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Initial Investigations into the Link Between Spatial and Technical Communication Skills

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Initial investigations into the link between spatial and technical communication skills

Abstract:

ABET requires that all engineering graduates are able to effectively communicate technical information; however, industry leaders often lament the technical communication skills of our engineering student graduates. Despite years of concerted effort, at a national level, the situation does not appear to be improving. In contrast, the spatial skills of engineering students are typically well above average. A significant body of research has demonstrated the link between high spatial skills and success in engineering overall. But is there a link between high spatial skills and low technical communication skills for some of our students? In other words, are the high spatial skills of engineering students negatively correlated with their technical communication skills? This paper reports on a portion of a larger study examining the relationship between technical communication and spatial skills. Data for this study was collected from 90 first-year engineering students at a large midwestern university. Students were administered two tests of spatial ability and completed phonemic and semantic fluency tasks individually while being video recorded. The focus of this paper is on the relationship between spatial skills and these two types of fluency— phonemic and semantic. Phonemic fluency is defined as how well you can put words together to form a cohesive sentence or paragraph; semantic fluency is related to the size of your vocabulary. Both types of fluency likely influence a person's ability to effectively communicate technical information. Preliminary findings suggest a weakly positive link between spatial skills and both types of fluency, which prompts further investigation into how technical communication abilities are evaluated and informs future research in the area. Implications for engineering education based on our findings are discussed in the paper.

Introduction

The following section will introduce the relevancy of spatial skills to engineering, current trends in engineering students' verbal abilities in the US through standardized testing, and preliminary research that relates to technical communication skills, represented through phonemic and semantic fluencies.

Spatial Skills in Engineering

There are numerous studies that have linked spatial skills as key predictors of students' deciding to major in and succeeding in STEM disciplines [1]-[5]. Spatial skills have also been found to be critical for development of expertise in STEM [6]. Other research has linked spatial skills to success in computer programming [7]-[8] and solving mathematical word problems [9]. Further research has established that there are differences in spatial skill ability based on gender and socio-economic status [10], but there is a large body of evidence that spatial skills are malleable and trainable [11]. This research has resulted in successful training and interventions for students with weak spatial skills to improve their likelihood of success in engineering. Subsequent impacts of this training allow at-risk and underrepresented students to have higher chances at success in engineering majors, which responds to calls for more diverse representations in engineering.

Technical Communication for Engineering Majors

Another well-established competence for engineers to have besides spatial skills is technical communication skills. This is particularly important for engineering students who aim to have continued success in industry [12]-[16]. Despite the importance of technical communication skills, there exists a disparity between what academia reports the technical communication capabilities of recently graduated engineering students is and what industry is reporting. Other research has found that 50 percent of mechanical engineering department heads considered recently graduated students to have strong technical communication skills, whereas industry leaders considered only 9 percent of graduates to have strong technical communication skills [17]. This disconnect may exist because of a lack of targeted communication and writing assignments that do not teach an iterative and peer review process for writing [18]. There may also be a need for engineering academia and industry to better understand industry's specific communication needs and priorities [19]. There have been many attempts to alleviate these concerns, which include requiring technical writing courses, modifying assignment structure to improve the iterative writing process, introducing engineers to interdisciplinary writing contexts, and teaching writing via self-reflection for experimental lab report writing [20]-[22]. These efforts are a useful start to address these issues, but there is a dearth of studies that demonstrate the long-term effectiveness of these interventions.

Spatial and Verbal Skills for Engineering Students

Prior work by Project Talent, which conducted a longitudinal study following 400,000 high school students 11+ years later, found that adolescent spatial reasoning skills were predictive of choice of STEM majors and careers, above and beyond the effects of verbal and mathematics abilities [6]. Project Talent analyzed the verbal, spatial, and mathematics testing for students who earned bachelor's degrees. For the majority of students who majored in non-STEM (e.g. education), they had similar verbal and mathematics scores with relatively lower spatial skills. Students in STEM fields (except biology) had lower verbal skills, followed by spatial and then mathematics. Students who pursued engineering had the highest spatial skill levels of all majors and had mathematics skill levels similar to those who majored in mathematics. Students who pursued humanities had the highest verbal skills of all students. What is significant in these findings is that the verbal skills of students who pursued engineering were not significantly worse than those who pursued other majors [6]. This trend also exists for ACT scores of students matriculating into the University of Cincinnati, where the average verbal scores of students in engineering were equal to or higher than other majors as shown in Table 1.

Table 1. Average ACT Scores at [blinded university] for First-Year Students by College

	Engineering			Arts and Sciences			Health			Business		
	Math	Verbal	Comp	Math	Verbal	Comp	Math	Verbal	Comp	Math	Verbal	Comp
2020	29	27	28	23	24	24	25	26	25	27	27	27
2019	29	28	28	24	25	24	25	25	25	27	27	27
2018	29	28	29	24	25	25	25	25	25	27	27	27
2017	29	27	28	23	24	24	24	25	25	27	27	27

Relationships between Spatial Skills and Semantic and Phonemic Fluencies

Researchers conducted a study that examined verbal skills, spatial skills, and their relation to production of hand gestures [23]. In that study, verbal skills were categorized as *semantic*, the size of vocabulary, and *phonemic*, how effectively an individual can form a cohesive sentence. For example, a semantic task would ask the participant to name animals, and a phonemic task would ask the participant to name words that begin with the letter "s." These tasks are normally timed (e.g., in 60 seconds). In that study, participants completed semantic and phonemic instruments, a spatial ability instrument, and other tasks [23]. The authors concluded that the individuals with low phonemic fluency, but high spatial ability had mental images that were not connected to verbal forms [23]. This phenomenon could be what is occurring for engineering students, particularly if the content knowledge of engineers may not be readily accessible through verbal forms.

Methodology

This section details a two-phase survey process. Phase 1 involved a proctored online spatial test. Phase 2 involved an in-person, recorded interview with participants who had complete data from Phase 1.

Participants

Participants were first-year undergraduate engineering students at the University of Cincinnati. Participants were enrolled in the second semester of a two-semester first-year engineering sequence taken by all engineers at the university. All participants would have practiced spatial thinking skills in the first semester of the course during a spatial visualization module that lasted two weeks. More than 1200 students were enrolled in the second semester course, of which 115 participants were recruited to participate in Phase 1 of the study. Participants received an incentive via a gift card for successful completion of required tasks. Of these 115 participants, 110 valid data points were acquired, with the other 5 removed due to incomplete data. Participants were invited to complete Phase 2 of the survey which involved a technical communication interview that was video recorded and lasted approximately 1 hour. Participants were incentivized with another gift card upon successful completion of the interview. Of these 110 participants, 90 participants were recruited to participate in Phase 2 of the study.

Of the 90 participants, 4 had to be removed due to technical issues during recording. A total of *n=86* participants were used in the analysis. Results from demographic surveys showed 71%

(n=61) of participants identified as Male, 28% (n=24) identified as Female, and 1% (n=1) preferred not to say. For student status, approximately 54% (28M, 18F) self-identified as domestic students, 44% as international students (32M, 6F), and 2% (1M, 1 undisclosed) preferred to not disclose this information.

Participants' standardized test scores were also examined to investigate trends in their verbal ability. For domestic students, the majority had either ACT Verbal or SAT Verbal scores reported which can be converted to one another. Due to the larger international student population, a variety of English proficiency scores were provided, which include the TOEFL, IELTS, Duolingo, and PTE. Unfortunately, there was no effective method to transfer these scores over to ACT Verbal scores, as they measured different abilities. Furthermore, the nuances of the individual language proficiencies were not deeply examined due to the scope of the project, and it was assumed by our team that all can represent English proficiency. Therefore, these different English proficiency scores were standardized into IELTS scores due to the larger sample size of these scores. A total of 49 participants (almost all domestic) had ACT Verbal scores and a total of 19 participants (all international) had an IELTS score. The remaining 18 participants had no ACT Verbal, IELTS, or corresponding score reported for conversion purposes.

Phase 1 Instruments

Phase 1 administered two spatial tasks and one verbal task for participants. This research analyzes the results from one spatial task, the Mental Rotation Task (MRT). The MRT is a validated instrument that measures spatial ability [24]. The MRT has strict time limits and can be difficult, but mental rotation skills have been shown to be important for overall success in engineering, and research has shown the largest gender differences in speeded mental rotation tasks [11],[25]. In the MRT, participants are given one figure on the left and are presented with four figures on the right that may be rotated views of the original left figure. Each answer has two correct options and two incorrect options, and participants earn 1 point if they select *both* rotated views, and 0 if they do not identify both figures. The time limit is 6 minutes with 24 total questions.

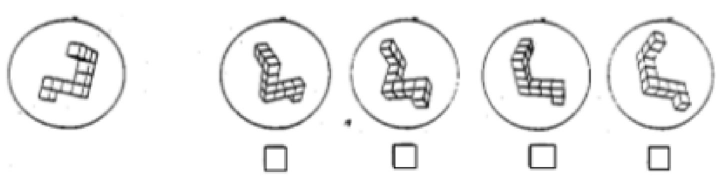

Figure 1. Sample Problem from MRT (Correct answer = 1, 3)

Phase 2 Instruments

Students participated in a recorded session that examined technical communication ability. For this paper, the focus is on a subset of tasks completed by participants that measured their semantic and phonemic fluency. The fluency tasks were asked by the interviewer to the participants in this order:

1. Name all the words that begin with the letter "s" within 60 seconds (phonemic)
2. Name all the animals you can think of within 60 seconds (semantic)
3. Name all the words that begin with the letter "t' within 60 seconds (phonemic)
4. Name all the fruits **and** vegetables you can think of within 60 seconds (semantic)

Tallying of word counts did not include proper nouns and morphological changes to a word (e.g., sixty-one, sixty-two, sixty-three) to follow conventions for task administration [23],[26].

Results

Analysis of the data was conducted in RStudio Build Version 2023.12.1+402. For all 86 participants, the five variables of MRT Scores, counts of t-words, s-words, fruit-veg, and animals were analyzed. The variables MRT Score, count of t-words, and count of fruit-veg departed from normality ($p < 0.05$). The variables count of s-words ($p = 0.06$) and count of animals were normally distributed ($p = 0.08$) Based on retrieved standardized test data, Tables 2 and 3 show average scores on the respective verbal tests and the MRT Scores

Table 2. Student average scores for Domestic ACT Verbal (n=49)

Group	Average ACT Verbal Score (out of 36)	Average Mental Rotation Score (out of 24)
All students (n=49)	30.0	15.4
Men (n=32)	30.0	15.9
Women (n=17)	30.1	14.5

Table 3. Student average scores on International IELTS (n=19)

Group	Average IELTS Score (out of 9)	Average Mental Rotation Score (out of 24)
All students (n=19)	7 .0	12.7
Men (n=16)	7.0	12.1
Women (n=3)	7.0	16.0

The hypothesis of this exploratory research was that the fluency skills of engineering students and their spatial skills are negatively correlated. A Pearson correlation coefficient was run to determine what types of linear relationships exist between these phenomena. The following table displays the association between MRT Score (out of 24) and the word counts on the four verbal tasks that were all timed for 60 seconds.

Table 4. Correlation matrix of MRT and four verbal tasks for All Students (n=86)

	MRT Score	S-Words	Animals	Fruit-Veg
MRT Score				
S-Words	0.213 (.049)*			
Animals	0.233 (.031)*	0.455 (<.001)***		
Fruit-Veg	0.233 (.031)*	0.392 (<.001)***	0.572 (<.001)***	
T-Words	0.068 (.532)	0.470 (<.001)***	0.367 (.001)***	0.315 (.003)**

**p < .05, **p<0.01, ***p<0.0001 | All counts were measured in 60 seconds.*

Results indicate a weak positive, but statistically significant, correlation between MRT Score and the count of S-Words, Animals, and Fruit-Veg. The results also indicate a not statistically significant correlation between MRT Score and the count of T-Words. Figures 1 and 2 are scatterplots that provide a visual image of strongest and weakest correlation

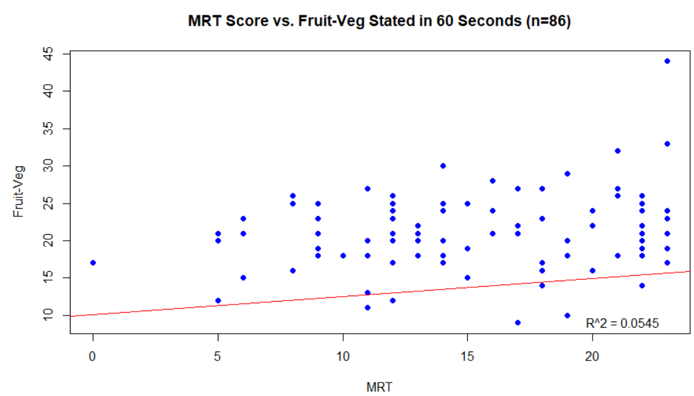

Figure 1. MRT Scores vs. Count of Fruit-Veg Words in 60 Seconds

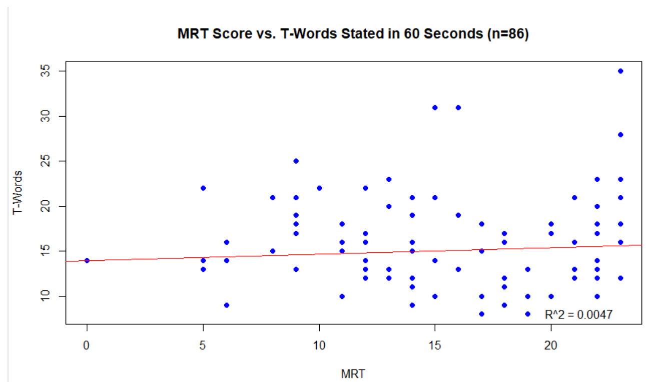

Figure 2. MRT Scores vs. Count of T-Words in 60 Seconds

As some participants standardized test scores were obtained from their ACT Verbal and IELTS scores, correlations were also calculated for this data (Table 5 and Table 6). Results indicate no statistically significant correlations between any of the fluency tasks and MRT Scores for students with ACT Scores. Results indicate a non-statistically significant and weak negative correlation between count of t-words and MRT Scores, and a statistically significant moderate correlation for animals and MRT Scores for IELTS students

Table 5. Correlation matrix for students with ACT Scores (n=49)

	MRT Score	S-Words	Animals	Fruit-Veg	T-Words
MRT Score					
S-Words	0.210 (.147)				
Animals	0.104 (.476)	0.535(<.001)***			
Fruit-Veg	0.252 (.081)	0.462 (.001)***	0.663 (<.001)***		
T-Words	0.134 (.358)	0.501 (<.001)***	0.339 (.017)*	0.153 (.293)	

ACT Score	0.417 (.003)**	0.231 (.111)	0.069 (.637)	0.233 (.106)	0.278 (.053)

**p < .05, **p<0.01, ***p<0.0001 | All counts were measured in 60 seconds.*

Table 6. Correlation matrix for students with IELTS scores (n=19)

	MRT Score	S-Words	Animals	Fruit-Veg	T-Words
MRT Score					
S-Words	0.159 (.517)				
Animals	0.520 (.023)*	0.377 (.111)			
Fruit-Veg	0.238 (.327)	0.457 (.049)*	0.458 (.049)*		
T-Words	-0.225 (.355)	0.602 (.006)**	0.064 (.795)	0.156 (.523)	
IELTS Score	0.293 (.223)	0.324 (.175)	0.603 (.006)**	-0.038 (.877)	0.384 (.105)

**p < .05, **p<0.01, ***p<0.0001 | All counts were measured in 60 seconds.*

Discussion of Results

This study began to examine the link between spatial and technical communication skills, with the hypothesis that the relationship is negatively correlated. However, results from this study indicated that there is a weak positive relationship between students' spatial skills represented by scores on the Mental Rotation Test and their semantic and phonemic fluencies, which represent a component of verbal ability. While not in direct support of the hypothesis, these generally weak correlations are useful to inform future directions of this exploratory research. These correlations may be representative of general intelligence and/or test-taking skills. The relationship between spatial skills and technical communication skills is thus likely to be more complicated than what this set of tasks were able to capture. Prior research into technical communication has shown that phonemic fluency tasks require larger executive control as most words are not organized using first letters [23]. Furthermore, the research showed that when tested for phonemic fluency:

> participants must effectively organize their lexicon into new subcategories. Success with the task is thought to rely on frontal lobe abilities such as task switching, strategic search, and effortful planning…[the] same frontal lobe processes [which] are presumably necessary for taking a holistic image and breaking it down into component parts for speaking, as speakers must efficiently organize the image in a way that coincides with the linear demands of speech and quickly switch their attention between different components that need to be mentioned. [23: 77]

These tasks may not be a good indication of technical communication skills, but rather share executive control with general spatial communication skills [23]. This relationship may also reveal that the difficulties of engineers' communication ability do not lie within the ability to find the words that fit specific categories but may be within different cognitive aspects that must be further explored. For instance, engineers may have access to semantic vocabulary when required, but understanding when and how to apply these to specific communication tasks, i.e., they have the words but are not good at stringing them together when writing. In industry, engineers must be capable of communicating to various audiences in different scenarios, and these multiple factors may need to be accounted for when attempting to examine these relationships.

Limitations and Future Work

Although this exploratory research has revealed insights from preliminary data, there were limitations in the data collection and analysis. Experiencing two different formats of data may have impacted participant performances. Phase 1 of the survey was proctored online. In Phase 2, students were placed within a room with an interviewer and were video recorded. For more authentic responses, students were not informed of the verbal fluency tasks beforehand, which may have caused undue difficulties in responses. Furthermore, the interview script did not inform students that they could not use morphological changes (e.g., sixty-one, sixty-two, sixty-three) for their answers.

Future work part of this research will explore students' responses to a question that asked them to describe an engineering project they completed in the previous semester. This more authentic discussion of an engineering project may reveal richer information regarding engineers' technical communication capabilities. Prior research into spatial skills has also utilized categories of spatial abilities, such as high, average, and low spatial skills alongside gender identification [11], [23]. Research into the area of spatial and technical communication has also used analysis of hand gestures, which is another factor that can be examined to a greater extent through collected interview tasks. Furthermore, data was gathered through a writing assignment as well as assessments addressed in this paper; the writing assignment data will be analyzed in the future.

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References:

[1] I. M. Smith, “Spatial ability: Its educational and social significance,” (No Title), 1964.

[2] 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, p. 604, 2001.

[3] S. Y. Yoon and E. L. Mann, “Exploring the spatial ability of undergraduate students: association with gender, STEM majors, and gifted program membership,” Gifted Child Quarterly, vol. 61, no. 4, pp. 313–327, 2017.

[4] D. E. Super and P. B. Bachrach, “Scientific careers and vocational development theory: A review, a critique and some recommendations.,” 1957.

[5] D. H. Uttal and C. A. Cohen, “Spatial thinking and STEM education: When, why, and how?,” in Psychology of learning and motivation, vol. 57, Elsevier, 2012, pp. 147–181.

[6] 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, p. 817, 2009.

[7] S. Jones and G. Burnett, “Spatial ability and learning to program,” Human Technology: An Interdisciplinary Journal on Humans in ICT Environments, 2008.

[8] S. Cooper, K. Wang, M. Israni, and S. Sorby, “Spatial skills training in introductory computing,” presented at the Proceedings of the eleventh annual international conference on international computing education research, 2015, pp. 13–20.

[9] G. Duffy, S. Sorby, and B. Bowe, “An investigation of the role of spatial ability in representing and solving word problems among engineering students,” Journal of Engineering Education, vol. 109, no. 3, pp. 424–442, 2020.

[10] J. E. Lauer, E. Yhang, and S. F. Lourenco, “The development of gender differences in spatial reasoning: A meta-analytic review.,” Psychological bulletin, vol. 145, no. 6, p. 537, 2019.

[11] S. A. Sorby, “Educational research in developing 3-D spatial skills for engineering students,” International Journal of Science Education, vol. 31, no. 3, pp. 459–480, 2009.

[12] R. M. Felder and R. Brent, “Designing and teaching courses to satisfy the ABET engineering criteria,” Journal of Engineering education, vol. 92, no. 1, pp. 7–25, 2003.

[13] M. Alley, The craft of scientific presentations, vol. 41. Springer, 2003.

[14] T. Nathans-Kelly and C. G. Nicometo, “Slide rules: design, build, and archive presentations in the engineering and technical fields,” IEEE Transactions on Professional Communication, vol. 2, no. 58, pp. 232–235, 2015.

[15] D. A. Winsor, Writing like an engineer: A rhetorical education. Routledge, 2013.

[16] J. W. Lynch, M. Vinnakota, S. Sorby, T. Murphy, K. Shannon, "Exploring The Link Between Spatial And Communication Skills In Engineering Students," 2023.

[17] J. A. Donnell, B. M. Aller, M. Alley, and A. A. Kedrowicz, "Why industry says that engineering graduates have poor communication skills: What the literature says," presented at the 2011 asee annual conference & exposition, 2011, pp. 22–1687.

[18] R. Gay, "Subverting the subject position: toward a new discourse about students as writers and engineering students as technical communicators," 2010.

[19] B. M. Aller, Writing practices in the engineering workplace: Findings and implications for teachers of engineering communication. Michigan Technological University, 2001.

[20] P. M. Berthouex, "Honing the writing skills of engineers," Journal of Professional Issues in Engineering Education and Practice, vol. 122, no. 3, pp. 107–110, 1996.

[21] G. Boyd and M. F. Hassett, "Developing critical writing skills in engineering and technology students," Journal of engineering education, vol. 89, no. 4, pp. 409–412, 2000.

[22] R. Selwyn and I. Renaud-Assemat, "Developing technical report writing skills in first and second year engineering students: a case study using self-reflection," Higher Education Pedagogies, vol. 5, no. 1, pp. 19–29, 2020.

[23] A. B. Hostetter and M. W. Alibali, "Raise your hand if you're spatial: Relations between verbal and spatial skills and gesture production," Gesture, vol. 7, no. 1, pp. 73–95, 2007.

[24] 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.

[25] D. Voyer, "Time limits and gender differences on paper-and-pencil tests of mental rotation: a meta-analysis," Psychonomic bulletin & review, vol. 18, pp. 267–277, 2011.

[26] E. H. Strauss, O. Spreen, and E. M. S. Sherman, *A compendium of neuropsychological tests: administration, norms, and commentary*, Third edition. New York: Oxford University Press, 2006.