NSF DUE: Everyday engineering: Leveraging craft to deepen engineering design and spatial visualization

Dr. Anna Keune, Technical University of Munich

Anna Keune is Tenure Track Assistant Professor of Learning Sciences and Educational Design Technologies and TUM-IAS Rudolf Mößbauer fellow at the Technical University of Munich. Anna's research and teaching stands at the intersection of learning sciences and design. Anna investigates high and low-tech educational design technologies to advance knowledge about STEM learning, transforming what counts as participation and expanding who participates. Her research is guided by constructionist, posthumanist, and participatory theoretical commitments.

Daniela Villarreal Bermúdez
Dr. Kylie Peppler, University of California, Irvine

Dr. Peppler is a professor of Informatics and Education at University of California, Irvine who engages in research that focuses on the intersection of arts, STEM, and interest-driven learning.

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Author Name 1, Institution 1, Email 1
Author Name 2, Institution 2, Email 2
Author Name 3, Institution 3, Email 3

Abstract: Spatial skills are crucial for success in STEM fields (e.g., Kersh et al., 2008; Case & Ganley, 2021), yet persistent gender disparities in spatial assessments continue to affect representation and achievement in these domains (Halpern, 2000; Lauer et al., 2019). While traditional research has documented male students outperforming female students in spatial tasks (Linn & Petersen, 1985; Sanders et al., 1982), recent studies suggest these differences may be influenced by assessment materials and methods rather than inherent abilities (e.g., Keune et al., 2021; Peppler et al., 2023; Bailey & Sims, 2014; Maryati & Prahmana, 2019). This research investigates how spatial visualization skills manifest in a fiber crafts activity, comparing the approaches of engineers and crafters to understand alternative pathways for spatial skill development.

Drawing on constructionist learning theory, which posits that knowledge emerges in diverse ways through engagement with the material world, we conducted artifact analysis sessions with 4 adult crafters and 6 adult engineers. Participants completed one standardized craft task: folding a 3-dimensional basket from felt. Video analysis of the 7 hours of recorded sessions revealed distinct approaches to spatial problem-solving between the two groups. Our findings challenge traditional assumptions about spatial reasoning. Crafters demonstrated successful spatial visualization through an intuitive, materials-first approach, integrating mental visualization with hands-on experimentation. In contrast, engineers' formal training often impeded practical problem-solving, as their emphasis on technical precision and extensive planning led to less functional solutions. These results suggest that engineering education might benefit from incorporating diverse approaches to spatial reasoning, particularly through craft-based activities that encourage direct material engagement and flexible problem-solving strategies.

This study has significant implications for engineering education, suggesting that incorporating craft-based activities and validating multiple approaches to spatial reasoning could enhance spatial skill development while potentially addressing gender disparities in STEM fields. Our findings support the value of epistemological pluralism (i.e., multiple ways of knowing and problem-solving) in spatial skill development and suggest promising directions for transforming engineering education through the integration of novel tools and materials.

Introduction

A persistent gender gap in STEM fields can be traced, in part, to differences in spatial skills development–abilities that are crucial for success in these disciplines (Kersh et al., 2008; Casey et al., 2008; Wai et al., 2009). These spatial abilities, essential for interpreting three-dimensional models, plans, and diagrams, show consistent gender disparities in common assessments, with male students typically outperforming female students (Halpern, 2000; Case & Ganley, 2021). This phenomenon has profound implications for gender representation and success in STEM careers, where spatial skills play a fundamental role in professional practice.

Gender differences in spatial ability emerge as early as age 4 (Levine et al, 1999) and appear to be significantly influenced by early childhood experiences. For example, differential exposure to construction toys and spatial play activities between genders can create an initial skills gap (Utta et. al, 2012) that is further shaped by interactions with caregivers (Reilly & Neumann, 2013). This disparity typically intensifies during adolescence and becomes more pronounced in adulthood, particularly after age 18 (Linn & Petersen, 1985; Sanders et al., 1982). Although these disparities tend to decrease in adulthood, they persist in academic and professional environments, particularly in STEM careers (Tsigeman et al, 2023), where they continue to impact both representation and success of women.

Recent research suggests that these gender differences may be more nuanced than previously understood. Keune et al. (2021) found that performance in mental rotation tasks varies significantly based on the gender-coding of test materials, with both genders performing equally well when using feminine-coded objects. This finding, combined with emerging research demonstrating connections between fiber crafts and spatial skill development (Peppler et al., 2023a; 2023b; Bailey & Sims, 2014; Maryati & Prahmana, 2019), suggests that traditionally feminine activities might offer unexplored pathways for spatial skill development. To investigate this possibility, the present research examines how spatial visualization skills are performed in a fiber craft activity (i.e., folding a basket) by engineers and crafters. We hypothesize that experienced crafters will demonstrate sophisticated spatial reasoning strategies in these tasks, potentially comparable to those employed by engineers, suggesting that fiber crafts may offer an alternative but equally valid context for developing and expressing spatial visualization skills.

Methods

Participant selection and sampling

We conducted artifact analysis sessions with a total of 10 adult participants (4 crafters and 6 adult engineers). Crafters were recruited through snowball sampling starting with personal networks and had at least five years of experience in fiber arts. Engineers were also recruited through snowball sampling starting with personal networks and held degrees in mechanical, aerospace engineering, and mechatronics professionals, with experience levels reaching up to 10 years. Both groups were diverse in age 26 to 40 and gender distribution. Participants engaged in a standardized craft task: the basket folding activity. In this task, they created a 3-

dimensional basket from a flat felt sheet (approximately 20 x 30cm / 8 x 12 inches) using only scissors, with no pre-marked guidelines.

Analysis methods

The analytical approach builds the constructionist principle of epistemological pluralism, which assumes that there are multiple valid ways for internalizing and externalizing conceptual understanding as people manipulate tools and materials in design situations (Turkle & Papert, 1990). All sessions were video recorded (approximately 7 hours total) and supplemented with think-aloud protocols where participants verbalized their spatial reasoning processes. Sessions averaged 43 minutes per participant. Three researchers independently coded parts of the recordings for spatial visualization strategies, problem-solving approaches, and tool manipulation techniques. Any disagreements in the independent coding was resolved through discussion, reaching agreement across codes.

Activity description

To fold a basket, participants saw an image of the folded basket and asked to use a flat piece of felt into the 3-D shape using scissors, pens, and a ruler (Figure 1, left). To transform the basket, participants had to imagine the schematic that the basket could unfold into before drafting a schematic that could replicate the shape in the photograph, involving spatial visualization and related skills (e.g., mental rotation, proportional reasoning; see Figure 1).

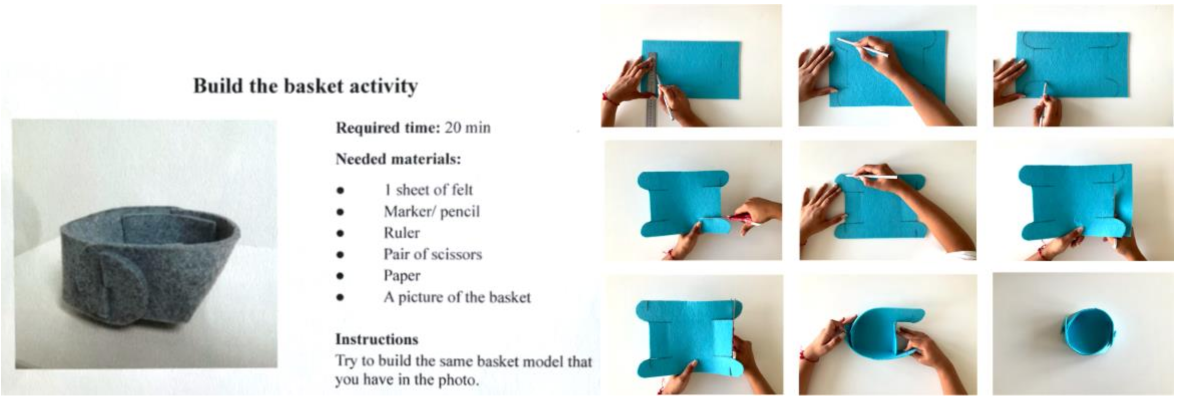

Figure 1. Basket folding activity instructions and ideal crafting process.

Findings: Contrasting Approaches to Spatial Problem-Solving

In analyzing the basket-folding task, we observed distinct approaches between crafters and engineers that reveal different spatial reasoning strategies.

Crafters' Intuitive-Exploratory Approach

Crafters demonstrated an iterative, materials-first approach to spatial problem-solving. Rather than extensive planning, they engaged in direct material manipulation, using the felt's properties to inform their spatial reasoning. As one crafter explained, *"I imagined the basket in 2D by unfolding it and then started to draw (...) I also tried to unlock it in my mind to understand the folding technique."* This approach integrated mental visualization with hands-on experimentation, leading to rapid development of viable solutions for both structural design and functional elements like closure mechanisms (Figure 2).

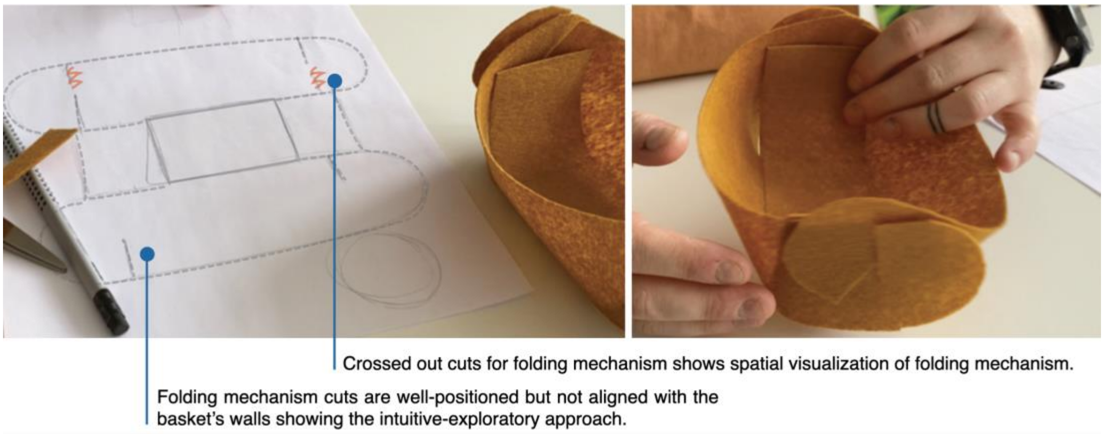

Figure 2. A crafters' drawn schematic and folded basket.

Engineers' Analytical-Planning Approach

Engineers approached the task through formal technical methods, prioritizing detailed planning over material exploration. A representative case showed an engineer creating multiple technical drawings from different perspectives before attempting the physical construction (Figure 3). While this approach demonstrated sophisticated spatial visualization skills, it sometimes led to impractical solutions, such as drafting a bottom-only design that omitted crucial structural walls. This disconnect between technical precision and practical functionality was observed consistently across the engineer participants.

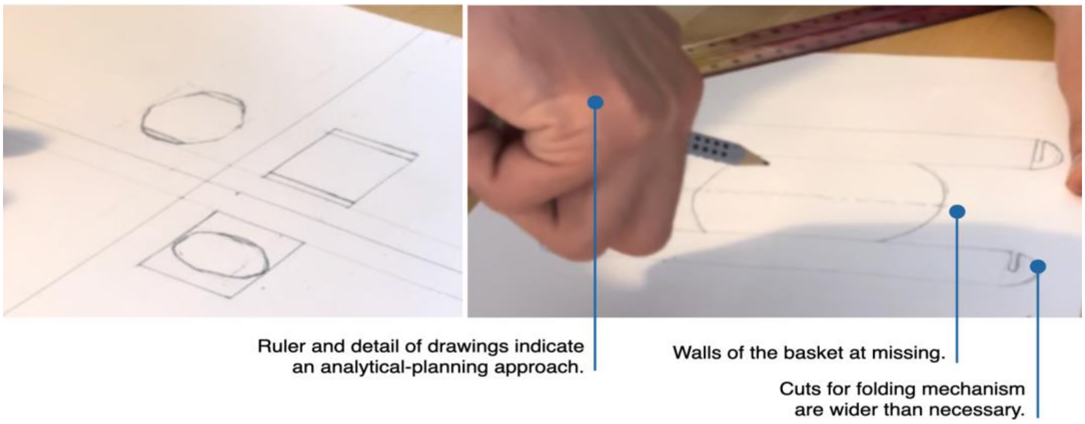

Figure 3. An engineer's drawn schematics

Discussion

Our findings reveal important insights about the nature of spatial visualization skills and their development in different domains. The contrast between crafters' and engineers' approaches challenges traditional assumptions about spatial reasoning in three key ways:

First, the success of crafters' intuitive-exploratory approach demonstrates that effective spatial reasoning can emerge through direct material engagement rather than formal technical training. Their ability to integrate mental visualization with physical manipulation suggests that hands-on craft experience develops sophisticated spatial skills that may be overlooked by traditional assessment methods.

Second, the engineers' challenges highlight potential limitations in conventional engineering education. While their formal training provided strong analytical tools, it sometimes impeded practical problem-solving by prioritizing technical precision over functional outcomes. This suggests that engineering education might benefit from incorporating more diverse approaches to spatial reasoning.

Third, these findings support epistemological pluralism by demonstrating multiple valid pathways to spatial understanding. The crafters' success through materials-first exploration validates alternative approaches to spatial reasoning that could make engineering education more accessible and effective for diverse learners.

Implications for Engineering Education

These results suggest several practical recommendations for engineering education that could be applied in engineering education: (1) Integration of craft-based activities to develop flexible spatial reasoning skills; (2) balanced emphasis between technical precision and practical functionality; and the (3) validation of multiple problem-solving approaches, including intuitive and materials-based exploration.

The potential of crafting activities as a context for practicing spatial visualization skills is particularly noteworthy. During basket folding, participants faced spatial challenges that required continuous mental visualization and manipulation of objects, as they had to perceive a three-dimensional basket in its flat form and mentally fold the components to obtain the expected result. The differences between crafters' and engineers' processes reaffirm the value of negotiating between intuitive and analytical approaches in engineering education.

Future research should examine how these different approaches to spatial reasoning might be effectively combined in engineering education to prepare students for both technical precision and practical problem-solving. Additionally, investigating how these findings translate across different craft activities and engineering contexts could provide valuable insights for curriculum development.

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