Visualization Skills and Student Success in Engineering Disciplines

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***Abstract*—Students in engineering-related disciplines need to have strong spatial visualization skills to be successful both in their education and in their careers. The current body of research indicates that students' innate visualization skills can be measured and improved through targeted exercises. Improved visualization skills have been shown to improve student grade point average (GPA) at a small, homogeneous university. The purpose of this work will be to determine if past research can be generalized to a large, diverse institution. Standardized spatial reasoning tests are administered to students at various course levels and scores are compared based on their student GPA, time to graduation, course level, ethnicity, socioeconomic status, and sex. From this baseline data and past research, an intervention will be implemented to improve student success and address any existing achievement gaps.**

Keywords— spatial visualization

I. Introduction

Graphic communication skills are paramount to the success of engineers and construction professionals in every discipline. In practice, much of the information related to the design and behavior of three-dimensional (3D) engineering solutions is communicated using two-dimensional (2D) graphics. In education, students are traditionally taught using 2D drawings which requires them to mentally construct these complex 3D configurations. Despite the need for strong spatial visualization skills to succeed in engineering or construction management careers, the innate spatial abilities of students beginning their education vary widely [1-2]. Students who begin their engineering education with less developed spatial visualization skills may struggle in a traditional engineering classroom environment. These skills can be improved through focused practice [3]. Studies at a small, homogenous university have indicated that improving spatial visualization can lead to higher grade point averages and retention in engineering disciplines for those who have entered engineering programs with less developed spatial skills [4-7].

This quantitative study serves to determine if past research can be generalized to a large, diverse university. The overall objectives of this study are to assess spatial visualization skills based on current curriculum, propose an intervention similar to ones shown to have an impact at small, homogenous institutions, and collect longitudinal data to assess the impact of the intervention at this and similar institutions. The research questions that will be addressed with this study are

Q1: Is there a correlation between students' visualization skills and student success (i.e. GPA and time to graduation) at a large, diverse institution?

Q2: Will improving students' visualization skills lead to improved student success?

Q3: Are there achievement gaps in visualization skills or student success between certain groups and the general student population?

Q4: Will improving students' visualization skills close any existing achievement gaps?

This paper presents the preliminary work to collect baseline data on the impact of the current curriculum and will focus on answering the first and third questions above.

II. Background

Spatial visualization can be classified as the ability to mentally form and move an object in space [8]. This can be further described by two separate skills - mental rotation and mental transformation. The former involves mentally moving the entire object while the latter involves moving only part of an object.

To evaluate these skills, several tests have been developed and validated including the Differential Aptitude Test: Space Relations (DAT:SR) and the Purdue Spatial Visualization Test: Rotations (PSVT:R). The DAT:SR questions ask for the correct 3D object that could be formed from the given unfolded 2D version of the object. The PSVT:R questions ask for the correct object orientation after it has been rotated in a specified way. Both of these tests have been shown to be significant predictors of success in Engineering Graphics courses [9].

Highly developed spatial skills have been correlated to numerous factors that many university faculty are not able to influence, such as playing with construction toys as a child or playing sports. However, many studies have shown that other activities involving hand-eye coordination, such as sketching and computer games, can contribute to more developed spatial visualization skills as well [9].

These findings led to the development of a spatial skills course at small, homogenous Midwestern University where weekly computer modules and workbook sketching were employed to improve the spatial visualization skills of students who entered unable to pass the PSVT:R [10].

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Longitudinal studies performed at this institution have been linked to statistically significant changes in GPA and retention rates [11]. The spatial training curriculum studied was adapted by six other institutions of various sizes, locations, and demographics. While one of these institutions was a small, Historically Black College on the East Coast, none of the institutions are comparable to the large, diverse institution in this study.

III. Methods

This study adopted a quantitative approach to assess the visualization skills of students at varying levels in varying engineering-related disciplines as seen in similar studies [11-12]. Students were presented with ten questions that reflect a shortened version of the DAT:SR [13]. Welch's t-tests were used to assess the statistical significance of the difference in mean values for student performance at various levels and disciplines to determine if current curriculum has an impact on student spatial ability. Welch's t-tests assume that the data are obtained from an independent, random sample that the distribution of any group is normal, but the variances of the two groups may be unequal [14]. Percentage point gaps were also calculated to identify any achievement gaps between specific groups and the overall student population in the departments [15].

A. *Curriculum and Participants*

The students involved in the study were enrolled in their first or last civil engineering (CE 1A or CE 190) or construction management course (CM 10 or CM 129) at a large, diverse West Coast University. California State University, Sacramento (Sacramento State) is a Hispanic Serving Institution (27% of the undergraduate student body) as well as an Asian American Native American Pacific Islander Serving Institution (21% of undergraduate student body) with 58.4% and 44.8% being minorities in the civil engineering (CE) and construction management (CM) departments respectively. Both departments are male dominated, have over a third of their students coming from first generation and/or low income families, and approximately 95% of the students commute to campus. A breakdown of department demographics as well as individuals who completed the survey are shown in Table I.

The construction management curriculum consists of four distinct areas of study: engineering, management, business and general education. The engineering and management courses are taught within the department and sequenced such that each class is designed to prepare the students for subsequent classes. Students advance through the curriculum in a linear fashion. Within the CM curriculum, engineering, business and general education courses are relatively limited in their use of construction graphics. The management courses are focused in large part on developing students' abilities to interpret 2D engineering and architectural drawings and translate them in to quantifiable work activities. The first several weeks of Construction Graphics, a lower division required course, is dedicated to introducing students to multi-view drawings among other visualization, spatial reasoning and sketching exercises. The balance of the course, and subsequent CM coursework, is spent working with electronic and physical construction drawings. From the drawings, students are expected to determine material quantities, and construction activity sequencing and durations. In order to accomplish this, students must first interpret the 2D lines and symbols depicted on the plan sheets then translate those into 3D mental images of the work as designed. Finally, students must break the 3D images into discrete components and a sequence of assembly. Aside from the few weeks of targeted exercise in the Graphics course, students are largely expected to learn these skills by completing the assignments and working with the drawings.

The civil engineering curriculum similarly requires students to have highly developed spatial skills, but does not provide much explicit training. Engineering Graphics, a lower division required course, engages students with construction drawings by using computer software to create and interpret information related to engineering projects. The course does not provide explicit training or practice that has been shown to aid in rapidly improving spatial skills. Many students transfer an equivalent community college course instead of taking the offered course at Sacramento State which leaves their practice in communicating using engineering graphics even more varied by the time they reach upper division courses that rely heavily on spatial skills.

TABLE I. Demographics for Students in CE & CM Students

	Department or Course					
	CM Dept.	***CM 10***	***CM 129***	***CE Dept.***	***CE 1A***	***CE 190***
Ethnicity						
Underrepresented Minority[a]	40.4%	48.0%	14.0%	35.0%	11.0%	22.0%
All Minority[b]	44.8%	56.0%	17.0%	58.4%	44.0%	38.0%
Multiracial	4.9%	0.0%	14.0%	5.0%	5.0%	10.0%
White	45.7%	37.0%	62.0%	30.7%	43.0%	44.0%
Other/Unknown	2.2%	7.0%	7.0%	2.9%	8.0%	8.0%
Sex						
Female	9.4%	4.0%	7.0%	23.6%	29.0%	24.0%
Male	90.6%	96.0%	90.0%	76.4%	65.0%	74.0%
Background						
Low Income	42.2%	59.3%	41.4%	50.7%	61.3%	64.0%
First Generation	35.4%	55.5%	48.3%	32.7%	29.3%	38.0%
Total Students	**71**	**29**	**27**	**734**	**75**	**50**

a. Underrepresented minorities include African American, American Indian, Latino, & Pacific Islander.

b. All minorities include underrepresented minorities and Asian.

B. *Limitations*

Due to a significant number of students who transfer to Sacramento State, it is difficult to identify student standing based on credit hours completed. There is no single course that would enable the capture of data for all traditional sophomore or junior students due to the flexibility of the paths to completion for each program. The authors were able to capture data from a required course for students in their first semester as declared majors and their senior capstone course which they are required to take their final semester.

Further limitations include the fact that the freshmen and senior groups are two distinct populations. Future research will follow the current, and subsequent entering classes through their academic career at Sacramento State to compare actual improvement and retention rates from entering to final years.

IV. Results

While the average student performance increases on the DAT:SR from when they enter their engineering program and when they exit it, the difference is not statistically significant for civil engineering (CE) students. This is somewhat surprising but may be attributed to the fact that the CE program at Sacramento State includes several different disciplines such as environmental engineering. Veurink and Sorby [16] reported significant differences in performance on the PSVT:R for incoming freshmen entering different engineering majors based on the perceived need for spatial skills of the chosen field.

Construction Management (CM) seniors scored, on average, 12.9% higher than CM freshmen, but still scored an average of only 74.8% overall. CM and CE freshmen scored almost identically (61.9% and 62.9% respectively). CE seniors scored 65.9%, a 3.0 point improvement over their freshmen counterparts. Further longitudinal data is required to rule out any statistical anomaly present within the current CM senior class. If corroborated, the data suggests that the graphics-intensive nature of the CM curriculum may prove beneficial to students' spatial abilities.

A. *Q1: Is there a correlation between students' visualization skills and student success (i.e. GPA and time to graduation) at a large, diverse institution?*

Current data does not provide a clear link between time to graduation and spatial ability as measured by this study. Among both CE and CM populations, the seniors that scored the highest reported either 4-year or over 7-year time to graduation. Those students that scored lowest fell between years 4-7. This may be explained by the high percentage of working or part-time students in both majors. Students taking more than 7-years to graduate may be among the top performers for each group but must balance scholastic efforts with work or family obligations. Further research is needed to test this hypothesis.

Similarly, a tenuous link was found between measured spatial ability and GPA. In both CE and CM groups, those students who self-reported a GPA of 3.5 or above were among the top performers on the test. For students below 3.5 GPA no statistically significant difference was measured by the test. This is likely explained by the relatively small population of students tested. Further data is needed to establish or eliminate a clear link between GPA and spatial ability.

B. *Q3: Are there achievement gaps in visualization skills or student success between certain groups and the general student population?*

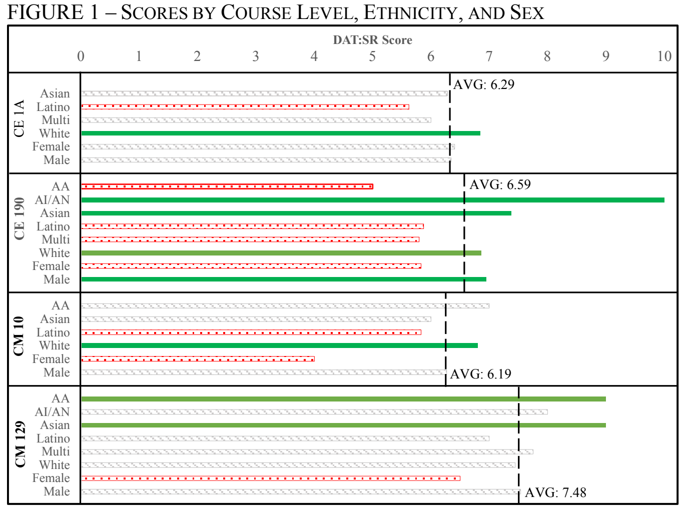
Figure 1 shows average scores broken out by ethnicity and sex for each course with disproportionate impact highlighted represented by red dotted bars, differences within the margin of error based on sample size represented by gray dashed bars, and disproportionately better performance than average represented as green solid bars.

Among CM freshmen, the single largest achievement gap exists among the Latino population which, as a group, scored 10 points lower than the average for the population as a whole. Among CM seniors, the Latino population had closed the gap to only 4 points lower than the general population. While this tends to suggest improved performance among Latino students from freshman to senior years, the relative percentage of Latino population dropped precipitously from freshmen to senior groups.

Similarly, within the CE population, the largest improvement from freshmen to seniors may be found among the Asian student population but again, the relative percentage of Asian students is significantly lower within the senior class. This trend is found among other ethnicities tested. Test scores are generally higher among seniors than freshmen, but the population of each ethnicity decreases significantly by senior year.

Consistent with the literature [17], achievement gaps are present in both the CM and CE department for women. The CM gap can be attributed to too few data points to represent the larger population. In the CE program, women only underachieve at the senior level, which may indicate a retention issue or a shift in the population.

FIGURE 1 – Scores by Course Level, Ethnicity, and Sex



Further longitudinal data is required to determine whether the change in test results is a function of true improvement in spatial ability or whether it is explained by the attrition of students with lower spatial ability from the major. Likewise, it is possible that shifting student demographics are responsible for the difference between the makeup of current freshman and senior groups. Clarification on these issues will be the subject of further research.

V. Future Work

Based on the results presented here, there appears to be some correlation between student spatial visualization skills and student success defined by higher GPAs and fewer years to graduation. The significant number of students with work and family obligations that impact their time to graduation makes it difficult to isolate the impact of spatial visualization skills without additional data looking into these and other factors affecting student success. Achievement gaps are apparent in the data. Additional data will need to be collected for other engineering majors to identify achievement gaps within each discipline. Future work will involve developing a workshop intervention geared towards groups most at risk for entering the university with lower spatial visualization skills. This workshop will likely consist of a combination of pencil sketch exercises, computer modeling, and virtual reality to utilize embodied learning. Activities used in past research will also be investigated and incorporated in the development of the workshop.

All incoming engineering freshmen and transfer students will take a longer version of a validated spatial reasoning test similar to the systems already in place for math and chemistry placement at Sacramento State. Those who do not achieve a certain percentage will be required to take a 1-unit workshop their first semester. Those who do pass the placement test can voluntarily take the workshop. A longitudinal study will track students who did and did not participate in the workshop intervention to address the second and fourth research questions.

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