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BOARD # 289: NSF-Supported DUE: Introducing Robotics through a Weaving-Based Undergraduate Curriculum: Towards Breaking STEM Stereotypes

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Introduction

Despite efforts to make STEM fields more inclusive, engineering and computer science are still perceived as exclusionary by women and people of color [1, 2]. STEM is also often seen as too abstract for everyday relevance [3, 2], affecting efforts to involve underrepresented groups in STEM [1] and change the sometimes exclusionary workplace and university cultures [4]. In this work, we recast the paradigm of a robotics course into a more inclusive space by highlighting interdisciplinary collaboration in engineering and the mutual value of engineering and crafting through weaving – a craft that has been alternately historically coded as masculine or feminine depending on time and culture [5].

We designed an undergraduate robotics course connecting weaving and engineering through the history of looms, cloth properties, e-textiles, and building robotic looms. Weaving patterns' binary, matrix-like nature [6] allow the physical properties (feel and drapability) of the cloth to be analyzed geometrically through an understanding of the properties related to engineering (yarn tension, weight and interlacement structure) [7]. The weaving process mirrors engineering design [8]. Weavers' desire to create more complex patterns and the industry's desire to mass produce these products has led to advancements in processes and many engineering innovations [9], like the punch-card Jacquard loom that drove modern automation and computing [9, 10].

Our research focused on three questions: (1) What did students feel they learned in their own discipline, other disciplines, and interdisciplinarily, (2) How did their interdisciplinary attitudes evolve regarding math, engineering, art, and their relation to one another, and (3) How did their attitudes towards interdisciplinary collaboration change? In Spring 2024, 18 students from various majors took the course. Pre- and post-surveys, observations, assignment reflections, and end-of-semester interviews tracked students' experiences and attitudes throughout the course. We received feedback from students who valued learning single discipline and interdisciplinary skills, changed their self-ideaology of their abilities in non-home disciplines, and valued interdisciplinary collaboration. In this work, we present our curriculum, findings, and recommendations for the design of interdisciplinary engineering curricula.

Course Design

The 14-week course integrated engineering, math, and weaving through lectures and hands-on activities that demonstrated the application of math and engineering to weaving. Our course was built around RoboLoom, an open-source Jacquard loom kit [7], and used the available materials [1]. Students worked individually using a traditional shaft loom[2] and interdisciplinarily using RoboLoom [7]. The course covered robotics and mechatronics, including mechanism basics, electricity, and electromechanical actuation; weaving techniques like tapestry, plainweave, twill, and krokbragd weaving; color theory, loom history, culturally relevant cloth; and linear algebra,

[1] Available online at `https://sites.google.com/view/roboloom`

[2] We used an Ahsford 8 shaft loom found here: `https://woolery.com/ashford-katie-table-loom.html`

Figure 1: Assembled RoboLooms used in the Spring 2024 course.

including matrices and matrix operations. For the final project, students designed and wove an interactive cloth, using math to analyze its properties and justify their engineering choices.

RoboLoom, Figure 1, is a robotic Jacquard loom designed to foster interdisciplinary collaboration as students build, program, and weave on it [7]. Provided as a kit of aluminum extrusion, 3D-printed parts, and off-the-shelf hardware, students first assemble RoboLoom collaboratively using instructional videos and optimizing their assembly process. Once built, students use RoboLoom's graphical user interface to design patterns, explore the matrix operations behind them, and control the loom to weave their designs. During weaving, one student operates the computer, another passes the shuttle to create the cloth, and a third adjusts the loom's tension as needed.

Methods

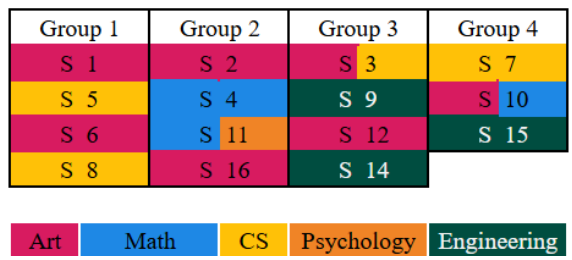

Figure 2: The groups of students and their self-reported backgrounds based on major. Interdisciplinary majors are multicolored.

Our home institution's IRB approved our study. Participants were recruited from the class and provided informed consent before collection of their data. 16 students chose to participate in our study, the other two students participated in the class as normal, but their data was not recorded. S13 dropped the course and their data has been excluded. The remaining 15 participants were: one sophomore, five juniors, six seniors, one fifth-year student, and two master's students. Participants came from diverse majors, including design (n=3), architecture (n=2), information systems (n=2), computer science (n=1), cognitive science (n=1), statistics and machine learning (n=1), electrical and computer engineering (n=1), mechanical engineering (n=2), computational design (n=1), and human-computer interaction (n=1). Students were grouped to maximize interdisciplinary groups, as shown in Figure 2. To understand how students perceived the impact of the interdisciplinary curriculum on their learning as well as how their interdisciplinary attitudes evolved we used pre- and post-surveys on disciplinary and interdisciplinary attitudes, recorded and observed lectures, captured per-assignment reflection questions, and conducted interviews.

Findings

We answer **research question (1)** through the use of end-of semester interviews where students reported learning in their non-home disciplines as well as interdisciplinarily. For example, S4 began with a self-reported weak background in art and in the interview said they "learned a lot about weaving, I think it was really interesting". S16 echoed this sentiment, saying "coming from... Fine Arts I definitely learned more about [the]... engineering side and the math side".

Students generally felt that building the loom did not enhance their engineering skills if they encountered no issues and had prior building experience. However, those who faced challenges reported learning problem-solving and engineering solutions. Most students noted that building the loom deepened their understanding of its mechanics and how to construct their own DIY device. S16 highlighted this, stating, “building the loom itself to see the engineering side of it just explains the weaving process in a more thorough way.”

Students also noted that they gained new skills in applying these concepts interdisciplinarily. Interestingly, while students did not label this as “learning,” they recognized the novelty and its effect on their prior knowledge. S9 reflected on their engineering skills, saying they were “thinking differently about... soft materials and how they can be manipulated with different characteristics like weave factor or the weaving pattern that you are using, how that can affect the properties of cloth as... an engineering material.” Similarly, S15 acknowledged applying their skills in an interdisciplinary context, although not categorizing it as learning, stating, “I don’t know if [my engineering skills] changed too much, but I feel like they were definitely applied a lot. ... I enjoyed applying the skills that I primarily exercise in ... a new creative aspect.”

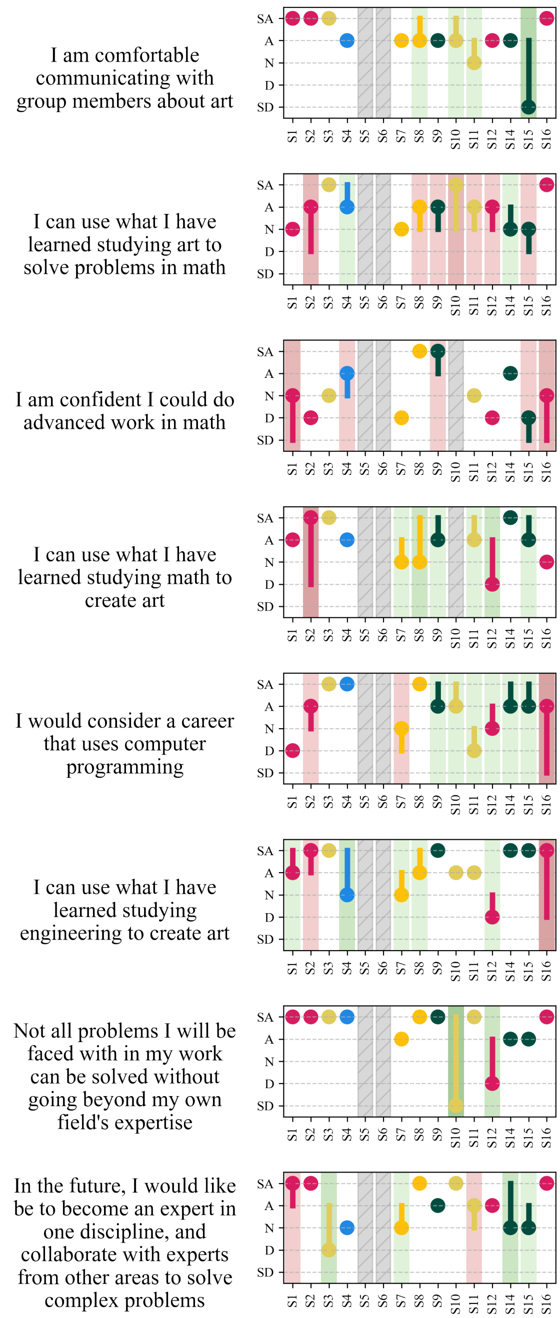

Figure 3: Answers to select survey questions. Each column represents a student’s answer with the dot being their pre-survey response. Color of marks reflect student background. Green highlighted boxes represent an improvement in attitudes. Students responded to each statement with “Strong Disagree” (SD), “Disagree” (D), “Neutral” (N), “Agree” (A), or “Strong Agree” (SA).

Research question (2) was answered using student self-assessment surveys that measured their attitudes toward each discipline, their perceptions of others in those disciplines, and their views on collaboration (selected answers in Figure 3). Although overall scores did not improve significantly, students showed some attitude changes on individual questions, showing increased confidence in art, engineering, and the ability to apply mathematics and engineering to art, but decreased confidence in math and the ability to apply mathematics to math or engineering. The initial scores for art, math, and engineering were high, potentially due to the self-selecting nature of the course, which was optional and did not count toward degree requirements.

Regarding student attitudes about art, five students had small gains in seeing themselves as artists, all of which did not have an art background. Four students got better at discussing art in groups, three from non-art backgrounds and one from an art background. Finally, seven students from many backgrounds agreed less that they can use art to do math showing an area for improvement.

Regarding student attitudes about math, five students felt less confident in their ability to do advanced work at the end of the course, despite their background (art, math, and engineering). Five students also felt less confident in learning math skills quickly despite their background (art, math, and engineering). However, six students, mainly those with a math or engineering background, increased their feeling of being able to use math in art.

Finally, students reported their attitudes about engineering. Seven students, particularly those from art, math, and CS backgrounds, reported increased experience with building robots and greater interest in programming careers. Four art, math, and CS students more strongly agreed that engineering could apply to art at the end of the class, although three students showed decreased belief in this application.

Students also reported changes in engineering attitudes during interviews seeing how easily accessible it was to use engineering to help them with art. S10 came from an art background and reported, “It was [a] lesson that ... it can be DIY work or easily accessible work to create [a] robot or ... automatic loom. Before that ... I thought it’s pretty mysterious how clothes are weaved.”

Finally, **research question (3)** was addressed with a survey measuring attitudes toward interdisciplinary collaboration. Although in general that survey did not show a change in the average score, some questions showed change. Two students more strongly believe that there are problems that cannot be solved with single-discipline knowledge after the class. Four students now more strongly agree that they would like to specialize and collaborate with those outside their field, recognizing the importance of interdisciplinary collaboration.

Conclusions

Our study examined the outcomes of integrating weaving, engineering, and mathematics in an interdisciplinary course. We aimed to understand student self-reported (1) learning in their own discipline, other disciplines, and interdisciplinarity, (2) changes in interdisciplinary attitudes regarding math, engineering, art, and their relation to one another, and (3) changes in attitudes towards interdisciplinary collaboration. We found that students valued exposure to new disciplines and applying their knowledge in novel contexts but did not label these experiences as learning, suggesting they did not view interdisciplinary work as an educational area. Pre- and post-surveys showed increased appreciation for interdisciplinary collaboration, group art-making, and the application of engineering and math to art.

The study also highlighted areas for improvement. Students reported decreased confidence in learning complex math, likely due to rushed presentation of concepts. They also did not perceive art as applicable to math, as the course emphasized applying math and engineering to art but not the reverse. Additionally, students felt they learned little engineering during the building process when it went smoothly, with most problem-solving stemming from prototype issues rather than planned challenges.

For future iterations of this course and the design of interdisciplinary engineering curricula like it, we recommend a slower, more in-depth exploration of concepts to prevent adverse effects. Interdisciplinary applications should be reciprocal, showing how art informs math and engineering as well as the reverse. Finally, we recommend more structured opportunities for problem-solving in the building process to deepen engineering education.

These findings provide a foundation for refining the interdisciplinary curriculum, with significant potential for further exploration and analysis. Future work will focus on analyzing student reflections and interviews to better understand how course design and student backgrounds influenced student attitudes and how these attitudes can broaden perspectives to encourage more diverse and inclusive STEM courses in the future.

Acknowledgments

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