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EXPLORING THE LINK BETWEEN SPATIAL AND COMMUNICATION SKILLS IN ENGINEERING STUDENTS (RESEARCH)

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ABSTRACT

Industry leaders rarely remark that the technical skills of engineering students are lacking; however, they frequently indicate that new engineers should be better prepared in communication skills, particularly written communication skills. In contrast, the visualization ability, or spatial skills, of engineering majors are typically excellent. Prior research has demonstrated that spatial ability is a significant predictor for graduating from STEM fields, particularly in engineering. This paper is part of a larger project that is exploring whether these two phenomena – poor written communication skills and well-developed spatial skills – are linked. In other words, is there a negative correlation between these two types of skills for engineering students? Data for this study was collected from first-year engineering students at a large university in the U.S. An online survey was administered that consisted of two validated spatial visualization tests, a verbal analogy task, and questions regarding

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students' self-perceived communication ability. Student scores on spatial visualization tests and a verbal analogy task were compared between student groups and students' perceived ability to communicate. Results identified statistically significant differences in test scores between domestic and international male students on all three tests. Interestingly, no gender-based differences were observed in spatial skills. Results from this study will contribute to future exploration of the link between spatial and technical communication skills. Results can also help inform the development of an intervention aimed at improving the written technical communication skills of our engineering students by helping them learn to write about spatial phenomena.

1 INTRODUCTION

1.1 Spatial Skills in Engineering

In the 1950s it was established that spatial skills are correlated with success in engineering and STEM (Super and Bachrach 1957, 24). Recent research has validated the claim that spatial skills are a reliable predictor of success in engineering disciplines and engineering careers (Uttal and Cohen 2012, 157) and is a critical skill in developing expertise in STEM (Wai, Lubinski, and Benbow 2009, 827). Research has shown marked differences in spatial skill ability, particularly in mental rotations, based on gender and socioeconomic status (Lauer, Yhang, and Lourenco 2019, 544), which could help explain the lack of representation of female and underrepresented minority students in engineering. However, there is a large body of evidence that spatial skills are malleable and can be trained, which can improve students' likelihood of success in engineering through interventions and training (Sorby 2009, 477).

1.2 Technical Communication Skills in Engineering

Another important skill for engineers to have is technical communication (Felder and Brent 2003, 13). Research has shown that technical communication abilities are crucial for engineers' success (Alley 2013; Nathans-Kelly and Nicometo 2014; Winsor 2013), but engineers often overestimate their technical communication abilities (Donnell et al. 2011, 3). Interventions for improving engineers' communication skills span a multitude of approaches, including courses and assignments that utilize interdisciplinary contexts for writing, which have resulted in improved grades and decreased writing times (Bertheoux 1996, 108; Boyd and Hassett 2000, 412). Other courses have taught engineering students writing skills that utilized self-reflection, which improved experimental lab report writing (Selwyn and Renaud-Assemat 2020). However, longitudinal studies that would demonstrate the durability of these interventions have not been conducted. Furthermore, due to the time and resource costs incurred to develop and sustain these courses, alternative approaches that could improve technical communication skills are desired.

1.3 Spatial Skills and Technical Communication

This study begins an exploration of a potential link between spatial thinking and technical communication skills. The overarching hypothesis is that spatial and technical communication skills are negatively correlated for most engineering students. If a negative relationship is found, an intervention could be developed in a future project to help these students learn to write about spatial phenomena. This paper is the first step in investigating that relationship.

2 METHODOLOGY

2.1 Participants

Participants were first-year undergraduate engineering majors at a large research university in the United States (U.S.). The students were enrolled in the second course of a two-course sequence taken by all engineering majors at the university. They had explicitly practiced spatial thinking skills in the first-semester course, through two weeks of in-class activities and graded assessments. Most students in the U.S. do not experience intentional spatial thinking content in formal education until those two weeks in that first-year course. Their training and practice with written communication came from their experiences prior to college as well as any communication courses they may have enrolled in in their first semester at the university.

Of the approximately 1200 students enrolled in the second-semester course, 115 participants were recruited for the study. Participating students received a small incentive for their participation in the form of a Visa gift card. Five participants were not included in the analysis because they did not complete the entire set of instruments, yielding a sample size of 110 for the analysis. This study was conducted with oversight from the Institutional Review Board for the university. Results from the demographic survey showed that 76 participants self-identified as male (M), 33 as female (F), and 1 chose not to disclose their gender identity. Of the 110 participants, 60% (39M, 27F) self-identified as a domestic student (meaning from the U.S.), 37% (35M, 6F) self-identified as international students; 3 (3%) students did not respond to this question.

2.2 Instruments

A number of separable spatial factors have been identified by psychologists over the years and tests have been developed to determine spatial skill levels for many of these factors. For this study, two measures of spatial skills were employed: the Mental Cutting Test (MCT) (CEEB. 1939) and the Mental Rotation Test (MRT) (Vandenburg and Kuse 1978, 599). With the MCT, students are shown an object with an imaginary cutting plane slicing through it and are asked to determine what the cross-section looks like from the choices given. There are 25 points possible on the test and it must be completed within 20 minutes. Anexample problem from the MCT is shown in Figure 1.

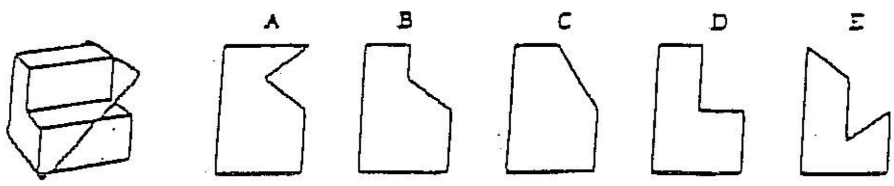

Fig. 1. Sample Problem from the MCT (Correct Answer = D)

In addition to the MCT, participants completed the MRT. An example problem from the MRT is shown in Figure 2. Although not as difficult as the MCT, the MRT has strict time limits and can be challenging for many students. Further, the MRT was included in this study because mental rotation skills have been shown to be important to overall success in engineering (Sorby 2009, 476) and speeded mental rotation tasks exhibit some of the largest gender differences in spatial ability (Voyer

2011, 267). This test is completed in two sessions of 3 minutes each with 12 items in each session. With the MRT, participants are presented with a criterion figure on the left and are instructed to find the *two* figures on the right that are rotated views of the criterion object. Scoring for this is 1 point if they identified both rotated views of the object, and 0 points if they fail to identify both.

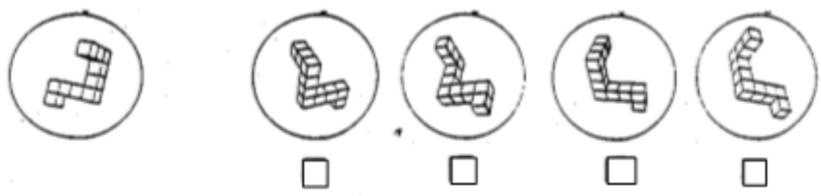

Fig. 2. Sample Problem from MRT (Correct answer is 1 & 3)

In addition to the spatial instruments, we administered a test of verbal skill level. The test was a verbal analogy task that consisted of 16 items. There was no time limit for the verbal analogy task. An example problem from the verbal analogy task is shown in Figure 3.

WOOD : (______) :: BUTTER : KNIFE

a) String b) Paper c) Saw d) Drill

Fig. 3. Sample Problem from the Verbal Analogy Task

In addition, participants responded to the following prompts on a 5-point Likert scale (1=Strongly Disagree, 2=Somewhat Disagree, 3=Neither Disagree nor Agree, 4=Somewhat Agree, 5=Strongly Agree).

- Q1: "I am confident that I am able to follow the instructions to efficiently put together a dresser from Ikea". (Image shown)
- Q2: "I am confident that I am able to come up with appropriate words or phrases when I am in a conversation with someone talking about my non-technical ideas".
- Q3: "I am confident in my ability to communicate my engineering ideas using verbal descriptions (words) that non-engineers can easily understand".
- Q4: "I am confident that I am able to express my thoughts, in writing, so that other engineers can easily understand my ideas".

2.3 Data Analysis

All analyses were conducted in RStudio 023.03.0 Build 386. Twelve t-tests were conducted. Specifically, for each of the three instruments measuring skills (MCT, MRT, verbal analogy test), t-tests were run to compare means between these groups:

- Male Domestic vs. Female Domestic
- Male International vs. Female International
- Male Domestic vs. Male International
- Female Domestic vs. Female International

Analyses were also conducted on student responses to their self-perceived communication ability and average scores on the MCT and MRT tests. As there was a lack of student responses on the non-agreement end of the Likert scale (strongly disagree/slightly disagree, neither agree nor disagree), student responses were categorized into three types: non-agreement, somewhat agree, and strongly agree. T-tests between the average scores of the MCT and MRT and students' self-reported ability was conducted only on somewhat agree and strongly agree categories. Table 1 provides descriptive statistics of the data gathered from the spatial and verbal analogy testing.

Table 1. Means (standard deviations) on spatial and verbal analogy tasks

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT) 25 pts possible	11.72 (std dev=5.63)	9.74 (std dev=4.59)	8.37 (std dev=4.45)	7.17 (std dev=4.67)
Mental Rotation Test (MRT) 24 pts possible	17.13 (std dev=5.69)	14.85 (std dev=6.02)	13.09 (std dev=5.27)	14.17 (std dev=3.49)
Verbal Analogy Test 16 pts possible	9.54 (std dev=2.5)	9.26 (std dev=2.35)	8.29 (std dev=2.32)	7.67 (std dev=1.37)

3 RESULTS

The data was tested for normality and was found to be normal except for the male domestic mental rotation test scores. Table 2 reports the results from the normality testing. In addition, tests of equal variances (H_0: $\sigma_1^2 / \sigma_2^2 = 1$) indicated that equal population variances could be assumed when performing t-tests. Table 3 reports the t-tests results for between groups based on student status (domestic or international) Table 4 indicates the t-test results for between groups based on gender.

Table 2. Tests for normality (p = 0.05)

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT)	p-value: 0.475	p-value: 0.869	p-value: 0.063	p-value: 0.565
Mental Rotation Test (MRT)	p-value: **0.00075**	p-value: 0.288	p-value: 0.512	p-value: 0.092
Verbal Analogy Test	p-value: 0.407	p-value: 0.322	p-value: 0.321	p-value: 0.093

Table 3. Significance of t-tests between groups based on status (Domestic/International)

	Male		Female	
	Domestic (n=39)	International (n=35)	Domestic (n=27)	International (n=6)
Mental Cutting Test (MCT)	p-value = **0.006275**		p-value = 0.2244	
Mental Rotation Test (MRT)	p-value = **0.002316**		p-value = 0.7914	
Verbal Analogy Test	p-value = **0.02918**		p-value = 0.1218	

Table 4. Significance of two sample t-tests between groups based on gender (Male/Female)

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT)	p-value = 0.136		p-value = 0.5459	
Mental Rotation Test (MRT)	p-value = 0.1238		p-value = 0.6323	
Verbal Analogy Test	p-value = 0.6491		p-value = 0.532	

No differences by gender were observed but this could be attributed to the fact that all participants, both male and female, practiced spatial thinking skills development as part of their first-semester course. The results of our analysis revealed that the only significant differences in all groups was between Male Domestic and Male International students on all three tests. Tables 5-8 report a comparison of the average scores of the MCT and MRT tests to students' self-perceived communication abilities (Q1-Q4).

Table 5: Students' self-reported ability to assemble furniture given instructions (Q1) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=4)	*Somewhat Agree (n=15)*	*Strongly Agree (n=91)*
Average score on Mental Cutting Test (out of 25)	12.75 (51%)	9.2 (37%)	9.82 (39%)
Average score on Mental Rotation Test (out of 24)	18.75 (78%)	13.66 (57%)	15.28 (64%)

T-test results indicated no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q1 on both the MCT ($t = 0.415$, $df = 104$, $p = 0.679$) and the MRT($t = 1.01$, $df = 104$, $p = 0.315$).

Table 6: Students' self-reported ability to create phrases or words for non-technical ideas (Q2) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=5)	*Somewhat Agree (n=35)*	*Strongly Agree (n=70)*
Average score on Mental Cutting Test (out of 25)	9.2 (37%)	11.54 (46%)	9.04 (36%)
Average score on Mental Rotation Test (out of 24)	19.4 (81%)	16.02 (67%)	14.47 (60%)

T-test results detected a statistically significant difference in the average scores between students who reported somewhat agree and strongly agree to Q2 for the MCT ($t = 2.433$, $df = 103$, $p = 0.017$), but not for the MRT ($t = 1.316$, $df = 103$, $p = 0.191$).

Table 7: Students' self-reported engineering communication ability for non-technical audiences (Q3) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=4)	*Somewhat Agree (n=44)*	*Strongly Agree (n=62)*
Average score on Mental Cutting Test (out of 25)	8.75 (35%)	10.32 (41%)	9.58 (38%)
Average score on Mental Rotation Test (out of 24)	14.75 (61%)	15.70 (65%)	14.85 (62%)

T-tests results indicated that no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q3 for the MCT ($t = 0.7313$, $df = 101$, $p = 0.466$) and the MRT ($t = 0.769$, $df = 104$, $p = 0.443$).

Table 8: Students' self-reported writing ability (Q4) vs. averages of spatial test scores

Response Rating (n=110)	Non-agreement (n=8)	*Somewhat Agree (n=40)*	*Strongly Agree (n=62)*
Average score on Mental Cutting Test (out of 25)	8.625 (35%)	10.45 (42%)	9.61 (38%)
Average score on Mental Rotation Test (out of 24)	17.5 (73%)	14.33 (60%)	15.45 (64%)

Final t-test results also indicated no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q4 for the MCT ($t = 0.807$, $df = 100$, $p = 0.422$) and the MRT ($t = 0.963$, $df = 100$, $p = 0.338$). Suprisingly, students who reported lower self-perceived communication abilities often had higher average scores on the spatial tests. However, the number of participants in the non-agreement category is small across all four questions.

4 SUMMARY AND ACKNOWLEDGMENTS

This work was completed as part of a larger research study that aims to explore a potential linkage between spatial and technical communication skills. An online survey was administered that consisted of two validated spatial visualization tests (Mental Cutting Test / Mental Rotation Test), a verbal analogy task, and questions regarding students' self-perceived communication ability. Results identified statistically significant differences in test scores between male domestic and male international students on all three tests. Interestingly, no gender-based differences were observed. Average student scores on the two spatial visualization tests were compared with students' self-perceived communication ability. Statistically significant differences were found on the average scores of the Mental Cutting Test between students who somewhat agreed and strongly agreed that they are confident in their ability to generate appropriate words or phrases about non-technical ideas. Interestingly, it was noted that students who reported lower self-perceived communication abilities often had higher average scores on the spatial tests. Future data analysis includes technical documents that participants created as well as video-recorded participant responses to a variety of linguistic tasks. This additional data can help explore a potential link between spatial and technical communication skills and allow for more direct measures to be developed targeting communication ability.

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