The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41738

Work in Progress: Assessing the Reliability of the Tactile Mental Cutting Test When Sampling Engineering Statics Students' Spatial Ability

Daniel Kane, Utah State University

Daniel Kane is a graduate student at Utah State University pursuing a PhD in Engineering Education with a concurrent master's degree in Civil Engineering. His research interests focus around the study of spatial ability with an emphasis on identifying patterns of spatial strategies and measuring spatial ability in blind and low vision populations.

Marlee Jacobs, Utah State University
Rosemary Yahne, Utah State University

Rosemary Yahne is an undergraduate student at Utah State University. She is pursuing a bachelor's degree in Civil Engineering with a minor in geology. Her research interests include determining spatial ability patterns in engineering students and testing spatial ability in underrepresented populations.

Dr. Wade H. Goodridge, Utah State University

Wade Goodridge is a tenured Associate Professor in the Department of Engineering Education at Utah State University. His research lies in spatial thinking and ability, curriculum development, and professional development in K-16 engineering teaching.

Work in Progress: Assessing the Reliability of the Tactile Mental Cutting Test When Sampling Engineering Statics Students' Spatial Ability

Introduction

Spatial ability is broadly defined as a cognitive ability to mentally create, manipulate, and retain spatial information [1], [2]. More specifically, spatial ability can be defined by a number of constructs including common constructs such as mental rotation, visuospatial memory, cross-sectional visualization, and navigation. [3], [4]. Applications of spatial ability are wide ranging and the number of constructs has not been formally agreed upon [5]. In this work, we refer to spatial ability as a quantification of performance on one or more specific constructs of spatial thinking assessed through a spatial ability test. This work specifically discusses constructs of mental rotation, cross-sectional visualization, and proportion.

The study of spatial ability holds great potential in the field of STEM education and has thus been an important focus of engineering education research. Past work has demonstrated a link between an individual's academic success in STEM fields and their spatial ability [6], [7], [8], [9]. Specific areas in which studies have shown increases in academic performance as a result of increased spatial performance include engineering [10], mathematics [11], chemistry [12], biology [13], geometric problem solving [14], geology [15], and anatomy [16]. A study by Wood et al. has shown that in addition to spatial ability influencing academic success, participation in rigorous undergraduate engineering courses also has a positive effect on students' spatial ability [17]. Beyond academia, spatial ability has also been linked to success in professional STEM fields [18].

Spatial skills are malleable meaning that they can be taught and enhanced through targeted interventions [19]. Such interventions that can be integrated into academic coursework include activities in engineering design, technological literacy, scientific inquiry, and mathematical thinking [20]. The format of spatial interventions ranges from the implementation of entire courses [21], [22] to physical manipulatives intended to teach specific concepts. Furthermore, once learned, spatial skills can be maintained over time [19].

In order to effectively measure gains in spatial ability as a result of intervention, proper instrumentation that has been validated and demonstrated sufficient reliability is required [23]. Commonly used instruments for assessing spatial ability include the Mental Cutting Test (MCT) which measures constructs of cross-sectional visualization and proportion [24], the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) which measures mental rotation [25], and the Mental Rotation Test (MRT) which also measures mental rotation [26]. In addition to classical spatial ability instrumentation, a wide range of new or adapted instruments have been developed for specific applications or for specific populations [27]. One spatial ability instrument that has been adapted to be more accessible for a specific population is the Tactile Mental Cutting Test (TMCT) [28]. The TMCT was developed as a three-dimensional tactile adaptation of the MCT intended to provide a fully accessible spatial ability assessment for blind and low vision populations. The TMCT has been validated [29] and has demonstrated reliability in blind and low vision populations [30], [31] and blind-only populations [32]. The TMCT has been utilized in past work to determine spatial strategies used by BLV individuals [33], [34] and to assess effects of the covid-19 pandemic on the spatial ability of BLV students at blindness training centers [35]. The purpose of this paper is to assess the reliability of the TMCT when administered to a sighted population with temporarily occluded vision.

Methods

The TMCT was created as a fully accessible three-dimensional adaptation of the MCT. When taking the MCT test, subjects are required to view a two-dimensional isometric drawing of a three-dimensional object with an imaginary plane intersecting the object [36]. The taker is then presented with five two-dimensional outlines of shapes that could represent the cross-sectional shape revealed by cutting the object at the intersection of the cutting plane. The TMCT was adapted from the same battery of items contained in the MCT. Three-dimensional objects from the MCT were digitally drafted using CAD software and materialized using 3D printing technology. Cutting planes were indicated by a laminated paper cutting through the object in the same orientation as shown on the MCT illustrations. Answer choice outlines were presented in large print for low vision participants and in a tactile graphics format with Braille labels for non-visual use. Large print answer sheets were excluded from this study due to the non-visual nature of the study. Figure 1 contains an example TMCT item featuring the large print answer sheet format. A more complete description of the development of the TMCT can be found in a previous publication [28]. After preliminary testing, the TMCT was split from its 25-item format into two subtests of equal difficulty [29]. One item was eliminated due to excessive difficulty.

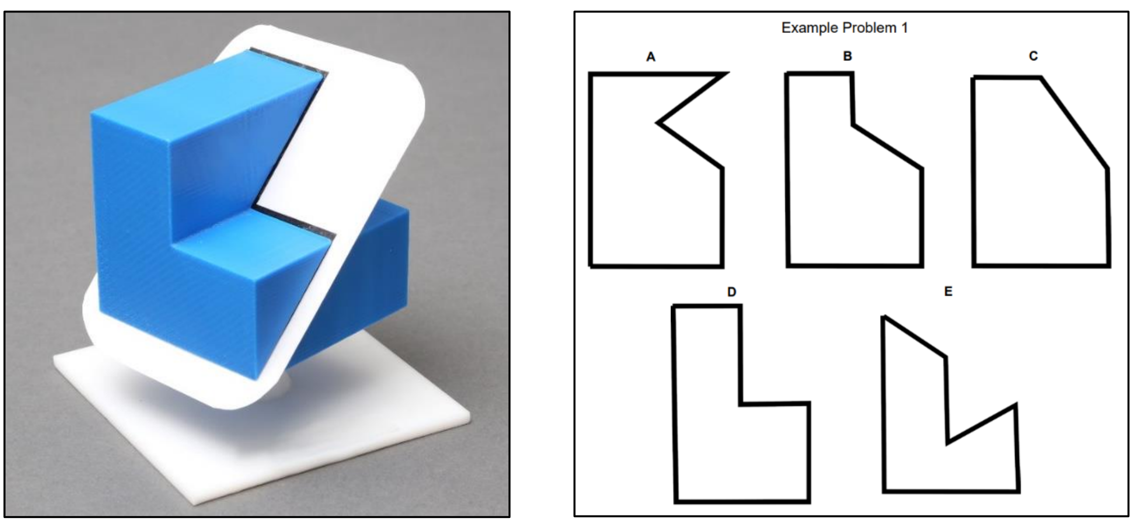

Figure 1. Example TMCT item with large print answer choices.

Population

The participants for this study were recruited to take the TMCT from three separate engineering courses, (Introduction to Mechanical Engineering, Statics, and Mechanics of Materials), at a large midwestern university. Participants were sampled by convenience due to the specificity of the target population and had no prior spatial ability training beyond those typically experience by engineering students at this stage in their education. The participants were recruited from their course over two spring and two fall semesters in the years of 2021 and 2023. As an incentive for participation in the study, students were offered extra credit in the course they were enrolled in. Participation in the study was voluntary.

Out of the 111 participants who took the TMCT, 88 identified as Caucasian, 3 as Hispanic/Latino, and 20 either unknown or preferring not to say. As shown in figure 1, 73 participants reported as Male, 37 as Female, and 1 participant preferred not to report gender. Out of the three classes selected for participation in the study, 22 participants were registered for Introduction to Mechanical Engineering, 41 for Statics, 30 for Mechanics of materials, and 18 participants did not specify which course they were registered for.

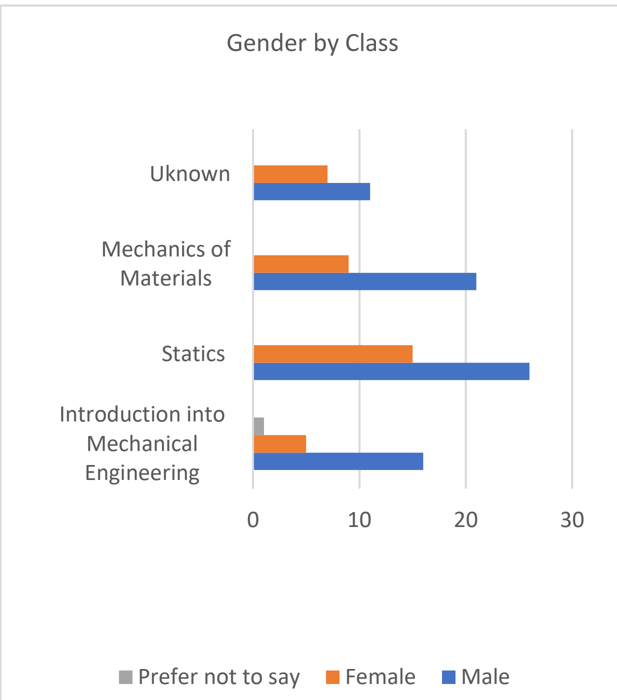

Figure 2. Gender by class.

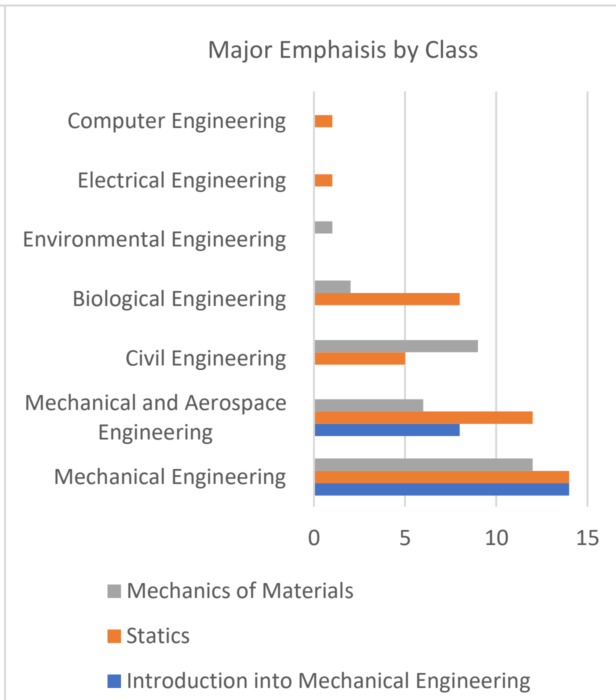

Figure 3. Major emphasis by class.

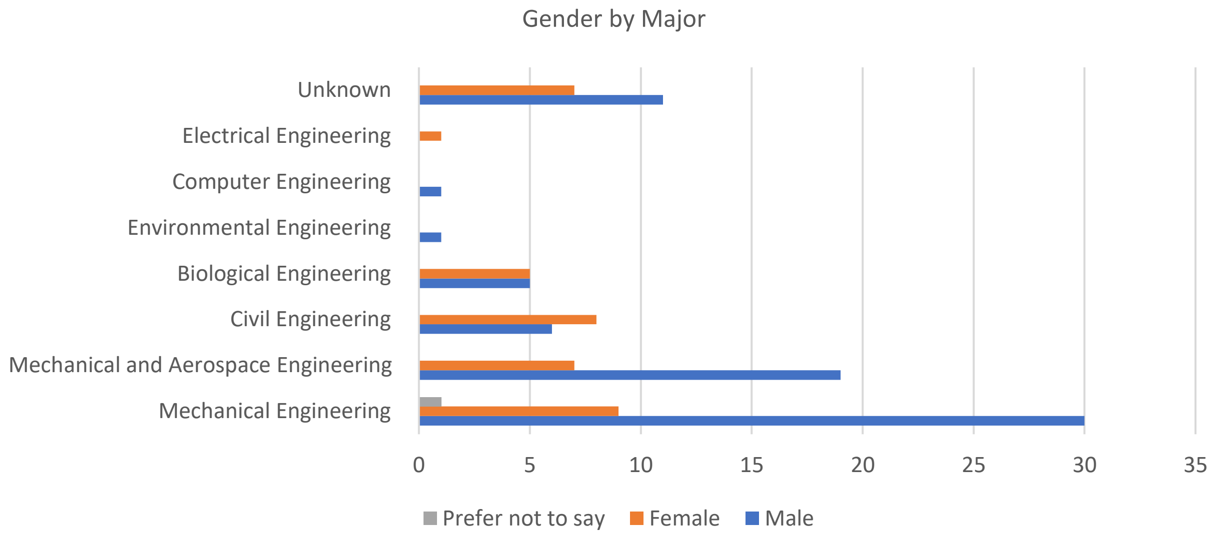

Figure 4. Gender by major.

Test Taking Procedures

Since the TMCT was originally created for visually impaired individuals, several adaptations were implemented for testing sighted subjects. Adaptations included blindfolding subjects, covering the test prior to testing, and assisting participants who could not use braille labels to identify the test problems.

The TMCT was administered in a controlled environment. Up to 5 participants took the test simultaneously and the 20-minute time limit from the MCT was eliminated to allow for more complete tactile interpretation. The average time to complete the TMCT among this population was 41 minutes. Each subtest was comprised of 12 questions presented on a turntable that was equipped with slots for each TMCT item. Slots resembled pie shaped volumes found in a rotary distribution around the table. Test questions were ordered in a counterclockwise fashion on the turntable and each problem was placed with the designated "front," as determined by the view shown on the MCT, facing outward towards the participant. This design allowed the participants to work through the problems at their own pace without requiring additional help to move to the next test problem. Next to the turntable, a binder with answer sheets was provided. Each testing setup also included a dispenser of sticky post-it tabs which were used to indicate the participants' selected answer choice for each question.

Prior to administering the TMCT, each test was covered in a black opaque cloth to prevent the participants from seeing the problems prior to taking the test. As participants entered, they would be directed to one of the tests. Once all participants had arrived, a standard information and instruction protocol was delivered verbally by proctors. Participants were then asked to put on provided blindfolds. Once the blindfolded participants were ready, they were provided with an example problem adapted from the MCT examples. Additional clarifying instructions were given as participants attempted to answer the practice problem. Once participants had successfully answered the practice problem, they were given a choice of doing a second example problem or beginning the test. Participants were allowed to work through the test at their own pace and could ask clarifying questions or ask for assurance that they were on the right problem.

After preliminary results from the internal consistency analysis, additional modifications were applied to the testing procedure. To reduce the possibility of cheating, administration of the test was moved to a windowless room. Additionally, after participants were blindfolded and prior to the start of the test, the lights were turned off. Administrators used flashlights to navigate around the room and assist participants when necessary.

Data Analysis

Analysis of the data was comprised of calculations of descriptive statistics related to students' mean TMCT scores and an analysis of reliability by assessing the test's internal consistency. Upon completion of testing, each student's answers were recorded in a dichotomous format, meaning that answers were recorded as either correct or incorrect. Correct answers from each student were summed to form a raw score and converted to a percentage form. Of the 111 students who took the TMCT, 108 completed all 12 items, including 63 who completed subtest A and 45 who completed subtest B. Missing data were assumed incorrect. Independent samples t tests were performed between groups to assess equivalence of means. All calculations were performed using Microsoft Excel 2019 or Jamovi 2.3.21 [37].

Internal consistency of the TMCT with a sighted population was assessed using both Cronbach's alpha and McDonald's Omega. Cronbach's alpha is a widely used measure of internal consistency for assessing instruments used in social research. The measure has been used to assess a variety of instruments including the TMCT in past studies with blind and low vision participants [30], [31], [32]. However, recent studies have shown that McDonald's omega, another measure of internal consistency, is better suited for assessing the reliability of instruments used in social research [38], [39], [40], [41].

After preliminary analysis of the TMCT's reliability with a sighted population, results indicated relatively low internal consistency. To mitigate potential opportunity for cheating, administration of the test was moved to a dark room and the reliability was assessed again. After finding favorable results, all subsequent testing was administered in the dark room format and Cronbach's alpha and McDonald's omega were assessed for both lighting formats. This paper reports on reliability of both subtests in the lighted format as well as reliability of subtest A in the dark room format. Future publications will report on the reliability of subtest B when an adequate sample size can be assessed.

Results

A total of 111 students took the TMCT over the course of the study. Of these students, 76 took the test before it was transitioned into a dark environment and 35 took the test in the dark. All participants who took the TMCT in the dark environment were assigned subtest A. A comparison of subtest A between the lighted and dark conditions show a slight decrease in the mean score t(61) = 0.909, p = 0.367. However, the difference is not statistically significant at a significance level of 0.05. Likewise, the difference in mean between subtest A and B with the test administered in lighted conditions was not statistically significant t(73) = 1.55, p = 0.125, suggesting an equivalency in difficulty.

Table 1. Descriptive statistics of the TMCT with a sighted population.

Lighting Conditions and Subtest	N	Mean Score (out of 12)	Standard Deviation (out of 12)
Lighted Subtest A	36	8.36	1.27
Lighted Subtest B	40	7.59	2.44
Dark Subtest A	27	7.85	2.65

Results of the reliability analysis revealed low internal consistency for subtest A in lighted conditions, with a Cronbach's alpha value of 0.327. McDonald's omega was undefined due to one of the items having zero variance in scores. Subtest B in lighted conditions had a higher but moderate internal consistency of 0.609 and 0.626 for Cronbach's alpha and McDonald's omega respectively. Subtest A administered in dark conditions had the highest reliability coefficients with a Cronbach's alpha value of 0.730 and a McDonald's omega of 0.766. Analysis of subtest B in a dark environment was omitted due to the relatively small sample size of 8 students.

Table 2. Internal consistency measures of the TMCT with a sighted population.

Lighting Conditions and Subtest	Cronbach's Alpha	McDonald's Omega
Lighted Subtest A	0.327	Undefined
Lighted Subtest B	0.609	0.626
Dark Subtest A	0.730	0.766

Although the primary purpose of this paper is to assess the reliability of the TMCT in sighted populations, there is construct-related evidence to argue for its validity. The TMCT inherits validity from the MCT since the TMCT is an adapted version of the MCT and utilizes the same problems in altered format. The validity of the MCT is evident from its correlation with other spatial ability tests. Using historic data from the Engineering Statics class, performance on the MCT was correlated with performance on the PSVT:R. The MCT was strongly correlated to the PSVT:R with a Spearman-Rho coefficient of 0.532 (n=209) [42]. Since both the MCT and PSVT:R aim to evaluate spatial ability, the strong correlation supports the convergent validity of both tests.

Discussion

Results indicate that mean scores on the TMCT were slightly lower for the group who was administered the test in a dark environment. This could point to potential evidence of cheating, although an independent samples t test comparing means yielded non-significant results. Further analysis of future data will likely yield a more complete explanation of differences between the two lighting environments. A review of past publications reveal that the blind and sighted populations show similar differences in mean scores between subtest A and B [31]. With both populations, the mean score for subtest A is slightly higher but results of a t test confirm no significant difference in means. Performance on the TMCT between groups tested in previous publications and results of this analysis should not be used to differentiate spatial ability of blind versus sighted populations due to the difference in demographics including previous experiences that lend themselves to the gaining of spatial ability through spatial experiences. Additionally, these participants are engineering students amidst their engineering education while blind participants were not necessarily engineering bound and did not have previous coursework that is comparable.

Based on current data, analysis shows that the subtest and lighting condition with the highest internal consistency is subtest A administered in a dark setting. While no widely accepted delineation of acceptable reliability coefficients have been established, a Cronbach's alpha value of 0.70 or higher is generally considered desirable [43]. From the results of the reliability analysis, there is sufficient preliminary evidence to indicate that the TMCT subtest A reliably measures spatial thinking in a sighted population of engineering students. Results from this "work in progress" paper are consistent with results from reliability analyses of the TMCT with blind and low vision populations [30], [31], [32] suggesting that the instrument is sufficiently suited for application among a variety of populations.

Reliability coefficients for subtest A increased dramatically when administration of the test was switched to a new "darkened" classroom part way through the study. One potential reason for this change in internal consistency may be related to the population being tested. During the first three semesters of testing, a large percentage of participants were recruited from the mechanics of materials course while a large percentage of the students who took the test in the dark setting were recruited from the statics course. This Statics course initiates with a focus on 2D and 3D vectors which require some spatial thinking and mental modeling of those vectors' interactions by the students. Mechanics may not have as distinct an initial spatial requirement for its students which means they may not be exercising their spatial modeling as much. With a larger majority of statics students in the dark format group taking the TMCT, we may have some impact on results from this factor. Participants were recruited during two fall and two spring semesters to negate seasonal effects in spatial performance.

Conclusion

An analysis of preliminary data on one subtest of the TMCT has established the reliability of the instrument as a tactile alternative to the MCT test. Results indicate that the TMCT can function as an effective assessment for measuring spatial ability in blind and low vision populations as well as in a population of sighted engineering students. Findings of this study contribute to the expanding exploration of tactile components of spatial ability and introduces a variety of implications for future spatial ability research, including the ability to measure gains in spatial ability as a result of non-visual targeted interventions.

Future Work

Additional data is still needed to solidify results from this "work in progress" to build on the conclusions made herein for the TMCT subtest A as well as to assess parallel forms reliability between subtests A and B. It is anticipated that after collecting student scores on subtest B that both subtests of the TMCT will demonstrate sufficient reliability. Future work with the TMCT will include using the instrument among sighted populations to measure gains in spatial ability as the result of tactile spatial interventions. In order to ensure quality of results from this study, future projects will include replicating the study with both lighting formats. Such a study will help narrow down possible reasons for the difference in test reliability between groups.

Further use of the TMCT among sighted engineering students will include a qualitative study to determine what strategies sighted individuals employ when solving spatial tasks on the TMCT. Results from this work may be able to better inform educators of the tactile components of spatial ability which may aid in the creation of more complete training.

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.

References

[1] K. S. McGrew, "CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research," *Intelligence*, vol. 37, no. 1, pp. 1–10, Jan. 2009, doi: 10.1016/j.intell.2008.08.004.
[2] D. F. Lohman, "Spatial Ability and G." 1993.
[3] A. Ramful, T. Lowrie, and T. Logan, "Measurement of Spatial Ability: Construction and Validation of the Spatial Reasoning Instrument for Middle School Students," *Journal of Psychoeducational Assessment*, vol. 35, no. 7, pp. 709–727, Oct. 2017.
[4] M. Hegarty, M. Keehner, and C. Cohen, "The Role of Spatial Cognition in Medicine: Applications for Selecting and Training Professionals," p. 49.
[5] H. B. Yilmaz, "On the Development and Measurement of Spatial Ability," *International Electronic Journal of Elementary Education*, vol. 1, no. 2, pp. 83–96, Mar. 2009.

[6] D. L. Shea, D. Lubinski, and C. P. Benbow, “Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study,” *Journal of Educational Psychology*, vol. 93, no. 3, pp. 604–614, 2001, doi: 10.1037/0022-0663.93.3.604.
[7] M. Stieff and D. Uttal, “How Much Can Spatial Training Improve STEM Achievement?,” *Educational Psychology Review*, vol. 27, no. 4, pp. 607–615, Dec. 2015.
[8] C. Julià and J. Ò. Antolì, “Enhancing Spatial Ability and Mechanical Reasoning through a STEM Course,” *International Journal of Technology and Design Education*, vol. 28, no. 4, pp. 957–983, Dec. 2018.
[9] S. Sorby, N. Veurink, and S. Streiner, “Does spatial skills instruction improve STEM outcomes? The answer is ‘yes,’” *Learning and Individual Differences*, vol. 67, pp. 209–222, Oct. 2018, doi: 10.1016/j.lindif.2018.09.001.
[10] D. H. Uttal, D. I. Miller, and N. S. Newcombe, “Exploring and Enhancing Spatial Thinking: Links to Achievement in Science, Technology, Engineering, and Mathematics?,” *Curr Dir Psychol Sci*, vol. 22, no. 5, pp. 367–373, Oct. 2013, doi: 10.1177/0963721413484756.
[11] N. S. Newcombe, “Picture This: Increasing Math and Science Learning by Improving Spatial Thinking,” *American Educator*, vol. 34, no. 2, p. 29, 2010.
[12] M. Oliver-Hoyo and M. A. Babilonia-Rosa, “Promotion of Spatial Skills in Chemistry and Biochemistry Education at the College Level,” *J. Chem. Educ.*, vol. 94, no. 8, pp. 996–1006, Aug. 2017, doi: 10.1021/acs.jchemed.7b00094.
[13] J. C. Castro-Alonso and D. H. Uttal, “Spatial Ability for University Biology Education,” in *Advances in Human Factors in Training, Education, and Learning Sciences*, S. Nazir, A.-M. Teperi, and A. Polak-Sopińska, Eds., in Advances in Intelligent Systems and Computing. Cham: Springer International Publishing, 2019, pp. 283–291. doi: 10.1007/978-3-319-93882-0_28.
[14] J. Buckley, N. Seery, and D. Canty, “Investigating the use of spatial reasoning strategies in geometric problem solving,” *Int J Technol Des Educ*, vol. 29, no. 2, pp. 341–362, Mar. 2019, doi: 10.1007/s10798-018-9446-3.
[15] A. U. Gold, P. M. Pendergast, C. J. Ormand, D. A. Budd, and K. J. Mueller, “Improving Spatial Thinking Skills among Undergraduate Geology Students through Short Online Training Exercises,” *International Journal of Science Education*, vol. 40, no. 18, pp. 2205–2225, Jan. 2018.
[16] J. Langlois, C. Bellemare, J. Toulouse, and G. A. Wells, “Spatial Abilities Training in Anatomy Education: A Systematic Review,” *Anatomical Sciences Education*, vol. 13, no. 1, pp. 71–79, 2020, doi: 10.1002/ase.1873.
[17] S. Wood, W. Goodridge, B. Call, and T. Sweeten, “Preliminary Analysis of Spatial Ability Improvement within an Engineering Mechanics Course: Statics,” in *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana: ASEE Conferences, Jun. 2016, p. 25942. doi: 10.18260/p.25942.
[18] J. Wai, D. Lubinski, and C. P. Benbow, “Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance,” *Journal of Educational Psychology*, vol. 101, no. 4, pp. 817–835, Nov. 2009, doi: http://dx.doi.org/10.1037/a0016127.
[19] D. H. Uttal *et al.*, “The malleability of spatial skills: A meta-analysis of training studies,” *Psychological Bulletin*, vol. 139, no. 2, pp. 352–402, 2013, doi: 10.1037/a0028446.

[20] C. Zhu *et al.*, “Fostering spatial ability development in and for authentic STEM learning,” *Frontiers in Education*, vol. 8, 2023, Accessed: Dec. 30, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/feduc.2023.1138607
[21] S. A. Sorby and B. J. Baartmans, “The Development and Assessment of a Course for Enhancing the 3-D Spatial Visualization Skills of First Year Engineering Students,” *Journal of Engineering Education*, vol. 89, no. 3, pp. 301–307, 2000, doi: 10.1002/j.2168-9830.2000.tb00529.x.
[22] Z. Hawes, J. Moss, B. Caswell, S. Naqvi, and S. MacKinnon, “Enhancing Children’s Spatial and Numerical Skills through a Dynamic Spatial Approach to Early Geometry Instruction: Effects of a 32-Week Intervention,” *Cognition and Instruction*, vol. 35, no. 3, pp. 236–264, Jul. 2017, doi: 10.1080/07370008.2017.1323902.
[23] A. C. de Souza, N. M. C. Alexandre, and E. de B. Guirardello, “Psychometric properties in instruments evaluation of reliability and validity,” *Epidemiol. Serv. Saúde*, vol. 26, pp. 649–659, Sep. 2017, doi: 10.5123/S1679-49742017000300022.
[24] “CEEB Special Aptitude Test in Spatial Relations (MCT),.” 1939.
[25] R. B. Guay, “Purdue Spatial Visualization Test: Visualization or Rotations,” Purdue Research Foundation, 1977.
[26] S. G. Vandenberg and A. R. Kuse, “Mental Rotations, a Group Test of Three-Dimensional Spatial Visualization,” *Percept Mot Skills*, vol. 47, no. 2, pp. 599–604, Dec. 1978, doi: 10.2466/pms.1978.47.2.599.
[27] D. Kane and Goodridge, Wade, “Quantifying Spatial Skills Across STEM Disciplines: A Systematized Literature Review of Assessment Tools,” presented at the 2023 ASEE Annual Conference, Portland, Oregon, Jun. 2024.
[28] T. J. Ashby, W. H. Goodridge, S. E. Lopez, N. L. Shaheen, and B. J. Call, “Adaptation of the Mental Cutting Test for the Blind and Low Vision,” presented at the 2018 ASEE Zone IV Conference, Mar. 2018. Accessed: Dec. 21, 2022. [Online]. Available: https://peer.asee.org/29599
[29] S. E. Lopez, W. Goodridge, I. Gougler, D. E. Kane, and N. Shaheen, “Preliminary Validation of a Spatial Ability Instrument for the Blind and Low Vision,” in *Roundtable Session*, San Francisco, CA, Apr. 2020. Accessed: Jan. 08, 2021. [Online]. Available: http://tinyurl.com/qlemtgm
[30] W. H. Goodridge, N. L. Shaheen, A. T. Hunt, and D. Kane, “Work in Progress: The Development of a Tactile Spatial Ability Instrument for Assessing Spatial Ability in Blind and Low-vision Populations,” presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Feb. 03, 2022. [Online]. Available: https://peer.asee.org/work-in-progress-the-development-of-a-tactile-spatial-ability-instrument-for-assessing-spatial-ability-in-blind-and-low-vision-populations
[31] C. Hamilton, E. Stratman, D. Kane, J. Blonquist, N. Shaheen, and W. H. Goodridge, “Parallel Form Reliability Analysis of a Tactile Mental Cutting Test for Assessing Spatial Ability in Blind and Low-vision Populations,” presented at the 2023 ASEE Annual Conference, Baltimore Maryland, Jun. 2023.
[32] D. Kane, J. R. Harris, W. H. Goodridge, and N. L. Shaheen, “Assessing the Reliability of a Tactile Spatial Ability Instrument for Non-Visual Use in Blind and Low Vision Populations,” presented at the 2023 ASEE Annual Conference, Portland Oregon, Jun. 2024.

[33] T. Green, W. H. Goodridge, D. Kane, and N. L. Shaheen, “Spatial Strategies Employed by Blind and Low-Vision (BLV) Individuals on the Tactile Mental Cutting Test (TMCT),” *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 5, Art. no. 5, Jul. 2023, doi: 10.3991/ijep.v13i5.38021.
[34] D. E. Kane, T. Green, N. L. Shaheen, and W. H. Goodridge, “A Qualitative Study of Spatial Strategies in Blind and Low Vision Individuals,” presented at the American Society for Engineering Education (ASEE) Zone IV Conference, 2022.
[35] D. Searle, D. Kane, N. Shaheen, and W. H. Goodridge, “An Analysis of Pre and Post COVID-19 Lockdown Spatial Ability Scores in Blind and Low Vision Participants,” presented at the 2023 ASEE Annual Conference, Baltimore Maryland, Jun. 2023.
[36] T. Green, W. H. Goodridge, J. Anderson, E. Davishahl, and D. Kane, “Comparing the Effectiveness of Newer Linework on the Mental Cutting Test (MCT) to Investigate Its Delivery in Online Educational Settings,” *International Education Studies*, vol. 16, no. 4, Art. no. 4, Jul. 2023, doi: 10.5539/ies.v16n4p1.
[37] “The jamovi project.” 2022. [Online]. Available: https://www.jamovi.org
[38] Y. Yang and S. B. Green, “Coefficient Alpha: A Reliability Coefficient for the 21st Century?,” *Journal of Psychoeducational Assessment*, vol. 29, no. 4, pp. 377–392, Aug. 2011, doi: 10.1177/0734282911406668.
[39] T. J. Dunn, T. Baguley, and V. Brunsden, “From alpha to omega: A practical solution to the pervasive problem of internal consistency estimation,” *British Journal of Psychology*, vol. 105, no. 3, pp. 399–412, 2014, doi: 10.1111/bjop.12046.
[40] A. F. Hayes and J. J. Coutts, “Use Omega Rather than Cronbach’s Alpha for Estimating Reliability. But…,” *Communication Methods and Measures*, vol. 14, no. 1, pp. 1–24, Jan. 2020, doi: 10.1080/19312458.2020.1718629.
[41] I. Trizano-Hermosilla and J. M. Alvarado, “Best Alternatives to Cronbach’s Alpha Reliability in Realistic Conditions: Congeneric and Asymmetrical Measurements,” *Frontiers in Psychology*, vol. 7, 2016, Accessed: May 11, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fpsyg.2016.00769
[42] H. Akoglu, “User’s guide to correlation coefficients,” *Turkish Journal of Emergency Medicine*, vol. 18, no. 3, pp. 91–93, Sep. 2018, doi: 10.1016/j.tjem.2018.08.001.
[43] K. S. Taber, “The Use of Cronbach’s Alpha When Developing and Reporting Research Instruments in Science Education,” *Res Sci Educ*, vol. 48, no. 6, pp. 1273–1296, Dec. 2018, doi: 10.1007/s11165-016-9602-2.