Weaving Collaboration: Promoting Effective Interdisciplinary Learning with a Robotic Loom

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Abstract: This study investigates the conditions that foster effective interdisciplinary collaboration—defined as the integration of knowledge, practices, and perspectives from different disciplines—through qualitative analysis of project-based learning in higher education. Grounded in theories from the Learning Sciences and Computer-Supported Collaborative Learning, we analyze how knowledge transfer and leadership dynamics mediate interdisciplinary engagement in a course combining robotics, mathematics, and textile arts. Systematic analysis of qualitative data from 23 undergraduate students across six groups reveals three distinct patterns of collaborative engagement. Our findings show that successful collaboration hinges on (1) fluid leadership transitions that leverage diverse expertise and (2) structured opportunities for knowledge exchange. Groups with distributed leadership and consistent knowledge-sharing practices produced higher-quality projects than those with centralized leadership. These findings contribute to theoretical understandings of interdisciplinary learning and offer practical guidelines for designing collaborative learning environments in higher education.

Introduction

As contemporary professional work increasingly demands cross-disciplinary solutions, higher education faces mounting pressure to prepare students for collaborative, interdisciplinary environments (Lyall et al., 2015; Warr & West, 2020). While universities have responded by introducing interdisciplinary programs—such as degrees in data science and sustainability—research shows that merely bringing together students from different disciplines does not automatically foster effective collaboration (Ashby & Exter, 2019; Arthars et al., 2024). This challenge raises a critical question: What conditions enable students to move beyond surface-level cooperation to achieve meaningful interdisciplinary integration?

Interdisciplinary learning, broadly defined, involves engaging with and integrating knowledge from different disciplines. However, despite increasing interest in this approach, current research faces three key limitations. First, most studies focus on final outcomes rather than the process of collaboration, leaving crucial questions about how students navigate disciplinary boundaries unanswered (Markauskaite et al., 2024). Second, while frameworks like epistemic network analysis (Shaffer, 2017) and Actor-Network Theory (Schwarz et al., 2024) provide valuable theoretical insights, they often overlook the practical mechanisms that facilitate or hinder interdisciplinary engagement (Kidron & Kali, 2015). Third, research tends to emphasize either individual learning outcomes or group dynamics, rarely examining how these elements interact in interdisciplinary settings (Miles & Rainbird, 2015). Our study addresses these gaps by integrating two theoretical perspectives: 1) Knowledge Integration Theory (Linn, 2006), which provides a framework for understanding how students combine insights from different disciplines; and 2) Distributed Leadership Theory (Spillane, 2006), which illuminates how leadership dynamics influence collaborative learning. We situate our research within the STEAM movement, which intentionally integrates the arts into STEM, emphasizing creativity and fostering diverse, equitable engagement. STEAM offers an ideal context for studying interdisciplinary collaboration because it naturally brings together diverse ways of knowing and making (Peppler & Thompson, 2024). Recent studies have shown how STEAM activities, particularly those involving physical computing and crafting, can promote equitable engagement and creative problem-solving (Quigley et al., 2020).

This paper addresses the need for a deeper understanding of how interdisciplinary learning unfolds in higher education contexts, focusing on collaborative team projects that integrate diverse disciplinary knowledge. Building on prior studies in both the Learning Sciences and Computer-Supported Collaborative Learning (CSCL), this research examines the dynamics of student collaboration in a multimodal project-based environment where learners of a range of disciplinary backgrounds collaborate on the construction of, and weaving with, robotic looms (RoboLoom). Our study examines two interrelated questions: 1) *How do leadership dynamics influence the quality of interdisciplinary collaboration in project-based learning?* and 2) *How do different forms of knowledge exchange affect students' ability to integrate diverse disciplinary perspectives?* By investigating these questions through detailed analysis of student interactions, reflections, and project artifacts, we aim to advance theoretical understanding of interdisciplinary learning processes, identify specific practices that promote effective cross-disciplinary collaboration, as well as provide practical guidelines for designing interdisciplinary learning environments. This research makes two key contributions to CSCL and the Learning Sciences. First, it demonstrates how different leadership patterns influence collaborative outcomes, such as the creation of high-quality products in interdisciplinary settings. Second, it posits that such leadership transitions should be accompanied by equitable knowledge transfer between members with diverse areas of expertise, allowing group members to learn from one another. By doing so, we aim to provide insights into how interdisciplinary skills can be cultivated in educational settings, ultimately preparing students for the collaborative demands of the modern professional landscape.

Background

Higher education institutions increasingly emphasize interdisciplinary collaboration to address complex modern professional and societal challenges (Lyall et al., 2016; Markauskaite et al., 2024). This shift reflects a growing recognition that traditional, siloed disciplinary approaches are inadequate for solving multifaceted real-world problems. In response, universities have developed interdisciplinary programs, such as degrees in sustainability and data science, along with project-based courses designed to mimic real-world problem-solving scenarios (Lyall et al., 2016; Warr & West, 2020). However, the effective implementation of interdisciplinary education poses significant challenges, particularly in fostering the skills required for productive collaboration, as students from different disciplines may lack shared vocabulary and conceptual frameworks (Ashby & Exter, 2019). Furthermore, traditional evaluation methods may not capture the complexity of interdisciplinary learning outcomes (Miles & Rainbird, 2015).

Theoretical frameworks

We understand interdisciplinarity as interactions between two or more disciplines to either unify knowledge across fields or challenge traditional methods of knowledge production (Moran, 2001). Interdisciplinarity helps overcome the limitations of individual disciplines, offering more culturally sensitive and historically informed approaches, such as challenging dominating and stagnant practices and assumptions about who can participate in specific disciplines (Peppler & Wohlwend, 2018), or addressing stringent assessment practices (Kaufman et al., 2008). Building on prior CSCL work, Vitiello et al., (2023) identified six key dimensions of interdisciplinarity: 1) team composition (diverse expertise), 2) work requirements (multiple disciplines needed); 3) product integration (evidence of multiple contributions); 4) thinking processes (drawing on multiple knowledge bases); 5) curricular design (exposure to diverse perspectives); and 6) individual capability (skills for effective team participation). Our study focuses particularly on the first and sixth dimensions— learning within a group with diverse expertise and developing individual capacity for effective interdisciplinary collaboration—while considering how this interacts with other dimensions. This conceptualization further aligns with the goals of Computer-Supported Collaborative Learning (CSCL), which focuses on how students leverage their skills within interdisciplinary contexts. In CSCL, frameworks like the 3Cs model—Communication, Coordination, and Cooperation (Ellis et al., 1991; Fuks et al., 2008)—have been employed to better understand how individuals engage in collaborative processes to achieve collective outcomes. Recent refinements to this model (Speer et al., 2025) have developed codes to capture the nuances between these modes of collaboration, analyzing types of communication (e.g., procedural, conceptual), leadership behaviors, and knowledge-sharing practices.

In the 2024 Journal of the Learning Science special issue on interdisciplinary learning, Markauskaite et al., (2024), highlights interdisciplinary group learning as one of the areas that needs further research, posing questions such as: "What is unique about learning in interdisciplinary teams? What conditions foster productive engagement? How do interdisciplinary problems shape team learning? What methodologies best study interdisciplinary learning processes and outcomes?" (p. 225). To bridge this gap, we draw from a number of theoretical frameworks for understanding interdisciplinary collaboration. First, to understand how disciplinary knowledge is transferred and integrated between members of a group, we use *knowledge integration theory* (Linn, 2006) as a framework for understanding how learners combine insights from multiple disciplines. This theory identifies four key processes: 1) eliciting existing ideas; 2) adding new perspectives; 3) developing criteria for evaluating ideas; and 4) sorting and connecting ideas across contexts. Recent research has extended this framework to collaborative settings, showing how group interactions can either facilitate or hinder knowledge integration (Markauskaite & Goodyear, 2017).

Second, in the analysis of the types of cross-disciplinary communication that occurs within teams, we further pull from research on *distributed leadership* (Spillane, 2006), which suggests that leadership in collaborative settings is not merely about individual actions but emerges through the interactions between multiple leaders, the specific context and tasks, as well as how they are mediated by available tools and resources. Studies have shown that whereas highly productive teams have stable leaders, innovation often operates in a decentralized fashion with various emergent leaders rotating leadership over the course of a project (Kidane & Gloor, 2007), where members share collective responsibility for their knowledge work through a high degree of connectivity, interactivity, and sharing. Ma et al.'s research on rotating leadership (2017) further underscores this point, highlighting that rotating leadership enables students to introduce influential ideas or relevant information at different times, fostering the spread of ideas and enhancing conceptual coherence within the group. Different leadership patterns affect group outcomes: centralized leadership may improve efficiency but limit participation, distributed leadership can lead to more innovative solutions, and hybrid approaches may be optimal for navigating different phases of a project.

STEAM as an context for Interdisciplinary learning

STEAM education provides a rich and well-studied context for interdisciplinary learning, as it intentionally bridges traditionally separate domains, emphasizes both technical and creative skills, and values multiple ways of knowing and making (Peppler & Thompson, 2024). In our curriculum design, the RoboLoom—a central focus of this research—exemplifies this interdisciplinary framework. The RoboLoom is an open-source, robotic Jacquard loom kit designed to interweave cloth fabrication, mathematics, and engineering, serving as a tool to support interdisciplinary learning in the classroom (Speer et al., 2023). Studies on STEAM education have specifically highlighted how boundary objects, such as e-textiles or tools like the RoboLoom, can facilitate learning across disciplines. Boundary objects refer to artifacts or media that serve as bridges across contexts and disciplines, enabling collaboration and integration (Star & Griesemer, 1989; Peppler & Wohlwend, 2018). Furthermore, STEAM research has explored how integrating the arts into STEM fosters more equitable participation (Quigley et al., 2020) and how physical computing projects promote deep interdisciplinary learning (Peppler & Wohlwend, 2018). This emphasis on creative and technical integration aligns with the goals of interdisciplinary education by creating opportunities for deeper engagement, collaboration, and innovation.

Methods

Participants

This study was conducted in one of the undergraduate elective courses in Informatics at a public institution on the West Coast. The course was led by one of the authors with the aim of exploring new approaches to interdisciplinary learning in computer science and computing. The course, titled "Re-Crafting Technologies," bridged robotics, matrix algebra, programming, and textile arts. During Spring 2023, it was offered as a 10-week course using a flipped classroom approach, where students watched video lectures as homework and engaged in interactive group activities during class.

A total of 23 participants enrolled in the course, divided into six groups of four based on their diverse disciplinary backgrounds. The cohort included 18 Informatics majors, three students from Business Information Management, one Math major, and one Spanish major. All participants had prior experience with college-level mathematics, statistics, or related courses, covering subjects such as Calculus, Linear Algebra, Logic, and Discrete Math. These students brought various skills from arts, design, STEM, programming, and Human-Computer Interaction. The class included 15 male, seven female, and one non-binary student. Demographically, there were 13 students of Asian or Asian-American descent, six White, two Latinx/e, and two Southeast Asian. The study was exempt from IRB review as it was part of regular class instruction with minimal risk involved. All participants were adults capable of providing informed consent and could opt out at any time.

Curriculum design

The course integrated the disciplines of Engineering, Arts, and Mathematics by exploring the intersection of weaving, computational thinking, and technology. The curriculum emphasized experiential learning activities, including weaving, constructing a robotic loom, and designing e-textiles, while introducing students to advanced mathematical concepts such as matrix algebra, group theory, and combinatorics and computing. In the first two weeks, students explored the cultural significance of weaving, learned fundamental weaving techniques, engaged with e-textiles and craftivism, and familiarized themselves with loom operation. As the course progressed, they moved into constructing and operating the Robo-Loom. Advanced mathematical concepts like group theory and combinatorics were introduced in the middle of the course to deepen students' understanding of textile design. The final weeks were dedicated to work a student-driven project that synthesized their interdisciplinary knowledge and skills. This final project was designed to be personally and culturally meaningful, allowing students to apply what they had learned in a way that resonated with their interests and backgrounds.

Data collection

Data was collected through multiple sources to capture the depth of students' experiences and their collaborative processes. 1. Videotaped observations capturing group interactions during class activities. This video data documented the collaborative construction of the RoboLoom and the execution of final projects, providing rich data for analysis on how students engaged with the interdisciplinary content. 2. Written reflections collected weekly on various aspects of their project work, including group dynamics, workload distribution, leadership roles, and their confidence and comfort levels during the project. 3. Classwork artifacts that included physical weaving projects and the accompanying documentation, such as project definition assignments, sketches, and final presentations. Importantly, during Week 8, each group outlined their project plans, detailing the cultural relevance and design elements of their intended weavings. These artifacts provided insight into the groups' design processes and the cultural significance of their creations.

Analysis

Our investigation employed a multi-layered analytical approach to examine the complex interplay of interdisciplinary learning and collaboration. Firstly, we focused on evaluating the groups' artifacts using a structured rubric, this to determine which groups were more successful. Our rubric evaluated three main aspects: 1. Technical execution through measures such as weave tightness and pattern complexity 2. Comparison of final products to original design proposals to evaluate design fidelity. 3. Innovations, such as the incorporation of additional elements beyond basic requirements, and 4. Integration of cultural elements into their designs, considering the meaningful use of symbolism and cultural references.

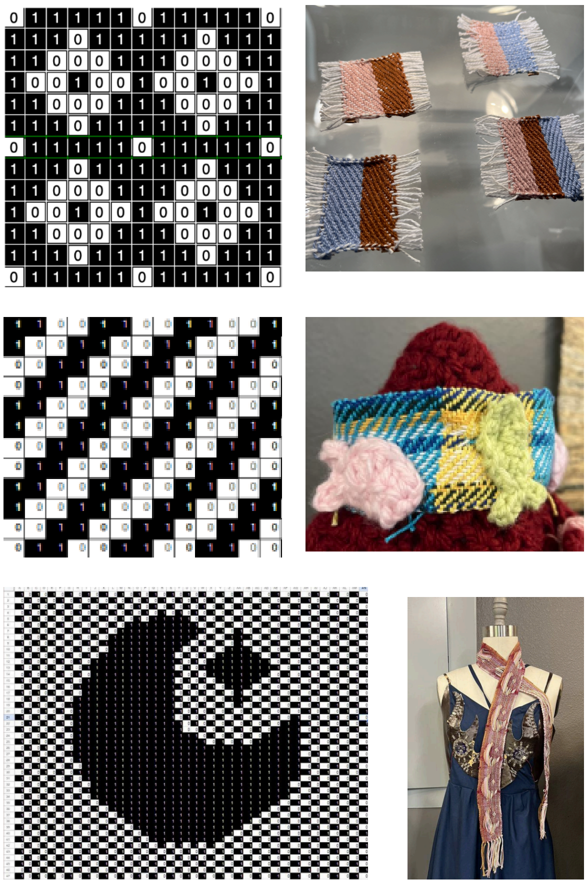
During the second phase of analysis,we familiarized ourselves with the overall video recording data, using an initial coding framework as a guide while staying open to emergent patterns. We applied a hybrid thematic analysis approach (Nowell et al., 2017), combining deductive and inductive coding strategies. Our codebook included elements from *knowledge integration theory* (Linn, 2006), such as 1. eliciting existing ideas; 2. adding new perspectives; 3. developing criteria for evaluating ideas; and 4. sorting and connecting ideas across contexts as well as elements from *distributed leadership* (Spillane, 2006) such as 5. leadership transitions, 6. problem-solving sequences and 7. moments of knowledge transfer.Based on overarching themes identified through our reflective documentation and peer debriefing sessions, we selected three focal groups that were both representative and exhibited contrasting collaboration patterns. These groups were selected because they exemplified behaviors observed across all groups while also highlighting key differences in leadership distribution, knowledge integration, and collaboration. This approach allowed us to contrast elements between different groups' interactions, thus shedding light on the conditions that may foster or inhibit successful interdisciplinary teamwork.

To gain deeper insights into group dynamics, we screened the recordings to identify critical incidents that showcased instances of our codes of interest. These selected episodes underwent interaction analysis (Jordan & Henderson, 1995) of video recordings from the three focal groups; this is, focusing on micro-level details of communication. This process involved the creation of content logs with timestamps, transcription of verbal exchanges, documentation of non-verbal interactions, and mapping of participation trajectories over time. This approach allowed us to track the evolution of group dynamics and identify patterns in how students engaged with interdisciplinary content. To ensure the trustworthiness of our findings, we employed several validation strategies. We triangulated findings across multiple data sources, maintained a detailed audit trail of analytical decisions, conducted member checks with participating students, and actively sought disconfirming evidence for emerging patterns. This comprehensive approach allowed us to develop a nuanced understanding of how different groups navigated the challenges of interdisciplinary collaboration.

Results

Each group employed distinct leadership and collaboration models, which directly influenced their ability to navigate interdisciplinary challenges, integrate diverse perspectives, and achieve their project goals. Group 1 adhered to a centralized leadership model, with Amanda (Informatics) taking on a dominant leadership role due to her prior expertise in mechatronics. This approach streamlined decision-making but limited the opportunities for peer learning and equitable engagement. Consequently, the group produced a simplified textile coaster using a diagonal weave, which was a shift from their original design plan. They described this as a pragmatic decision made when they encountered difficulties translating their initial idea into the RoboLoom program (see Figure 1, Top). While Groups 1 and 2 both produced diagonal weave patterns, Group 2's artifact reflected their original design plan, which included specific technical and aesthetic goals from the outset—such as using color pairings and adding crochet details. In contrast, Group 1 described the diagonal pattern as an adjustment after realizing their initial design was not feasible to implement due to limited group participation and challenges in the translation to RoboLoom. This contextual difference informed how each artifact was interpreted.

Figure 1.
Proposed weaving pattern (left) and final artifact (right) of the three groups.



Top, Group 1: This group abandoned their original design for the textile coasters, replacing it with a simpler diagonal pattern. Center, Group 2: This group maintained their original pattern, executing it with tight weaving, alternating colors, and adding crochet-knit fish decorations. Bottom, Group 3: The group's fluid leadership dynamics and specialized skill application resulted in a technically intricate and culturally meaningful artifact; showcasing a complex pattern with moon and star motifs symbolizing the Lunar New Year.

Their final artifact—a textile featuring diagonal patterns, color combinations, and creative crochet-knit fish additions—reflected their original design vision, which they were able to realize through consistent collaboration and knowledge exchange (see Figure 1, center). Group 3 adopted a hybrid approach, transitioning from shared leadership in the initial stages to task specialization in the later phases. While this model allowed for efficient task allocation, it resulted in workload imbalances, with some members feeling overburdened. Nonetheless, the group successfully produced a scarf featuring intricate moon and star motifs inspired by the Lunar New Year, blending technical sophistication with cultural depth (see Figure 3). These groups illustrate a spectrum of collaborative dynamics that we will describe in terms of leadership transitions and knowledge integration and exchange between group members.

Fluid Leadership Transitions That Leverage Diverse Expertise

Leadership transitions played a pivotal role in shaping the collaborative processes and outcomes of the three groups. The dynamics of leadership in each group underscored the importance of shared responsibility and the strategic use of expertise to drive innovation and engagement. For example, Group 2's distributed leadership exemplified how fluid transitions between leaders can foster collaboration and innovation. In Jane's own words: "Prakhar took the lead when it came to mathematical parts and overall was very proactive in giving out instructions and feedback. Richard took the lead when it came to building the robotic loom portion since he had experience with building many things. I took the lead when it came to organizing, yarn picking and colors, as well as organizing the documentation for our labs that we turn into canvas." We saw then that members rotated leadership roles based on their areas of expertise, enabling them to leverage their strengths while supporting each other's learning. As the project progressed, leadership naturally transitioned to Prakhar (Informatics), whose expertise in matrix math became central to the design of threading patterns. In Week 4, Prakhar introduced the group to matrix algebra, explaining how it could be applied to create specific weaving patterns. This moment of knowledge transfer not only enriched the group's understanding of the technical aspects of weaving but also enhanced the complexity of their designs. Richard acknowledged the impact of Prakhar's contributions, stating, "Prakhar suggested using matrices to create specific patterns, which was fascinating and directly impacted our weaving."

In the final weeks, Jane emerged as the leader during the weaving phase, applying meticulous attention to detail to ensure the group adhered to their design plan while incorporating creative embellishments. She explained,"We took the popsicle sticks and put them into our yarn to start making the pattern of our choosing. It was crucial for us to ensure symmetry." Her leadership was instrumental in translating the group's technical planning into a cohesive and visually striking artifact. Reflecting on their collaborative process, Prakhar summarized, "By working together and learning from each other's strengths, we managed to create something that we were all proud of." The group's final artifact (see Figure 1, center) reflected how their distributed leadership supported both technical precision (tightness of the weave), allowing them to carry out their original plan and add aesthetic elements collaboratively. Rather than making a direct claim about improved learning outcomes, we suggest that Group 2's distributed leadership enabled more fluid knowledge exchange and co-creation, allowing all members to participate meaningfully in both technical and creative aspects of the project.

Group 3's hybrid approach to leadership evolved over the course of the project, reflecting the adaptability of their collaborative model. In the initial stages, the group employed a shared leadership model, with all members contributing equally to foundational tasks such as loom assembly. Nick (Informatics) described this phase as highly collaborative: "All four of us worked on the base frame together. We've distributed tasks equally so that no one is having to work more than the others." This shared responsibility fostered a sense of collective ownership and camaraderie among the group members. As the project advanced, leadership became more specialized, with members assuming roles aligned with their emerging strengths. Nick's expertise in matrix math positioned him as the leader during the design of complex weaving patterns. His ability to connect abstract mathematical concepts to the practical task of weaving earned him the nickname "the matrix guy" from Dana (Informatics). However, the reliance on specialized roles introduced challenges, particularly for Dana, who found herself solely responsible for managing the weaving software. Reflecting on this imbalance, Dana noted, "I felt a lot of pressure to complete the weaving because no one else had the software." Despite these challenges, the group produced a culturally meaningful artifact that showcased both technical intricacy and artistic depth (see Figure 1, bottom).

While Group 3's final artifact was indeed more complex and closely aligned with their original design plan—featuring innovative patterns and aesthetic detail—this productivity came at a cost. The leadership transitions were characterized more by task specialization than by fluid, shared leadership. As a result, while individuals assumed clear roles, the burden of expertise and execution was unevenly distributed, particularly for Dana. This dynamic limited opportunities for interdisciplinary learning through reciprocal knowledge exchange. Compared to Group 2, whose members actively taught and learned from one another, Group 3's collaboration was less about integration of disciplinary perspectives and more about efficient division of labor.

In contrast, Group 1's centralized leadership model limited opportunities for shared responsibility and innovation. Amanda (Informatics) consistently assumed a dominant role, directing tasks and making key decisions throughout the project. While her expertise in mechatronics ensured the efficient execution of tasks, it also discouraged her teammates from taking initiative. Daniel (Informatics) reflected, "Amanda was often the one distributing tasks and staying the longest after class to get more work done." Observations revealed that Amanda's authoritative role sometimes created dependency among her teammates, as seen during loom assembly when she corrected Daniel's mistake without encouraging him to understand the underlying error. This dynamic aligns with Howley & Rosé's (2016) findings, which suggest that centralized leadership can reduce engagement and authoritativeness among non-leading members.

By the final stages of the project, the limitations of Group 1's centralized leadership became evident. Amanda's dominant role resulted in social loafing, with other members becoming increasingly passive. The group's final artifact, a simplified textile coaster using a diagonal weave, reflected a shift from their initial design plan. This change was influenced by uneven participation and difficulties in translating their intended pattern into a working program (see Figure 1, top). Amanda acknowledged the challenges of working within this dynamic, stating, "It was hard for the team to work together, and I ended up taking on most of the responsibilities." This case highlights how centralized leadership, while efficient in task execution, can hinder interdisciplinary collaboration by limiting opportunities for knowledge exchange and shared ownership.

Structured Opportunities for Disciplinary Knowledge Exchange

Group 2 excelled in creating consistent opportunities for knowledge exchange by actively teaching one another and maintaining alignment. Their collaborative dynamic facilitated the elicitation and integration of ideas across disciplines, enabling them to achieve a cohesive and innovative final artifact. During the initial stages of the project, Richard (Informatics) took the lead in assembling the loom. His clear instructions and hands-on guidance helped Jane (Informatics) overcome her initial lack of confidence. For instance, in Week 3, he guided Jane (Informatics) through the loom assembly process, explaining, "You can see this one here, and this one is here... this matters because otherwise it won't fit." This interaction exemplified the elicitation of existing knowledge and its effective transfer, enabling Jane to contribute confidently to the group's efforts. Reflecting on this experience, Jane noted, "Richard had built computers many times, which was really helpful when we were putting the loom frame together." This early interaction set the tone for the group's collaborative dynamic, characterized by mutual respect and active knowledge exchange.

In Week 4, Prakhar (Informatics) introduced matrix math concepts to the group, connecting these mathematical ideas to the practical task of weaving. He reflected, "I realized that matrix math could be used for threading patterns... This will allow us to create a specific pattern ahead of time." On their reflections both Richard and Jane acknowledged the value of this contribution. Moreover, at the end of the course, each member was able to reflect on how their disciplinary background and expertise help them to build and operate the Roboloom as a team, for example, Richard wrote: "With my background in informatics and experience in assembling computers, I brought my technical expertise to the team. I was involved in designing and building the physical components of the RoboLoom, ensuring that it functioned properly.", as Prakhar wrote: "With my background in engineering and coding, I was able to calibrate the RoboLoom and run the GUI off the PyCharm IDE. This familiarity allowed us to test our RoboLoom extensively and ahead of time, enabling us to spot many problems before we continued. Along with building the loom, I assisted with the calculations of the pattern strength, using the matrix math we had learned earlier in the quarter." . By adding new perspectives such as the math matrix being used to weave mentioned by Prakhar, connecting ideas across disciplines, the group exemplified the knowledge integration processes outlined by Linn (2006).

Group 3 showed moments of effective knowledge exchange and integration but lacked consistency, impacting their ability to sustain knowledge integration processes. Knowledge Integration, and more specifically developing criteria for evaluating ideas (Linn, 2006) was seen when Nick communicated the need to check if the math pattern would be coherent between the software and the woven product: " I think it's better to see how the full pattern looks before changing anything. We should see how this pattern looks when we actually weave it, and then we can start making adjustments," he asserted. While Nick's (Informatics) expertise in matrix math enriched the group's understanding and advanced their design goals, the reliance on specialized roles hindered reciprocal knowledge sharing. Dana, responsible for managing the weaving software, reflected, "I was the only person who had the software downloaded on my computer, so I felt my group heavily depended on me to do the weaving." This isolated responsibility limited opportunities for collaborative engagement and collective learning. Lastly, Group 1 struggled with limited opportunities for knowledge exchange, which hindered their ability to integrate ideas and perspectives effectively. Amanda's (Informatics) centralized leadership constrained the *elicitation of ideas* (Linn, 2006), as stated by Amanda, they: "... did not have a specific distribution pattern for this week. Each member was working on almost everything and helping each other, but my prior experience gave me the confidence that I knew what I was doing." shows that while she was confident eliciting ideas, the group was disperse, mostly motivated by productivity rather than by the recognition of knowledge and expertise on one another.

Discussion and Implications

Our findings illuminate key conditions that support productive interdisciplinary collaboration in STEAM settings, particularly the role of fluid leadership transitions and structured peer knowledge exchange. Rather than simply rotating leadership roles, what proved effective was groups' ability to leverage members' disciplinary expertise at different stages of the project while avoiding overburdening any one participant. Drawing on Knowledge Integration Theory (Linn, 2006), we observed how eliciting, sharing, and connecting ideas across disciplinary boundaries enabled deeper learning. For instance, in Group 2, members took turns leading based on their strengths—Prakhar introduced matrix math, Richard supported loom assembly, and Jane coordinated aesthetics and documentation—leading to a cohesive final artifact aligned with their initial plan. By contrast, Group 1's centralized leadership limited peer learning and engagement, resulting in a less collaborative and simplified outcome. Group 3, though highly productive, relied on task specialization that led to uneven workload and fewer opportunities for reciprocal knowledge exchange. These findings align with prior research suggesting the benefits of shared leadership (Ma et al., 2017; Howley & Rosé, 2016), but extend it by showing how fluid leadership paired with intentional knowledge sharing fosters both equitable participation and authentic interdisciplinary learning.

The RoboLoom itself functioned as a boundary object across disciplines, enabling groups to translate abstract math, cultural symbolism, and mechanical skills into a tangible artifact. Yet the tool's potential was only fully realized in groups that engaged in collaborative reflection and mutual teaching. While Group 2's iterative adjustments to design and troubleshooting showcased this integration, Group 1's interaction with the tool was characterized by dependency. We thus expand CSCL understandings of how tools mediate interdisciplinary collaboration—not just through access or design affordances—but through the discursive and leadership practices that shape their use.

Our study points to two key implications for the design of STEAM learning environments in higher education. First, facilitating fluid leadership transitions enables students to take initiative when their expertise is most relevant, while still supporting one another's learning. Second, structured opportunities for peer teaching—such as prompting students to articulate disciplinary insights or rotate tool access—can support authentic knowledge exchange. Teachers and facilitators should actively monitor group dynamics to ensure that no individual dominates critical tools or practices, and encourage explicit moments for teaching and learning among peers. While limited in scope, this study provides a grounded account of how leadership dynamics interact with interdisciplinary learning. Future research should explore these dynamics across longer timelines and varied cultural contexts. As interdisciplinary collaboration becomes increasingly central in STEAM education, we argue that equity and learning outcomes depend not just on participation or diversity, but on designing for shared ownership, structured peer learning, and the fluid transfer of leadership and knowledge.

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