Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45700

Spatial Problem-Solving in the Dark: A Qualitative Study of Sighted Engineering Students' Spatial Strategies on the Tactile Mental Cutting Test While Blindfolded

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Introduction

This is a work-in-progress empirical research paper. Spatial ability can be defined as an intelligence related to one's ability to generate, retrieve, or manipulate mental imagery [1]. Definitions of spatial ability in the literature are broad and span a wide range of constructs and applications [2]. Commonly discussed constructs of spatial ability in the literature include mental rotation, perspective taking, orientation, and proportional reasoning [3-4]. Past research has linked spatial ability with performance in STEM fields, both in the academic realm and with professionals in industry [5]. Further research has shown the malleability of spatial skills meaning that spatial ability can be taught, strengthened, and maintained through targeted interventions [6]. Spatial ability interventions range from the implementation of entire courses to physical manipulatives intended to teach specific constructs of spatial thinking. Research has shown that typical content in a rigorous engineering mechanics course has a positive effect on students' spatial ability [7-8]. Providing spatial ability training and understanding how students approach solving spatial tasks holds great potential to increase student success and enhance retention efforts [9-10]. This work utilizes the Tactile Mental Cutting Test (TMCT) to evaluate spatial strategies employed by blind and low vision (BLV) individuals. The TMCT was developed in collaboration with the National Federation of the Blind (NFB), and multiple BLV individuals as well as spatial ability experts were involved in the design of the instrument [11]. The TMCT has been validated and demonstrated reliability in use with both blind and sighted populations [12-16].

Research Purpose and Research Question

This work builds off of spatial problem-solving theory presented by Hegarty which classifies spatial problem solving into two main categories including holistic and analytical strategies [17]. This work builds on Hegarty's work by expanding the focus on problem-solving to non-visual applications. Holistic strategies refer to either mentally or physically moving an object around oneself or changing one's perspective of the object by moving around the object. Analytical strategies refer to processes that involve sequentially analyzing pieces of the problem. Findings from past research on strategies BLV individuals use on the TMCT [18-19] indicate that in a tactile format, BLV participants tend to follow holistic strategies, analytical strategies, and a mixture of the two. Participants who used multiple strategies tended to achieve higher scores on the TMCT. This work seeks to build on past research to qualitatively examine non-visual components of spatial problem solving on the TMCT within the context of a sighted undergraduate engineering population. The overarching goal of this work is to develop interventions that effectively teach spatial thinking in a non-visual format. This work is guided by the following research question: What spatial strategies are employed by sighted engineering students when solving TMCT items while blindfolded?

Positionality Statement

The first author is a graduate student studying engineering education. He has completed a bachelor's degree in mechanical and aerospace engineering and a master's degree in civil engineering. Despite identifying as sighted, much of his research has focused on applying spatial interventions to make engineering education more accessible to blind and low vision students.

Methodology

This work follows a case study methodology to provide preliminary insights on student strategies within a sighted student population. Given the exploratory nature of this research and the need to compare individual variations in strategy use between high and low spatial performers, a case study approach provides the depth of analysis necessary to identify patterns in spatial problem-solving that broader methodologies with larger sample sizes may overlook [20-21]. In this work, each participant constitutes a case such that variations between high and low spatial performers are apparent in the analysis.

Participants

Participants in this study include five undergraduate students completing the sophomore-level engineering mechanics: statics course at a western university. Participants were selected based on their previous TMCT performance following a maximum variation sampling technique that purposely selected participants at the extremes of TMCT performance as well as the middle. Each of the students interviewed had declared a major field of study in mechanical or mechanical and aerospace engineering. None of the participants had received a significant level of prior spatial ability training beyond what is normally accumulated by sophomore engineering students. All five of the participants in the study identified as White or Caucasian and gender identities were reported as male, female, and gender non-conforming. Two students were identified as high-scorers on the TMCT and two were low-scoring.

Research Design

Students were recrited from an engineering statics course during the spring 2024 semester. As an incentive to participate in the study, students were awarded extra credit. Other extra credit options were available for those wo did not want to participate. All participants were required to provide informed consent which was developed in accordance with IRB guidelines.

All students were asked to complete the TMCT, and those who had provided consent to be contacted about further research were asked to volunteer to participate in an interview. The interview consisted of a think-aloud protocol and eight semi-structured interview questions. The interview protocol is provided in Appendix 2. Before the interview began, while wearing a blindfold, each participant was given a specific item from the subtest version that they had not already been exposed to. An image of the TMCT item and potential solutions is given in appendix 3. Each interview was transcribed automatically during the interview using Microsoft Dictate. To triangulate sources of information, participants were also video recorded while solving the problem. When the participants' reported strategies were unclear or not fully explained, participants were asked to elaborate. Appendix 1 presents a visual of the process.

Data Analysis

Interview transcriptions were analyzed using first cycle descriptive coding. Codes were adopted from past qualitative work that has been conducted on the TMCT with BLV populations following a directed content analysis procedure [22]. No additional codes emerged while coding the transcripts from the sighted student interviews. Subsequent to first cycle coding, axial coding was utilized as a second cycle coding process to form categories to represent the general type of strategies being employed. For this preliminary work, coding was completed by one researcher. Future iterations of the study will involve multiple coders.

Findings and Discussion

Results of second-cycle coding yielded three major categories of spatial strategies including analytical, holistic, and mixed strategies. In the context of this study, analytical strategies are defined as those strategies that are algorithmic in nature and do not require a solid understanding of spatial relations such as counting lines on an object. Holistic strategies are defined as strategies that require viewing the object in its entirety while using spatial skills to determine how features are organized. Mixed strategies are defined as strategies that have elements related to both analytical and holistic approaches. Students who scored high on the TMCT tended to use more holistic and mixed strategies and used analytical strategies to check their answers. Low scoring students tended to rely more on analytical strategies and used fewer strategies overall.

Identifying basic shapes was an analytical code that was applied in the transcript for each of the five participants, although the higher scoring participants tended to *identify basic shapes* at a higher frequency than the low scoring participants. For example, a high scoring participant said the following while searching through potential answer choices:

> “There was no square cut out like that from the big square, if you can imagine that.”

Analyzing each line sequentially was an analytical code applied when the participant felt around the perimeter of either the 3D object or any of the 2D answer choices and memorized the sequence of lines including their associated distances, directions, and angles. Of the five participants, the middle-scoring student utilized this strategy the most:

> “Pretty flat. Vertical here. That’s angled a bit downward. Feels a little bit shorter than that vertical piece on the side on the right. It comes to a point here in the like downwards it goes back up. On the left there’s another vertical line but not as far as the first one. It goes horizontal and then angles back to the left, down again, where it's flat.”

Participants who utilized the holistic strategy *creates mental image of model* typically felt the 3D object first and then created a mental prediction of what the 2D cross-sectional area should look like. A high scoring participant reports after feeling the 3D object:

> "And then I just kind of get it in my head what I think it might look like and then I will go to the paper."

One code that was related to *creates mental image of model* was *analyzes basic shape before details*. This code was applied when the student reported feeling the whole object to get a basic idea of what the cross-sectional shape could be before feeling for specific details.

When students described portions of either the 3D object or 2D outline in terms of directions such as "top," "bottom," "left," or "right" the mixed-strategy code *sense of direction* was applied. For example, when a low scoring participant explained their answer selection:

> "I think, I don't know. I just followed it around and it seems the same. I think maybe the point on the top right side and the point on the top left and on the front bottom and then the little indent on the left side."

Prior research on spatial strategies in tactile applications is limited. This study expands on prior work with BLV populations and reveals similar use of strategy between blind and sighted populations. Similar to BLV individuals, sighted students often described complex TMCT objects using simple geometric shapes [18]. However, BLV participants relied more on holistic physical manipulation of TMCT items [18]. This suggests that training sighted students in more hands-on, dynamic approaches, such as are common in BLV populations, could promote adoption of more efficient holistic strategies. Implementation of these strategies will lead to enhanced spatial ability and improved engineering performance in engineering education.

Conclusion

This case study explores the spatial strategies employed by sighted engineering statics students when solving TMCT items while blindfolded. The three main categories of strategies that were used by these participants include analytical, holistic and mixed strategies. Holistic strategies tended to be the most successful in solving TMCT items. However, high scoring participants tended to be ones who utilized a variety of strategies, often to double check answers. These findings provide a foundation for understanding how sighted students approach spatial tasks in non-visual formats and can inform the development of future spatial interventions.

Future Work

Future work will include expanding the sample size and recruiting students from other disciplines to participate in the project. Differences in how BLV versus sighted participants approach solving TMCT items will also be explored. Finally, tactile hands-on spatial interventions will be developed for sighted students to encourage tactile spatial skills.

Acknowledgements

This material is based upon work supported by the U.S. National Science Foundation under Grant No. 1712887. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Appendix 1.

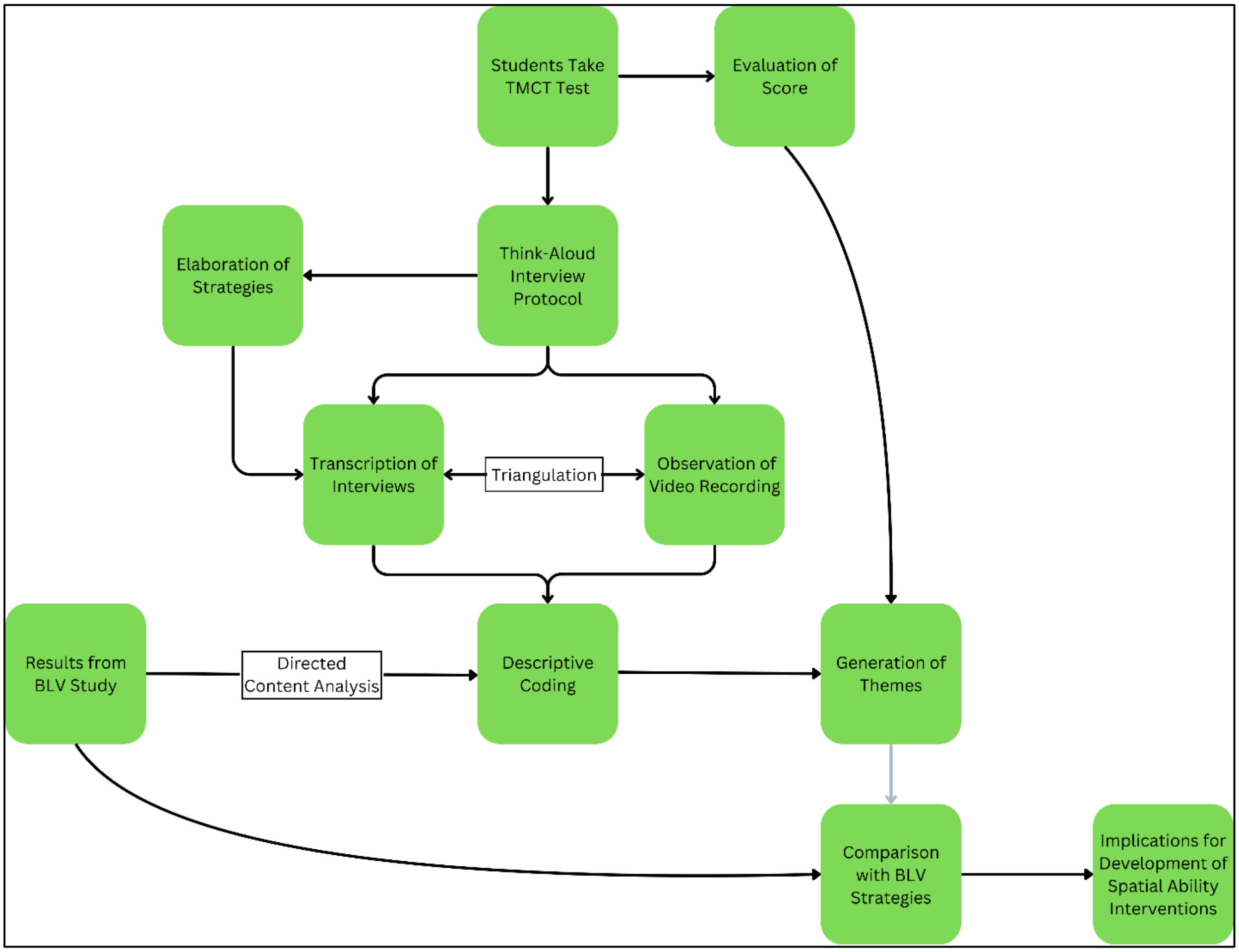

Figure 1. Design of study.

Appendix 2.

Interview Protocol

Upon completing the TMCT, ask the student if they are willing to answer some questions about their strategies and solve one more problem.

Before the student enters the interview room, ensure that the TMCT problem and binder are covered by the cloth.

If the student took subtest A, give them problem 136

If the student took subtest B, give them problem 135

Start the recording and ask the student to “think aloud” and explain what is going through their head as they solve the problem.

When they have selected an answer, ask them the following questions if they were not already answered during the think-aloud process:

- **Tell me why you selected the answer you did?**
    - Where did you start?
    - Why did you pick that point to start from?
- **What strategies did you use?**
    - Did you have any strategies for eliminating possible answers?
- **During the test did you ever change your strategy?**
- **Did you look at problems as a whole, or did you focus on specific details?**
- **Would you consider this problem difficult?**
    - Why?

Appendix 3.

TMCT item used in study.