International Society of the Learning Sciences

Performing Algorithms: Weaving as Promising Context for Computational Learning

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Abstract: An important aspect of diversifying STEM fields, including computing, is to better understand how tools and materials that are associated with socio-historical practices of underrepresented populations are aligned with disciplinary concepts and what these materials contribute to teaching and learning. Taking a constructionist stance, this study builds on the precedent of electronic textiles in the learning sciences to investigate the alignment of non-electronically augmented fiber crafts with core computer science concepts through the idea of epistemological pluralism. Through an artifact analysis with computer science instructors, the study found that weaving and manipulating fabric are aligned with core computational concepts and that one craft activity requires multiple approaches to computational concepts. The work points to a particular instance of epistemological pluralism and the potential of fiber crafts as a context for understanding transfer of computational concepts across multiple representations.

Introduction

International communities are calling for more sustainable STEM and digital education (European Commission, 2021). One important aspect of this is to diversify STEM fields and to ensure underrepresented groups, including women, persist. Women's persistence in computing can be supported by fostering a sense of belonging that expands dominant computing cultures (Lewis et al., 2017). An opportunity for expanding computing cultures are tangible manipulatives–especially those that consist of materials that are associated with socio-historical practices of underrepresented populations in computing. For example, educational research on electronic textiles, which augment the feminized practice of sewing with electronic components (Buechley, 2006), demonstrated new leadership opportunities for girls (Buchholz et al., 2014), improved learning outcomes for all students (Peppler & Glosson, 2014), and inroads for rupturing dominant computing cultures (Kafai et al., 2021).

Yet, it remains underexplored how fiber crafts in their own right–without electronic components–align with core computational concepts and whether they present relevant contexts for further inquiry of computational learning while fostering a sense of belonging. Building on the precedent of educational research on e-textiles, the present study investigated weaving and manipulating fabric as a context for performing computational concepts, and asked: How do fiber crafts (i.e., weaving and manipulating fabric) align with computational concepts?

The present study builds on constructionist approaches to learning that posit that disciplinary concepts can be practiced through a range of expressive creations of personally meaningful artifacts (Papert, 1993). It also builds on design studies that call attention to the material relationships of digital things (Dourish, 2017). To begin to understand fiber crafts as contexts for computational learning, this qualitative study analyzed artifact analyses sessions with computer science instructors of middle school students' projects. The findings align fiber crafts with computational concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting) and show that fiber crafts require multiple approaches to computational concepts within the same craft activity (i.e., syntax-oriented, spatial, and performative approach). The work has implications for the design of interventions for computational learning of and with fiber crafts and points to an instance of epistemological pluralism and the potential of fiber crafts as a context for understanding transfer of computational concepts.

Potential of fiber crafts for inclusive computer science learning

To counter the trend of early drop-out of women in computer sciences, researchers have called for the recognition of women's leadership skills (Saavedra et al., 2014) and specialized computer science programs for girls (e.g., Pinkard et al., 2019). The movement toward identity-based groups frames computing as a form of community empowerment (Abbate, 2018) and presents a response to research that shows that women's persistence in computing can be supported by fostering a sense of belonging (Lewis et al., 2017).

The relationship of fiber crafts to women and computing promises a starting point for fostering computational belonging. For centuries, fiber crafts have been centrally positioned in the life experience of women (Barber, 1995). In a girl's education, fiber crafts were used to prepare her for domesticity while some women have used their needle work for socio-political expression (Parker, 1984). In early computing, the socio-historical relations of fiber crafts and domestic work were used to recruit women (Abbate, 2012) who went on to profoundly contribute to technology innovation (Essinger, 2004). For instance, the woven memory of Apollo Mission computers was produced by women and derogatively dubbed "little old ladies' memory" (Rosner et al., 2018).

Within educational research, electronic textiles (Buechley, 2006) have consistently proven to be a cogent context for introducing youth—especially girls—to STEM ideas (e.g., Buchholz et al., 2014). Yet, despite research linking textiles to computing, computing with fiber crafts is frequently focused on adding (programmable) electronic components to textiles. How textile production is in and of itself computational remains an underexplored yet promising starting point for contributing to computational belonging.

A material dimension of epistemological pluralism

The constructionist idea of *epistemological pluralism* theorizes multiple ways of getting to know an idea as a key to domain learning (Turkle & Papert, 1992). Particularly productive for the present study is an underlying ontological dimension of epistemological pluralism. Turkle and Papert (1992) showed that technological innovations of computational materials, such as changes from command-line interfaces to object-oriented graphical interfaces, facilitated relationship-forming and expressive approaches to computing.

This resonates with research related to technology design that calls attention to the underlying material relationships of digital things (Eglash et al., 2020). For example, although often de-materialized, digital concepts, such as bits, are bound to an underlying tangible materiality (Dourish, 2017). Focusing on the materials and the practices they bring to learning, can teach about how materials "contribute to forms of learning and collaborating that are unexpected but that may be fruitful if developed further" (Sørensen, 2010, p. 7).

For example, when looking at weaving as a form of algorithmic doing, the process of programming, in which writers determine the outcome, becomes closer to live coding that produces an unfolding algorithm of person and loom combinations (Griffiths & McLean, 2017). In this case, the socio-material practices of loom and people frame the typical programming approach to algorithmic doing as something very different yet valuable. The ontological threads within constructionist ideas of epistemological pluralism and technology studies prompted the present study to consider what fiber crafts materials bring to computational learning.

Methods

This qualitative study investigated the alignment of computational concepts with fiber crafts. The study facilitated artifact analysis sessions with computer science instructors at research focused universities on whether and how they saw computational concepts in youth fiber craft projects. Computer science instructors were engaged because of their expert understanding of computing and their experience teaching computing to beginners. While this risks to position textiles in a supporting role, the instructors presented a starting point for aligning textiles with computing concepts all along being able to inform understanding of what textiles do that is typically not done in introductory courses. Recruiting happened through snowball sampling and systematic search of university websites. The projects were produced by middle school students during a fiber crafts course (Keune, 2021).

The data sources consisted of artifact analysis sessions and photographs of youth projects. The *artifact analysis sessions* (average 60 minutes long) introduced instructors to the crafts and facilitated analysis of youth projects. The instructors were presented with youth-created projects and were asked to identify how the craft require the use of computational concepts. *Close-up photographs of youth projects*, taken after each course session, captured the project plans and fiber-craft projects from a range of angles to capture project dimensionality. On average, this resulted in 20 photographs per youth per session (1886 photographs in total). The photographs showed details of youth-produced artifacts, including stitches and weaving techniques.

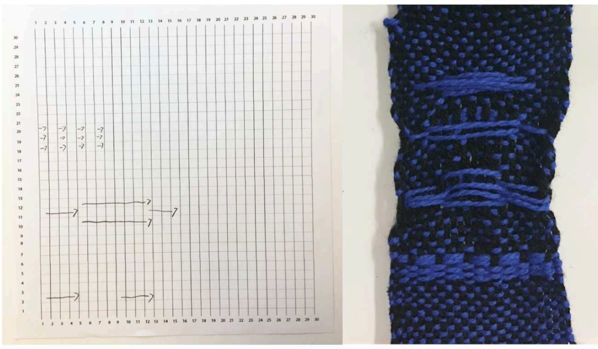
The *analysis of the artifact analysis sessions* followed iterative thematic coding related to K12CS framework (2016) core concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting) to align computer science concepts with fiber crafts. Descriptive codes built on language that the instructors used to capture expressed nuances. To collapse the descriptive codes, the codes were related to core concepts of the K12CS framework and subcategories of core concepts. The codes were discussed for agreement with a fellow researcher and presented for discussion to a research team. This approach made it possible to focus on descriptions by the instructors that elaborated what fiber crafts could bring to computing education.

Findings

The analysis of the artifact analysis sessions identified that computer science instructors aligned fiber crafts with five computational concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting). While the research aligned all five concepts with both weaving and manipulating fabric, in the interest of space, this paper focuses on showing the alignment of algorithms with weaving and what this alignment contributes.

Algorithms are routines that can be performed by people and computers to accomplish tasks. Algorithms require effective communication with a computer by sorting algorithmic tasks and sub-tasks for computers to read and respond to. Across both crafts, instructors mapped algorithms directly onto crafts because of the crafts' reliable artifact transformation. Artifact transformation consisted for both crafts of opportunities for three types of approaches to algorithms: 1) Syntax-oriented, 2) spatial, and 3) performative approaches to algorithms (see Figure 1 for weaving). Instructors highlighted the need to translate across approaches within the same activity.

Figure 1
Spatial-material and performed approach to algorithms in weaving



For weaving, 92% of instructors (n=11) highlighted the repetitive process of changing heddle positions paired with shuttle directions in a plain weave as algorithmic. A heddle is a flat piece with long and short openings for lifting threads. A shuttle is a carrier of yarn. For example, to create a plain weave pattern, weavers had to lift the heddle to part lengthwise threads and draw the shuttle with yarn between the threads in one direction. Then, to weave another row, weavers had to lower the heddle and draw the shuttle with yarn between the threads in the opposite direction. This pairing of heddle positions and shuttle directions remained for the duration of the weave.

Instructors connected the algorithmic aspects of weaving to a syntax-oriented approach of instructing a computer, like a programming language. One said: “It seems very algorithmic. You could (...) write instructions that [are] pretty robust that could be used to describe the behavior.” The instructor’s quote leads to the idea that weaving patterns can be described in a formal language, for instance, by writing a pattern down on paper, creating an interactive representation, or automating the functions of the loom through a computer program.

Rather than considering syntactic programming languages as the only way to engage with algorithms, the instructors suggested that algorithms are anchored with coordinate systems. One instructor said:

> Coordinates [in the computer] correspond to the states of the algorithm. To implement [an] operation on a computer, you have to think in terms of coordinates and where [to] put that number eventually (...). This is how the computer thinks.

Instructors also connected weaving with spatial approach to algorithms through the project plans on coordinate paper that youth drew (Figure 1, left). The coordinate grid paper showed warp threads of the loom as vertical lines and youth drew weft threads as horizontal lines. All warp and weft threads were numbered so they could plan personal patterns. Such coordinate patterns graphically represented the steps that would result in the woven fabric. One instructor said: “You just follow it very graphically (...) It’s basically a line of code where you do right to left then you just follow it. Right to left, top to bottom.” Through its position on the coordinate paper that corresponded to the weft threads of the loom, each drawn line was spatially anchored and could be located on the loom.

Instructors further connected weaving with a performative approach to algorithms. The algorithmic performance (i.e., the repetitive process of changing heddle positions paired with shuttle directions done by the loom and the youth) translated coordinate patterns on fabric into fabric. Instructors recognized the youths’ process of weaving yarn into a matrix of warp threads as the way a computer would process a program (see Figure 1, right). Youth performed the algorithm, like how a computer would process a program, rather than communicate it in a machine-readable form for a computer to perform.

Discussion and Implications

Looking across the three approaches to algorithms in weaving, suggests that weaving is a context worth investigating for computational learning. Additionally, because weaving includes different approaches to algorithms in one activity, the craft presents a unique context for transfer. The research highlights the utility of supporting all three approaches (i.e., syntax-oriented, spatial, and performative) within one activity. For example, to foster the syntax-oriented approach to algorithms, activities could include opportunities to articulate the tasks and subtasks of weaving or opportunities to correct or complete pseudocode translations of common patterns. Where the first would be aligned with established weaving practices, the pseudocode activity could highlight intersections among weaving and computing.

The relationships among approaches to algorithms were nonlinear. Rather than one leading approach, the translations across approaches to algorithms inform each other. For example, while a graphed plan could be implemented one to one by performing the illustrated algorithm, changes to the pattern can happen on the go, resulting in edits to the graphed plan. The fact that weaving fabric can involve multiple nonlinear approaches to algorithms within the same craft presents a particular instantiation of epistemological pluralism. Where weaving provides several ways of engaging with a domain idea that weavers can select from, weaving also makes it possible to engage with more than one approach to algorithms. This leads to considering epistemological pluralism in terms of recognizing multiple ways to approach a domain conceptual understanding simultaneously by one person. Along with the socio-historical promise of fiber crafts as fostering computational belonging for women in computing, the expanded understanding of epistemological pluralism further warrants additional studies that explore the utility of fiber crafts as context for computational learning.

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Acknowledgments

This work was supported by the Anita Borg Institute and a grant from the Center for Craft. Any opinions, findings, and conclusions or recommendations expressed are not those of the Anita Borg Institute and the Center for Craft.