SPEERLoom: Collaboratively Re-Crafting CS Education

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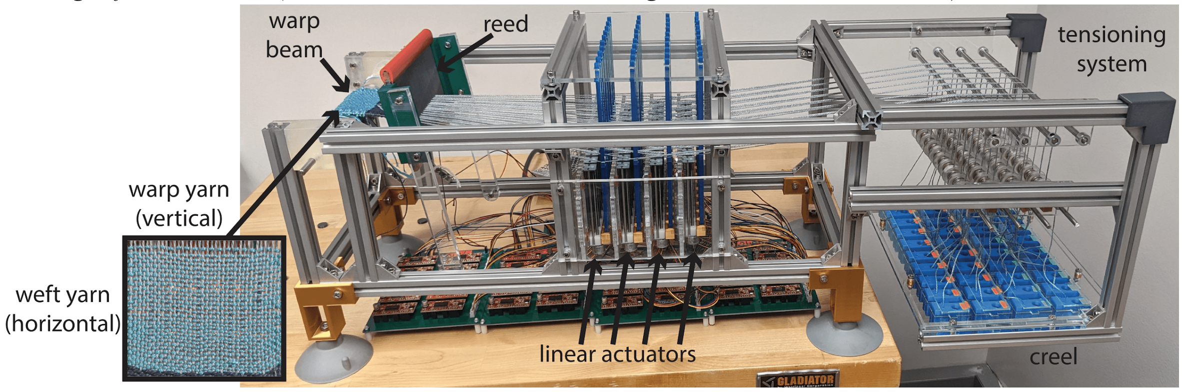
Abstract: Our work aims to increase the collaborative ability of college students in computer science classrooms where students must work towards a shared goal with peers from different backgrounds and abilities. Our work focuses specifically on leveraging high-quality collaborative design to bridge the gap between fiber arts and robotics by enlightening students to their shared foundations in mathematics and computational thinking. We achieve this goal through the design of SPEERLoom (Semi-automated Pattern Executing Educational Robotic Loom), a new open-source Jacquard loom kit designed to foster students' exploration of weaving, mechatronics, mathematics, and computational thinking. In this demonstration we present SPEERLoom and allow the exploration of a sample lesson using the loom.

Introduction

Computational thinking (CT) is identified as an essential skill in the 21st century as part of the other 4C skills - creativity, communication, collaboration, and critical thinking (Grover & Pea, 2018). Particularly, both collaboration and computational thinking are mandated as essential skills in the current Next Generation Science Standards (NGSS) (NGSS, 2013). As demand for both skills increases, studies in learning sciences have examined how students work together to solve CT tasks regarding robotics and programming (Grover et al., 2018; Huang & Parker, 2022). Additionally, recent studies explored how CT can be integrated and promoted in a STEAM context (e.g., Conde et al., 2019). Our work bridges the seemingly disparate fields of robotics and textiles by bringing attention to their shared foundations in different mathematical principles and the exploration of these principles through CT. To accomplish this, we designed SPEERLoom (Figure 1): an open-source Jacquard loom kit designed for teachers to use to develop interdisciplinary collaborative curricula. All of our designs, assembly instructions, and software can be found at: https://sites.google.com/view/roboloom.

Figure 1
An image of SPEERLoom (Semi-automated Pattern Executing Educational Robotic Loom)



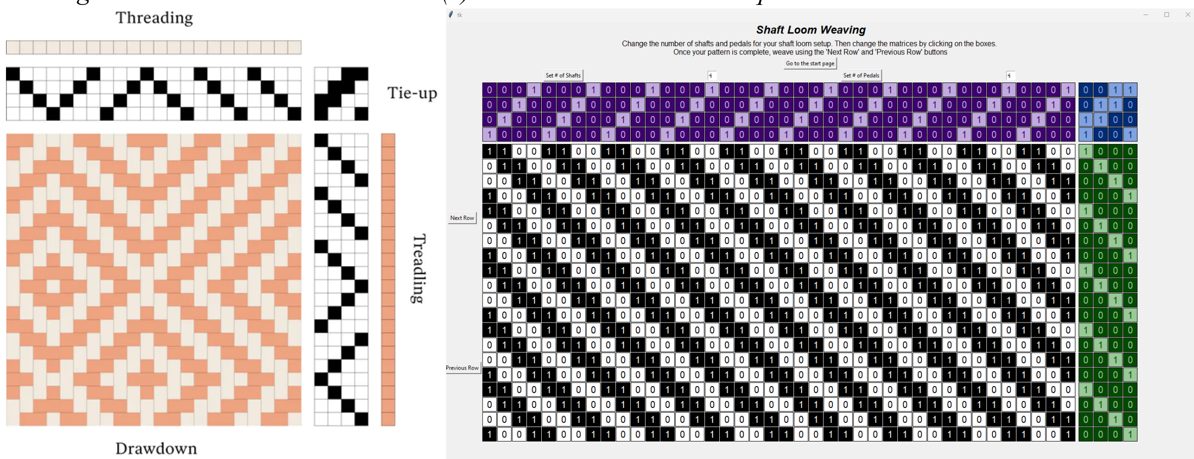
SPEERLoom combines weaving and engineering while allowing for the exploration of their common foundations in mathematics, specifically linear algebra, geometry, and CT. Many of engineering's core principles rest on foundations of linear algebra, specifically in the use and manipulation of matrices. Weaving, though commonly thought to be disparate from math, also has foundations in matrices and the manipulation of these matrices to create something new (Harlizius-Klück, 2017). Additionally, the physical product of weaving, the cloth, holds different properties that can be engineered through the use of geometry and CT (Peirce, 1937; Pollitt, 1949). SPEERLoom was designed to foster collaboration between students as it requires them to work together to complete the construction. Once built, the final machine allows opportunities for students with different backgrounds to contribute to a singular goal: the production of cloth that expresses shared meaning.

Theoretical background

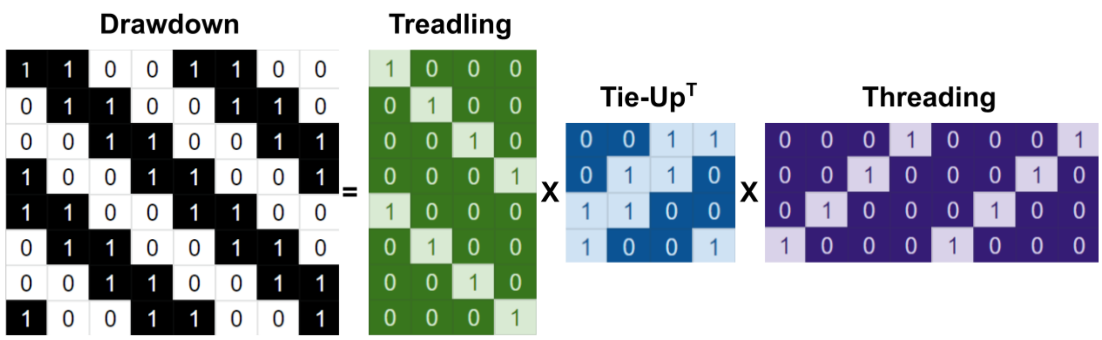
By leveraging weaving and computation, we designed a curriculum that draws upon students' diverse identities as enhancements, affords the design and enactment of social scaffolds, and provides a rich context for learning. Within this context, properly supported collaborative learning has been observed to have positive impact (Van Ryzin et al., 2020; Cooper & Slavin, 2001). Weaving is a fabrication process that has been used to express much of what we value in culture through the choice of material, cut, color, shape, and weave (Postrel, 2021), while remaining grounded in mathematics (Harlizius-Klück, 2017; Peirce, 1937; Pollitt, 1949) and computation (Harlizius-Klück & McLean, 2021). Woven cloth is made from the interlacement of warp and weft yarns (Figure 1). Weaving patterns for shaft looms are created from the manipulation of the threading (which warp yarns are actuated by which shaft), tie-up (which shafts can be raised together by a single pedal), and treadling (which pedal the weaver should press at a given time step). Each of which can be represented as a binary matrix (Harlizius-Klück, 2017). These binary matrices can then be multiplied to create the weaving pattern (Figure 2c). These mathematical principles and many others in cloth geometry and physical properties of cloth (Peirce, 1937; Pollitt, 1949) connect the art of weaving to mathematics. Weaving is also connected to coding, and computational thinking not just through the computational nature of looms influencing the advancement of technology (Essinger, 2010) but also through the decomposition, abstraction, and algorithms involved in weaving pattern creation (Harlizius-Klück & McLean, 2021). Prior research demonstrates how weaving fosters mathematical insights through this patterned activity (Peppler et al., 2022).

Figure 2

A weaving draft shown in three configurations. (a) shows a typical draft with threading, tie-up, treadling, and drawdown (the final weaving pattern). (b) shows a screen capture of SPEERLoom's UI mimicking (a) and showing the user-editable matrix values. (c) shows the mathematical equation to create the drawdown.



(a) (b)



(c)

SPEERLoom

SPEERLoom (Figure 1) is an open-source Jacquard loom kit that students can assemble, thread, program and weave on. SPEERLoom is designed as a tool to foster interdisciplinary collaboration in the classroom while providing a hands-on opportunity for students to explore the interesting intersection of many different disciplines. Using SPEERLoom, students can create weaving drafts (Figure 2b), explore the mathematical principles of their weaving draft, predict their cloth properties using mathematics, and finally create a woven piece of cloth.

A collaborative user experience

SPEERLoom was designed not only to fit into an educational setting, but also to foster collaboration between students of different backgrounds. SPEERLoom was designed with a systems engineering mindset, meaning that it breaks down into subsystems that can be assembled separately by small groups. The assembly of the subsystems requires multiple sets of hands simultaneously interacting with parts and tools to be efficiently assembled, affording an opportunity for collaboration. For example, working to build the tensioning system (Figure 1) requires one person to hold pieces together, while another person secures the pieces with a bracket. Once assembled, warp yarns are threaded through the tensioning system to apply proper tension. This process benefits from students with domain knowledge in multiple areas. Tensioning the warp is a balance between creating enough tension to make quality cloth while staying within the bound of the forces the linear actuators can achieve to move the warp yarns. Students possessing knowledge within these domains can share their knowledge as the team works to balance the constraints from both weaving and mechatronics in order to create a working mechanical loom.

To finish the system, it is necessary for SPEERLoom's subsystems to come together, requiring individuals to engage different disciplinary knowledge and skills (e.g., design thinking, mechatronics concepts) and work as a group to achieve the final integration. Small groups come together to inform the larger group of what they have built and what is required to connect the subsystem into the larger system. Then small groups must work together to balance different needs, creating a space where collaboration is necessary to create a working final product. Even though the design of SPEERLoom allows for work to be split up into smaller tasks, these tasks still afford collaboration while reducing the overall time for assembly. Once built, domain concepts pertaining to weaving, math, and mechanics that are taught as part of the accompanying curriculum are made visible through SPEERLoom. As students design patterns using matrix math, they see the results reflected in SPEERLoom's software. As they use this software, they see how it commands the motors to move into the pattern they input into the software. As they work with SPEERLoom, students from different backgrounds are provided opportunities to both take and follow the lead as they work through the process of combining art, math, computer science, and mechatronics to produce their final cloth.

Hardware and kit features

We designed SPEERLoom to be monetarily feasible, educationally advantageable, and quick and easy to build, program, and use all while maintaining a minimum quality of cloth production that allows students to explore and execute complex patterns and walk away feeling accomplished.

SPEERLoom is a fully Jacquard loom capable of actuating each heddle (i.e., wire with an eye in its center through which a yarn is threaded to move the yarn up and down) individually. This feature increases the flexibility of patterns students can weave, and decreases the time necessary for students to change their patterns allowing for more exploration in less time than a shaft loom. Further, SPEERLoom is capable of individually actuating 40 warp yarn simultaneously. Individual actuation was chosen to allow simultaneous motion that keeps actuation time low and constant rather than proportionally increasing with the number of warp yarns.

SPEERLoom comes as a kit for students to assemble. In order to ensure SPEERLoom is easily assemblable by novice users, its frame is constructed from t-slotted aluminum. The other three main components of the SPEERLoom (the warp beam, the heddles, and the tensioning system and creel) consist of 3D printed or laser-cut acrylic parts so the kit can be open-source, easily reproducible, and low-cost.

SPEERLoom software UI

SPEERLoom is controlled through a Python-based (Python Software Foundation, 2019) user interface (UI) (Figure 2b) that allows the user to control SPEERLoom's motors individually or collectively in accordance with a user created weaving draft. SPEERLoom's UI allows students to weave using shaft loom weaving drafts or Jacquard weaving drafts. For shaft loom weaving, students are able to manipulate the three matrices in a weaving draft and see their multiplied result in the drawdown (i.e., diagram of the cloth's pattern). Once created, students then update SPEERLoom's firmware to match their shaft loom setup and begin their weaving. For Jacquard weaving, students upload a file with their pattern in it and can explore the mathematical properties that predict the physical properties of their final cloth. The UI is designed to be used after the students learn the mathematical principles involved as a tool to connect the math to the control of the loom.

Proposed interactive demo session

In this demonstration, we propose an interactive session with SPEERLoom where participants will be given an abbreviated explanation of matrix multiplication and its ties to weaving, then participants will be allowed to explore these concepts through SPEERLoom's UI, and finally participants will be able to weave a pattern of their own creation on SPEERLoom. Finally, there will be a group reflection from participants about their experience using SPEERLoom and how it can be applied in classrooms. SPEERLoom's software is available online here: https://sites.google.com/view/roboloom/software, allowing virtual participants to explore the mathematical principles involved in cloth creation and use them to create their own weaving pattern.

Conclusion

The design of SPEERLoom aims to foster collaboration between students of diverse backgrounds in support of collaborative hands-on computer science, math, and art education. Our on-going work brings SPEERLoom to post-secondary classrooms in support of interdisciplinary curricula. In the future we will use the data collected from our research in these classrooms to improve SPEERLoom and its support for collaborative learning.

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