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Further Investigations into the Link Between Spatial and Technical Communication

Mr. John William Lynch, University of Cincinnati

I am a PhD student in Engineering and Computing Education at the University of Cincinnati, with a focus on improving undergraduate computer science education and student retention. My research explores the intersections of computer science, spatial skills, technical communication abilities, and how to use current technologies to enhance learning experiences. My ultimate goal is to improve retention rates in computer science across all education levels and make the field more accessible to a broader range of students.

Dr. Sheryl A. Sorby, University of Cincinnati

Dr. Sheryl Sorby is currently a Professor of STEM Education at the University of Cincinnati and was recently a Fulbright Scholar at the Dublin Institute of Technology in Dublin, Ireland. She is a professor emerita of Mechanical Engineering-Engineering Mec

Prof. Teri J Murphy, University of Cincinnati

Dr. Murphy is a professor in the Department of Engineering & Computing Education at the University of Cincinnati.

Dr. Betsy M. Aller, Western Michigan University

Betsy M. Aller is a retired associate professor in engineering management and manufacturing. At Western Michigan Univ., she coordinated and taught capstone design courses for 20 years, and developed courses in sustainability and project management. Her focus was on students' professional development and support for underrepresented groups in engineering.

Examining the Link Between Spatial Skills and Verbal Fluency

Abstract

This paper expands upon findings from prior exploratory research investigating the link, if any, between spatial visualization and technical communication skills. First-year engineering students at the University of Cincinnati enrolled in the second semester of a two-semester first-year engineering program were invited to participate in the research. An online proctored survey was distributed to students that included two spatial visualization tests, a verbal analogy test, and selfreported demographic information. Participants who completed all instruments were invited back to a one-on-one session where verbal fluency tests that measured phonemic and semantic fluency were administered. Eighty-eight valid data points were collected. A principal component analysis was applied to the spatial skills test results to classify each participant into categories of high, medium, and low spatial visualizers. This paper investigates verbal fluency in engineering students, an important aspect of overall technical communication ability. Results from this study will contribute to understanding how verbal fluencies interact with spatial visualization skills which could, in turn, be useful in understanding overall technical communication skills in further research.

Introduction

The subsequent sections of this paper will introduce the background of spatial and communication skills in the context of engineering and discuss research findings on the intersection between these two skillsets.

Spatial Skills in Engineering

There has been a significant body of research that suggests a relationship between strong spatial skills and overall success in engineering [1]-[6]. Further research has shown that spatial skills can be correlated with success in the subjects of mathematics [7]-[9], physics [10], chemical engineering [11], and areas of programming and computer science [12]-[15] Research has also shown differences in spatial skills based upon gender and socio-economic status [16]-[19] which could explain gaps in diversity in engineering; however, studies have also shown that spatial skills are malleable [20], which means disparities in graduation rates in engineering can be reduced through spatial skills intervention.

Communication Skills in Engineering

One crucial ability for engineering graduates is communication abilities, including visual, oral, written, and other forms of communication aimed at various audiences. Technical communication skills are critical for engineering graduates' success as they enter an increasingly globalized market and must interact with those from various cultures. The importance of communication for career success is reflected by ABET's mandate that new engineering graduates must have the skills to communicate with a broad range of audiences [21]. There have been decades of research aiming to improve the communication skills of engineering students, ranging from revamping curricula, creating specific courses to address these skills, or developing cross-departmental initiatives to improve communication abilities [22]-[28]. Significant efforts have been made to improve the communication abilities of engineering graduates, yet there is a disconnect between what communication skills industry expects engineering students to have and what engineering students' capabilities are upon graduation [29] – [31]. These disparities can result in risks for new graduates and industry, as vague descriptions, imprecise language, and complex sentences can become liabilities in practice for engineers [32].

This study focused on verbal semantic and phonemic fluencies. These skills are typically a small but important aspect of overall communication ability in students. Research in neuroscience and linguistics have explored these areas and have shown that recollection of words that begin with specific letters (phonemic fluency) or that belong to categories (semantic fluency) require different cognitive processes and are important to aspects of communication [39], [40]. While focused on younger students, neuroscience research has shown these types of fluencies are correlated with reading capabilities [41], spelling ability [42], and can be improved through lexical enrichment programs [42]. These fluencies are typically not analyzed in traditional engineering communication courses, which instead focus more broadly on oral and written skills, with impacts measured through student self-reported efficacy [27] or course-related project completion [24], [26]. In contrast, research that targets English as a Second Language (ESL) engineering students, explicitly analyzes improvements in communication based on speech rate, speech duration [43], lexical access, and semantic fluency [44]. While fluency training is essential for these students, the findings from neuroscience and linguistics regarding the benefits of having strong fluencies suggest that enhancement of fluency may benefit all engineering students, both traditional and ESL. It may be argued that a stronger focus on semantic and phonemic fluency could support the more typical research and teaching on written and oral communication.

Potential intersections between spatial and communication skills

Spatial abilities are typically strong in engineering students who succeed, in other words recent engineering graduates are more likely to have strong or excellent spatial skill abilities compared to their non-engineering peers. One potential reason for the perceived lack of communication ability among engineering students may be related to their strong spatial ability, where students may have a great depth of knowledge about a particular "product," but find it difficult to transform this knowledge into writing that various audiences can understand. Strong spatial visualizers may have difficulty in expressing, in words, products or phenomena they perceive to be "spatial." Prior work by the authors hypothesized that these abilities are negatively correlated, such that engineers may have the vocabulary (i.e., fluency) required to explain the topic, but not the skillset to string words together in an effective manner [33], [34]. Exploring the intersection between spatial and communication skills could lead to innovative solutions that enhance communication abilities of engineering students while maintaining their excellent spatial skills.

Methodology

The following sections will introduce the research setting, participants, data collection and analysis from the two-phase study. The instruments discussed are limited to the ones used for data analyzed in this paper.

Participants

Data for this study was collected as part of a larger study at the University of Cincinnati. Participants were students in the second semester of a two course first-year engineering sequence taken by all engineering students. Participants had completed a team-based robotics project in their first semester and were a few weeks into their second semester course at the time of testing. A total of n=115 participants volunteered to be a part of the study and completed an online proctored zoom survey. Students were incentivized with gift cards for their participation. The survey included two spatial skills instruments, a verbal analogy task, and basic demographic information. Participants signed up for a timeslot to join a zoom call proctored by a member of the research team where they were provided with the link to complete the survey.

Phase 1 Instruments

Mental Rotation Task (MRT)

The MRT was included as an accurate measurement of mental rotation skills [9]. Historically mental rotation skills have been a significant indicator of success in engineering and have typically shown large gender differences [35], [36]. The MRT contains 24 questions and participants were given 8 minutes to complete it. Participants are shown an original criterion figure on the left and are provided with four other figures. They are then asked to select the two figures out of the four that are the original image rotated. Participants must select both options to earn a point for the question, resulting in a potential total of 24 points. After 8 minutes all answers would be submitted. An example problem from the MRT is provided in Figure 1.

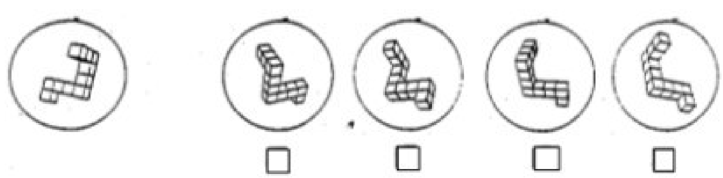

Figure 1: Sample Mental Rotation Task Question (Answer = 1 & 3)

Mental Cutting Test (MCT)

The MCT was also included as a validated measurement of spatial skills [37]. Participants are shown an image on the left with an imaginary plane slicing through the image. Participants are then provided with four other images and are asked to determine the correct cross-section produced by the intersection of the cutting plane with the object. Each question has only one correct answer; there are 25 points possible, and participants are provided with 20 minutes to complete the test. An example problem from the MCT is provided in Figure 2.

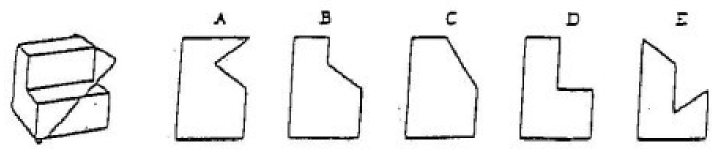

Figure 2: Sample Mental Cutting Task Question (Answer = D)

The last instrument was a demographic survey that allowed participants to disclose gender, student status (domestic/international), age, parental education, and other general information. After a participant completed all instruments, they could leave the proctored zoom call.

Phase 2 Instruments

Based on full completion of phase 1 (all questions answered), participants were invited back for Phase 2 of the study. This portion involved an hour-long one-on-one interview with a member of the research team

Fluency Tasks

Students participated in the recorded Phase 2 session and were administered four fluency tasks:

- Name all the words that you can that begin with the letter "s" within 60 seconds (phonemic)
- Name all the animals you can think of within 60 seconds (semantic)
- Name all the words that you can that begin with the letter "t' within 60 seconds (phonemic)
- Name all the fruits and vegetables you can think of within 60 seconds (semantic)

The word totals were tallied for each unique instance of a word and no morphological changes were counted (twenty-one and twenty-two would not count as two words) to follow normal conventions for evaluation of the tasks [39].

Data Analysis

All data analysis was conducted in RStudio 2024.12.0 using build 467. Eighty-eight participants completed all Phase 1 and Phase 2 items described in this paper. Scores on the MRT, and MCT (Phase 1) and semantic / phonemic fluency (Phase 2) passed tests of normality. An individual principal component analysis was applied to generate a single spatial score that was used to categorize visualizers into high, low, and medium levels [36]- [38]. The following section provides descriptive statistics and trends in low and high visualizers across student groups.

Table 1. Descriptive statistics of domestic and international visualization groups (n=26)

Visualizer Group	**Low**	**High**
Amount	12	14

Table 2. Significance levels between semantic/phonemic fluencies and spatial ranks (n=26)

Fluency Task	High Mean	Low Mean	t-Statistic	P-value	95% Confidence Interval	Significance
S-words	17.86	13.08	2.69	0.01	1.11, 8.43	**Yes**
Animals	26.21	22.08	2.24	0.04	0.31, 0.80	**Yes**
T-words	16.79	12.58	2.38	0.03	0.51, 7.90	**Yes**
Fruits and Vegetables	20.71	18.00	1.08	0.29	-2.53, 7.90	No

Correlations were applied to the low and high visualizer groups to examine trends between spatial score and communication tasks using the Pearson-method.

Table 3. Correlations between spatial score and verbal fluency tasks (n=26)

	Spatial Score	*S-Words*	*Animals*	*T-Words*	*Fruits and Vegetables*
S-Words	0.52 *(.01)*				
Animals	0.49 *(.01)*	0.47 *(.02)*			
T-Words	0.51 *(.01)*	0.67 *(<.001)*	0.30 *(.14)*		
Fruits and Vegetables	0.30 *(.14)*	0.51 *(.01)*	0.55 *(<.001)*	0.50 *(.01)*	

Computed correlation used pearson-method with listwise-deletion.

Discussion of Results

This study explored the relationship between verbal fluencies and spatial skills in engineering students. A principal component analysis applied to the collected data categorized participants into low-scoring and high-scoring spatial visualizers. Table 2 shows the comparison of low and high visualizers' significance levels from the phonemic tasks (recalling s-words / t-words) and one semantic task (recalling animals). Significant differences were found between the high and low visualizers for the phonemic tasks, but only one semantic task. Table 3 shows that differences in spatial scores were significant for the phonemic tasks of naming s / t words and the semantic task of animal recollection but was not for fruits and vegetables. Spatial ability being less correlated with a semantic task could indicate that the stronger spatial visualizers may have more difficulty with accessing similar word categories. Previously mentioned was the possibility that capable engineers have a depth of knowledge about specific products or concepts, and the required vocabulary but not the ability to bring this all together to communicate the information for various audiences. The production of words is typically associated with semantic fluency, or the ability to recall words in categories and transition between those categories in the context of communication [42], [43]. To this end, engineering coursework can adapt content from humanities courses that teach ESL engineering students and ensure that aspects of speech duration, speech rate, and lexical fluency are also improved [44], [45].

Limitations and Future Work

The collected data had about half the international student population, which may shift results in phonemic and semantic fluency tasks and may not represent domestic student trends. Gender was not included within this data analysis as most female participants ranked in the medium visualizer scores. Future research may extend similar analyses to medium visualizers (n=62), as this sample has more balanced distributions of gender and domestic / international students. When administering the phonemic and semantic fluency tasks, participants were recorded in an interview style setting with no prior explanation. Any undue difficulties due to this format may have impacted phonemic and semantic fluency counts. Furthermore, participants were not informed that morphological changes (twenty-one, twenty-two) would not count towards overall word count, which could skew some results in the data. Other data collected as part of the larger study included more communication tasks (written and oral) that can provide more information on the link between spatial and technical communication skills. For instance, higher scoring visualizers will have their written reports scored and analyzed. This written sample analysis will utilize a rubric that focuses on key features of effective written communication. A combination of the results from this current verbal skill analysis and the eventual written communication scoring will help this team answer the hypothetical questions of this research study.

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