Pictorial Visual Rotation Ability of Engineering Design Graphics Students

Dr. Jeremy V Ernst, Virginia Tech

Jeremy V. Ernst is an Assistant Professor in the Department of Teaching and Learning at Virginia Tech. He currently teaches graduate courses in STEM education foundations and contemporary issues in Integrative STEM Education. Jeremy specializes in research focused on dynamic intervention means for STEM education students categorized as at-risk of dropping out of school. He also has curriculum research and development experiences in technology, engineering, and design education.

Dr. Diarmaid Lane, University of Limerick

Diarmaid is a Lecturer in Technology Teacher Education at the University of Limerick. His research interests are in the areas of freehand sketching, cognition and spatial visualization. He is currently Director of Membership of the Engineering Design Graphics Division (EDGD).

Dr. Aaron C. Clark, North Carolina State University

Aaron C. Clark is a Professor of Technology, Design, and Engineering Education within the College of Education and is the Director of Graduate Programs and Associate Department Head for the Department of Science, Technology, Engineering and Mathematics Education. He has worked in both industry and education. Dr. Clark's teaching specialties are in visual theory, 3-D modeling, technical animation, and STEM-based pedagogy. Research areas include graphics education, game art and design, scientific/technical visualization and professional development for technology and engineering education. He presents and publishes in both technical/technology education and engineering. He has been and continues to be a Principle Investigator on a variety of grants related to visualization and education and has focused his research in areas related to STEM curricula integration. Dr. Clark has been a member of the Engineering Design Graphics Division of the American Society for Engineering Education (ASEE) since 1995; and has served in leadership roles and on committees for the Division since that time, as well as for the K-12 Outreach Division. He has also served in various leadership roles in disciplines related to Career and Technical Education. Dr. Clark is recognized as a Distinguished Technology Educator by the International Technology Engineering Education Association. He currently consults to a variety of businesses, educational agencies and organizations.

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Abstract

The ability to rotate visual mental images is a complex cognitive skill. It requires the building of graphical libraries of information through short or long term memory systems and the subsequent retrieval and manipulation of these towards a specified goal. The development of mental rotation skill is of critical importance within engineering design graphics. It promotes the ability to comprehend complex engineering drawings, communicate design ideas through freehand sketching and develop CAD modeling strategies. Considering this, exploratory development research was conducted in efforts to investigate student ability levels measured by parallel pictorial items of an existing geometric mental rotation measure. Images of rotated general consumer objects were captured and composed in a corresponding format to that of the Purdue Spatial Visualization Test: Visualization of Rotations. An expert review panel from engineering/technical graphics was convened to analyze consistency of format, rotation, and solutions of the corresponding pictorial items instrument. A group of post-secondary Engineering Design Graphics students were randomly administered the Purdue Spatial Visualization Test: Visualization of Rotations where the remainder of the group was administered the pictorial item instrument. The developed pictorial instrument represented orientation familiarity while geometric forms in the Purdue Spatial Visualization Test: Visualization of Rotations represented unfamiliar structures. Comparative analyses were conducted and differences identified pertaining to student abilities in mental rotation of geometric forms and pictorial visual rotation abilities. Summary statistics, frequency analyses, and hypothesis testing uncovered that student mental rotation abilities of geometric forms collectively exceeds that of ability of pictorial rotation ability.

Introduction

Contemporary curriculum policy and planning largely focuses on the development and promotion of numeracy, literacy and articulacy skills[1]. However, research has identified the importance of graphicacy across the education system in developing well-balanced human citizens[2; 3]. *"Graphics"* are the representation of visual images with the purpose of communicating some information. Representations differ vastly in their purpose, mode of creation and in their level of abstraction[4]. They can be in the mind (internal) or they can be physically perceivable (external).

The ability to mentally rotate and manipulate geometry is of fundamental importance in terms of being able to graphically communicate. Keen spatial skill is a strong indicator of achievement and attainment in science, technology, engineering, and mathematics fields[5]. These abilities are significant for an assortment of reasons, including "effective education in the science, technology, engineering, and mathematics (STEM) disciplines", (p. 352). Predominantly, previous academic studies concentrated on spatial ability, but did not offer attention to the circumstances under which spatial skill was developed or the transfer of those abilities to untrained areas[6; 7]. Within STEM education, however, engineering design graphics literature has a concentrated focus of exploratory and experimental research pertaining to spatial and visual skill development, paired with efforts to enhance mental rotation abilities for students. In a 2000 study, Branoff highlighted a criticism of traditional mental rotation measures in their use of "isometric projections for the display of three-dimensional objects", (p. 15) as well as further introducing the concept of object familiarity and unfamiliarity as an influential variable within visualization measurement. The influence and/or diagnostic impact that object familiarity has on mental rotation measure is largely undetermined.

Research Questions

To further explore object familiarity, a study was formed to examine paired engineering design graphics student mental rotation outcomes using traditional geometric form instrumentation and pictorial-based instrumentation of identical constructs. There was one principal research question guiding this mental rotation study: Does object familiarity provide for greater visual rotation attainment? This question was investigated through an exploratory development research study conducted in efforts to investigate student ability levels measured by parallel pictorial items of an existing geometric mental rotation measure.

Methodology

To begin, the research team met and formalized the investigational query, where they subsequently formulated a proposed research method. The full research protocol was generated and submitted for and received Institutional Review Board approval. A single instructor of 102 students on an initial technology teacher education program at the University of Limerick, Ireland served as proctor and participants for this exploratory development study. Particular focus in this undergraduate program is on the development of core graphical competencies including, graphical communication skills, understanding of geometric principles and spatial visualization skills.

The study constituted two sections of introductory course offerings affiliated with engineering design graphics concepts and applications. The instructor/proctor randomly determined which instrument would be administered to which section. The Purdue Spatial Visualization test Visualization of Rotations (PSVT-VOR) was administered to the 52 course participants in Section 001 while the Pictorial Visual Rotation Test (VRT) was administered to the 50 course participants in Section 002.

The PSVT-VOR employed in the present study is one element of the Purdue Spatial Visualization test battery (PSVT)[9]. The test measured students' ability to mentally rotate geometric objects depicted in drawing in three-dimension space. A standard time limit of 20 minutes was given for the test, which consisted of thirty items of increasing difficulty[8]. Each question in the test contained three lines. The directions of the PSVT-VOR test instructed the students to study how the key object in the top line of the question is rotated, and from among the five response options select the one that corresponds to the rotation of the depicted key object[10]. The PSVT battery provides a valid measure of cognitive abilities[10].

The second instrument relied on rotational sequences of acquainted consumer/household objects to construct a metric for object familiarity (see Figure 1 for PSVT-VOR and PSVT comparison). Images of these objects were captured in parallel format to the established PSVT item sequences and response choices. A single key object was identified, just as was developed for the PSVT instrument. An expert review panel from engineering/technical graphics was convened to analyze consistency of format, rotation, and solutions of the corresponding pictorial items instrument. Feedback was obtained and incorporated based on diagnostic usability, image clarity, rotational accuracy, and uniformity in terms of PSVT metric consistency.

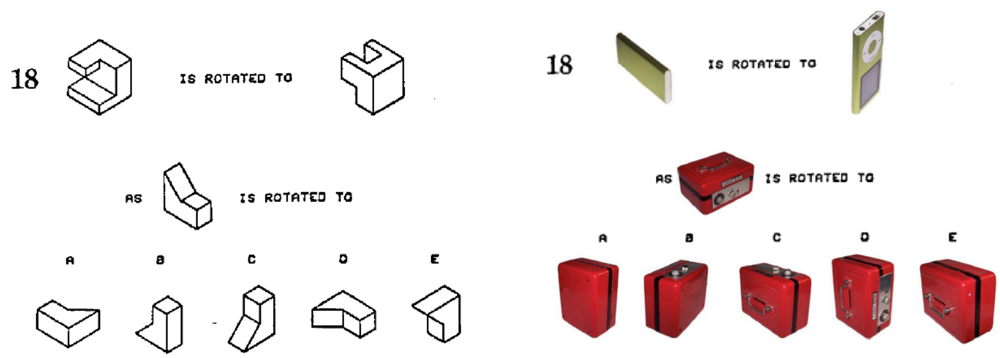

Figure 1. PSVT-VOR and Pictorial VRT item comparison

The developed Pictorial VRT represented orientation familiarity while geometric forms in the PSVT-VOR represented unfamiliar structures. Comparative analyses were conducted and differences identified pertaining to student abilities in mental rotation of geometric forms and pictorial visual rotation abilities.

Findings

Table 1 shows the summary statistics of the two visual rotation metrics. The average Pictorial VRT score (19.36 of a possible 30) for the 50 participants is lower than the average of PSVT-VOR scores (23.21 of a possible 30) for the other 52 participants. The variance (20.684) and standard deviation (4.548) of Pictorial VRT scores are low in comparison to the variance (22.837) and standard deviation (4.779) of PSVT-VOR scores indicating a slightly smaller spread of Pictorial VRT scores. The standard error (0.643) of Pictorial VRT scores is lower than that of Purdue SVRT indicating a smaller fluctuation in score values from participant to participant for the Pictorial VRT. The medians of both tests exhibit minimal deviance from the means respectively suggesting a somewhat symmetrical score distribution for both tests. The same range on both tests reiterates the comparable degree of difference in variability of participants between the two tests. Figure 2 and Figure 3 represent the number of occurrences for PSVT-VOR scores and Pictorial VRT scores.

Table 1 Summary Statistics

Assessment	n	Mean	Variance	Std.Dev.	Std.Err.	Median	Range
PSVT-VOR	52	23.21	22.837	4.779	0.663	24	18
Pictorial VRT	50	19.36	20.684	4.548	0.643	19	18

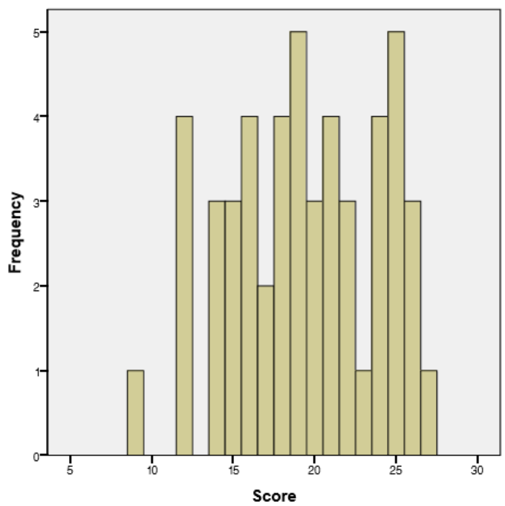

Figure 2. PSVT-VOR Histogram

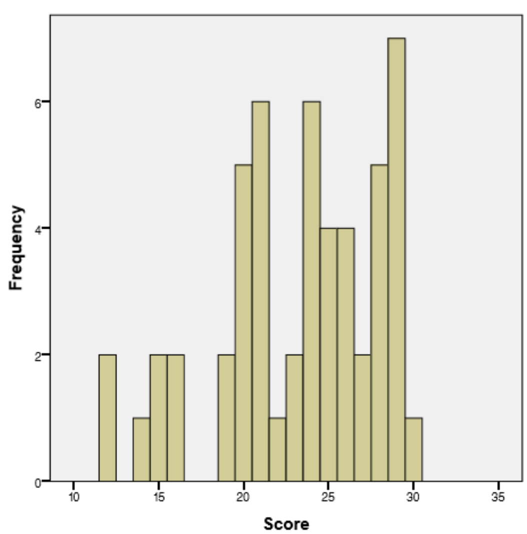

Figure 3. Pictorial VRT Histogram

The primary hypothesis was non-directional provided the experimental nature of the study and the lack of basis for a directional hypothesis. A single null hypothesis was evaluated: There is no difference in the score distributions of PSVT-VOR and Pictorial

VRT. This hypothesis was evaluated in Table 2 using the nonparameric Mann-Whitney U-test. Due to the sampling methodology, in that two single groups of students were selected to represent the engineering graphic student population, a Gaussian population cannot be assumed. In this case, a Mann-Whitney U test, which "is often thought of as the nonparametric analogue of the t test for two independent samples", was adopted to compare the means of the scores from two unpaired groups, Purdue SVRT and Pictorial VRT (Howell, 2013, p.668). The test statistic for the Mann-Whitney U-test was compared to the designated critical value table. The critical alpha value was set at 0.05 for this investigation. The p-value for the test (<0.0001) uncovered that the null hypothesis was rejected. The result suggests that the collective outcome scores of the PSVT-VOR is significantly different than the score of Pictorial VRT. Summary statistics, frequency analyses, and hypothesis testing uncovered that student mental rotation abilities of geometric forms collectively exceeds that of ability of pictorial rotation ability.

Table 2 Mann-Whitney U-test

Purdue SVRT (n)	Pictorial VRT (n)	Diff.Est.	Test Stat.	P-value
52	50	0	717.500	<0.0001

Conclusions

This study was conducted with the premise that forms of assessment can be extended or built upon to reflect the needs and values of a discipline. Specifically, the researchers wanted to see if replacing the PSVT-VOR with one that uses pictures of everyday objects (i.e. Pictorial VRT), that by common everyday associations students might do better using images on visual-based tests. But, as the findings indicate it is just the opposite, students that participated in this study did statistically better using the traditional geometry or isometric drawing version of the same test that was repurposed with everyday images.

Based on the study findings, the authors offer the following recommendations. First, comparative analyses uncovered that students that took part in the study demonstrated existing levels of mental rotation ability proficiency with the geometric forms found in the PSVT-VOR. Early on in the participants' University studies, they learned about projection systems and principles associated with descriptive geometry with particular focus on cubes, rectangular prisms, pyramids, cones, and spheres. However, there is rarely a focus placed on the purposeful rotation and manipulation of everyday objects. Perhaps the students are influenced by what they observe in everyday media? For example, they will rarely see an iPhone turned upside down in a television commercial. Also, the participating students completed some spatial visualization instruction previous to this module and some of the developmental tasks would have been similar in nature to the PSVT-VOR. It would be interesting to investigate whether object familiarity and general interest with particular objects had an influence on performance. The second major deduction and recommendation lends itself to the pedagogy that engineering design graphics teachers use in the classroom. It could be that students are directly influenced by the type of drawings used each day and are unable or not as proficient in directly articulating classroom-based study and exercises to everyday objects. If this were the case, it would argue to enhance transferability of skill through the inclusion of more real-world images throughout the teaching of fundamental concepts related to visual science and theory. The final supposition and recommendation is that the role of graphics related background instruction, visual skill development, and the use of computer graphics software needs to be considered and factored in these types of investigations.

Further research in the use of alternative visual-based tests with familiar and unfamiliar properties is suggested. Overall, more research is needed in what are best practices for using technology to enhance students learning of visual-based materials, as well as test their visual skills and abilities. The tests that are commonly used today were made in an era where computers were not as prevalent. Finally, research is needed on how we can more accurately diagnose student visual abilities, knowing that they will most likely use three-dimensional modeling and printing, as well as image processing and simulation, as major components within their careers. An industry-modeled and/or field-based course of study within engineering design graphics has potential to enhance the necessary trajectory for visual skill preparedness for the workplace.

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