Welcome!

Dear Delegates,

We would like to welcome you to Daytona Beach, Florida for the 70th MidYear Meeting of the Engineering Design Graphics Division (EDGD) of the American Society for Engineering Education (ASEE).

The conference team would like to extend our sincere thanks to the team of reviewers for giving up their time and sharing their expertise. The review team included:

- Holly Ault – Worcester Polytechnic Institute
- Nicholas Bertozzi – Worcester Polytechnic Institute
- Judy Birchman – Purdue University
- Ted Branoff – Illinois State University
- Bob Chin– East Carolina University
- Aaron Clark – North Carolina State University
- Thomas Delahunty – University of Nebraska-Lincoln
- Kevin Devine – Illinois State University
- Dennis Lieu – University of California, Berkley
- Mary Sadowski – Purdue University
- Niall Seery – University of Limerick
- Nancy Study – Penn State Erie - Behrend College School of Engineering
- Lulu Sun – Embry-Riddle Aeronautical University
- Norma Veurink – Michigan Technological University

We would like to extend our deepest gratitude to Embry-Riddle Aeronautical University and to our corporate sponsors for their generous support of this conference.

Best Wishes,
The Conference Team

Lulu Sun
Embry-Riddle Aeronautical University
Conference Chair

Heidi Steinhauer
Embry-Riddle Aeronautical University
Conference Chair

Diarmuid Lane
University of Limerick
Program Chair

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Thank you to our sponsors!
Conference Program Schedule

Saturday, January 23, 2016
08:00-17:00 Golf outing at LPGA Golf Course / Disney / Kennedy space (on your own)
13:00-16:00 Registration at Hotel Central Lobby
18:30 Dinner/social night at Don Vito's Italian Restaurant (137 West International Speedway Blvd., Daytona Beach, FL 32114)

Sunday, January 24, 2016
08:30-16:00 Registration at Hotel Central Lobby
09:00-12:00 Pre-conference workshops I and II
13:00-16:00 Pre-conference workshops III and IV
16:00-17:30 EDGD Executive Board Meeting
17:30-19:30 Welcome Reception sponsored by ERAU at Henderson Welcome Center… Transportation from hotel lobby at 17:15
Key Note Address 1 by Dassault Systemes
19:30-21:00 Media / Poster Showcase… Chair: Holly Ault

Monday, January 25, 2016
07:00-16:00 Vendor Exhibition
07:00-08:30 Continental Breakfast in Atlantic Room
08:30–16:00 Registration
08:30-08:45 Welcome Address in Richard Petty Ballroom
08:45-09:15 Key Note Address 2
09:15-10:45 Paper Session 1 – Investigating and Assessing Performance… Chair: Frank Croft
10:45-11:15 Break in Ballroom Prefunction
11:15-13:15 Paper Session 2 – Pedagogy… Chair: Nancy Study
13:15-14:30 Lunch in Atlantic Room
14:30-16:00 Paper Session 3 – Visuospatial Skills… Chair: Aaron Clark
18:30:20:00 Embry-Riddle Astronaut night (Telescope Tour)…Transportation from hotel lobby at 18:30
20:00 Dinner on your own
Tuesday, January 26, 2016

07:00-13:00 Vendor Exhibition
07:00-08:30 Breakfast in Atlantic Room
09:00-11:00 Paper Session 4 – Emerging Techniques and Technologies… Chair: Thomas Delahunty
11:00-11:30 Break in Ballroom Prefunction
11:30-13:00 Paper Session 5 – Future Research Agendas… Chair: Judith Birchman
13:00-14:30 Lunch / EDGD business meeting & post-conference discussion in Atlantic Room
14:30-17:00 Flight Training Device tour…Transportation from hotel lobby at 14:30
18:00-20:00 Awards Banquet Reception (Open Bar) and Banquet at Oceanside Terrace

Wednesday, January 27, 2016

All day Golf Outing / Disney / Sea World / St. Augustine / Kennedy Space Center / NASCAR racing experience etc. (on your own)
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Development of CAD-Related Items for a Concept Inventory for Engineering Graphics

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Lulu Sun
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Neil Littell
Visual Analytics of High-dimensional Data Sets *A Hyperspectral Imagery Test Case*
Forrest Gasdia, Benedict Pineyro & Hyun Jung Cho

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Framing Spatial Cognition: Establishing a Research Agenda
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Lamethrower Tactical Fire Extinguisher

Yunxiao Liu
Department of Aerospace Engineering
Embry-Riddle Aeronautical University

Abstract

Normal fire extinguishers are inaccurate because they are fired from a hip position. They are also slow to use due to its complicated design. The LAMETHROWER is both fast and accurate, thanks to its rifle-like inspiration. Under stressful emergency conditions, it can be hard to use a fire extinguisher because of the lengthy process required to prime the fire extinguisher. The LAMETHROWER fixes these flaws by making a system that is fast and instinctive to use. Fire extinguisher manufacturers recommend users to spray in a sideways sweeping pattern. This is inefficient and wasteful because it uses much more fire retardant material than necessary. The LAMETHROWER fixes this by having a design that is easier to aim. The LAMETHROWER works by modifying a normal fire extinguisher. First, the nozzle is turned 90 degrees so that its line of fire is parallel to the axis of the cylinder that holds fire retardant material. A pistol-style grip is then added so that the LAMETHROWER can be easily held. A firing mechanism is attached from the grip to the front. These changes allow for the LAMETHROWER to be utilized like a rifle. After this, the LAMETHROWER receives Picatinny tactical rails on the top (and the bottom, if needed) to mount attachments such as scopes, red dot sights, tactical grips, lasers, or flashlights. All of these modifications allow for the user to more easily aim the LAMETHROWER to increase its fire fighting effectiveness.
Abstract

Our team, the jet engineers, set out to find solutions for the obsolete KJ66 model turbine engine used for static testing and RC plane flying. Our goal was to design a more efficient and performance enhanced model that will compete with new models on the market. We found plans for the original model on the “John-Tom.com” website. The website also has design improvements for certain parts that will improve performance. Using that as our basis, our team modeled the turbine engine using a computer-aided design program called CATIA. Through this model we changed the turbine stator vanes so that they are now removable instead of welded. This improves maintenance and is cost efficient because of how simple it is to remove a selected stator vane when it is damage. The team incorporated hydrodynamic bearings instead of ball bearings for performance under operating speeds of over 100,000 RPM. The cowl was a simple improvement that most model engines had but was not in the plan sheets. Electrical components such as the full authority digital engine control are stored inside the cowl and it improves aerodynamic properties of the engine when mounted outside of RC airplanes. Mounting brackets and exhaust cone struts were also incorporated into our model. Materials were selected based on properties such as heat resistance, strength, and price. Upon completion of modeling and adding materials we completed our model successfully with a price of only $1081.89 and other models on the market going for as little as $2000.
A Mechanical Model for Hip Reduction via Pavlik Harness in Newborns

Shanice Jones, Janina Helwig, Josean Ruiz
Department of Mechanical Engineering
Embry-Riddle Aeronautical University

Abstract

Developmental Dysplasia of the Hip (DDH) refers to an abnormal hip condition in infants characterized by anomalous development of the hip joint, in which hip joint dislocation, misalignment, and musculoskeletal instability are present. Clinical reports and previous research show very low success rates for the Pavlik Harness for severe grades of hip dislocation. Statistically, it has been shown that for reduction rate for the International Hip Dysplasia Institute (IHDI) Grades I-III is 92% while only 2% for grade IV. DDH is found responsible for 29% of primary hip replacements in people up to 60 years of age. The primary goal of this project is to assist in the improvement of the success rate on non-surgical interventions for patients with DDH, as well as the ensuing consequences in adulthood. In order to experimentally verify the computational model of the hip reduction and abduction in severe cases of DDH, a mechanical bench-top model is to be designed, built and tested for the four grades of dislocation. This approach will be repeated for three patient-specific infant’s musculoskeletal models, as to corroborate the use of this experimental bench-top design in the validation of the patient-specific computational model.
Abstract

The beach is great - the sand, the sea, the salt... the sand. Except when it follows you home. You know what we’re talking about - those nitty gritty bits of beach funk that you just cannot seem to remove, the ones that remain long after the memories of that glorious beach day has faded. Thus, Project Beach Funk was born. The focus of the project quickly changed from the prevention of sand, to the removal of sand. The largest problem area seemed to be the feet and legs, as they were the biggest culprits for carrying sand into the car or home. The idea of combining a brush and an air compressor to remove sand from the feet/legs came up, and testing ensued. Air blown at 40 PSI gave the desired results - removing excess sand, and drying the remaining fine bits so they could be easily swept away by the brush. The most efficient brush proved to be a rotating facial cleanser, as the bristles were firm enough to remove sand, yet still gentle on the skin. Improvements on the design of the Sand Be Gone, or SBG for short, would include an updated head with a longer air compressor hose, and a larger gearbox housing with room for the air nozzle to be placed in the middle of the brush. A new plastic head for the brush would need to be created to house the larger gearbox and air nozzle combination, and a grooved handle design would be incorporated to increase grippage of the handle. The redesign is currently being created in CATIA.
ASCE Concrete Canoe Design and Construction

Matthew Gallup, Stephanie Cleary, Mohammad Qahwaji, Nadia Correa, Liam Goodall, & James Staite
Department of Aerospace Engineering
Embry-Riddle Aeronautical University

Abstract

The National Concrete Canoe Competition (NCCC), hosted by the American Society of Civil Engineers (ASCE), is a collegiate competition for universities to find more efficient, stronger, and lighter canoes made with lightweight concrete and lightweight reinforcement. Each canoe has a set of design criteria which it must uphold, which can be found at: http://www.asce.org/rules-and-regulations/. The overall objective of the NCCC is to allow students to gain hands-on experience with concrete construction as well as improving leadership skills and project management skills. Each year, universities modify or design a new canoe mold or mix in efforts to improve the overall performance of the canoe. The goals within Embry-Riddle’s student chapter is to improve the construction process, design, performance, and strength of the canoe. The improvement of the construction and design is a trial-and-error based method with the understanding of material properties. For the previous two years, Embry-Riddle’s ASCE student chapter has actively competed in the NCCC with great improvements and modifications in the construction process from the 16-ft, 450 lbs Miracle to most recent canoe, the 19-ft, 200 lbs Moe Moe Mano. Embry-Riddle’s ASCE student chapter will continue to improve the design, construction, and performance of the concrete canoe with the implementations of new mold designs, exploration of new design mixes, and the casting of the concrete.
Redesigning the Razor Scooter

Sky Comarsh White, Tucker Hawkinson, Kaijus Palm, Ambrose Contreras
Department of Aerospace Engineering
Embry-Riddle Aeronautical University

Abstract

The Razor A-Type Foldable Kick Scooter was designed to improve the safety and maneuverability for the user. After research and consumer input, it was deemed most important to include an attached cup holder to allow the rider to use both hands since instability is a major issue while riding the scooter. This addition increases balance and the safety for the customer. The base was then run through Inspire, an optimization program. After several tests and load cases, Vulcan Engineering found that the original base was just as, if not, more safe than the redesigned part proving both to be sufficient, especially since the load simulated was a 200lb person, above the recommended weight for the average rider. This comparison can also be made in reference to the displacement, which is highly similar in the original and redesigned bases. The new base however, would be optimal for older customers who favor aesthetics rather than recreation. In the future, the company hopes to tackle more of the user un-friendly aspects of the scooter like the wheel thickness. Conversely, the cup holder is extremely effective and will allow various sizes of cups and/or bottles and smaller objects to be securely held, free from major sway without interfering with vital mechanisms, the team plans to further perfect the holder by using a double screw set up rather than a single to secure it further. Vulcan Engineering worked to better the product for the user and meet their demanded needs.
The Re-designed Lego

Renee Spear, Connor Powers, Derek Wood, & Abhi Harrish
Department of Aerospace Engineering
Embry-Riddle Aeronautical University

Abstract

Our team’s goal is to redesign and improve upon the Lego brick. We believe that Legos are an incredible outlet for creativity for all ages, but as builders grow older and more experienced with Lego construction the complexity that stimulates the creative mind begins to dwindle. To remedy this issue, we re-designed traditional Lego bricks to have stronger links between pieces as well as greater constructive maneuverability. Our improved Lego aims to benefit the community of Lego enthusiasts that create grand complex structures. The new Lego allows for more defined features in large builds and greater structural integrity in all sizes of creations. To improve the Lego our team redesigned the cylindrical fit that links most all Lego pieces, using Catia (a CAD software). We replaced the simple cylindrical fitting with, instead, a much stronger ball and socket joint fit. In considering several possible ways to apply this improvement, our team decided to design and create several prototypes. To continue the progress we have made on this project we plan to 3-D print and test each piece to see which design is superior and to validate theorized design advantages. For instance in theory all re-designed parts are compatible with one another as well as the original Lego bricks. Along with qualitative testing we hope to compare cost effectiveness in production of this new Lego brick and original Lego brick to further evaluate our proposed improvement.
Enhancing the Novice Optical Telescope

Karen Maurer, Haoran Deng, & Hunter Magill
Aerospace Engineering Undergraduate
Embry-Riddle Aeronautical University

Abstract

This project attempts to visualize and model modifications to the Tasco “Novice” telescope in order to provide users more convenience and comfort. While the small personal telescope was functional, there were some limitations that could be a hindrance to users. The telescope originally contained a tripod that could not collapse completely for transportation and storage due to a triangular accessory stand located between the legs. The telescope also did not include lenses that provided users with a place to rest their face against the eyepiece at the appropriate distance from the lens for viewing; thus, users often struggled to readjust their eyes to the appropriate distance to focus. When switching magnification, the telescope required users to completely remove, store, and replace lenses, which could be a hassle. Finally, the telescope did not contain a location for users to store their personal items, forcing users to set items flashlights, cellphones, and bug spray on the ground. Therefore, in order to combat the inconveniences with the original telescope design the team first modeled the original design, then envisioned and modeled improvements. The improvements included a new system for spreading and folding the tripod legs, a cushioned eyepiece, a rotating lens system, and a pouch for holding miscellaneous items while using the telescope. An adjustment handlebar was also added to facilitate the ease of changing the direction which the telescope is pointed. With these modifications, the telescope was made more ergonomic and user-friendly.
Mock Flow Loop (MFL) For Self-Powered Fontan Circulation

Shanice Jones, Kristin Sverrisdottir, Arka Das, & Gabriela Espinoza
Department of Mechanical Engineering
Embry-Riddle Aeronautical University

Abstract

The Fontan procedure is the current treatment for babies born with Hypoplastic Left Heart Syndrome (HLHS). The surgery entails multiple severe complications and a survival rate of less than 50% by adulthood. Modification to the Fontan surgery is proposed to lower mortality rate in patients. A bifurcating graft (IJS) has been designed and validated via computational fluid dynamics (CFD) to increase velocity and reduce pressure within the pulmonary arteries. A dynamically scaled mock flow loop (MFL) will be configured to validate the optimized IJS results obtained from the CFD design. The MFL will be based on a reduced Fontan lumped-parameter model (LPM) and will be comprised of RLC components of the systemic and the pulmonary circuit. These RLC values are obtained from clinical references to approximate normal human physiology specific to each vessel bed. The Harvard Medical pulsatile pump provides the targeted flow rate through the IJS. Flow and pressure sensor data at critical points in the MFL are acquired via National Instruments multichannel data acquisition board and processed using LabView. A patient-specific 3D model of the Fontan junction (test section) will be produced via 3D printing (inferior and superior vena cavae attached to left and right pulmonary arteries).
Psychometric Properties of the PSVT:R Outcome Measure: A Preliminary Study of Introductory Engineering Design Graphics

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Integrative STEM Education
Virginia Tech

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North Carolina State University

Daniel P. Kelly
Science, Technology, Engineering, and Mathematics Education
North Carolina State University

Abstract

The Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R) is among the most commonly used measurement instruments to assess spatial ability. This paper presents the preliminary findings of a factor analysis of the PSVT:R given to 335 introductory engineering design graphics students. Psychometric analysis of the student sample data indicated alternate loading patterns, divergent from a single factor solution.

Introduction

Calls for greater numbers of practitioners with skills in the fields of science, technology, engineering, and mathematics (STEM) are only increasing as global and societal demands for innovation in technology, medicine, transportation, communications, and other markets continue to advance. Spatial visualization skills represent a key component in a variety of STEM fields and of crucial importance in technical professions such as engineering (Sorby, 1999; Torpey, 2013). STEM credentialed professionals tend to demonstrate notable levels of spatial ability as students with skills significantly greater than those of their peers (Lubinski, 2010).

Spatial ability assessments have been shown to have strong correlations with, and be a possible predictor of, success in engineering graphics courses (Maeda, Yoon, Kim-Kang, & Imbrie, 2013; Sorby, 1999). Several measurement instruments frequently used in engineering
education include the Mental Rotations Test (MRT), Mental Cutting Test (MCT), Revised Minnesota Paper Form Board Test (RMPFBT), Differential Aptitude Tests: Spatial Relations (DAT:SR), and Purdue Spatial Visualization Tests: Visualization of Rotations (PVST:R) (Maeda et al., 2013).

Along with holding significance as a factor in STEM education, spatial ability has also been shown to have some levels of malleability with respect to instruction with some training having an overall effect size of 0.47 standard deviations (Uttal, Miller, & Newcombe, 2013). Sorby (2009) demonstrated that spatial skills, as measured with a standard instrument, can be improved with training in an undergraduate engineering class environment. Current literature contends that increased spatial thinking or reasoning abilities provide potential predictive value for success in academic and career pursuits as well as being a demonstrable need as a focus in STEM learning environments.

**Instrumentation**

The PSVT:R is among the most popular tests within engineering education to measure students’ spatial visualization, specifically mental rotation, abilities (Field, 2007). Initially developed by Guay (1976), the PSVT:R is an extended subsection of the Purdue Spatial Visualization Tests (PSVT). The original PVST included three subtests of 12 items each titled Developments, Rotations, and Views. Each subtest also had 30-item extended independent versions: the Visualization of Views (PSVT:V), Visualizations of Rotations (PVST:R) and Visualization of Developments (PSVT:D) (Maeda et al., 2013).

Along with its popularity as an assessment tool in engineering education, the PSVT:R (along with the MCT) also appears to have high construct validity when measuring spatial visualization ability (Branoff, 1998). The PVST:R is also unique due to its use of inclined, oblique, and curved surfaces as they are more demanding to visualize than simple cubically-shaped objects (Yue, 2004).

Part of the impetus for the development of the PVST:R was that other tests may be vulnerable to analytic or non-spatial strategies for the solving of items (Yoon, 2011). Participants may be able to employ strategies other than mental manipulation of objects to solve items, thereby negating a test’s capacity to genuinely measure spatial abilities. The PSVT:R was revised by Yoon (2011) in part to address figural errors such as missing lines as well as changes to the format of the instrument to address possible measurement errors and limit the possibility for participant distraction by limiting the number of items per page to one (Maeda et al., 2013).

Whether the original or Revised PVST:R, little empirical research exists into the psychometric properties of the test. While Maeda et al. (2013) describes the Revised PSVT:R as “a psychometrically sound instrument” (p. 763) with respect to first-year engineering students,
limited evidence to that claim involves the study described in that paper and the doctoral dissertation of Yoon (2011) in which the Revised PVST:R was developed. However, Yoon (2011), Maeda and Yoon (2011), and Maeda and Yoon (2013) cite a lack of empirical study investigating the psychometric properties of the PVST:R.

Need for Further Research

While some studies focus on engineering students as a general population (Field, 2007; Maeda et al., 2013; Sorby, 2009), few studies focus specifically on engineering graphics courses (Branoff, 1998; Sorby & Baartmans, 2000). As a factor for student success and as a key component of many engineering graphics courses, study into spatial ability training and assessment in these courses is notably sparse. Focused research in this area is needed to determine the impact of spatial ability in this area and the role assessing that ability has on instruction and outcome.

Methods

In this study, the number of factors to retain was examined through multiple methods as there is no singular exacting process (Gorsuch 2003). Because the PSVT was designed to measure one factor, an \textit{a priori} one-factor solution was examined, the scree test (Cattell, 1966; Cattell & Jaspers, 1967) and parallel analyses (Lorenzo-Seva & Ferrando, 2006) were also employed to determine factor retention. The results of the scree test appeared to support a three-factor solution. A parallel analysis suggested a two-factor solution. Therefore, one-, two-, and three-factor solutions were examined.

Data were analyzed using Factor 9.3 (Lorenzo-Seva, & Ferrando, 2006). Raw scores for the PSVT were submitted to unweighted least squares factor analysis with the oblique promax rotation. The promax rotation was selected because any factors resulting from the analysis were hypothesized to be correlated. The polychoric correlation matrix Factor 9.3 generated for the analyses is shown in Table 1. Based on the number of participants, pattern coefficients of .30 or greater were considered to be salient (Gorsuch, 1983; Hair, Anderson, Tatham, & Black, 1998).
Results

Table 1 shows the loadings for the three-factor rotated solution. In the three-factor rotated solution, approximately 26 percent of the variance was explained with the first factor accounting for 12 percent and the second factor accounting for eight percent and the third factor accounting for six percent. Two items loaded on factor one and four items loaded on factor two, and 10 items loaded on factor three. The interfactor correlation for factor one and factor two was .21; factor one and factor three was .25; and factor two and factor three was .32. The reliability of the two items for factor one was .99, the four items for factor two was .64, and .75 for the 10 items on factor three.

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Note: Salient pattern coefficients are in bold type.
Conclusion


There is evidence that the PSVT:R was a significant predictor of student success in first year graphics courses (Sorby & Baartmans, 2000). However, our analysis demonstrates multiple unknown measured factors. This analysis raises questions as to what the test measures concerning specific constructs. More investigation is needed to determine what factors the PSVT:R consistently measure and its use as a single construct predictor.

References


Development of CAD-Related Items for a Concept Inventory for Engineering Graphics

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Abstract
This paper describes the initial development of a concept inventory for Engineering Graphics. As instructional methods continue to evolve in the area of graphics, there is a need for a concept inventory instrument that is able to measure the students’ misconceptions of important graphical concepts. In a 2014 Delphi study, CAD was identified as an important component of the graphics curriculum to be included in the concept inventory. There have been unanticipated challenges in the creation of multiple-choice items designed to assess the understanding of the concepts in the CAD construct. This paper is a work-in-progress describing the evolution of possible CAD items. Details documenting the evolution of a representative item will be highlighted in this paper.

Keywords: CAD, computer aided design, concept inventory, engineering graphics, Delphi Technique

Introduction
Teaching methods in engineering graphics are ever changing; as technology advances, so do the means by which engineering students learn this form of communication. Often, instruction is centered on methods of creating graphics instead of the underlying fundamental concepts. While it is important to stay relevant in regard to current technologies, it is also important to keep in
context the concepts that serve as an underpinning for the methods being employed. It is generally agreed that students should have a certain level of proficiency in standard practices upon completion of a graphics course of study. However, there is no consensus regarding the topics considered to be the fundamental concepts. This lack of consensus can lead to nonconformities in educational practices, and may decrease effectiveness in graphics education.

**Background**

Concept Inventories are assessment instruments used to identify understanding or misconceptions regarding a set of related conceptual ideas. Misconceptions are often deeply rooted beliefs, and can be problematic for instruction. To address these misconceptions, the constructs that students are having difficulty with first need to be identified. In a previous project, a Delphi Study was conducted to help identify core topics in engineering graphics (Sadowski & Sorby, 2014). The Delphi is a consensus building, forecasting technique typically consisting of three to four rounds, using a panel of experts to reach consensus on defining the important elements related to the questions posed. A Delphi study also lends itself to reaching consensus without a need for face-to-face meetings among panel members, making the study relatively easy to implement, especially for a panel with broad geographic representation among its members (Sadowski & Sorby 2013). Delphi studies have been used extensively in educational development projects (e.g., Clark & Scales, 1999) including concept inventory development (Streveler, et al. 2011). The Delphi technique typically encourages panelists to include comments as they make their ratings, resulting in a rich written conversation about choices made, possible options, and changes that might be made in future rounds (Sadowski & Sorby, 2015).

We selected the assessment triangle model proposed by Pellagrino (Pellagrino, et al. 2001) as our theoretical framework for CI development. This model has been recommended by the National Research Council as a framework for creating state-of-the-art assessment instruments and consists of three interrelated elements – cognition, observation, and interpretation. More information about the assessment triangle and its use in concept inventory development can be found has been reported by Streveler (Streveler, et al. 2011).

**Process to Date**

The initial solicitation of topics took place at a workshop consisting of graphics professionals and resulted in a total of 120 unique topics. From this, the list was consolidated into 80. An expert panel of industry representatives, high school teachers, community college instructors, and university faculty was convened for the three rounds of the Delphi study. Round 1 had a panel of 40 experts and moved 58 of the 80 topics forward. Round 2 had a panel of 31 and coalesced the 58 topics into 12 major concepts. With this manageable number of concepts to work with, constructs
to describe the topics could be formed. These constructs would serve as the basis for instrument item development. The third and final round of the Delphi had 31 panelists, who refined the list to a final 10 concepts with a total of 37 identified constructs. Table 1 includes the final list of concepts with their importance as rated by the panelists on a 1 – 5 scale with 5.00 being very important. (Sadowski & Sorby, 2015)

Table 1: Concepts by Importance as Identified by Delphi Panel of Experts

<table>
<thead>
<tr>
<th>Construct</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualizing in 2D and 3D</td>
<td>4.81</td>
</tr>
<tr>
<td>Sectional Views</td>
<td>4.63</td>
</tr>
<tr>
<td>Dimensioning</td>
<td>4.60</td>
</tr>
<tr>
<td>Drawing Conventions</td>
<td>4.50</td>
</tr>
<tr>
<td>Planar Graphical Elements</td>
<td>4.48</td>
</tr>
<tr>
<td>Projection Theory</td>
<td>4.47</td>
</tr>
<tr>
<td>Mapping between 2D and 3D</td>
<td>4.45</td>
</tr>
<tr>
<td>Methodologies for Object Representation</td>
<td>4.29</td>
</tr>
<tr>
<td>Parallel Projection Methodologies</td>
<td>4.27</td>
</tr>
<tr>
<td>Solid Modeling Constructs</td>
<td>4.27</td>
</tr>
</tbody>
</table>

In December 2014 a survey was sent to the Delphi panelists and members of the EDGD listserv as well as to some graduate students who routinely grade and assess graphics learning among first-year engineering students. The survey included the ten graphics concepts and the 37 constructs that had been identified through the Delphi study. Eighty professionals participated and were asked to rate the difficulty a typical student might have understanding each of the proposed constructs. (1=easy/5=difficult)

Initially seven CAD constructs were included in the Delphi study: Blending, Boolean, Extruding, Lofting, Revolving, Scaling, and Sweeping. At the conclusion of the Delphi only Sweeping, Revolving, Extrusion, and Features were retained. While Solid Modeling as a concept was rated of high importance (4.27/5.00) by the Delphi panel, the difficulty of the four constructs was rated low between 2.39 – 3.70 on a 5.00 scale. (Table 2)

Table 2: Difficulty and Importance Ratings of CAD Topics and Concepts

<table>
<thead>
<tr>
<th>Construct</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping</td>
<td>3.70</td>
</tr>
<tr>
<td>Revolving</td>
<td>2.98</td>
</tr>
<tr>
<td>Features</td>
<td>2.95</td>
</tr>
<tr>
<td>Extrusion</td>
<td>2.39</td>
</tr>
</tbody>
</table>

With the concepts identified, work on item development began. Discussions between the project principals provided collective guidance for the drafting of pilot questions. These questions
were designed to address each of the concepts individually whenever possible. An open-ended format was selected for the pilot questions in order to better observe the misconceptions held by average students. The participants were beginning graphics students at three different universities. The questions generally required participants to provide a response in the form of a sketch.

Administering open-ended questions generated formative feedback in two areas. The first was that subjects’ answers could provide information on potential distractors, as patterns in the responses could reveal tendencies in student misconceptions. The second area was related to item structure and framing. Subjects were encouraged to comment on the format of the questions, making note of interpretations and errors. Test packets were administered in the pilot study in a uniform fashion. Pilot responses from all institutions were collected and the results were aggregated. The responses were coded by the researchers to identify trends. With the data from the pilot study coded, work could begin on drafting potential distractors.

Herein lies the problem with the Solid Modeling (or CAD) Constructs topic. Pilot Items were presented in what was intended to be an appropriate format for participants to provide open-ended, non-software-specific, responses. Figure 1 shows an example item from the pilot study. Participants were asked to describe in general terms the creation of the provided object if using a CAD system.

![Figure 1: Example Open Ended Pilot Study Item](image)

Figures 2 through 5 are examples of typical student responses to the sample item. The high degree of variation in these responses could be problematic when identifying distractors for concepts. It was observed that there was much less sketching in the responses than anticipated. Figures 2, 3, and 5 show additive approaches to construction, while Figure 4 shows a subtractive approach. Figure 5 provides a more terse description than the others, while still providing an
arguably correct description. When considering the constructs that applied to CAD items, additional questions arose among the researchers on how to make inferences about students’ work. What should be done when the answers differ from the proposed solution? How does one assess design intent in the creation of the object? Or should design intent even be considered if the resulting geometry of the model is visually correct? What makes one response more or less valid than another? Further, are the difficulties students demonstrate cited by instructors associated with specific software commands rather than the fundamental concepts? Are the CAD concepts, as concepts, really misunderstood by students?

Initial review resulted in the decision to set aside the CAD problems for later evaluation, with the intent that additional review of other items in the pilot test would provide experience in the coding of items and distractor generation. Later attempts by the team to assess the students’ answers for the CAD problems continued to prove unproductive, and only yielded questionable results for potential distractors.

![Figure 2: Sample Open Ended Student Response.](image-url)
Figure 3: Sample Open Ended Student Response

Figure 4: Sample Open Ended Student Response
Current Status

The research team is currently making revisions to the items that will be included in a draft version of a multiple choice concept inventory instrument. Once the distractors have been selected for the remaining items, they will be created electronically and consistently formatted. However, this is not the case with the creation of the CAD items whose development remains at a standstill. Results from the Delphi study indicated that the topic of Solid Modeling and CAD were considered an important part of the graphics curriculum; yet, it is proving to be increasingly difficult for the research team to make progress with the creation of items to measure these constructs. Further, it is not clear that CAD concepts are misunderstood and thus should be included in a concept inventory that results from this project.

Conclusions

The work in the development of a concept inventory for engineering graphics has yielded valuable insights thus far. Items addressing the topic of Solid Modeling/CAD Constructs tended to generate a range of unexpected responses. Unsuccessful attempts at consistent response coding and meaningful development of distractor items resulted in the idea of seeking further input from graphics experts. It is the research team’s intent to reach out to the graphics community for more feedback in the area of CAD constructs. While Solid Modeling/CAD was rated as very important by the Delphi panel, most of the individual constructs were not rated as difficult for students to understand. A possibility for CAD constructs to have a separate concept inventory has been discussed within the team. Evaluations on whether to pursue this option, or any alternative strategy are welcomed by the research team.
Acknowledgement
The authors gratefully acknowledge the support of the National Science Foundation for this project through collaborative grants DUE-1432280 and DUE-1432288.

References


Spatial Skills and Success in Engineering Education: A Case for Investigating Etiological Underpinnings

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Abstract

One of the most consistent findings within engineering education research is the relationship between spatial skills achievement and success within STEM disciplines. A critical dearth in this research area surrounds the question of causality within this known relationship. Investigating the etiological underpinnings of the association of spatial skills development to success in engineering education is a contemporary research agenda and possesses significant implications for future practice. This paper presents a starting point through a review of some of the pertinent literature to consider this current agenda.

Introduction

One of the most widely established research findings within engineering education research is the relationship between heightened spatial skills and success among students. Research by Sorby (2007, 2009) has consistently demonstrated significant gains in performance across different domains of STEM learning as a result of students’ participation in a targeted spatial skills intervention. Although, the relationship is widely established and repeatedly demonstrated, the precise etiological foundations of the relationship are not well explored (Seery et al. 2015). This may be a limiting factor in the acknowledgement of the fundamental importance of spatial skills to the development of future engineering graduates. Bodies such as the National Science Board (NSB) have made the case for STEM talent among those individuals with high aptitudes in verbal, mathematical and spatial skills (NSB 2010). Understanding the causal relationship(s) between spatial skills and success in engineering education may strengthen the rationale for the focus on developing high-level spatial skills among students. This paper represents a starting point in this
investigation and looks to explore some of the key rationales for understanding the causality of the relationship between spatial skills achievement and success in engineering education.

**Spatial Ability and Performance in Engineering Education**

It has been widely established that improving spatial skills among engineering students has significant benefits for a variety of aspects of their study. In an extensive meta-analytic study, Uttal et al. (2013) demonstrated that generally spatial skills training results in an improvement (equating to an effect size of 0.47) in spatial ability. This demonstrates that spatial skills can be effectively learned and have the potential to facilitate significant gains in learning within engineering (Uttal et al. 2013).

The exact causal nature of this association is not well understood and there are only limited hypotheses currently that explore this. For example, spatial visualization skills are necessary for developing 3-D CAD expertise (Sorby 2000). Branoff and Dobelis (2014) have investigated this relationship further and have found that spatial visualization plays a key role in the quality of CAD modelling strategies students adopt when operating CAD software. The ability to visualize has also been discussed as an important component of "designerly" thinking (Kimbell and Stables 2008). Given the large amount of divergent design processes evident in engineering disciplines it is apparent that spatial visualization has a role to play in this activity.

A less obvious area where spatial visualization skills are hypothesized to be advantageous is in problem solving. Tversky (2005) posits that possessing advanced spatial skills allows an individual to construct robust mental representations of problems. These representations are known to be critical in solving all manners of problems but particularly in the case of "insight" problems where overcoming an impasse is necessary (Ollinger and Goel 2010, Pretz et al. 2003). Dealing with an impasse in a problem often necessitates re-representing the problem situation so that a different approach may be adopted.

Given the brief evidence presented in this section it is possible that the role of spatial skills in engineering education performance is multi-faceted. It is at this stage necessary to consider in short the construct of spatial skills and examine the difficulties of determining the causal relationship between spatial skills and engineering education performance.

**Construct and Issues of Causality**

Spatial skills are a vast and complex construct, which encompasses several different elements known as spatial factors (McGee 1979). A number of different spatial factors have been identified by various researchers such as Lohman (1979) who proposed the existence of three different
spatial factors, Spatial Visualization, Spatial Relations and Spatial Orientation. There have been a number of debates surrounding the specific nature of various spatial factors that have been proposed over the years. As a result there is no agreement as to which specific factors constitute spatial skills (Uttal et al. 2013). However, within the pertinent literature there is some general agreement that the factor of spatial visualization does constitute a significant component of spatial cognition (McGee 1979, Pittalis and Christou 2010, Pellegrino et al. 1984). Additionally, Uttal et al. (2013) have demonstrated that spatial visualization transfers well to other spatial factors following targeted interventions. Given the contentious history surrounding attempts to develop a unified definition of spatial skills, it is not surprising that determining a casual underpinning has been so obstinate. Recent work by Seery et al. (2015) has begun developing a comprehensive spatial factors framework with the objective of presenting a unified and coherent definition of spatial abilities.

As well as the debates surrounding the exact definition of spatial skills there are also various methodological limitations in studies investigating the relationship between spatial skills and STEM success. This work provides a comprehensive taxonomy of spatial factors from which we can begin to consider the etiological role spatial cognition has in engineering education success.

Another issue cited by Uttal and Cohen (2012) is that of the “third variable” problem that appears in many of the correlational studies on spatial skills and success in STEM disciplines. This refers to studies, which have found a significant relationship but have failed to control for several other variables that have also been shown to contribute to performance in STEM education such as mathematical ability (Uttal and Cohen 2012). Making this issue even more problematic is the role that spatial abilities have been shown to have with other cognitive abilities such as verbal intelligence (Carroll 1993). Therefore, it may be the case that spatial cognition provides a support for some other cognitive process, which in turn has the positive impact on performance in engineering education. With the potential for third variable contributions in a study, exposing a direct etiological link for the role of spatial skills in STEM success becomes difficult if not impossible. With any potential study that endeavors to investigate the etiology of this well-established relationship, a method capable of capturing data relating to the underlying cognitive processes students use when completing developmental tasks or problems is necessary.

In a more recent study, Delahunty et al. (2015) investigated the cognitive approaches STEM students utilized in conceptualizing problems. The findings of this study indicated a distinct advantage in utilizing spatial visualization processes in conceptualizing the tasks. The data showed that students who adopted spatial approaches, as opposed to other cognitive processes
such as analytical reasoning, were able to gain broader access to different types of memory systems, which facilitated more adaptive problem solving behavior (Delahunty 2015). Problem solving plays a large and critical role in engineering education. It is possible that the gains in performance in engineering education in general are attributable to the impact of spatial skills on problem solving performance. However, the key strength of this study in the context of investigating the underlying causality is the novel approach of gathering EEG data. This allows an objective approach to observing evidence of participants’ cognitive processing during problem solving episodes.

Conclusions

This short literature review presents a starting point to begin a focused investigation into the etiological foundations of the well-established link between spatial skills and success in engineering education. Understanding this link has numerous potential implications for teaching and learning within engineering education. If it were possible to isolate the direct causal source for the role of spatial cognition in STEM learning then it would be possible to enhance and develop precise educational approaches with engineering programs. Engineering graphics instruction, which has been minimized or eliminated entirely in recent years, could play a dominant role in curricular reform aimed at improving spatial skills across engineering education. Felder and Silverman (1988) discuss the potential mismatch between learners’ preferences and teaching styles. Explicating the etiological foundations of the relationship between spatial skills and STEM success may aid in bridging this gap by informing educators of the critical role of spatial cognition in different aspects of engineering education. For example, if spatial cognition is key in the conceptualisation of engineering problems (Delahunty et al. 2015) then focused interventions of visually conceiving and representing problems could be further developed.

As discussed by Barak (2011) further exploration of the cognitive processes underlying learning within engineering education will foster the development of self directed and self regulated learners capable of solving complex and multi-faceted problems in society. A critical issue among engineering education graduates currently is the sub-standard problem solving and reasoning abilities observed in the workforce (National Academy of Engineering 2004). Therefore, it is important to consider manners in which the development of these cognitive aptitudes can be fostered within current conceptions of engineering education. Exploring the causal link between success in engineering education and spatial achievement is a necessary step in enhancing the potential of engineering graduates.
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Work-in-Progress:
Introduction for Flipping the Classroom Techniques to Improve Instruction of Software-Specific Techniques and Methods

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Abstract

One specific objective of engineering graphics courses is to teach how to communicate engineering design. An observation is that a significant amount of class time is spent teaching students how to use CATIA in order for them to develop the necessary skills before they can begin to learn design and modeling techniques. This work is an effort to use videos as short, specific reference for particularly challenging techniques to students. The goal is to shift the software-learning time away from the classroom in order to be able to focus the class on design and design expression.

Introduction

The concern that initiated the modification of the course is the considerable amount of class time used to teach CAD software utilization, in this particular case CATIA. The focus of the graphical communication course is to teach standard forms of design graphics and view layout to express engineering designs. While the use of computer aided drafting is part of curriculum, time spent teaching repetitive tasks or tools could be better spent on design communication.

The traditional source of guidance is the use of written tutorials, usually from a textbook. While these are effective and provide high detail, they are difficult to use as reference given the use of very specific parts that can limit the creativity of the student (Yip-Hoi, 2015). They may also be used as step-by-step process to obtain a single result without giving the tutorial any in-depth thought; thus not actually learning how to use the tools effectively.

Another common source used by students are online videos provided by other users. Videos length and content play a key role and their accessibility by the students. There is plenty of material available on the Internet on how to use CATIA’s workbenches. However, this material can be very challenging to understand by the students due to their complexity and length. In addition, these videos do not always include the most correct method for modeling.

The user provided videos online usually cover complex models in high detail and as such they cover a multitude of tools at once. This leads to a few problems. First, given the complexity, it is
difficult to dissect the video to understand what section may be relevant to them. Second, given the length of the videos, they are not always an easy reference when doing homework or preparing for a test. Being able to manage the source materials also permits the instructor to release them in a particular order to coincide with the class curriculum.

This work is an attempt to provide the students with quick references that can be used to prepare or refer back for specific information. This will allow the instructor to spend more time on design and design expression.

**Methodology**

In order to make the videos accessible as quick but effective guides, they need to be just long enough to cover specific tools given that the intention is to present specific pieces of knowledge (Johnson, 2011). The recordings have two main characteristics:

1. They are short. About 2-5 minutes long (Bristow, 2008). The instructor in the Graphical Communication course tested this concept in Summer 2015. Feedback from the students in this term reflected approval for that format. In a short, informal, survey 86% of the class approved of the approach.

2. They have no sound track. All information is conveyed using appropriate demonstrations and captions. While multi-modal videos would be beneficial as a stand-alone guide (Pohl, 2015), this initial approach is the result of a practical limitation. The students will use the material as reference during class time to start work on homework problems. It would be impractical to have them use audio listening devices during the class time.

The approach to these changes occurs in three main stages, in three separate semesters. If a significant issue is noticed on a particular term, it can be addressed prior to the next term. The three semesters are:

1. **Summer 2015.** A small set of 5 videos, one per week, was created and made available to students. The purpose was to get preliminary feedback on the material to see if the format was acceptable or usable to them. The class had a total of 15 students enrolled.

2. **Fall 2015.** Additional videos are created (currently in progress) and the already existing videos were made available on CANVAS for reference. However, a concern was brought up; if the material were used during the semester, it would alter the baseline. In turn, the material was not used during class.

3. **Spring 2015.** The chosen video material will be used to replace the procedurally intense sections of lectures by hands-on work during class time. Additional to material may be developed if need to cover a specific topic but it will adhere to the semester format for delivery.
The videos are made available through the CANVAS learning system. It allows the instructor to track the number of views per video.

Results

Tracking the number of views using the learning system was used collect initial feedback during the summer ’15 term. In addition, a small, simple survey at the end of the semester was used to measure student opinion of the quality, length, and availability of the videos.

At the time of this writing, only the preliminary results from the summer term are available. This feedback was meant to provide information about whether the students would find the videos useful or even practical. The purpose of the survey during this semester was solely to help the instructor decide if the format change was desirable at all. There was no assignment that required watching the material and no points or academic incentive was offered to view them. The material was made available purely as a reference on CANVAS. The results to the summer survey were as follows:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Responses</th>
</tr>
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</table>
| When did you watch the videos provided in class (if you did watch the videos)? | 21% - As soon as posted  
43% - When doing homework  
21% - When studying for a test |
| Regarding the length of the videos (About Right?) | 86% - Approve |
| Would more videos covering other topics be useful? | 64% - Agree |

During the fall semester, the average grade per assignment for the whole class will be recorded. It will be used as a baseline for comparison with the upcoming spring semester results. It is worth noting that, as a continuation from the summer, the portions of the material were already posted on CANVAS. A concern was brought up early on that this material having been available would affect the baseline; this allowed the instructor to introduce changes to diminish the possible effects. While some of the videos were made available, the students were not encouraged to use them and they were not required in any way for classwork. According to the tracking data from CANVAS, 10 students accessed the media files, however, three of them watched only two videos and seven watched only one recording. Since the spring 2015 section has 26 students and a total of nine CATIA-based assignments, the instructor does not believe that this is enough to have significant impact on the overall performance evaluation of the class.

In the spring semester, the methodology would change from having media as reference to having media as an integral part of the course. Specific media will be made available to correspond to specific topics during class. As such data collection will change. At this stage, the average grade per assignment will be collected and compared to the fall semester results.
Conclusions

While no conclusions have been drawn so far, a few things can be expected to happen. First, student performance in the assignments used for comparison should objectively improve. In addition, there will be more class time available to the instructor in order to focus on the design and design communication aspects of the course.

These modest gains might be of interest to other instructors since the restructuring of the class content and delivery is minimal at this stage. The addition of support material might take some work outside of the classroom but it is generally reusable and could provide the timesaving advantage, for instructors and students, of providing with an easily accessible reference for the most often used tools or procedures.

References


Enhancing Engineering Students’ Communication Skills through a Team-Based Graphics Course Project

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Abstract
Although communication skills are highly valued by engineering associations and companies, instructors may find it difficult to incorporate them into specific engineering courses. Some attention has been given to research on undergraduate students’ communication skills. However, additional research and training is needed to help instructors develop curricula – the type that can enhance students’ communication skills – in technical subjects like engineering graphics. Such work can help engineering programs offer increased opportunities for students to continually develop desirable professional traits throughout their collegiate experience. This paper will explore the implementation of a team-based graphics course project – one that focused on enhancing engineering students’ communication skills – and provide recommendations for faculty teaching similar courses. Findings from open-ended survey questions indicate that students learned the importance of preparation, time management, organization, clarity, detail, and engagement. By working in a project team, students also learned patience and task delegation.

Introduction
Communication skills are important for success in various corporate and community roles, especially leadership. Teamwork, creativity, and problem-solving abilities are also essential in industrial settings. Since a present-day goal of engineering education is to prepare students for their desired career, educators should continually strive to develop the aforementioned competencies through their courses and curriculum. Effective communication is critical in fields that require individuals to collaborate across cultures and disciplines, and produce products for everyday consumer use.

Numerous national organizations have highlighted the significance of specific skills and abilities within the engineering profession. In The Engineer of 2020: Visions of Engineering in the New Century, the National Academy of Engineering (NAE) provided a comprehensive list of strategies to improve engineering education and better prepare future engineers (NAE, 2004). The list included (a) good communication and teamwork skills, (b) practical ingenuity to solve problems, and (c) creativity. While identifying several desired learning outcomes for engineering undergraduates, the Accreditation Board for Engineering and Technology (ABET) also stressed the
importance of (a) communicating effectively, (b) working on multidisciplinary teams, and (c) designing and solving realistic problems (ABET, 2015). Scholars have also examined the importance of teamwork and collaboration in science, technology, engineering and mathematics (STEM) fields (Long, Williams & Strayhorn, 2013; Springer, Stanne & Donovan, 1999; Stump, Hilpert, Husman, Chung, & Kim, 2011; Terenzini, Cabrera, Colbeck, Parente & Bjorklund, 2001). In fact, the Engineering Communication and Performance minor, developed at the University of Tennessee, has embraced the notion that “working with other people is a learned skill” (Seat, Parsons, & Poppen, 2001).

Although academics and national organizations (e.g., ABET, NAE) offer recommendations for improving STEM education, instructors may find it difficult to integrate them into particular undergraduate engineering courses. Building upon previous research on undergraduate students’ communication and teamwork skills, this paper focuses on these abilities in a specific technical subject like engineering graphics. This paper offers additional knowledge concerning ways to help students develop desirable professional traits throughout their undergraduate engineering experience.

**Course Description**

An introductory graphical communications course at one small, private Southeastern school is designed to familiarize students with basic principles of drafting and engineering drawing as well as to improve students’ three-dimensional (3-D) visualization skills and ability to use a computer-aided design (CAD) program. A variety of topics are covered such as orthographic projection, section and auxiliary views, assemblies, dimensioning, and tolerances. When completing a team-based, semester-long design project, students focus on three forms of communication (i.e., visual, written and oral). The following course objectives were created around the aforementioned types of communication skills (Figure 1):

![Students will be able to.](image)

- Use CATIA as a computer-aided drafting tool to produce multiview, isometric, auxiliary, and section views (i.e., through visual drawings)
- Describe how their team modeled the components of a product explicitly in a detailed assembly (i.e., in written form)
- Discuss the steps taken to achieve their final drawing package and convince panelists to buy their product (i.e., through an oral presentation)

**Figure 1. Graphical communications learning objectives (communication skills)**

To meet the requirements of the course project, students are provided the following specifications (Figure 2):
The primary purpose of the course project is to have students model the components of a product explicitly in a detailed assembly. Students must also effectively communicate their designs and thought process during each design phase of the project. Students are free to choose a product of interest to their team. Each part and assembly of the product must have a detailed drawing. Each team uses hand/drafting techniques and a software program called Computer-Aided Three-Dimensional Interactive Application (CATIA) to create their drawings. For extra-credit, students

<table>
<thead>
<tr>
<th>Final Project Specifications</th>
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<tbody>
<tr>
<td><strong>Due Date:</strong></td>
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<tr>
<td><strong>Final Grade Contribution:</strong></td>
</tr>
<tr>
<td><strong>Purpose:</strong></td>
</tr>
<tr>
<td><strong>Deliverables:</strong></td>
</tr>
<tr>
<td>1. Cover page</td>
</tr>
<tr>
<td>2. Statement of Work</td>
</tr>
<tr>
<td>3. Detailed Sketch</td>
</tr>
<tr>
<td>4. Assembly Drawings</td>
</tr>
<tr>
<td>5. Detail drawing for each part in the assembly</td>
</tr>
<tr>
<td>Additionally each team will give a 15 minute “Shark Tank” presentation discussing the steps taken to achieve their final drawing package. The ultimate goal is to convince panelists to buy your product.</td>
</tr>
<tr>
<td><strong>Grade Calculation:</strong></td>
</tr>
<tr>
<td><strong>Individual Parts</strong></td>
</tr>
<tr>
<td>- Well Modeled</td>
</tr>
<tr>
<td>- Appropriate Views</td>
</tr>
<tr>
<td>- Appropriate Dimensions</td>
</tr>
<tr>
<td>- Necessary Notes</td>
</tr>
<tr>
<td>- Title Block</td>
</tr>
<tr>
<td>20% <strong>Assembly Drawing</strong></td>
</tr>
<tr>
<td>- Compact View</td>
</tr>
<tr>
<td>- Exploded View</td>
</tr>
<tr>
<td>- Parts List</td>
</tr>
<tr>
<td>- Balloons</td>
</tr>
<tr>
<td>- Title Block</td>
</tr>
<tr>
<td>20% <strong>Presentation</strong></td>
</tr>
<tr>
<td>- Attire</td>
</tr>
<tr>
<td>- Clear Problem Statement</td>
</tr>
<tr>
<td>- Detailed Project Timeline</td>
</tr>
<tr>
<td>- Creativity</td>
</tr>
<tr>
<td>20% <strong>Project Binder</strong></td>
</tr>
<tr>
<td>- See Template</td>
</tr>
<tr>
<td>20% <strong>Peer Evaluation</strong></td>
</tr>
</tbody>
</table>

**Figure 2. Graphical communications final project specifications**
are also encouraged to improve a current product, meet a grand challenge of the 21st century (NAE, 2008), provide a quote to have their product 3-D printed, and/or create a poster for participation in a course-wide competition.

In the engineering graphics course, eighty percent (80%) of the final project score deals with visual (40%), written (20%) or oral communication (20%). Students are to develop a “Shark Tank” presentation – based on the television show – whereby they present their design orally to a panel of instructional staff members who are interested in buying their product. Each team also submits a binder to their instructor that contains an executive summary, needs assessment, background research, alternative solutions, and engineering drawings.

Lastly, twenty percent (20%) of the final project grade comes from peer evaluations. Individual members provide feedback on team dynamics such as (a) how effectively the team worked together, (b) whether there were behaviors of any member that were valuable or detrimental, and (c) what they learned from working in a project team, specifically in terms of communication, that they will carry into their future experiences.

**Course Feedback**

Open-ended responses from the Fall 2015 semester provide insight into students’ perceptions of the course project. Students learned several transferrable skills as it relates to visual, written, and oral communication, as evidenced by the following survey excerpts. When focusing on visual communication, students stated:

“I learned to always make sure that if I was handed my drawing and told to manufacture the part or assembly that I would have all of the dimensions and information otherwise to accomplish the task.”

“Keep the work neat, clear, and marked with proper notations. The drawings need to be descriptive and concise, especially with the dimensioning, in order to convey the information more effectively.”

In terms of written communication skills, numerous students revealed:

“Start early and revise often for the best results.”

“It is very important to have a very structured and organized [written] report.”

“Be thorough, but concise with the language used in any [written] report.”
For oral communication, several students highlighted:

“Preparation is key to a good oral presentation.”

“It is important to make eye contact and to really know your project or topic because the more you know, the more confidence you have which really affects the way you present.”

“Speak up, speak slowly, and take your time to go in-depth about important topics.”

“Enthusiasm for the subject is important for a well-received presentation.”

Overall, when seeking to communicate effectively, students noted the importance of preparation, time management, organization, clarity, detail, and engagement.

Students in the graphical communications course also spoke of positive experiences while working in a team:

“I learned to trust my teammates.”

“I learned that communication is everything in a group environment”

“I learned that patience and respect are some of the most crucial elements of a team member. It is imperative for a team member to listen to others’ ideas and respect their thoughts, opinions, and feedback.”

I learned that each person has a unique skill set. If you take the time to thoroughly get to know each member of the team, and understand their strengths and weaknesses, it will save time in the long run when delegation of tasks is necessary.

Findings from prior research support the above quotes. For example, facilitating teamwork among fundamental engineering courses promotes peer teaching and collaborative learning. These strategies provide students with an “authentic learning context” and enhance the student’s sense of ownership (Missingham and Matthews, 2014).

Despite these positive reflections not all students feel that team projects are beneficial. When reflecting on their experiences, students said the following:
Group projects at this early of a stage in our college career do not fair too well. Many students are fairly new to the college experiences and most would do work the day of or the day before it is due.

[Through the team project, I learned to] make sure that all of the team members contribute to the project and alert the professor earlier to any problems with one of the group members.

These quotes are consistent with previous research results. For engineering students, difficulties in team projects arise from students’ inexperience working in teams (McGuire, Li & Gebali, 2015). Considering the above feedback from students along with the goals of engineering organizations and faculty, conclusions and recommendations are offered in the next section.

**Conclusion & Recommendations**

Incorporating visual, written, and oral communication in a graphical communications course has produced positive feedback from student evaluations. Students saw the benefit of communication when completing a team-based, semester-long design project. Students noted the importance of preparation, time management, organization, clarity, detail, and engagement. However, problems sometimes occurred with respect to communication among team members. Student concerns included non-responsive teammates and procrastination.

To address these concerns, instructors should convey clear objectives at the beginning of the semester in terms of what students are expected to learn with respect to visual, written, and oral communication. Instructors should consider having students create team working agreements to establish a primary means of communication, schedule for meetings, general responsibilities for all team members, and methods for resolving conflict. Instructors can also have students submit team participation agreements for each assignment to document how each member equally contributed to the task. Instructors should assign project deliverables throughout the semester so students can periodically work towards deadlines and receive feedback. Additionally, assigning roles for each team (e.g., leader, organizer, negotiator, and graphic designer) can allow tasks to be properly delegated and issues to be rectified in a timely fashion.
References


Flipping the Classroom to Engage Students in a Graphical Communications Course

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Abstract
The flipped classroom is not a new concept. It requires students to study concepts before the class, apply what they learn in the classroom, and work with other students, which then makes it possible to get immediate feedback from the instructor. However, the effectiveness of the online study and student’s perception of the flipped classroom were not widely investigated in the area of engineering graphics. This paper presents a pilot study of the flipped classroom in a Graphical Communications course. Students are required to study course material online before the face-to-face classroom experience. The online course study includes multimedia materials and an online quiz that they are required to take. The results of anonymous student surveys and exam scores verify that flipped classroom is effective when used for teaching graphics and is well accepted by students.

Introduction
Both the American Society for Engineering Education (Jamieson & Lohmann, 2009) and the National Academy of Engineers (2005) have called for education reform that focuses on developing engineering graduates that are self-learners and problem-solvers. The idea of the flipped classroom is to train students to be self-learners, to study concepts before the class, and to dedicate more classroom time to learner-centered activities so that immediate feedback and assistance can be provided to the students (Vygotsky, 1978; Foot & Howe, 1998; Lage & Platt, 2000). A flipped class is different to an online class because it still involves face-to-face class time with the instructor and it emphasizes interactive group learning activities during the class time (Branoff & Kelly, 2009; Bishop & Verleger, 2013). Especially in today’s world, it offers students computer-based individual instruction and requires them to finish closed-ended quizzes and exercises online (Bishop, 2013). Instructors will clarify and reinforce the misconceptions in the class based on the online assessment that is collected (Lage, Platt & Treglia, 2000; Bishop & Verleger, 2013). A pilot study of flipped classroom was conducted in a Graphical Communications course at a private institution in the southeast. Five topics, which include lines and scales, normal surface, inclined surface, oblique surface, dimensions, were chosen to be flipped so that more class time could be dedicated to the clarification of misconceptions, team exercises, hands-on activities, and homework completion. The
The objective of the study was to incorporate the flipped classroom to part of the course to examine the effectiveness on teaching and student learning.

Course Structure

The Graphical Communications course was designed to familiarize the students with the basic principles of drafting and engineering drawing, to improve three-dimensional (3D) visualization skills, and to teach the fundamentals of computer-aided design. The class met twice a week in the laboratory during this three-credit-hour semester-long course with each class lasting one hour and forty-five minutes. Online materials and quizzes were available to students about three days before each face-to-face class. The materials were used to explain the concepts and include both audio or video recorded lectures, power point slides, and numerous examples. After each online study, there was a formal assessment which consisted of five tiered multiple-choice questions. Students were allowed to take the quiz up to two times and the better score was included in their weighted grades. The quiz needed to be completed no later than the midnight before the class so that the instructor could catch common mistakes and clarify the misconceptions in the class. Classes were always interactive and focused on questions and answers, the team exercises, hands-on activities, and homework completion. A screenshot of the online study of lines and scales, and a screenshot of the online study of auxiliary view are shown in Figure 1 and Figure 2 respectively.

![Figure 1. Online study of lines and scales](image1.png)
An online quiz of lines is shown in Figure 3. An online quiz of auxiliary view is shown in Figure 4.
Assessment

The data from eight online quizzes were collected. A comparison of student’s quiz completion rate, second attempt completion rate and performance is shown in Figure 5. Over 77% students typically finished each quiz and their average scores were all above 71 (out of 100). Dimensioning was one of the most difficult topics in this pilot study. It turned out that students’ quiz completion rate and performance on dimensioning study were worse than the other topics investigated here. More students tried second attempt to correct the mistakes and achieve higher scores on dimensioning study.
Since the non-flipped class offered in spring 2015 and flipped class offered in fall 2015 were taught by the same instructor and covered the same topics, it provided an opportunity to evaluate the effectiveness of the flipped classroom on student learning. The identical quizzes and exams were given in these two semesters and were graded by the same instructor using the same rubric. The data were collected and compared in Figure 6. Overall flipped class grades were higher than the non-flipped class except for the first quiz. Since this quiz covered easier topics such as lines and lettering when compared to other engineering graphics topics in the flipped classroom study, it was difficult to evaluate the effectiveness of the flipped classroom. As more difficult topics were covered as the semester went, the flipped class grades were much higher than the non-flipped class grades, which probably due to substantially more practice online and in the class time. Flipped class improved student’s learning effectiveness.
To understand students’ perceptions of the flipped classroom, an anonymous midterm survey was administered by Center for Teaching and Learning Excellence (CTLE) at the institution. Eighty-two percent students (44 out of 54) in two sections of Graphical Communications course completed the survey. Figure 7 indicates that about 80% students are in favor of the flipped class format. Over 63% students spent one hour or more on each online study as shown in Figure 8. Figure 9 illustrates that about two-thirds students would like to continue in the flipped classroom format for the remainder of the semester. Do they prefer the flipped format if they had to take the course again? The students’ responses were split as shown in Figure 10, although they did not know about the impact on their grades at this time. The flipped classroom approach shows certain positive effects on students’ learning, but it needs continuous improvements as is common with all classroom experiences. Modifications such as interactive screencasts, more exercise problems, and online discussion are needed to maximize the advantages of the flipped classroom so that more students can accept it and take advantage of it.
Question 1: How would you compare the flipped class format to the traditional lecture format?

<table>
<thead>
<tr>
<th>Response</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Like it</td>
<td>36%</td>
</tr>
<tr>
<td>Sort of</td>
<td>43%</td>
</tr>
<tr>
<td>Do not like it</td>
<td>20%</td>
</tr>
</tbody>
</table>

Figure 7. Survey question 1 responses

Question 2: How long does it take you to finish each online study?

<table>
<thead>
<tr>
<th>Duration</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than one hour</td>
<td>36%</td>
</tr>
<tr>
<td>One hour</td>
<td>32%</td>
</tr>
<tr>
<td>More than an hour</td>
<td>32%</td>
</tr>
</tbody>
</table>

Figure 8. Survey question 2 responses
The following are comments from students regarding the flipped classroom approach (not corrected for grammatical errors or spelling mistakes).

- The online resources like powerpoints and whatever help because we usually look over it at home before doing it in class, so we kinda get a preview and that helps.
- By going over examples and then being able to start the homework in class. We can watch her do examples and do them on our own as well. The study material being posted online was very helpful.
- The attention to detail; online study guides/power point presentations; the in class examples. The two chances to take the online quizzes at the beginning of the course was very helpful.
- This course is partly depending on practice and out of class learning, which has allowed me to develop autodidactic skills. However, Professor Sun is very proficient in explaining things that we might find difficult to understand. For example, lettering was something that we had to learn ourselves, but it just required practice. On the other hand, she made us learn line types but helped us understand the difficult subjects concerning their use.

Conclusions
A pilot study of the flipped classroom in the Graphical Communications course was conducted in the early part of the fall 2015 semester. Student’s quiz completion rate, second attempt completion rate, and performance were collected and compared. When the topics got harder such as scales and dimensioning, the second attempt completion rate increased. Students’ grades were compared with those from spring 2015. Students’ scores increased dramatically through the comparison of the quizzes and exam over the two semesters. A midterm survey was administered to understand student’s perception. An anonymous student survey found that most students viewed the flipped approach favorably, and two-thirds would like to continue in that format. The results of quiz and exam scores verify that flipped classroom is effective. In summary, the flipped classroom approach shows many positive impact on students’ learning and achievement, but it needs continuous improvement based on student input.

Acknowledgment
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References


Comparison of Spatial Visualization Skills in Courses with Either Graphics or Solid Modeling Content

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Abstract  
This paper presents a comparison made between visualization skills in a group of students that take a course with graphics topics, and those that take a course with solid modeling. The graphics course (2D) is in the context of manual drafting and a drafting software, while the solid modeling course (3D) is based on the utilization of concepts and software for solid modeling. The objective pursued is to identify any possible benefit, from the point of view of improved spatial visualization skills, from either of these two approaches. The visualization aptitude of the students was measured by administering the standard PSVT:R test before and after the respective topics were covered. This evaluation was done at two different academic institutions, with each one of the institutions using either a graphics or a solid modeling approach. Results from this study have relevance when defining course content, particularly with the current trend of including 2D and 3D topics in one single course. The result of the comparison indicates that although there are numeric differences between the two groups, particularly with standard deviations, they are not statistically significant to make a claim about the visualization skills of courses with 2D or 3D approach.

Introduction  
Visualization has received significant attention from practitioners and researchers in fields such as education, psychology, and engineering. Visualization skills have been often linked to mental capabilities that indicate likeliness or aptitude to perform certain tasks or professions. Similarly, there are numerous reports on exercises that focus on developing, evaluating, and improving visualization skills, both, for development of imagination and creativity, as well as development of competencies directly related to technical fields such as engineering graphics and design.

In this field of graphics and design, which is more linked to STEM education, there are test such as the Purdue Spatial Visualization Test - Rotations PSVT:R (Guay, 1977), the Mental Cutting Test (MCT) (Sorby, 1999) and Shepard-Metzler Rotation (S-M) Test (Shepard, 1971) and its modification (Vandenberg, 1978). The underlying concept in these tests is the mental rotation of 3D objects. PSVT:R is perhaps one of the most commonly used test, and after its initial development in 1977, there have been reports about improvements and
expansion of tests for spatial visualization and spatial orientation. For PSVT:R in particular, there are reports based on trinomial representation (Branoff, 2000), the use of realistic 3D views (Yue, 2008), and the use of pictorials (Ernst, 2015).

As well, there are reports on techniques being utilized in order to develop spatial visualization skills (e.g., use of computer software [Shavalier, 2004], use of 3D printed models [Katsioloudis, 2014], just as there are reports on the applicability and usefulness of various approaches (e.g., new and improved course content [Sorby, 2005], training for drafting [Samsudin, 2011]. These reports are a very small set that indicates the interest in having appropriate materials for improvement of spatial visualization skills, perhaps given the reports [Sorby, 2005] that such skills are a significant factor predicting success in technological programs.

Methodology

This study was designed to ascertain any difference in the spatial visualization skill of students that have 2D-based (drafting) or 3D-based (solid modeling) instruction. In most engineering and technology degrees students are required to have a course in technical graphics. There is variety of contents and approaches being used nowadays, with the most typical offering being a first-year course where students are offered spatial visualization topics using 2D concepts, such as orthogonal views and multi-views. In the past couple of decades it has been a trend to have first-year courses that cover similar visualization topics but in the context of 3D solid modeling. Nowadays, there is another trend where academic institutions have a hybrid course, where approximately half the course is in 2D concepts, and the second half covers 3D concepts. This study pursues the assessment of any benefits on spatial visualization by students having 3D concepts in addition to 2D concepts in their curriculum.

The study was completed at two institutions, in institution A (University of Wisconsin - Waukesha) there is now a hybrid semester course where half of the course uses Autodesk’s AutoCAD, and the other half of the semester is done utilizing Autodesk’s Inventor. The other participating institution B (Western Michigan University) offers a semester course which is based on instruction utilizing solid modeling packages, first Siemens’ NX and then Desault Systems’ CATIA. One reason of having two institutions is the independent offerings, implying that there are no students that might have taken other courses. The students at both institutions have already decided on engineering or engineering technology programs, and both institutions are in a semester schedule.

The instrument selected to evaluate spatial visualization skills of the students was the Purdue test for rotations (PVST:R), given that it is an instrument that requires higher level of spatial visualization skills because of the use of inclined, oblique, and curved surfaces [Yue, 2004]. This set of 30 questions, where the number of mental manipulations increases as the test progresses, was administered three times to both groups of students: at the beginning of the semester, midway through the semester, and at the end of the semester. The decision to include a midway evaluation was due to the fact that it is the moment when 2D instruction switches to 3D instruction at institution a, and it is the moment when institution B switches from the first 3D software
(NX) to the second one (CATIA). Additionally, demographic information was collected from each participant, mainly gender, race, and program of study.

Results

The surveys were administered to the students, and their participation was completely optional, during the current semester. The demographic information for both groups is provided in Table 1. In the first institution there was a total of 19 students participating (from a total of 20 registered), and at Institution B there was a group of 36 participants (from 42 students registered students). The breakdown based on gender is similar at both institutions (10.5% at A, versus 13.9% at B), with higher percentages of under-represented and no traditional students at institution B.

Table 1. Demographics for each institution participating in the comparison.

<table>
<thead>
<tr>
<th>Demographic Information</th>
<th>Institution A (UWW) (Graphics)</th>
<th>Institution B (WMU) (Solid Modeling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>%</td>
<td>#</td>
</tr>
<tr>
<td>Number of Students</td>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>Female Students</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Male Students</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Under-represented (gender, race)</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Non-traditional (&gt;25)</td>
<td>3</td>
<td>12</td>
</tr>
</tbody>
</table>

Participation in the survey was without any incentive offered, besides the explanation indicating that this will be used to possible redefinition of course content, and their help will be greatly appreciated. The test was administered during lecture time, during the last 25 minutes, and there has been a high level of participation (95% at location A, and 90% at location B). Two examples went explained before the first time they did the test, and as clarification it was indicated that all figures represent solid objects (3D).

Descriptive statistics for the compiled test scores at both institutions are provided in the upper part of Table 2. From the table it can be stated that the scores have some minor difference between institutions, these results indicate as well that the average scores, as the semester progresses, show slight increase at both institutions. Similarly, the results show the decreasing trend of the standard deviation as the semester progresses. Regarding the minimum/maximum, both institutions show a small increase in the minimum score as the end of the semester.
In order to find out if there is any statistically significant differences between results from each institution, or from pre- to post-, a T-test was performed on the different sets of data. The lower part of Table 2 shows the results when 95% confidence is applied. In this case all confidence intervals indicate that there is no statistical significance between the sets analyzed. In order to have statistical significance, as shown in the table for each institution, there needs to be a confidence probability of 35% at institution A, and 55% at institution B, which are very low confidence levels.

Table 2. Summary of Results Comparing 2D and 3D Course Content.

<table>
<thead>
<tr>
<th>Evaluation Results</th>
<th>Institution A</th>
<th>Institution B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-</td>
<td>Mid-</td>
</tr>
<tr>
<td>Average</td>
<td>22.84</td>
<td>23.83</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>4.48</td>
<td>4.86</td>
</tr>
<tr>
<td>Minimum Score</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Maximum Score</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Median Score</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Probability (T-test)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Lower Limit (LCI)</td>
<td>20.681</td>
<td>21.413</td>
</tr>
<tr>
<td>Probability (for significance)</td>
<td>-</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Some additional information was observed, during the tests, only once a student asked for clarification on a problem, and the response given was that all representation are solids. From the data, question #30 was the one with the lowest percentage of correct answers, with only 29% correct answers recorded across the board, no other question had lower than 50% correct answers. The effect of not including question #30 in the results in less than 1.6% in the overall values, which will not have any significant effect on the data being used for conclusions in this study.

Conclusions

The results from this comparison indicate numerical differences between the two course approaches, but there is no statistically significant (p < 0.05) difference in the results. Similarly, the results indicate an improvement in the performance at each institutions as the semester term progresses, but without statistical significance. Therefore, even though there is no objective conclusion in terms of the benefit of one instructional
approach over the other (2D vs 3D), this study has brought attention to other aspects that need to be investigated (e.g., course exercises, teaching approaches, test applicability).

At both institutions there was anecdotal reference to ‘doing better with visualization exercises’, which is reflected in the descriptive statistics, particularly with standard deviation and minimum score. It can be stated that the scores for each group of students become more compact (i.e., smaller range, better performance), with the largest improvement at the end of the semester at institution B.

References


Application of Color on 3D Dynamic Visualizations for Engineering Technology Students and Effects on Spatial Visualization Ability: A Quasi-Experimental Study

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Abstract

There are several reasons for exploring the potential of color information and its effects on improving spatial visualization ability. Color is one of the fundamental properties of objects and is detected preattentively with other primary properties like brightness and line orientation (Enns & Rensink, 1991; Treisman, 1986). Even though the role of color in object constancy and depth perception is clear, the value of adding redundant color as spatial stimuli has attracted very little attention (Alington, Leaf & Monaghan, 2001). According to Mehta & Zhu (2009) a large amount of research has been done in this domain; however, the psychological processes through which color operates have not been fully explored.

Introduction

Color theorists believe that color influences cognition and behavior through learned associations (Elliot, Maier, Moller, Friedman, Meinhardt, 2007). However, research provides inconsistent results when using visual cues like color (Seddon & Shubber, 1985). For example the amount of color may have an effect on the results when comparing color versus monochrome. Too much color, however, may have an adverse effect on the subjects when comparing color versus monochrome (Seddon & Shubber, 1985).

As a result, the field has observed certain conflicting results. To add to the related body of knowledge the following study was conducted.

The following was the primary research question:
Is there a difference in spatial visualization ability, as measured through technical
drawings, among the impacts of visual cues (adding blue color) on dynamic
visualizations for engineering technology students?

The following hypotheses will be analyzed in an attempt to find a solution to the research
question:

\[ H_0: \] There is no difference in spatial visualization ability, as measured through technical
drawings, among the impacts of visual cues (adding blue color) on dynamic
visualizations for engineering technology students.

\[ H_A: \] There is an identifiable difference in spatial visualization ability, as measured
through technical drawings, among the impacts of visual cues (adding blue color) on
dynamic visualizations for engineering technology students.

**Methodology**

A quasi-experimental study was selected as a means to perform the comparative analysis
of spatial visualization ability during the fall of 2014. The study was conducted in an engineering
graphics course. The participants from the study are shown in Figure 1. Using a convenience
sample, there was a near equal distribution of the participants between the three groups.

![Figure 1. Research Design Methodology](image-url)
The students attending the course during the Fall semester of 2014 were divided into three groups. The three groups \((n_1=24, n_2=21\) and \(n_3=22\), with an overall population of \(N=67\)) were presented with a visual representation of an object (visualization) and were asked to create a sectional view. The first group \((n_1)\) received a dynamic 3D printed dodecahedron visualization, self rotated at 360 degrees on the top of a motorized base at about 4 rounds per minute (slow rotation was used to prevent optical illusion and distortion of the original shape) during the creation of the sectional view (see Figure 2). The second group \((n_2)\) received the same dynamic 3D printed dodecahedron visualization, also self rotated at about 4 rounds per minute at 360 degrees on the top a motorized base at about 4 rounds per minute with students wearing blue glasses; thus, it created a blue background around the visualization during the creation of the sectional view (see Figure 4). The third group \((n_3)\) received a blue, shaded PC developed, dynamic 3D dodecahedron visualization, also self rotated at about 4 rounds per minute at 360 degrees at about 4 rounds per minute (see Figure 3). A color test was also implemented and no students were identified as color blind since everyone stated the correct colors.

![Dodecahedron 3D Printed Dynamic Visualization](image)

**Figure 2. Dodecahedron 3D Printed Dynamic Visualization**
Figure 3. Blue Dodecahedron 3D Dynamic Computer Generated Visualization

Figure 4. Blue glasses treatment used for Group 2
Data Analysis

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instrument prior to the treatment to show equality of spatial ability between the three different groups. The maximum score that could be received on the MCT was 25 and, as it can be seen in Table 1, n1 had a mean of 14.45, n2 had a mean of 12.75, and n3 had a mean of 13.25. A one-way ANOVA was run to compare the mean scores for significant differences, as it related to special skills among the three groups. There was no significant difference between the three groups as far as spatial ability, as measured by the MCT instrument (see Table 2).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean Lower Bound</th>
<th>95% Confidence Interval for Mean Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printed (n1)</td>
<td>24</td>
<td>14.45</td>
<td>4.564</td>
<td>.847</td>
<td>12.71</td>
<td>16.18</td>
</tr>
<tr>
<td>3D Printed Blue (n2)</td>
<td>21</td>
<td>12.75</td>
<td>4.561</td>
<td>.931</td>
<td>10.82</td>
<td>14.68</td>
</tr>
<tr>
<td>PC Blue Image (n3)</td>
<td>22</td>
<td>13.25</td>
<td>4.046</td>
<td>.826</td>
<td>11.54</td>
<td>14.96</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td>13.55</td>
<td>4.412</td>
<td>.503</td>
<td>12.54</td>
<td>14.55</td>
</tr>
</tbody>
</table>
Table 2. MCT ANOVA Results

<table>
<thead>
<tr>
<th>Quiz</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>40.918</td>
<td>2</td>
<td>20.459</td>
<td>1.053</td>
<td>0.354</td>
</tr>
<tr>
<td>Within Groups</td>
<td>1438.172</td>
<td>65</td>
<td>19.435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1479.091</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes statistical significance

Analysis of Drawing

The second method of data collection involved the creation of a sectional view drawing. As shown in Table 3, the group that used the 3D Printed Model, and wore the blue glasses as visual aid (n = 21), had a mean observation score of 3.26. The groups that used the PC computer generated model, and used no blue glass visual (n = 24), and the PC generated blue shaded image (n = 22), had lower scores of 3.17 and 3.00 respectively. A one-way ANOVA was run to compare the mean scores for significant differences among the three groups. The result of the ANOVA test, as shown in Table 4, was not significant, F(2, 62) = 6.525, p < 0.802. The data was dissected further, through the use of a post hoc Tukey’s honest significant difference (HSD) test. As it can be seen in Table 5, the post hoc analysis shows no statistically significant difference between the 3D printed Blue vs. PC Model (p < 0.968, d = 0.96) and the 3D Printed Blue vs. PC Blue Image (p = 0.792, d = 0.263), with PC Blue Image vs. PC Model being equal and higher than the first one in both cases (p=.792, d=.263).

Table 3. Sectional View Drawing Descriptive Results

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Lower Bound</th>
<th>95% Confidence Interval for Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printed</td>
<td>24</td>
<td>3.17</td>
<td>1.465</td>
<td>0.299</td>
<td>2.55</td>
<td>3.79</td>
</tr>
<tr>
<td>3D Printed Blue</td>
<td>21</td>
<td>3.26</td>
<td>1.046</td>
<td>0.240</td>
<td>2.76</td>
<td>3.77</td>
</tr>
<tr>
<td>PC Blue Image</td>
<td>22</td>
<td>3.00</td>
<td>1.272</td>
<td>0.271</td>
<td>2.44</td>
<td>3.56</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td>3.14</td>
<td>1.273</td>
<td>0.158</td>
<td>2.82</td>
<td>3.45</td>
</tr>
</tbody>
</table>
Table 4. Sectional View Drawing ANOVA Results

<table>
<thead>
<tr>
<th>Quiz</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>.736</td>
<td>2</td>
<td>.368</td>
<td>.222</td>
<td>.802</td>
</tr>
<tr>
<td>Within Groups</td>
<td>103.018</td>
<td>62</td>
<td>1.662</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>103.754</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes statistical significance

Table 5. Sectional View Drawing Tukey HSD Results

<table>
<thead>
<tr>
<th>Visual Aids (1 vs. 2 vs. 3)</th>
<th>Mean Diff. (1-2)</th>
<th>Std. Error</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 vs 1 3D Printed Blue vs. 3D Printed</td>
<td>.096</td>
<td>.396</td>
<td>.968</td>
</tr>
<tr>
<td>2 vs 3 3D Printed Blue vs. PC Blue Image</td>
<td>.263</td>
<td>.404</td>
<td>.792</td>
</tr>
<tr>
<td>3 vs 1 PC Blue Image vs. 3D Printed</td>
<td>.263</td>
<td>.404</td>
<td>.792</td>
</tr>
</tbody>
</table>

* Denotes statistical significance

Discussion

While not statistically significant, the students who received treatment using the 3D printed Dynamic visualization, with the addition of the blue glasses visual cue, outperformed their peers who received treatment from the other two types of visualizations. Previous research supports that the effect of color on those with high spatial ability may result in little benefit, as high spatial ability learners develop mental models on shape alone. Khooshabeh & Hegarty (2008) suggested that color affects the performance of learners with low spatial ability more so than those with high spatial ability.

Due to the findings in this study and the relatively high scores recorded from the MCT given to the participants prior to the treatment, the researchers believe that the population used (engineering technology students) did not demonstrate a statistically significant difference in spatial abilities from the addition of the color, due to the fact that spatial abilities were well developed in this population.
References


3D Spatial Visualization Instruction within an Introductory Constraint-Based CAD Modeling Course

T. J. Branoff, J. W. Brown, & K. L. Devine
Department of Technology
Illinois State University

Abstract

Since the Fall 2010 semester, spatial visualization instruction has been integrated into the Introduction to Technical Drawing and Constraint-Based Modeling course at Illinois State University. In addition to these materials, the course also includes instruction in constraint-based CAD modeling and other engineering graphics topics. During the Fall 2015 semester, students were asked to complete the PSVT:R and the MCT to assess their spatial visualization abilities at the beginning of the course. These two assessments will also be given at the end of the course to determine the impact of the course activities on students’ spatial visualization. This paper describes the activities in the course, gives demographic information on the students, presents descriptive statistics related to the pre-test scores, examines the relationship between the PSVT:R and the MCT, and compares the means on the PSVT:R and MCT between students who took the course as a requirement versus those who took it as an elective.

Introduction

Educators have known and have written for more than 75 years about the importance that spatial visualization ability plays in developing successful engineers and technicians (Branoff, 2007; Clark & Scales, 2000; Howe, 1940; Meyers, 2000; Miller & Bertoline, 1991; Sorby, 1999; Sorby & Baartmans, 2000; Veurink & Sorby, 2012). One might assume that the nature of engineering design graphics activities exercises and strengthens spatial abilities, but students entering introductory courses with deficient skills in this area often get left behind others who have strong skills. Along with her colleagues, Sorby has developed curriculum materials to help improve the spatial visualization abilities of undergraduate engineering students who perform poorly on standardized measures (Sorby & Baartmans, 2000; Sorby, 2005). Research on these materials in a stand-alone intervention course has been well documented (Sorby, 2005; Sorby, 2006; Sorby, Drummer, Hungwe, Charlesworth, 2005; Veurink, et al., 2009). Students completing a course using the spatial visualization materials made significant gains in spatial visualization ability (Sorby, 2005; Veurink, et al, 2009), performed better in later engineering courses, and persisted in engineering at a higher rate than their peers who did not complete the spatial visualization course (Sorby, 2005). The materials have also been shown to improve spatial visualization abilities in non-engineering
undergraduate students (Sorby, Drummer, Hungwe, Charlesworth, 2005) and middle school students (Sorby, 2006).

**Spatial Visualization Assessment**

Several instruments have been used to assess the spatial visualization abilities of students in engineering and technical graphics courses. Some of these include the Mental Rotations Test – MRT (Vandenberg & Kuse, 1978), the Purdue Spatial Visualization Test: Visualization of Rotations – PSVT:R (Guay, 1977), and the Mental Cutting Test – MCT (CEEB, 1939). Several studies indicate a significant correlation between the PSVT:R and the MCT (Branoff & Dobelis, 2013a, 2013b, 2014). These studies also indicate a significant correlation between these measures of spatial visualization and students’ ability to create constraint-based solid models.

**Technical Drawing Course at Illinois State University**

Since the Fall semester of 2010, the spatial visualization materials from Sorby, Wysocki, and Baartmans (2003) have been integrated into the TEC 116 – Introduction to Technical Drawing and Constraint-Based Modeling course at Illinois State University. The course is designed to give students an overview of mechanical product design, including industry accepted technical drawing practices (orthographic projection theory, dimensioning, sectional views, threads and fasteners, and assembly drawings), constraint-based CAD practices, and basic print reading skills. Specific topics for the course focused on spatial visualization include isometric sketching, coded plans, rotations of objects, and Cartesian coordinate systems. Building upon the spatial visualization skills, the course introduces specific solid modeling skills such as fundamentals of modeling, sketching, extrusions, rotations, assemblies, and documenting models.

**Research Questions**

The current study was designed to conduct a preliminary investigation into the effectiveness of integrating spatial visualization materials into an existing introductory engineering graphics course. The research questions for this study were:

1. Is there a significant correlation between students’ scores on the PSVT:R and the MCT?
2. Do students’ taking an introductory engineering graphics course as a requirement perform differently on the PSVT:R and MCT than students taking the course as an elective?
3. Do students’ scores on the PSVT:R and MCT increase significantly after completing an introductory engineering graphics course with integrated spatial visualization materials (NOTE: data will not be available to answer this research question until the end of the Fall 2015 semester)?
Participants

In the Fall 2015 semester, 56 students from two sections of TEC 116 at Illinois State University participated in the study. Tables 2-4 summarize the demographic information of the participants.

Table 1. Gender of Participants.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>8</td>
<td>14.29%</td>
</tr>
<tr>
<td>Male</td>
<td>48</td>
<td>85.71%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>56</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Table 2. Academic Year of Participants.

<table>
<thead>
<tr>
<th>Year</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman</td>
<td>11</td>
<td>19.64%</td>
</tr>
<tr>
<td>Sophomore</td>
<td>17</td>
<td>30.36%</td>
</tr>
<tr>
<td>Junior</td>
<td>23</td>
<td>41.07%</td>
</tr>
<tr>
<td>Senior</td>
<td>4</td>
<td>7.14%</td>
</tr>
<tr>
<td>Graduate Student</td>
<td>1</td>
<td>1.79%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>56</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Table 3. Academic Major of Participants.

<table>
<thead>
<tr>
<th>Major</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer Systems Technology</td>
<td>10</td>
<td>17.86%</td>
</tr>
<tr>
<td>Engineering Technology</td>
<td>19</td>
<td>33.93%</td>
</tr>
<tr>
<td>Graphic Communications</td>
<td>12</td>
<td>21.43%</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>3</td>
<td>5.36%</td>
</tr>
<tr>
<td>Technology &amp; Engineering Education</td>
<td>5</td>
<td>8.93%</td>
</tr>
<tr>
<td>Graduate Student</td>
<td>1</td>
<td>1.79%</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>10.71%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>56</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Most of the students in the course were male, with almost 75% of students enrolled in either computer systems technology, engineering technology, or graphics communications. The course is required for engineering technology, graphic communications, and technology & engineering education majors. Other students on campus take the course as an elective.

Methodology & Results

During the second class period of the semester, students were administered electronic versions of the PSVT:R and the MCT within the campus-wide learning management system. These assessments were selected based on previous research which showed strong correlations between the two assessments and correlations with 3D constraint-based modeling ability (Branoff & Dobelis, 2013a, 2013b, 2014). Each assessment was set up to terminate after 20 minutes. Table 4 displays the descriptive statistics for two assessments.
Table 4. Descriptive Statistics.

<table>
<thead>
<tr>
<th>Assessment Category</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants – PSVT:R</td>
<td>56</td>
<td>2</td>
<td>30</td>
<td>21.21</td>
<td>5.58</td>
</tr>
<tr>
<td>Female participants – PSVT:R</td>
<td>8</td>
<td>13</td>
<td>26</td>
<td>19.38</td>
<td>4.53</td>
</tr>
<tr>
<td>Male participants – PSVT:R</td>
<td>48</td>
<td>2</td>
<td>30</td>
<td>21.52</td>
<td>5.72</td>
</tr>
<tr>
<td>Computer Systems Technology – PSVT:R</td>
<td>10</td>
<td>2</td>
<td>24</td>
<td>16.80</td>
<td>6.89</td>
</tr>
<tr>
<td>Engineering Technology – PSVT:R</td>
<td>19</td>
<td>15</td>
<td>30</td>
<td>24.26</td>
<td>4.19</td>
</tr>
<tr>
<td>Graphic Communications – PSVT:R</td>
<td>12</td>
<td>10</td>
<td>27</td>
<td>20.50</td>
<td>5.55</td>
</tr>
<tr>
<td>Renewable Energy – PSVT:R</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>17.33</td>
<td>5.51</td>
</tr>
<tr>
<td>Technology &amp; Engineering Ed. – PSVT:R</td>
<td>5</td>
<td>18</td>
<td>27</td>
<td>22.40</td>
<td>4.04</td>
</tr>
<tr>
<td>Other majors – PSVT:R</td>
<td>6</td>
<td>16</td>
<td>26</td>
<td>21.83</td>
<td>3.54</td>
</tr>
<tr>
<td>All participants – MCT</td>
<td>56</td>
<td>2</td>
<td>24</td>
<td>11.09</td>
<td>5.18</td>
</tr>
<tr>
<td>Female participants – MCT</td>
<td>8</td>
<td>3</td>
<td>15</td>
<td>9.75</td>
<td>3.96</td>
</tr>
<tr>
<td>Male participants – MCT</td>
<td>48</td>
<td>2</td>
<td>10</td>
<td>11.31</td>
<td>5.36</td>
</tr>
<tr>
<td>Computer Systems Technology – MCT</td>
<td>10</td>
<td>2</td>
<td>10</td>
<td>6.60</td>
<td>2.07</td>
</tr>
<tr>
<td>Engineering Technology – MCT</td>
<td>19</td>
<td>7</td>
<td>24</td>
<td>15.05</td>
<td>5.40</td>
</tr>
<tr>
<td>Graphic Communications – MCT</td>
<td>12</td>
<td>7</td>
<td>17</td>
<td>11.42</td>
<td>3.29</td>
</tr>
<tr>
<td>Renewable Energy – MCT</td>
<td>3</td>
<td>4</td>
<td>13</td>
<td>8.33</td>
<td>4.51</td>
</tr>
<tr>
<td>Technology &amp; Engineering Ed. – MCT</td>
<td>5</td>
<td>6</td>
<td>12</td>
<td>9.60</td>
<td>2.61</td>
</tr>
<tr>
<td>Other majors – MCT</td>
<td>6</td>
<td>3</td>
<td>10</td>
<td>7.33</td>
<td>4.27</td>
</tr>
</tbody>
</table>

A scatterplot of the scores on the PSVT:R and the MCT was generated to determine whether a graphical relationship existed between scores on the two assessments (Figure 1). The scatterplot shows a positive relationship between the scores. Since the descriptive statistics indicate that some of the scores were spread out, histograms were created for the two assessments to determine if the data followed a normal distribution (Figures 2 & 3).

![Figure 1. PSVT:R vs. MCT.](image-url)
Since the distributions of the data do not appear to be normal, a non-parametric Spearman’s Rho test was used to determine if there was a correlation between the PSVT:R and the MCT. Table 5 displays the data for this analysis. The Spearman’s Rho analysis revealed a significant correlation between the PSVT:R and the MCT ($\rho = .518, \alpha = .000$).

### Table 5. Spearman’s Rho Correlations.

<table>
<thead>
<tr>
<th>Spearman’s rho</th>
<th>PSVT:R</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSVT:R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>MCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.518*</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>56</td>
<td>56</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.01 level (2-tailed).

Students in engineering technology, graphic communications, and technology & engineering education take TEC 116 as a major requirement. All other students take the course as an elective. A Mann-Whitney U test was used to determine if there was a difference in scores on the PSVT:R and the MCT for students who took the course as a requirement versus those who took it as an elective. Table 6 displays the means for the two groups, and Table 7 shows the results of the analyses.
### Table 6. Means by Major Requirement.

<table>
<thead>
<tr>
<th>Major Requirement</th>
<th>PSVT:R</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>18.474</td>
<td>7.105</td>
</tr>
<tr>
<td>Elective</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>6.0127</td>
<td>3.1428</td>
</tr>
<tr>
<td>Required</td>
<td>22.622</td>
<td>13.135</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>4.8497</td>
<td>4.8371</td>
</tr>
<tr>
<td>Total</td>
<td>21.214</td>
<td>11.089</td>
</tr>
<tr>
<td>N</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>5.5815</td>
<td>5.1814</td>
</tr>
</tbody>
</table>

### Table 7. Mann-Whitney U for Major Requirement.

<table>
<thead>
<tr>
<th>Major</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSVT:R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elective</td>
<td>19</td>
<td>20.55</td>
<td>390.50</td>
<td>200.50</td>
<td>.009 *</td>
</tr>
<tr>
<td>Required</td>
<td>37</td>
<td>32.58</td>
<td>1205.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elective</td>
<td>19</td>
<td>15.00</td>
<td>285.00</td>
<td>95.00</td>
<td>.000 *</td>
</tr>
<tr>
<td>Required</td>
<td>37</td>
<td>35.43</td>
<td>1311.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Test is significant at the 0.01 level (2-tailed).

The analyses revealed a significant difference in scores on the PSVT:R for students who were required to take TEC 116 and those who took the course as an elective. The same was true for the MCT. In both cases students who were required to take the course (engineering technology, graphic communications, and technology & engineering education) scored higher than students who were taking the course as an elective.

### Conclusions

As has been shown in other studies where the PSVT:R and MCT have been given (Branoff & Dobelis, 2013a, 2013b, 2014), this study revealed a strong correlation between the two assessments. This is expected since the two tests purport to measure the same construct of spatial visualization ability.

The descriptive statistics connecting student major to performance on the PSVT:R and MCT show that students in the three majors that require TEC 116 scored consistently higher than students in majors which do not require the course. The Mann-Whitney U test confirmed that the difference is significant. Comparing the scores of students required to take the course shows that students majoring in engineering technology scored higher than all majors on both assessments. Graphic communications students scored higher on the MCT than technology & engineering education.
students, but the graphic communications students scored lower than the technology & engineering education students on the PSVT:R. It is unclear why the graphic communications students and technology & engineering education students were consistently different between the two assessments, especially when an overall strong correlation between the tests was observed.

Future Work

To determine the effectiveness of the spatial visualization materials on students’ spatial visualization abilities, post-tests must be completed at the end of the semester. Future plans are to conduct these assessments during the last week of classes when all assignments have been completed.

To further explore the relationship between student major and spatial visualization abilities, research could be conducted on the factors that contribute to students required to take the course performing better on spatial visualization tests. Factors could include motivation, student interest in the topic, student background experiences related to spatial visualization, or other factors. Also, while there is a well-documented history of strong correlation between the PSVT:R and the MCT, this research shows that students in a specific major may not perform consistently between the two tests relative to other majors. Research could be conducted to discover if subtle differences in the two tests might assist students with different backgrounds to perform differently.

References


College Entrance Examination Board. (1939). Special aptitude test in spatial relations. CEEB.


Visualizing Success: Investigating the Relationship between Ability and Self-Efficacy in the Domain of Visual Processing

Jason Power, Jeffrey Buckley and Niall Seery

Department of Design and Manufacturing Technology
University of Limerick

Abstract

The purpose of this study is to investigate the spatial reasoning capacities and related self-efficacy beliefs of student teachers. In recent years self-efficacy has been a focal point for those investigating various modes of determinism. The relationship between an individual’s perceptions of their ability to succeed within spatial reasoning tasks is examined in conjunction with their spatial reasoning ability. In this study three tests of spatial ability were administered to align with three unique spatial factors associated with mental rotation. These include Spatial Relations, Speeded Rotation and Spatial Orientation. Self-efficacy within the spatial domain is measured using an adapted Academic Self-Efficacy scale.

Introduction

Bandura’s (1986) social cognitive theory proposed that individuals perform or behave in a manner that is governed primarily by internal mechanisms such as self-reflection, cognition and vicariousness. When considered in terms of self-efficacy these factors are said to be task orientated rather than general environmental factors. Bandura (1997) suggests that what an individual believes, rather than what is objectively true, is a stronger indicator of performance, motivation and well-being. If an individual does not believe that their actions can have a meaningful and positive result they have no incentive to attempt said action. It is for these reasons that an individual’s belief can often be a better indicator of future performance than actual ability in a given field. Self-efficacy can affect the manner in which an individual negotiates problems, both in cognitive constructions of solutions and analyses of requirements, and in emotional response (Bandura 1997). Pajares and Miller (1995) examined the performance of third level students in mathematical problem solving and found that self-efficacy was a more accurate predictor than domain specific self-concepts, perceived usefulness, gender or prior mathematical experience. Pajares (1996) noted that self-efficacy as a predictor increased in correlation with the specificity and equivalence to a skill.

The identification of self-efficacy as being such a critical component in task performance within specific disciplines, coupled with the identification of high levels of spatial ability correlating with success in a number of engineering and graphics related disciplines (Harle &
suggests that viewing spatial ability through the lens of self-efficacy could uncover a new research avenue in spatial cognitive development. The studies which have identified this correlation have typically adopted tests requiring mental rotations such as the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) (Guay, 1977). However, significant literature suggests additional spatial factors pertinent to mental rotations and the debate concerning the existence of these additional factors persists (Seery, Buckley, & Delahunty, 2015). For example, Hegarty and Waller (2004) present empirical evidence suggestive that perspective taking abilities are dissociable from mental rotation abilities. It is posited that their shared variance is the reason for previous studies identifying them as a common factor. The results of this and various other studies have identified a multiplicity of unique spatial factors. Carroll's (1993) meta-analysis of human cognitive abilities presents substantial empirical data to support this view. As such, it is important that studies concerning areas of spatial ability such as mental rotations take cognizance of this concept and employ a variety of measures to ensure an accurate representation of ability is generated.

Method

The study cohort consisted of a group of 3rd year undergraduate students in Initial Technology Teacher Education (ITTE) (n=90) of which 11 were female and 79 were male. The mean age of the participants was 21.41 with a standard deviation of 2.90. They were selected based on their inclusivity within a Design and Communication Graphics module as this was the student’s 4th graphical education module and all such modules have an inherent focus on the development of spatial reasoning capacities.

Figure 1: Examples of the spatial ability tests adopted within this study
Initially, each student completed a Sources of Self-efficacy in Spatial Ability scale (Appendix A) which was adapted from Sources of Self-efficacy in mathematics (Usher and Pajares 2009). Following their engagement with the self-efficacy questionnaire, each participant completed 3 spatial ability tests selected to align with 3 unique spatial factors pertinent to mental rotations (Figure 1). The participants were divided into 6 different groups and the tests were administered in a unique order to each to control for order bias. The PSVT:R (Spatial Relations) (Guay, 1977), Card Rotations Test (Speeded Rotations) (Ekstrom, French, Harman, & Derman, 1976) and the Object Perspective Test (Spatial Orientation) (Hegarty & Waller, 2004) were administered. Due to a lack of access to the Object Perspective Taking Test, 16 questions were designed under the exact conditions as the original test, using the exact same array of visual images. These factors were selected for inclusion in this study to align with the previously discussed correlational studies which typically included tests of mental rotation. A primer was delivered verbally which described what was meant by a spatial reasoning problem to ensure clarity of this concept.

**Results**

A descriptive statistical analysis was initially conducted on the average results from the three spatial ability tests which revealed three outliers within the data sample (See Figure 2). The results from these participants were removed from the subsequent correlational analysis.

![Figure 2: Boxplot illustrating statistical outliers within the data sample](image)

The results from each of the variables within the study were compared by Pearson’s correlation coefficient (See Table 1). The reliability of each of the spatial ability tests was measured using Cronbach’s alpha. The alpha coefficient for the PSVT:R was 0.726, for the Object Perspective Taking Test it was 0.865 and for the Card Rotations Test it was 0.978.
Table 1: Correlation Matrix for Study Variables

<table>
<thead>
<tr>
<th></th>
<th>PSVT</th>
<th>Object Perspective Taking Test</th>
<th>Card Rotations Test</th>
<th>Mastery Experience</th>
<th>Vicarious Experience</th>
<th>Social Persuasions</th>
<th>Psychological State</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSVT</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object Perspective Taking Test</td>
<td>.228*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Card Rotations Test</td>
<td>.263**</td>
<td>.230**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mastery Experience</td>
<td>.249**</td>
<td>.191*</td>
<td>.162*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vicarious Experience</td>
<td>.086*</td>
<td>-.011*</td>
<td>-.036*</td>
<td>.403***</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Persuasions</td>
<td>.120*</td>
<td>.092*</td>
<td>.088*</td>
<td>.535***</td>
<td>.252**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Psychological State</td>
<td>-.014*</td>
<td>-.207*</td>
<td>-.182*</td>
<td>-.562***</td>
<td>-.399***</td>
<td>-.293***</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: * Correlation is non-significant; ** Correlation is significant at the 0.05 level (2-tailed); *** Correlation is significant at the 0.01 level (2-tailed).

Discussion

Although each of the 3 tests used are considered tests of spatial ability, it is posited that each measure targets a unique spatial factor pertinent to mental rotations. This is evident from multiple theoretical and empirical perspectives (e.g. Carroll, 1993; Hegarty & Waller, 2004) and is supported by the significant but small correlations with \( r \) values ranging from .228 to .268 (\( n=87, p<0.05 \)) (See Table 1). As shown in Table 1, Physiological State negatively and significantly correlates with each additional posited source with \( r \) values ranging from -.293 to -.562 (\( n=87, p<0.001 \)). As supported by the literature, Mastery was the only source that held any predictive value (Parker et al. 2014, Usher and Pajares 2009, Pajares 2007) however this was limited to performance in the PSVT:R (\( r=0.249, n=87, p=0.014 \)). This highlights concerns relating to variance across domains. Often what researchers consider a sole domain is considerably less homologous than the original conception. This echoes the warnings of Bandura (2006) who cautions that researchers must be cognizant of the domain when examining self-efficacy. This is reflected in this study as pertinent research often suggests the non-existence of some spatial factors relative to mental rotations however the results of this study suggest that the three contentious factors may be unique. The significance in these results for engineering and graphics educators stems from the previously discussed correlation between spatial ability and success in the domain. One important finding is that high levels of self-efficacy pertinent to Mastery of spatial ability correlated with success in the PSVT:R. This suggests that fostering the belief within students that their levels of spatial ability can be developed could be a significant pedagogical approach to developing these skills and thus increasing capacities within STEM education. In addition to this, the distinction between 3 types of mental rotation offer additional lenses to continue research into this correlation as tests associated with mental rotations are often utilized in the studies which uncovered this relationship.
Reference List


Appendix A – Sources of Self-efficacy in Spatial Ability Scale

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I score highly on spatial ability tests (ME-1)</td>
<td>Mastery Experience</td>
</tr>
<tr>
<td>2</td>
<td>I have always been successful with spatial reasoning tasks (ME-3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Even when I try very hard, I do poorly in spatial reasoning tasks (ME-6)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>I have gotten good grades in previous spatial ability related modules (ME-8)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I do well on spatial ability related assignments (ME-9)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I do well on even the most difficult spatial ability assessments (ME-12)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Seeing others do well in spatial ability related activities pushes me to do better (VA-4)</td>
<td>Vicarious Experience</td>
</tr>
<tr>
<td>8</td>
<td>When I see how my TA solves a problem, I can picture myself solving the problem in the same way (VA-6)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Seeing others do better than me in spatial ability related tasks pushes me to do better (VP-1)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>When I see how another student solves a spatial reasoning problem, I can see myself solving the problem in the same way (VP-9)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>I imagine myself working through challenging spatial reasoning problems successfully (VS-4)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>I compete with myself in spatial reasoning exercises (VS-5)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>My TAs have told me that I am good at spatial reasoning tasks (P-4)</td>
<td>Social Persuasions</td>
</tr>
<tr>
<td>14</td>
<td>People have told me that I have a talent for spatial reasoning tasks (P-5)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Adults in my family have told me that I have a talent for spatial reasoning tasks (P-7)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>I have been praised for my ability in spatial reasoning tasks (P-13)</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Other students have told me that I’m good at spatial ability related activities (P-14)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>My classmates like to work with me on spatial ability related activities because they think I’m good at it (P-16)</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Working on spatial reasoning tasks makes feel stressed and nervous (PH-2)</td>
<td>Physiologic State</td>
</tr>
<tr>
<td>20</td>
<td>Doing spatial ability related work takes all of my energy (PH-3)</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>I start to feel stressed-out as soon as I begin spatial ability related work (PH-5)</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>My mind goes blank and I am unable to think clearly when doing spatial ability related work (PH-7)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>I get depressed when I think about spatial ability related work (PH-9)</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>My whole body becomes tense when I have to do spatial ability related work (PH-12)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>It’s important to me that other students in my class think I am good at spatial ability related tasks.</td>
<td>Personal Performance</td>
</tr>
<tr>
<td>26</td>
<td>One of my goals is to show others that I’m good at spatial ability related tasks.</td>
<td>Approach Goal</td>
</tr>
<tr>
<td>27</td>
<td>One of my goals is to show others that spatial ability related tasks are easy for me.</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>One of my goals is to look better in comparison to the other students in my class.</td>
<td></td>
</tr>
</tbody>
</table>

Notes: All items were scored on a 7-point Likert scale ranging from 1 = “Not at all true of me” to 7 = “Very true of me”.
Bridging the Divide Between Users and 3D Printers

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Abstract

A system model and associated parameters for the design of a web-based 3D printer selection system is envisioned. Accessible through a webpage that will be mapped to a central 3D printer database, the system will provide users with access to the database of 3D printers available around the world. The purpose of the selection system is to match user 3D printing requirements to available 3D printers. It is anticipated that the selection system will help bridge the divide between users and 3D printers by helping to facilitate the 3D printer selection process.

Introduction

Friedman (1999) has suggested that technology—ie computers, modems, cell phones, cable systems, the Internet, and the like—have enabled us all to reach further into more and more countries and into one another’s lives, faster, deeper, and cheaper than we’ve ever done before. Referring to this phenomenon as “the democratization of technology”, this phenomenon, according Friedman, has put banks, offices, newspapers, bookstores, brokerage firms, schools, and even factories in our homes.

3D printing has paved a path for the democratization of manufacturing and is perceived by some as the next industrial revolution (Berman, 2012). It has created a paradigm shift in the practice and process of traditional manufacturing aided by the interconnectivity and digitization offered by information technology. It has become an integral part of the visualization, design, and prototyping process and in the production of goods.

3D printing is also equipping users ranging from the novice to manufacturing professionals with the ability to quickly transform ideas into tangible products. As 3D printing becomes more accessible, demand continues to increase aided by numerous 3D printers being introduced to the market every year. That is, as more and more users flock to this technology, purveyors of 3D printers from around the world are seizing upon this opportunity to launch various types of 3D printers. This has spawned new 3D printing industries and small businesses as well as industries and small businesses that take advantage of the technology. As a result, end users around the globe
are experiencing greater difficulty in making educated decisions during the selection of 3D printers. This has resulted in incorrect pairing of ideas/designs with 3D printer causing unwanted delays and unexpected costs for an average user.

Roberson (2013), Wong (2012), Rao (2007), Mahesh (2004), Masood (2002), and Brown (2002) and other 3D printer experts have studied and reported on strategies for selecting suitable 3D printers based on a given design. However, many have either limited their investigations to professional users or restricted their research to 3D printer parameters and part accuracies. Also, at any point in time, research is superseded as new and improved 3D printers are introduced to the market. Moreover, many 3D printer manufacturers such as 3D systems, Stratasys, and Makerbot provide their printer specifications either differently or in disparate format making “apples to apples” comparison difficult for the end-user. As well, the layperson and even professionals may not have access to these resources or may have difficulty assimilating these through conference and journal papers. And in many instances, jargon and many terms may make no sense to the layperson as they study the literature. Thus a system design and associated parameters of a web based 3D printer selection system, which will enable end users to match product specification to 3D printers via a webpage is envisioned.

System Model and Method

Figure 1 depicts the high level architecture of the system. Kind of like a digital index, this resource will enable any category of end user to match their product specification to 3D printers by means of a webpage mapped to a central 3D printer database. Any users connected to a network can enter the CAD geometry and product specifications into a web based form to enable selection of a 3D printer. The parameters that drive the selection of 3D printers have been reverse engineered from most common and widely used 3D printer specifications such as 3D Systems, Stratasys, and Makerbot.

The system level architecture has been designed as an improvement over previous research to include a web based entry and display system making the selection system more accessible. Also the purpose of the selection system is to display printer specification in a common format for “apples to apples” comparison. It is anticipate that any user will be able to access the selection webpage and can enter data from any platform including PCs, Macs, cellphones, and tablets.

Level 1 of the system is used by a user to enter user category and desired product specifications and submit them to the 3D printer server. System Level 2 converts the users’ inputs into matching and mapping query to the large database of 3D printers.

Once a suitable match has been found, a webpage containing suitable 3D printers will be displayed in Level 3 with a hyperlink to the machine webpage hosted on the manufacturer’s website. At level 3, the user will be prompted to complete a quick survey summarizing their
experiences with using the system. In addition they will be asked for their thoughts on how to improve the system. The feedback will be used to improve the system.

Figure 1. 3D printer selection system architecture.

As new 3D printers become available commercially, they will be added to the database. The authors and the graduate student dedicated to creating this database of 3D printers will continuously update the database as new 3D printers become available. The webpage of the system and the resource will be hosted on a campus library webpage as depicted in Figure 2.
3D Printer Selection System User Interface

The selection parameters of the web based 3D printer selection system are the product and design specifications such as model dimensions, material type and the category of users to name a few. Figure 3 depicts the parameters of the system that the end user inputs at Level 1. These parameters that drive the selection of 3D printers have been reverse engineered from most common and widely used 3D printer specifications such as 3D Systems, Stratasys, and Makerbot.
Figure 3. Selection parameters based on selected 3D printers.

Broadly these parameters are classified as category of user, the part dimensions of the product, the material of the product, different colors needed, the overall part costs, and the resolution of the desired product. The Novice users who may need further help on the material can visit a webpage tab (part of future work) to learn more about the material properties. A radio button is used to select the user type ranging from a hobbyist to design, manufacturing professional, or a medical professional. Three sliding inputs are incorporated for entering the part build volume indicating the length, width, and height of the part. The users will have the ability to select the product’s material using a drop down menu. Choice of part color is entered by means of a radio button. Range of part costs such as cost/cubic inch and resolution is entered through a slider input. Figure 4 illustrates an example of the system interaction.
Conclusions

The goal of this endeavor was to further the democratization of manufacturing by making 3D printing more accessible to the broader community of users. The problem for this population is identifying suitable 3D printer to fit their needs. Previous research has been somewhat inaccessible, and archaic to the novice user in the rapidly increasing market of 3D printers. Also many big 3D printer manufacturers such as 3D systems, Stratasys, and Makerbot provide their printer specifications either differently or in disparate format making “apples to apples” comparison difficult for the end-user. A system model and system parameters has been identified, which will aid users in the process of identifying appropriate 3D printers and meet their unique needs. Initially the system, along with the website interface will be hosted by a library. The resource on the library webpage and the database will continuously expand and improve the 3D printing pairing engine. Researchers and educators in the engineering design graphics community will benefit greatly from the use of this tool. They will save time by using the 3D printer selection webpage instead of visiting the hundreds of 3D printer manufacturers’ webpages available to match their design requirements with an appropriate 3D printer.

Acknowledgement

The authors wish to thank Ms. Abigail Sweet Graves for her assistance in compiling the data for the 3D printer database and for preparing this manuscript.
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Components of Product Lifecycle Management and Their Application within Academia and Product Centric Manufacturing Enterprises

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Abstract

Modern manufacturing companies are utilizing advanced technologies to manage their engineering data to enable them to create products with advanced features faster than ever before. People, culture, product data management (PDM), process management, and project management are combined to achieve synergies within the company. The technological automation of these components is the core of product lifecycle management (PLM). These components are discussed relative to their contribution to a modern PLM vision. Because PLM is a standard method of engineering data management, modern educators must be aware of the methodologies deployed within the modern manufacturing engineering environment to successfully teach engineers.

Introduction

As companies strive to develop products with advanced features in complex configurations and with compressed design lifecycles, they are increasingly relying on tools to help organize their information among the teams of people involved with the project (Vezzetti, Violante, Maria Grazia, & Marcolin, Federica, 2014). PLM strives to enable individuals to be able to access the data that they require to perform their task as efficiently as possible. The strategy to maintain continuity between all data related the engineering specification is one of the goals of PLM. Fundamentally, this vision is implemented through the systematic control of engineering data, process management and project management (Stark, 2011).

Product Data Management or PDM

Engineering specifications begin with functional requirements. From these requirements, engineers and designers can develop the form of the components to execute the function of the system as defined by the requirements. The goal of this design activity is the documentation of the engineering specifications through the creation of computer aided design (CAD) data. The purpose of the engineering specifications are to provide the documentation required to produce the parts and assemblies required to fulfill the requirements of the product. The cornerstone of product realization processes are computer aided design (CAD), Bills of Materials (BOMs) and analysis
and simulation data (Stark, 2011; Bosch-Mauchand, Belkadi, Bricogne, & Eynard, 2013). These documents are derived from many sources, and are synthesized to create the fully realized product definition.

It is important to realize that product definition encompasses not only the 3D and 2D CAD, but it also comprises secondary data such as certification reports, supplier specification documents, analysis and simulation reports and information such as emails between engineers and suppliers. The myriad of communications between company personnel both within the company and between the company and suppliers comprise components of the digital story of the part. The challenge of providing continuity to the digital thread of each component is one of the fundamental challenges and opportunities faced by manufacturers with respect to their PLM strategy (Stark, 2011).

One of the core business components of PLM includes product data management (PDM) concepts. The data vault exists as a central repository of information to which users have controlled access. Once a company centralizes the data, it must be controlled to prevent multiple people from attempting to edit documents simultaneously. Additionally, the data must be revision controlled. Centralized vaulting, single user and file revisioning, comprise the core components of a PDM strategy (Stark, 2011).

**Process Management**

A PLM implementation extends the fundamental capacity of PDM through building process management onto the PDM foundation of file management. After a company can revision control their files, it is desirable to automate the approval processes related to the engineering specifications. For example, typically several people review the CAD data with respect to various aspects such as manufacturability, quality and cost implications. These reviews and approval processes are manual approvals without a system to digitally capture the process. By transitioning to a digital system, the company is able to enforce a standard process for documentation control as well as capturing secondary information such as comments from the team of people who are implementing the parts.

**Project Management**

The value proposition of the PLM system can further be enhanced through the incorporation of project management methodologies. Because the development of CAD and the approvals related to this documentation are centralized within the PLM system, it can be leveraged to manage new product development projects. For example, a project manager can track the status of the approvals related to the CAD of new parts involved in their project. Through leveraging the PLM system to control secondary data such as test reports and production part approval process.
(PPAP) reports, the project manager can gain insight into issues that may prevent their team from achieving the goals they need to accomplish. Through reporting, these insights can be brought forward earlier in the project timeline allowing the project manager to mitigate challenges before they negatively impact the project.

**Defining Product Lifecycle Management or PLM**

Geceveska, Stojanova and Jovanovski, (2013) define PLM as a comprehensive strategy to be combined with a technological infrastructure to enable innovation. The intent is to enable companies to recycle information across the business enterprise in a way that creates synergies amongst the functional departments. “PLM supports the capability of innovation, creation, management, share, and use of product data, information and knowledge in virtual enterprise networks by integrating people, processes, and technology (p.219)”. Stark (2011) defines PLM as “…the activity of managing a company’s products all the way across their lifecycle in the most effective way” (p.2). There are many generic definitions of PLM, but they distill into several core components as illustrated in Figure 1.

At the core of a PLM strategy are the people who are employed by the company. These individual stakeholders are the decision makers and the creators of the data that is being leveraged by the PLM system. The company culture determines how open the individuals within the company are to changing from managing the information via independent methods to a single PLM infrastructure (Stark, 2011; Martin, 2015). One of the problems many companies face is that of change management. For example, the actions of personnel in one department greatly impact the ability of others to accomplish their tasks. To achieve greater efficiencies within the company as a whole, the PLM ecosystem may require some individuals or departments to do more work. The receptiveness of this proposal to the discrete departments of the company can determine the success or failure of a PLM initiative. Once the people and the culture are compatible with a vision of a unifying PLM infrastructure, the company can implement a product data management (PDM) system to provide fundamental revision control to engineering and project related data (Stark, 2011). Engineering and business processes can then be defined to allow the company to be able to track the thread of data through the appropriate approval processes within the company (Bosch-Mauchand, Belkadi, Bricogne, & Eynard, 2013). Finally, the data can be consolidated and controlled within the context of the portfolio, programs and projects relevant to the company. The combination of these components provide software, configuration and the willingness to adopt PLM as a strategic methodology for innovation management within the company (Stark, 2011).
Conclusions

Because PLM is typically a corporate initiative, it may not be feasible for an academic institution to be able to have access to a true PLM implementation. In many cases Information Technology, time, and cost constraints combine to prohibit an academic institution to implement a PLM system. However, while these constraints are significant, it is possible for an academic institution to replicate the core components that a PLM system automates, such as signoffs involved in engineering and business processes.

Academics should work to help students understand the concept of the digital thread of product design data as well as replicating the core concepts of PLM such as revision control, process management and collaboration between individuals. While historically PLM systems have been difficult to implement within an academic setting, the future holds the promise of academic access to PLM through cloud based offerings. Academics will become enabled to build competencies and authentic learning experiences related to collaborative engineering into the curriculum as PLM systems become available to institutions of higher education.
References


Abstract
Visualization and interpretation of big data poses new and unique challenges. As engineering students enter the work force, many will be tasked with analyzing increasingly large and complex data sets with which they have little experience. This paper presents simple heat map and multi-line plotting techniques used to select critical spectral attributes produced from data mining a hyperspectral satellite image for bathymetry mapping. Additionally, good graphic design practices regarding color choice and reducing visual distraction are suggested in order to more quickly and clearly communicate information to an audience. These techniques can be applied to all types of data visualization as an effective way of communicating data.

Introduction
Modern technology, such as social network sites or airborne and satellite remote sensing, produces a massive amount of data. And with 50 times more data expected to exist in 2020 compared to 2010, demands for individuals with big data analysis skills are growing rapidly (UMUC, 2015). Big data consists of not only social information gathered on users by companies like Facebook or Google, but also consists of sensor data used to monitor factors from environmental changes to stresses in airframes and the sequence of DNA. Although engineering students will frequently encounter two or three variable relationships in their classes, few are exposed to high dimensional and extremely large data. Unfortunately, the tools and techniques that work for visualizing a few variables does not carry over to more complex data sets.

In order to demonstrate the challenges and techniques of visualizing high dimensional data, data mining of a hyperspectral image is presented as a case study. The image data used in this project is from the Hyperspectral Imager for the Coastal Ocean (HICO) on the International Space Station and was obtained February 28, 2014 over the Indian River Lagoon (IRL) on the Atlantic coast of Florida. HICO provided 87 spectral bands in the visible through near infrared wavelengths. The image area was covered by about 34,000 target pixels each of which is 90m x 90m.
Methods

Spectral features which appeared to be strong predictors of water depth were determined by data mining the hyperspectral image and ground-truth sonar data of the same area. Rather than directly using the raw light intensity (pixel value) in every spectral band, several attributes were produced for each sample pixel combination: slope, average, ratio, log ratio, and log slope of every combination of the intensities over the spectra range. This results in a total of about 10,000 individual attributes. Dissecting the intensity curves along the spectra in this way facilitates the identification of physically meaningful features of the spectra.

By definition, big data cannot be analyzed using conventional data visualization and analysis techniques. There are simply too many data points or dimensions for standard scatter plots or bar graphs to effectively reveal patterns and relationships among variables. In order to understand the 10,000 dimensional data extracted from the HICO image, binned correlation matrix graphics and multi-line plots were implemented. We present these simple visualization methods alongside information visualization theory that dictates good practice for the design and presentation of information in graphics.

Information Visualization

Information Visualization Theory (InfoVis Theory) is the science of quantification, coding, and communication of information (Chen, 2010). InfoVis Theory includes objective measures, such as the proportion of ink used on a graphic for non-redundant data (Ink-Data Ratio), to evaluate how effectively data is presented based on cognitive psychology. The goal of InfoVis Theory is to make data interpretation easier and more efficient through minimization of redundant features and effective use of visual elements. Cleveland and McGill (1985) empirically verified a general hierarchical taxonomy of basic visual properties in human perception. Humans most accurately perceive the orientation and length of data visuals while least accurately perceiving the color, volume and density of data visuals. Although the brain has a stronger response to color and volume, these attributes can potentially add undesired dimensionality to a simple graphic.

To demonstrate the effects dimensionality has on graphics, two plots of the Indian River Lagoon bathymetric distributions were created for comparison. Each graph shows the distribution of sampled depths, which is useful in identifying sampling bias. If a depth is under represented in the training data, our model cannot accurately predict that depth from the hyperspectral image. The binned depths are shown in Figures 1 and 2.

Figure 1 uses color and volume as unnecessary features that distract the viewer from interpreting the data. These extra flashy features are known as “chartjunk”. The use of different colors is chartjunk since it is an unused dimension of the visual. Extra color adds ambiguity to the data which increases the chances of a subjective interpretation from the observer. For example, the
Figure 1. A visual with excessive dimensionality. The color and volume give no additional information about the bathymetric distribution which distracts the viewer from the objective of the graph.

Figure 2. A visual that uses color and volume effectively. One color was used since the data was obtained from the same place. One color was used since the data was obtained from the same place. The numbers on top of the histograms remove ambiguity from the true value of the binned depths.
different colors could suggest the depths used in the analysis come from different bodies of water, when in fact all of the depths were collected in the same geographic extent. Volume of the bars is also chartjunk in Figure 1 since it does not help describe the representation of depths. Based on Figure 1, the number of instances for the depths cannot be clearly determined. The 8-ft sampled depth appears to have less than 600 instances due to the three-dimensional effects.

In order to create a better visual, the typeface, color, volume, and graph design were taken into consideration. Figure 2 shows a clearer representation of the binned depths. The typeface was chosen as a sans-serif because it is more legible and removes style which could be distracting. The volume and color over dimensionality from Figure 1 was removed in Figure 2. The number of instances is displayed over the bar graph which provides exact values without comprising the trend of the graph. These changes were made so that the viewer can quickly observe the trend of the data, gather as much information as quickly as possible with the least amount of confusion.

InfoVis theory differs with larger data sets. During the analysis of HICO hyperspectral profiles, it was known a priori that reflected light intensity decreases with depth due to increasing light attenuation through the water column. In order to test the proposed hypothesis 200 water depths between 4 and 8 feet were sampled from the thousands of measured spectral curves. Figures 3 and 4 provide another example of how data can become unclear with improper use of graphic elements and how InfoVis Theory can be used to form a clearer visual. The line color variation in Figure 3 represents the different depths but no pattern emerges at first glance and anomalous data is not easily detected. The lines in the graph are the default colors from the Matplotlib graphing software. Since most plotting programs have similar default color schemes, it is easily seen that the programs have not been designed for high-dimensionality data.

Ascending lightness values of a monotonic hue were used as a gradient which assigns the lighter colors to shallower depth and gradually darker colors to deeper depths. Pattern recognition is easier using Figure 4 compared to Figure 3 because of the simple presentation of the relationship between and depth. Each of the examples has drawbacks; and the key to InfoVis theory is to balance the trade-off of added dimensionality. Figure 4 shows the distribution of depths through the color ramp. Although it is easily seen how the depths vary, resolving each depth isn’t as easily done. On some parts of the spectral profile, deeper depths have higher intensity values than the shallower depths. This can be observed in Figure 3 more easily than in Figure 4.
Heat Maps for Identifying Relationships in High Dimensional Data

The HICO instrument measured 87 unique spectral intensities at every pixel. In order to identify features of this spectral curve that are good predictors of water depth, 10,000 total combinations of average intensity, slope, ratio, log slope, and log ratio were calculated for every combination of the spectral bands. Although techniques such as Principal Component Analysis (PCA) identify unique features and help reduce the dimensionality of the problem, they rearrange the raw spectral information such that the information contained in the original intensities is lost in

Figure 3. Sample depths from the Indian River Lagoon and their spectral profile.

Figure 4. Sampled depths from the Indian River Lagoon and their spectral profiles. The color palette ‘blues’ makes use of color as a gradient which aids pattern recognition.
Figure 5. Binned correlation matrix for the 10,000 attributes which describe the spectral curves. The rejection threshold is at $r^2 = 0.9$. Each position in this matrix represents the average of 100 correlation coefficients between given attributes. As the viewer moves from left to right or up to down across the graphic, the spectral bands being compared are toward the redder wavelengths. This repeats for each of the 5 attribute types.

Once each of the 10,000 spectral curve features are calculated, it is necessary to remove redundant information. Because each attribute was calculated for every combination of spectral band (e.g. average intensity between band 4 and 7 and average intensity between band 4 and 8), many attributes are similar and can be removed without loss of critical information. In order to identify the most unique attributes, we calculate a correlation matrix and remove attributes for which their correlation with another attribute falls above some threshold. However, if each correlation coefficient were to be displayed, the user would need to look through 100,000,000 values. In order to quickly view patterns and identify outliers, correlation matrices are commonly displayed using heat maps: graphics in which each matrix position is colored with a color which represents the value
it holds. However, with a 10,000 square matrix, to view each point would require several computer monitors arranged in an array. Because of the slowly varying nature of our attribute values, we average every 100x100 matrix positions into a single bin. This greatly reduces the number of points plotted in the heat map while maintaining the overall attribute correlation trends.

Figure 5 demonstrates the binned heat map approach for analyzing the relationship between variables. To emphasize the uniqueness of each variable, a simple diverging color map was chosen and centered on the correlation threshold value for attribute rejection. By changing the correlation threshold, we can choose how many attributes are rejected before the next phase of our bathymetry mapping routine. Correlations that fall above the threshold appear as red while correlations below the threshold are blue. Additionally, stronger positive and negative correlations have more saturated colors. This color scheme enables the viewer to quickly distinguish between spectral attributes that are strong or weak identifiers of depth. For example, in Figure 5, average intensities contain little unique information and are clearly above the rejection criteria. Many patterns exist across the other attributes and are visible as white stripes or patches in the correlation matrix. Although these are not colored red, they are still just at the edge of rejection and the corresponding attributes are not very unique.

Conclusion

Data mining provides a unique way for many fields to monitor and analyze data. Given the nature of big data, it is necessary to apply special methods of visualization while avoiding the use of dimensionally ambiguous visual features. InfoVis Theory offers techniques to create effective visuals so a viewer can gather the maximum information in the least amount of time without compromising data or creating chartjunk. Visual analytics and InfoVis Theory can be used in school curricula and work force training to teach the sometimes non-intuitive skills necessary to create an effective data graphic.

References


Direct Modeling: Easy Changes in CAD?

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Abstract

Direct Modeling is an emerging CAD technology that uses direct manipulation of the geometry to effect changes in the part model, and is based on a boundary representation database. This paper highlights the differences between Direct Modeling and conventional history-based solid modeling, compares emerging technologies, and discusses what this means for engineering graphics educators.

Introduction

Direct Modeling (DM), a.k.a. synchronous modeling or dynamic modeling, is an alternative approach to feature-based parametric solid modeling that has gained popularity in the past few years. Many of the major CAD software vendors have added direct modeling capabilities to their offerings: PTC Creo Elements/Direct, AutoDesk Fusion, and SolidWorks Direct Editing to name a few. Software vendors claim that Direct Modeling solves numerous problems that are inherent with the use of history-based systems.

What is Direct Modeling?

Direct Modeling is an intuitive approach to creating geometry without the burden of history-based dependencies. History-based (procedural) parameterization of models requires the user to thoughtfully consider the important model input/output parameters – dependent dimensions are calculated based on procedure (history tree rebuild). However, instead of storing the sequence of feature creation, a direct model is based on the boundary representation of the solid. The model is regenerated based on a set of constraint equations rather than the sequential reconstruction of feature history (Ushakov, 2008).

Construction methods are similar to those used in conventional solid modeling; the user can design a 2D profile and then develop the model using commands like extrude, revolve, mill, bore, etc. Without the presence of a parameterized history tree, manipulation of the geometry is greatly
simplified. Local geometry and topology changes can be made using both direct “push-pull”
interactions or using dimension-driven methods. Users can directly manipulate model geometry
without needing to know how that geometry was created by simply grabbing, pulling and dragging
faces, edges and features. Direct Modeling also utilizes everyday software methods such as
“copy/paste” and “drag/drop”. Direct modeling closely follows these same Microsoft derived
principles, which means the user can simply cut and paste elements from an existing design and
start building an entirely new model (PTC, 2011).

**Advantages of Direct Modeling**

Direct modeling creates geometry rather than features so it is perfect for conceptual modeling
where the designer doesn’t want to be tied down with the interdependencies of features and the
ramifications making a change might have. The direct modeling approach to 3D CAD provides an
environment where users can design directly on the model’s geometry. This is especially
beneficial when creating one-off designs or facing unexpected and late changes in the design
process (PTC, 2011). The Direct Modeling approach simplifies the design process, so pre-
planning a modeling strategy is not necessary as compared to history-based modeling. Users
working on existing models will not have to understand the modeling strategy used to create the
model, and will not need to search through the feature tree to identify specific feature parameters
in order to make a change to the geometry. The Direct Modeling approach is about quickness and
responsiveness-to-change, making it an ideal approach where speed and flexibility are important
(Brunelli, 2014).

Due to the absence of the history tree, models created using the direct modeling approach
exhibit greater interoperability. Files can be saved in standard formats such as STEP, Parasolid,
ACIS, etc. and imported into other CAD packages without loss of information. Direct Modeling is
an ideal tool for manipulating imported geometry from other systems that generate a simple closed
volume from these conversion formats. Variational direct modeling technology can automatically
recognize design intent of a “dumb” geometry in the form of geometric and dimensional
constraints between boundary elements (Ushakov, 2008).

Direct Modeling is ideal for freeform ergonomic parts and parts with complex surface
gеometry. Freeform manipulation of NURBS surfaces using push-pull operations is similar to
modeling with clay.

**Comparison of Technologies**

As the major engineering CAD vendors begin to integrate Direct Modeling methods into their
products, significant differences in implementation and functionality are currently observed. These
differences result from the need to merge the capabilities of the history-based systems with the
new direct approach. The result is a number of hybrid systems that exhibit the features of both history-based parametric solid modelers and the push/pull user interface and boundary representation database of direct modeling. These differences in implementation are as follows:

PTC Creo Direct uses Push / Pull technology to create new geometry or modify existing 3D CAD design, regardless of file format. Direct interaction with the geometry makes it easy to learn and use. Part files created in Creo Direct or Creo Parametric can be read and manipulated using the tools in either software package, but the feature tree shows that the history-based structure is maintained in both files, although it is hidden from the user in Creo Direct. Figure 1 shows a simple part created in Creo Direct by extruding a square, adding a blind hole, moving the bottom face of the hole with the push/pull interface, then adding a round on one edge and a draft on the front face. Note that the feature tree shows only the datum planes and the original sketch for the square extrusion. There are no other features available to the designer for modification, even though the software provides tools to create the hole and draft. Figure 2 shows the same file imported into Creo Parametric. Note that the model tree for the part includes all of the feature operations that would be used to create the part in Creo Parametric (extrude, hole, round, draft), as well as an additional feature representing the Move operation that was applied to the bottom of the hole. Manipulating the model in Creo Direct results in the creation of additional features in the Creo Parametric feature tree, such that the tree can become quite long after a few modifications (Menezes, 2011). The parametric features can be edited within the Creo Parametric software; however, changing the Hole feature from a blind depth to a through hole causes the Move feature to fail. This demonstrates that the software is most suited for tasks such as generating proposals, defining the initial design for tooling fixtures or capturing design input from customers in the field.

Figure 1. A simple part modeled in Creo Direct
SolidWorks Direct Model Editing is not Push/Pull; this is a feature-based parametric tool. Direct editing enables the user to copy, move, split, replace, offset, push, and drag geometry to create the desired result. Patterning creates features, faces, and solid bodies by clicking directly on the geometry to be patterned. Direct Edit capabilities automatically convert non-native, imported model geometry into intelligent SolidWorks features that can be modified parametrically or through direct geometry manipulation. Similar to Creo, SolidWorks adds Direct Edit features to the model tree, as shown in Figure 3.
Catia Live Shape is a feature based system, similar to SolidWorks’ Direct Model Editing, which makes sense since both are Dassault products. Live Shape is called “declarative modeling.” It looks like direct modeling, but with declarative modeling, specifications can be “declared” or assigned. This is a free modeling approach, but with a precise modeling capability that captures design intent. The focus of this product is on sketching ideas freely and improving collaboration between design and simulation or manufacturing.

AutoCad Inventor Fusion is a Push / Pull system with a parametric component that enables designers to combine parametric, history-based modeling with the more freeform productivity of direct modeling. Freeform creates smooth and precise surfaces with T-Splines technology or with sketch curves, patches, and extrusions.

NX Synchronous Technology is a Push/Pull system that has a parametric component. The user can easily modify complex 3D models without understanding how the model was constructed, and without knowing the feature relationships and dependencies. The user applies modifications directly to the model faces, edges and cross-sections using simple, direct “push-and-pull” tools. Direct modeling with synchronous technology automatically finds and recognizes collections of faces representing functional features, and enables the designer to modify them quickly and easily. Freeform design with simple push-and-pull shaping techniques begins with solid or surface, analytic or B-rep geometry, and the user can then insert isoparametric curves and model organic forms by moving constraint points, surface poles and handles.

Impact on Engineering Education

Direct interaction afforded by Direct Modeling offers a large advantage for non-CAD specialists in that it is generally more intuitive and very easy to learn, thus making it easier for students to develop more complex engineering designs quickly. Direct Modeling eliminates many of the problems associated with traditional feature-based tools. Engineers and students that may not use CAD on a regular basis can easily make changes to models without having to fully understand all the ‘constraints’ of a feature-based model and concern for causing regeneration failures from the changes being made. Not only is it easier to create and modify simple geometries such as those commonly modeled in introductory CAD courses, but students can also create more complex shapes using freeform modeling of NURBS surfaces, such as the beverage containers shown in Figure 4. These models were created with Creo freestyle using a push/pull interface after a two hour introductory lab session.
Current history-based CAD users and educators need to modify their mindset and thinking to incorporate this new modeling methodology into their existing design strategies and teaching or training approaches. Currently, parametric, history-based CAD is considered to be unsuitable for use in the concept phase due to the lack of knowledge regarding suitable parameterization of the model and feature dependencies. Conceptual design development is a process where many threads of possibilities are developed in parallel (Krish, 2010). Although the use of Direct Modeling, as yet an emerging technology, has been limited in industry, it is primarily being used in the concept / prototype phase for new projects where producing multiple “quick and dirty” concepts is necessary. After the concept has been adequately defined, companies are transferring the project to the history-based modeling packages to create assemblies and to document the design through the 2D detail drawing phase (Bodein et al., 2014).

The creative use of history-based parametric CAD software depends greatly on the user’s cognitive ability to visualize the design, decompose the model into functional features, identify parameters that incorporate design intent, manage feature dependencies and constraints, and interact with the developing model of the product (Gaughran, 2002). New teaching methods will be needed to develop skills to properly incorporate design intent into these new DM and hybrid models while maintaining the flexibility that is inherent in the use of direct methods. Effective use of DM systems, on the other hand, will require the user to have a deeper understanding of boundary representation and constructive solid geometry (Boolean) methods rather than history-based concepts such as parent-child relationships (Wang et al., 2015).
Whether teaching Direct Modeling or history-based modeling it is important to develop three elements necessary for obtaining CAD expertise. “Declarative Command Knowledge” is knowledge about the commands or algorithms that are unique to specific CAD software packages, “Specific Procedural Command Knowledge”, knowledge that enables the operator to execute the necessary commands and “Strategic 3D CAD knowledge”, knowledge that includes a range of metacognitive processes including planning, monitoring and revising (Chester, 2007).

It appears that the major CAD vendors are moving towards a hybrid of Direct Modeling and history-based parametric feature-based solid modeling systems. Educators need to be aware of these changes and future trends, but it appears that these hybrid systems are not yet sufficiently robust, and modeling strategies for using the direct modeling tools are not well developed. Therefore it will be important to provide students with a thorough understanding of both technologies in the near term, while developing cognitive models for the use of direct modeling systems.

Conclusions
Various implementations of Direct Modeling have become embedded in mainstream 3D CAD software. As these new tools are adopted by industry, CAD educators will need to develop ways to teach relevant new concepts to engineering students.

References


Abstract

An analysis of articles published in the Engineering Design Graphics Journal (EDGJ) from 2003 - 2014 was conducted following the methodology used by Robert Chin in his 2003 study of articles published in the EDGJ from 1987 - 2002. Both studies look at feature-articles published in the EDGJ that were later indexed by ERIC (Educational Resources Information Center). ERIC provided abstract data that was compiled into a spreadsheet, which was then sorted and analyzed. The data collected from ERIC was also verified using the archives on the EDGJ website. The similar nature and analysis of the data gathered in the two studies allows direct comparisons to be made between the results of the studies.

Overview

The Engineering Design Graphics Journal (EDGJ) is a publication of the Engineering Design Graphics Division (EDGD) of the American Society for Engineering Education (ASEE). A core objective of the EDGD is to promote teaching, research, discussion, and communication of engineering design graphics (EDGD, 2015). The purpose of this study was to document the nature of the work published in the EDGJ to help identify publication patterns in the EDGJ. Data from this study can help guide authors who contribute to the EDGJ because trends in publication topics is a reflection of the evolving research interests of the EDGD membership.

The methodology used in this study was chosen to closely match that of Robert Chin’s (2003) analysis of the EDGJ. Chin’s study investigated articles that were indexed in the Educational Resources Information Center (ERIC) database and were published in EDGJ volumes 51-66 (1987-2002), a 15 year timespan. The current study focused on articles published in EDGJ volumes 67-78 (2003-2014), an 11 year timespan.

ERIC is an online database that catalogs over one million education related articles. They collect from thousands of journals and other sources. Articles submitted to ERIC must fulfill many requirements in order to be indexed. “All documents under consideration are evaluated by ERIC’s
subject experts for their quality. That is, they are evaluated for their contribution to knowledge, significance, relevance, newness, innovativeness, effectiveness of presentation, thoroughness of reporting, relation to current priorities, timeliness, authority of source, intended audience, and comprehensiveness. Thus, feature articles published in the EDGJ and indexed later by ERIC are scrutinized twice” (Chin, 2003, p. 7). One of the original goals of ERIC was to provide pertinent information to the field of education research through accessibility (ERIC, 2014). An assessment of the EDGJ through ERIC is a metric to illustrate the journal’s direction.

Methodology

On April, 1st 2015, a search was conducted on ERIC for EDGJ articles that have been indexed in volumes 67-78. Information about each ERIC-indexed article was entered into a spreadsheet making note of the author, title and subject headings. Additional information was then obtained from the EDGJ website. The Data were then organized and counted in such a way that summary tables could be compared, and in some cases combined, with the data published in Chin’s 2003 study. This methodology was chosen because it will provide consistent measuring of the EDGJ from 1987 to 2014. The authors and subject headings were measured by frequency. The volumes and issues were used to compare how many articles were indexed in each EDGJ issue and volume.

A key difference between Dr. Chin’s study and this one is caused by a change in ERIC’s use of clearinghouses. Prior to January, 2004, ERIC used sixteen different clearinghouses to assist with indexing articles. In 2004, ERIC consolidated into a single clearinghouse entity. Expiration in contract with the individual clearinghouses and a slow bureaucratic system resulted in no submissions to ERIC entirely in 2004, and no submission from the EDGJ occurred in both 2004 and 2005 (Corby, 2009). Despite the absence of ERIC indexed articles in 2004 and 2005, the available ERIC data still gives a representation of key ideas discussed among contributors of the EDGJ.

Another key difference is ERIC’s current use of the Subject Heading, which is a combination of ERIC’s Major Descriptors and Minor Descriptors used in Dr. Chin’s study. In this study a direct comparison was made between for the former Major Descriptors and the current Subject Heading used by ERIC.

Results

From 2003 to 2014, 98 articles were published by the EDGJ. The number of articles published per issue ranged from 8 (V76 n3 – a special edition of 67th midyear papers) to 1 (in 9 issues). The average number of articles published per issue was 2.7; the standard deviation was 1.4. In comparison, the average number of articles published in each issue between 1987 and 2002 was 4.2 and the standard deviation was 1.2. Table 1 presents a comparison of the statistics between the
current study and Chin’s 2003 study. Figure 1 illustrates graphically the number of articles published in each volume of the EDGJ from 1988 (Volume 52) to 2014 (Volume 78). Each volume typically contains three issues. Although several volumes are omitted from Figure 1 (several issues were unavailable to the researchers or were special issues that skewed the data), the downward trend in articles published in the EDGJ is readily apparent.

<table>
<thead>
<tr>
<th>Table 1 Articles per EDGJ Issue</th>
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<tr>
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<tr>
<td>Current Study</td>
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<tr>
<td>Vols. 67-78 (2003-2014)</td>
</tr>
<tr>
<td>Chin Study</td>
</tr>
</tbody>
</table>

Figure 1 Articles per EDGJ Volume from 1988-2014

Of the 98 articles published by the EDGJ between 2003 and 2014, 68% (N=67) were indexed by ERIC. By EDGJ volume, the proportion of articles indexed ranged from 0% (during the aforementioned ERIC clearinghouse changeover) to 100%. Table 2 summarizes the distribution of ERIC-indexed articles by volume. Between 2003 and 2014, the EDGJ published 296 articles, of which 147 (50%) were indexed by ERIC.
Table 2 Percent of EDGJ Articles Indexed by ERIC

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</tr>
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<td>0</td>
<td>100</td>
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<td>100</td>
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<td>100</td>
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<table>
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<tr>
<td>% Indexed</td>
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<td>76</td>
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<td>0</td>
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<td>25</td>
<td>13</td>
<td>86</td>
<td>62</td>
<td>38</td>
<td>75</td>
<td>31</td>
<td>40%</td>
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</table>

When ERIC indexes articles a variety of fields are populated in their database including items such as author, journal citation, and subject headings. As previously discussed, when Dr. Chin completed his study in 2003, ERIC listed Major Descriptors and Minor Descriptors for the articles they indexed. Today ERIC lists a single Subject Heading. Table 3 presents a direct comparison between the most frequently used Major Descriptors from Chin’s study and the most frequently used Subject Headings found in the current study. While the list has changed modestly over the years, many of the key topics discussed among the EDGJ authors are consistent. Engineering Education, Computer Aided Design, Spatial Ability, Visualization, Computer Graphics, and Computer Software are the most frequently used subject descriptors for the EDGJ ERIC-indexed articles in both studies. Engineering Education remains the most frequently used descriptor among the indexed articles. This is not surprising since ERIC is a database for educators, and the EDGD is a community of educators.

Table 3 Frequency of Subject Headings

<table>
<thead>
<tr>
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<tr>
<td>ERIC Subject Heading</td>
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<td>Teaching Methods</td>
<td>13</td>
<td>Design</td>
<td>10</td>
</tr>
</tbody>
</table>

Of the 98 articles published by the EDGJ between 2003 and 2014 that were later indexed by ERIC, 26 were written by individual authors. Table 4 lists five authors who contributed more than 1 article individually. Of the same 98 articles, 9 different authors were the first-author of 2 or
more jointly-written articles (refer to Table 5). Table 6 lists 16 second and subsequent authors who published 2 or more articles in the EDGJ that were later indexed by ERIC.

**Table 4 Individual Authors**

<table>
<thead>
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<th># Articles</th>
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<tr>
<td>Mohler, James L</td>
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<td>Yue, Jianping</td>
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</table>

**Table 5 First Authors in a Group**

<table>
<thead>
<tr>
<th>First Study (2003-2014)</th>
<th># Articles</th>
<th>Chin Study (1987-2002)</th>
<th># Articles</th>
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<td>Ernst, Jeremy V</td>
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**Table 6 Second and Subsequent Authors in a Group**

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<th>2nd and Subsequent Author</th>
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</table>
Conclusion

Following the methodology used by Chin (2003), the authors conducted a literature search of the ERIC-indexed articles published by the EDGJ from 2003-2014 (volumes 67-78). A search of the EDGJ website was also conducted to gather additional information about EDGJ publication records. The gathered data were entered into a spreadsheet and analyzed. Descriptive data tables were prepared to match those presented by Dr. Chin, thus allowing direct comparisons to be made between the two studies. Several observations can be made by comparing the data from the two studies.

- EDGJ articles published between 2003 and 2014 are indexed by ERIC with greater frequency than those published between 1987 and 2002. The greater indexing frequency is likely due to changes in ERIC indexing procedures.
- The number of articles published in each volume of the EDGJ between 1987 and 2014 is trending downward.
- Based on the frequency of study headings listed by ERIC, the common topics of the articles published in the EDGJ has remained consistent between 1987 and 2002.

References

Visualizing Electric Circuits: The Role of Spatial Visualization Skills in Electrical Engineering  

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Sheryl Sorby  
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B. Bowe  
College of Engineering and Built Environment  
Dublin Institute of Technology

Abstract

A significant and sizeable correlation is established between engineering students’ scores on a spatial visualization test and their scores on an electric circuits concept test with about 25% of the variation shared between the two tests. Visualization appears to play a very important role in the analysis of electric circuits which requires the mental transformation of pictorial representations of circuits to formal circuit diagrams.

Introduction

Competence in the understanding and analysis of electrical circuits is a fundamental requirement for electrical engineering students. Circuits classes taken in the first year of the curriculum typically cover topics related to simple direct current (D.C.) electrical circuits and these learning outcomes are fundamental to the rest of the curriculum. However, tests of conceptual understanding of simple D.C. circuits have shown how many students have great difficulty in grasping these concepts as revealed in the low scores achieved on these tests. For example, for university students in the US the average score on the DIRECT electric circuits test was 52% (Engelhardt & Beichner, 2004); in Ireland, for a group of common 1st year engineering students, the average score on the same test after the circuits classes had been completed was 47% (compared to 29% prior to instruction) (Duffy & O'Dwyer, 2015). Clearly, at a conceptual level, developing an understanding of simple DC electric circuits is very challenging.

At a general level, spatial skills have been shown to be a very important indicator of success in science, technology, engineering and mathematics (STEM) education (Wai, Lubinski, & Benbow, 2009). However, relatively little is known about which particular aspects of engineering curricula are most influenced by spatial thinking. Correlations between spatial tests and tests of conceptual understanding in physics of a moderate size have been measured (Kozhevnikov & Thornton, 2006; Mac Raighne et al., 2015) with this correlation attributed to visualization skills (Kozhevnikov, Motes, & Hegarty, 2007). Some studies in maths education have also revealed
moderate to large correlation sizes (e.g. Casey, Nuttall, & Pezaris, 2001). Perhaps spatial visualization also has an important role to play in the understanding of electric circuits given the heavy use of diagram representation of circuits in the subject. The purpose of this study was to examine the role spatial visualization has to play in a specific aspect the electrical engineering curriculum, the understanding of simple DC electric circuits.

Procedure

Two spatial skills tests, the Mental Rotations Test A (MRT-A) (Peters et al., 1995) and the Mental Cutting Test (MCT) (CEEB, 1939), and an electric circuits concept test, DIRECT 1.1 (Engelhardt & Beichner, 2004), were administered, in that order, during a 1 hour class period to those in attendance from a 3rd year Bachelor in Electrical Engineering class, Dublin Institute of Technology. The tests were administered as recommended by their authors with one exception: since the majority of the class had finished the MCT after 13 mins, it was concluded after 16 mins rather than 20 mins due to time pressure. The MRT was scored by giving 1 point for correctly identifying both matching figures; identifying one only was scored as 0. Both the MCT and the DIRECT tests have only one correct answer per question. While the DIRECT test does not have separate sections, instructions from the authors are to group different questions together at the analysis phase into 4 groups – A, physical aspects of DC electric circuits, B, energy, C, current and D, voltage. The DIRECT test scores for each group were computed along with the overall score. Correlations were computed using the Pearson correlation coefficient.

Results and Analysis

Descriptive statistics are provided in Table 1 and the correlation matrix for these data is provided in Table 2. The sample size was n = 27, 6 female and 21 male participants.

<table>
<thead>
<tr>
<th>Test</th>
<th>MRT-A 1 (12) 1</th>
<th>MRT-A 2 (12)</th>
<th>MRT (24)</th>
<th>MCT (25)</th>
<th>DIRECT A (12) 2</th>
<th>DIRECT B (4)</th>
<th>DIRECT C (5)</th>
<th>DIRECT D (9)</th>
<th>DIRECT (29)</th>
<th>DIRECT (100 %)</th>
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</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5.00</td>
<td>5.63</td>
<td>10.41</td>
<td>10.63</td>
<td>6.93</td>
<td>1.07</td>
<td>1.63</td>
<td>3.26</td>
<td>12.33</td>
<td>42.48</td>
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<tr>
<td>S. D.</td>
<td>3.000</td>
<td>2.989</td>
<td>5.337</td>
<td>5.583</td>
<td>2.541</td>
<td>.997</td>
<td>.967</td>
<td>1.559</td>
<td>3.843</td>
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</table>

1 Number of questions on the test is shown in brackets
2 Question 27 is counted twice in this group

Table 1. Descriptive statistics for the tests (no. of questions in brackets)

<table>
<thead>
<tr>
<th>MRT-A</th>
<th>MCT</th>
<th>DIRECT29</th>
<th>DIRECT A</th>
<th>DIRECT B</th>
<th>DIRECT C</th>
<th>DIRECT D</th>
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<tr>
<td>.643**</td>
<td>.264</td>
<td>.505**</td>
<td>-.112</td>
<td>.138</td>
<td>-.081</td>
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<tr>
<td>.492**</td>
<td>.527**</td>
<td>.666**</td>
<td>.298</td>
<td>.001</td>
<td>.320</td>
<td></td>
</tr>
<tr>
<td>.906**</td>
<td>.367</td>
<td>-.090</td>
<td>.442*</td>
<td>.630**</td>
<td>.015</td>
<td></td>
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</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2. Correlation matrix for all test results from this study (Pearson correlation)
There is no significant correlation between the MRT-A and the DIRECT test overall scores. However, there is a moderate ($r = .505$) and highly significant ($p < .01$) correlation between the Group A questions on DIRECT and MRT-A. The correlation coefficient between the MCT and the DIRECT test is moderate ($r = 0.492$) and highly significant ($p < .01$). This correlation is almost entirely related to the questions in Group A, ‘physical aspects of circuits’ ($r = .527$, $p < .01$, $r^2 = 0.28$). Approximately 25% of the variation in the answers to this group of questions is shared with the MCT. The apparently large amount of scatter in the plot (not included due to length restriction) prompted the calculation of confidence intervals for the correlation coefficient. The confidence intervals, derived from bootstrapping, for the correlation between the MCT and DIRECT Group A were found to be .201 (lower) and .765 (upper) indicating the persistence of a weak to moderate correlation despite a more robust statistical analysis. The very high significance level of the correlation along with positive values for lower and upper confidence intervals indicates the correlation has not emerged by chance and is very likely to be found in the population (of electrical engineering students) or in another sample of these students.

**Discussion**

Any correlation between spatial ability and DIRECT test scores is due to the Group A questions - ‘physical aspects of circuits’. Correlations of similar magnitudes and significance levels were found in another study with a common first year engineering class in DIT in which the MCT and the Purdue Spatial Visualization Test of Rotations (PSVT:R)(Bodner & Guay, 1997) was used (Duffy & O'Dwyer, 2015). The physical group tests the ability to identify and explain a short circuit, a complete circuit and to interpret pictures and diagrams of a variety of circuits among other things (see Engelhardt & Beichner, 2004 for more detail).

![Figure 1. Question 13 on the DIRECT test (Engelhardt & Beichner, 2004)](image)

Question 13, shown in Figure 1 and included the physical group, illustrates a requirement to mentally transform a circuit from an informal, toy sketch into a formal circuit diagram. Either the visual representation in the informal sketch must be held in working memory and transformed into the correct formal diagram or each of the formal diagrams must be cross checked against aspects...
of the toy sketch to see if they match. In each case, the ability to visualize and mentally transform the circuit is vitally important as failure at this step implies the subsequent analysis of the circuit will be flawed. For example, if several resistors are involved and the task is to calculate the total resistance, an incorrect diagram at this point will result in the wrong answer. A similar process can be found in a Thévenin analysis of a circuit as this involves the conversion of the circuit from one shape to another. For example, consider transformation involved in converting the Wheatstone bridge on the left of Figure 2 to a Thévenin equivalent circuit on the right. A correct calculation of the Thévenin resistance can only follow if the graphical transformation step is successful. Such operations are fundamental to electrical engineering education.

![Figure 2. Thévenin transformation of the Wheatstone bridge circuit](image)

**Conclusions**

Highly significant correlations of a moderate to large size have been observed between scores on spatial tests and an electrical concept test for two samples of engineering students. This correlation is almost entirely due to the scores on questions related to physical aspects of circuits. It appears that the ability to mentally transform circuit diagrams shares much in common with the ability to answer questions on tests of spatial visualization and mental transformation. It is planned to repeat these tests with different samples in several locations.

**References**


Framing Spatial Cognition: Establishing a Research Agenda

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Department of Design and Manufacturing Technology
University of Limerick

Abstract

A significant aim of research concerning human intelligence is to develop a comprehensive cognitive map of the human intelligence structure. The evolution of this knowledge base is mirrored through the chronological development of models which frame cognitive domains. The domain of Visual Processing (Gv), commonly known as spatial ability, is a domain which has seen significant advances in the pertinent knowledge base. Models framing this cognitive structure are arguably under-evolved through a lack of representation of factors identified in contemporary research. This paper presents the initial conception of a more comprehensive theoretical framework which builds upon existing theory. It is envisioned that such a framework could support further research exploring the nature of thinking in graphics and other related disciplines. A research agenda is discussed concerning the validation of this framework and its utilization in the holistic assessment of spatial ability.

Introduction

Previous research has comprehensively established the significance of spatial ability in a number of fields. For example, Harle and Towns (2010) note its significance within Chemistry, Lubinski's (2010) longitudinal study illustrates its significance across a variety of STEM disciplines such as Maths and Engineering and Sorby (2009) illustrates significant correlations between spatial ability and a number of introductory engineering, maths and science courses. Graphics and graphical education is another field where attaining a high spatial capacity is often cited as being advantageous (Sorby, 1999) and this link is supported by results from variety of correlational studies (e.g. Kelly Jr, Branoff, & Clark, 2014). The conception of a visualizing faculty was borne through research investigating the nature of peoples thinking, where a high capacity to visualize was recognized as a substantial tool supporting advanced numerical and graphical reasoning (Galton, 1879). Within the pertinent literature a multiplicity of research avenues have been established resulting in spatial ability being discussed through a variety of lenses. The rationale for exploring a variety of spatial factors stems from the agenda aiming to better understand the nature of peoples thinking and how this thinking can be operationalized in problem solving. For example, Hegarty and Waller (2004) discuss the discrimination between the spatial factors of mental rotation and perspective taking which is a critical avenue within graphical education due to the results of the previously discussed correlational studies. Burton and Fogarty
(2003) empirically describe the cognitive structure of imagery factors and it has been posited that the capacity to produce vivid mental imagery is pertinent to solving geometric problems (Schneider & McGrew, 2012). These avenues illustrate the complex nature of this cognitive domain. With such complexity, and the significance of this domain to graphical reasoning, the need for an underpinning theoretical framework has emerged (Harle & Towns, 2010) coinciding with the need to understand the characteristics of individual spatial factors (Kelly Jr et al., 2014). This paper presents an initial conception of a spatial ability framework, discussing a research agenda concentrating on its validation and presents a strategy for the utilization of the framework in the holistic assessment of spatial ability.

The Development of the Spatial Ability Framework

Since the conception of spatial ability it has been recognized as a cognitive domain inclusive of a variety of unique factors (Galton, 1879). Over time a variety of factors have been empirically uncovered and a significant amount is now known about the many areas of spatial cognition. The generation of such a vast body of knowledge in a relatively short time period has resulted in contention regarding the identification and classification of spatial factors and in the evolution of many related misconceptions (Carroll, 1993). Seery, Buckley and Delahunty (2015) discuss this issue noting how the concept of spatial ability itself is ambiguous within the literature. Through a systematic literature review they identify prominent definitions of spatial ability. These include Lohman's (1979) definition as “the ability to generate, retain, and manipulate abstract visual images” (p.126), Gaughran's (2002) definition as “the ability to visualise, manipulate and interrelate real or imaginary configurations in space” and Sorby's (1999, p.21) definition as the “innate ability to visualize that a person has before any formal training has occurred”. They further discriminate spatial ability from spatial factors, spatial skills and spatial aptitude.

A number of theoretical frameworks have been developed which describe the structure of human intellect and are inclusive of a cognitive domain relating to space (e.g. Schneider & McGrew, 2012; Thurstone, 1938; Vernon, 1950). The Cattell-Horn-Carroll (CHC) theory (Schneider & McGrew, 2012) is arguably the most comprehensive of these frameworks and culminates a large body of human intelligence research into a framework inclusive of a domain of Visual Processing (Gv), otherwise known as spatial ability. However as noted by Carroll (1993), (one of the main contributors to the theory), there is significant potential for more factors to exist within the domain. One reason presented for this is the historical inability to test posited dynamic factors due to technological constraints. This view is echoed by Schneider and McGrew (2012) in their welcoming of research focusing on the expansion of the domain.
Seery et al.'s (2015) literature review uncovered four core considerations which merit recognition in the development of a theoretical spatial ability framework. These include ensuring the uniqueness of each factor, ensuring the clear classification of factors, ensuring that the factors are generic such that prior semantic knowledge will not load on them and recognizing the difference between static and dynamic stimuli. The result of this work has served as a foundation for subsequent analysis of factors posited within the pertinent literature in conceptualizing an initial framework (Figure 1). While it is beyond the remit of this paper to present references for all analysed factors, a systematic chronological review of spatial factor literature was conducted beginning from the initial conception of the domain (Galton, 1879) where each posited factor was analysed against the criteria presented by Seery et al. (2015).

**Figure 1: Conceptual spatial ability framework**

**The Research Agenda and Developing of a new Approach to Measuring Spatial Ability**

The framework (Figure 1) has not yet been validated. The core methods adopted for identifying cognitive factors within this domain are exploratory and confirmatory factor analysis and while many factor analytic studies have been conducted which resulted in the identification of factors in the above framework, no study exists which is inclusive of all the identified factors. While many of the included factors are well supported within the literature and significant empirical evidence supports this, some factors may not exist and may instead be representative of one of the other well established factors. As such, a research agenda is proposed which targets the qualification and validation of the presented framework.

The significance of this agenda is illustrated through its existence as a research focus of the newly established National Spatial Skills Research Network (NSSRN) in Ireland (NSSRN, 2015). Under one of the networks active projects there are currently four studies being conducted.
concerning the qualification of the existence of factors within the framework. These studies are aimed at developing valid psychometric tests capable of discerning the existence of the less well supported factors and establishing if varying the nature of the stimulus between static and dynamic changes the nature of the cognitive activity adopted in spatial reasoning episodes. The results of these studies will provide the necessary results to empirically underpin each of the included factors with the next phase of the project being to gather a suitably large dataset capable of qualifying the entire framework. The overall aim of the project is to develop a strategy to comprehensively measure an individual’s level of spatial ability. The project has resulted in the conceptualization of a strategy involving the generation of a person’s spatial profile, a measure of a person’s capacity within each spatial factor, through the conduction of psychometric tests which validly measure each unique spatial factor.

**Conclusion**

It is envisioned that identifying a person’s capacity within each of the spatial factors may aid in identifying the causation underpinning the correlation between spatial ability and graphical competency through the provision of insight into the nature of graphical thinking and problem solving. As many of the correlational studies discussed earlier have identified factors pertinent to mental rotation and mental cutting as being substantially important, viewing spatial ability through a more holistic lens could identify a broader selection of important factors. Spatial profiles afford the potential to determine if specific groups of factors are important within specific contexts and an understanding of these groups may suggest distinct types of thinking.

**References**


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