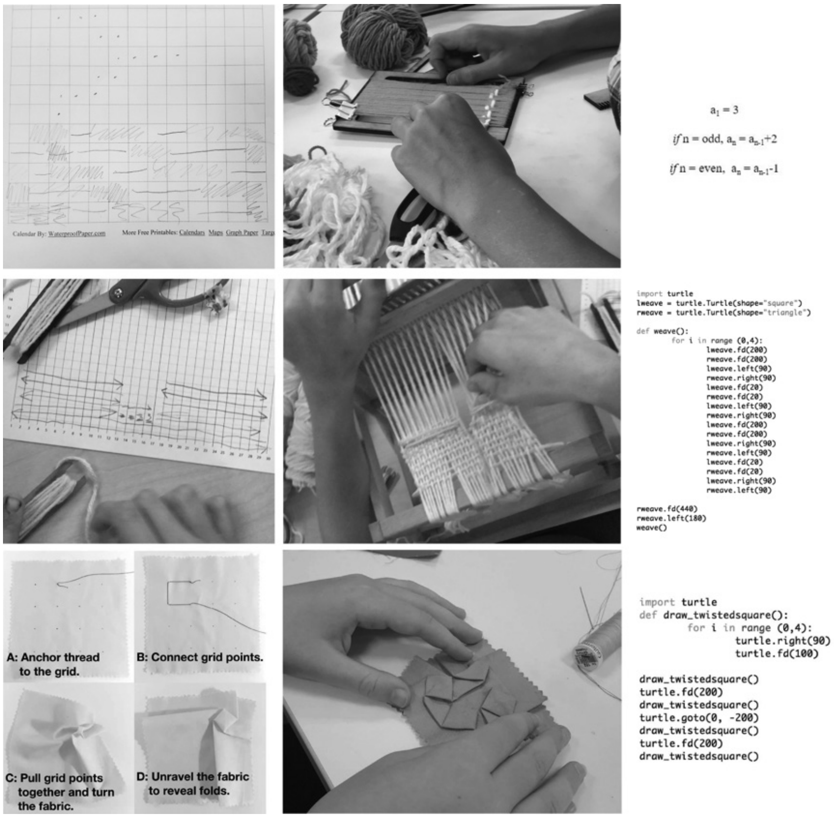

FIGURE 11.1

Top: Kade weaving (left), Kade's project plan (center), Recursive function for Kade's pattern (right). *Center:* Jasmine's project plan (left), her weaving project (middle), parallel process translated into Python (right). *Bottom:* Twisted square technique (left); Emma's project (center); Python code of stitch pattern (right).

Kade's engagement with the loom led to the creation of a unique and beautiful woven tapestry as well as the invention of a recursive sequence that exceeded some measures of mathematical proficiency. The materiality of weaving, composed of Kade's hands and his threaded shuttle moving "over over over, under under" the vertically warped thread, produced a grid pattern that shifted form through movement and invited playful recursive number sequences. The mathematical concept spilled across rows, transformed, and became form in the world that could be further manipulated.

PARALLEL PROCESSING: WEAVING WITH TWO SHUTTLES

Parallel process while developing a computer program is an advanced and challenging mental exercise that requires keeping in mind the simultaneous progression of multiple moving parts. At the same time, middle-school-aged weavers, such as Jasmine, who participated in a weaving course, seem to grasp this idea immediately as they created beginner lace patterns. Jasmine intended to weave an opening into her tapestry and explained her graphical project plan (figure 11.1, *center left*):

> So this is the hole right here. And [the yarn] goes one way, then [the yarn] goes the other way. And then [the yarn] goes this way and then you skip these strings, where the hole is going to be, and then you go the same way and then you go this way and do the same as you did.

In her explanation of the first three lines in her project plan, which include the first lace weft, Jasmine's use of "skip these strings" suggests that she plans to use one color of yarn on only one shuttle to produce the lace design. This is mirrored by the direction of the arrows on her project plan, where the arrow on line three points into the same direction before and after the "hole." This seems to continue the row, rather than build both sides of the fabric in parallel.

However, after seven rows into her weave, Jasmine arrived at a place in her tapestry where she decided to introduce her simple lace pattern, the "hole." Here, she started to engage two yarn colors, teal and rose, that she wrapped around two separate shuttles. Alternating between the colors, she moved the teal yarn from left to right and the rose yarn from right to left, before turning the handle of the loom to shift the warp positions. On the graph paper, this would have been represented as two arrows pointing toward one another rather than in the same direction as was present in Jasmine's plan, a conceptually more complex task. Figure 11.1 (*center*) shows Jasmine's tapestry with five rows into the lace pattern. Compared to the non-lace weave (rose), the lace pattern shows inconsistencies. This suggests that the added complexity of alternating colors and directions before changing the warp thread positions requires additional practice. However, it is also evident that the teal and rose side of the tapestry are advancing in parallel. This means that the conceptual articulation, rather than the craftsmanship, was foregrounded for Jasmine.

Epistemological pluralism allows us to recognize and value broader definitions of disciplinary engagement than would otherwise be possible. Thus, Jasmine's two weaving shuttles are identifiable as complex programming processes, no less authentic or important than programming that occurs in more traditional or standardized ways. Material feminisms focuses in on the new kind of material instantiation that is being produced as Jasmine, the loom, and the shuttled yarn come together to tangibly reformulate a computational unit that would otherwise not exist. In this example, Jasmine is performing the computation that would typically be delegated to the computer, making the process transparent and possible to ask questions about.

LOOPS AND FUNCTIONS: SEWING

To produce effective code that can be reused in other projects, programmers need to recognize and abstract repetitions. Functions are powerful computational concepts that can do just that. Programmers use functions to define and describe a procedure of steps that can be recalled in the body of a computer program. Functions are challenging to learn even for undergraduate students, yet their use is inherent to fiber crafts. A compelling example emerged when a participant, Emma, recalled and modified a 2D grid pattern while sewing a 3D texture. Emma used the *twisted square* expression (see figure 11.1, *bottom left*): From the point of origin, where her thread was anchored to the fabric, Emma connected four corners of a square by sewing one grid point to the left, one down, one right, and back up where she pulled all points together. Emma repeated this loop three more times and then unfolded her ruffled fabric into four twisted squares (see figure 11.1, *bottom center*). She explained, "I had to separate each little thing to make it square. I had to push it down. It looked like a mess when I finished sewing." Each expression enclosed a particular amount of fabric that, when pulled together, ruffled the surrounding fabric, distorted the grid, and challenged Emma's orientation to the fabric.

The process of exploring the effects of a combination of steps on the resulting texture foregrounded the use of functions. This becomes apparent

581-84689_ch01_1aP.indd 135 5/6/20 6:53 PM

when translating the 2D grid pattern into Python code (see figure 11.1, *bottom right*) that defines a function at the start of the script and then recalls it in the body of the code. The computation was inherent to the performance of the craft and seemed to present an intimate approach to practicing abstractions that are typically performed by the computer.

Emma's tucking and folding brings loops and functions into the physical world, transforming how abstracted repetitions can be understood and advanced. It is not in spite of, but because of, Emma's engagement with "every little thing" of her fabric, needle, and thread that she was able to create such complex computational expressions. It is her physical hands and her orientation to the material that brings about the computation rather than imagining herself in place of the material and then translating this cognitive capacity into a computer program.

DISCUSSION

The examples broaden ideas of what math and computation can look like and demonstrate high-level engagement with existing and authentic STEM concepts through fiber crafts. Although it may be expected that fiber crafts involve basic, low-level actions such as counting and measuring, the learners in these examples go far beyond. This is one of the promises of intersections between crafts and STEM crafting; the union seems to invite deep engagement with concepts by presenting them in ways that necessitate repetition and "big picture" aesthetic coherence. The artifacts that emerge from these crafting experiences are personally meaningful and relevant. As such, learners' aesthetic desires lead to mathematical and computational complexity, deeply entangling craft and STEM. Where our constructionist perspective on learning provides a productive lens through which to view the work being done in these crafting interactions, the material feminist framing allows us to identify aspects of material-disciplinary workings that would otherwise go unnoticed.

Body syntonicity allows us to understand how interactions in space with materials signal deep learning about traditionally abstract concepts. Beyond the children imagining themselves crawling between warp thread, what produced the computation and mathematical engagement was the way the children's bodies, the looms, the yarn, and the over-and-under came together to form an entity that enclosed the mathematics in ways that did not exist before and that could be further manipulated. The physical form of the children's bodies was a material that came together with other materials at the craft table and produced the crafting activity as well as the new STEM form. Following a material feminist approach to learning, we begin to articulate this as a novel observation. This kind of syntonicity with the material makes it possible to recognize a child's body as a component part rather than the intentional driver of the STEM instantiation. It expands the idea of body syntonicity into the physical realm. The computational and mathematical nature of fiber crafts is a promising context through which to further investigate what this may mean for learning processes for a range of learners.

Epistemological pluralism allows us to see the sewing and weaving activities as compelling and alternative ways for children to get to know complex disciplinary concepts in their own ways and on their own terms. Material feminist perspectives of learning allow us to recognize the coming together of component parts as significantly changing how we can conceive of the nature of STEM, for instance, a computer. In both Jasmine's and Emma's case, the children performed actions that would usually be delegated to the computer. They became part of the physical form of the computer, extending its form to the human. This has the potential to transparently show underlying workings of computers, with which repeated human movements could be freed through automation. This allows researchers to speculate new forms of computers and the children to transparently become part of blurred software and hardware relationships. For example, when the warp threads on the loom, despite their physical form, are perceived as software, the way in which Jasmine weaves two shuttles through top and bottom warp threads to create the lace becomes an artistic way of manipulating a program, similar to ASCII art. At the same time, the shuttles could also be considered the central processing unit of the computational machine that controls its input/output mechanisms. These dual hardware/software roles of material aspects of fiber crafts expand epistemological pluralism. It is no longer just ways of knowing the world but also ways of being in the world that productively enable us to theorize about the role of the youth in the STEM performance.

The examples given here showcase the immense potential in reclaiming traditionally feminine craft techniques for STEM learning. Threading, tucking, weaving, and folding need not be separated from their feminine histories to be valued as intellectually and materially innovative. Our ongoing work, beginning with e-textiles, continues to show the intrinsic and disciplinary value for all types of learners to engage with textile crafts, as well as threads on how to advance theoretical concepts of constructionism.

ACKNOWLEDGMENTS

This work was supported by a collaborative grant from the National Science Foundation (DRL #1420303) and a grant from the Center of Craft, Creativity, and Design awarded to Kylie Peppler. Any opinions, findings, and conclusions or recommendations expressed in this article are not those of National Science Foundation, Indiana University, or the University of California. Portions of this chapter are derived from the dissertation work of Anna Keune and Naomi Thompson. We also thank teachers at the Project School and Indiana Kids as well as Creativity Labs members Janis Watson, Joey Huang, and Suraj Uttamchandani, without whom the work would not have been possible.

REFERENCES

Alaimo, S., & Hekman, S. J. (Eds.). (2008). *Material feminisms*. Bloomington, IN: Indiana University Press.

Alper, J. (1993). The pipeline is leaking women all the way along. *Science, 260,* 409–411.

Barad, K. (2003). Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs: Journal of Women in Culture and Society, 28*(3), 801–831.

Buchholz, B., Shively, K., Peppler, K., & Wohlwend, K. (2014). Hands on, hands off: Gendered access in crafting and electronics practices. *Mind, Culture, and Activity, 21*(4), 278–297.

Buechley, L. (2006, October). A construction kit for electronic textiles. In *Wearable Computers, 2006 10th IEEE International Symposium* (pp. 83–90). Montreux, Switzerland: IEEE.

Buechley, L. (2013, October). Closing address. *FabLearn Conference,* Stanford University, Palo Alto, CA. Retrieved from http://edstream.stanford.edu/Video/Play/883b61dd951d4d3f90abeec65eead2911d

de Freitas, E., & Sinclair, N. (2013). New materialist ontologies in mathematics education: The body in/of mathematics. *Educational Studies in Mathematics, 83*(3), 453–470.

Hyde, J. S., Lindberg, S. M., Linn, M. C., Ellis, A. B., & Williams, C. C. (2008). Gender similarities characterize math performance. *Science, 321*, 494–495.

Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review, 84*(4), 532–556.

Landivar, L. C. (2013). Disparities in STEM employment by sex, race, and Hispanic origin. *American Community Survey Reports*, ACS-24, U.S. Census Bureau, Washington, DC.

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core Mathematics State Standards*. Washington D.C.: National Governors Association Center for Best Practices, Council of Chief State School Officers.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Peppler, K., Halverson, E., & Kafai, Y. B. (Eds.). (2016). *Makeology: Makerspaces as learning environments* (Vol. 1&2). New York, NY: Routledge.

Plant, S. (1995). The future looms: Weaving women and cybernetics. *Body & Society, 1*(3–4), 45–64.

Sax, L. J., Lehman, K. J., Jacobs, J. A., Kanny, M. A., Lim, G., Monje-Paulson, L., & Zimmerman, H. B. (2017). Anatomy of an enduring gender gap: The evolution of women's participation in computer science. *The Journal of Higher Education, 88*(2), 258–293.

Taimina, D., & Henderson, D. W. (2005). How to use history to clarify common confusions in geometry. *MAA NOTES*, 68, 57.

Turkle, S., & Papert, S. (1992). Epistemological pluralism and the revaluation of the concrete. *Journal of Mathematical Behavior, 11*(1), 3–33.