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Online Distribution

The online EDGJ is a reality as a result of support provided by **East Carolina University** and **Biwu Yang**, Research & Development, ECU Academic Outreach.

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Message from the Chair

Lulu Sun, EDGD Chair
Embry-Riddle Aeronautical University

Dear EDGD family members,

I am so pleased and honored to be the Chair of this prestigious division. I want to thank the Division's confidence in me and the great support provided by my predecessors, Bob Chin, Norma Veurink, Nick Bertozzi, Kevin Devine, Dennis Lieu etc. I want to thank our immediate past chair, Bob for his contributions he made to the vitality of the Division. I also wish to express my thanks to all our former Division officers for their superb leadership and service over the past years and to our newly selected officers, Vice chair, Heidi Steinhauer, Secretary/Treasurer, Petros Katsioloudis and Director of Publications, Nancy Study for their upcoming work on behalf of the Division.

My heartfelt thanks to conference site chair, Dennis Lieu, program chair, Daniel Kelly and Thomas Delahunty for their endless effort in organizing and hosting EDGD 73rd Midyear Conference, despite the massive Camp Fire and bad air quality Dennis had experienced, and the personal health issues Dan and Tom had faced respectively. Thanks to our Director of Communications, Jennifer McInnis for managing our conference web page on our new Division website. Make sure to check our website for latest conference information. The theme is "The visualizing instinct for contemporary education". Through technical sessions, workshops, and tours I am sure you will have fruitful and rewarding exchanges about static and dynamic visualization in multimedia learning and engineering education.

I want to give a HUGE THANK YOU to our sponsors, Autodesk, Solidworks, Solid Professor, and Bowles Hall for their continuous support of our conference and our Division. As our long-time partners, they play a critical role in making our midyear conference an exceptional event.

Thanks to our Vice Chair, Heidi Steinhauer for drafting two exciting travel grants and managing the selection of travel grants. Our first Rising Educator Award goes to Dr. Leroy Long from Embry-Riddle Aeronautical University. He will give his invited lecture on Tuesday, January 8th, 2019 at lunch time.

The Professional Interest Councils (PICs) of ASEE announced a call for proposal to support innovative special projects up to $500 during 2018-2019. EDGD submitted the proposal and agreed to match $500 supported by PIC III to propose an EDGD participation grant, which will encourage and promote

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Message from the Chair

educators and/or researchers to implement an engineering graphics related project. Stay tuned.

To the 126th ASEE annual conference on June 15-19, 2019 in beautiful Tampa, FL, the EDGD program chairs are Ted Branoff and Heidi Steinhauer. I can assure you that they will have a fantastic program created and a fine dining restaurant for our award banquet on Tuesday, June 18th, 2019 selected. I hope to see you there.

We have some minor changes to our own journal, *Engineering Design Graphics Journal*. Beginning with Volume 83 in 2019, articles will be published as accepted and there will be a single volume each year. If you are interested in publishing your graphics related work, please contact our current Director of Publications, Nancy Study for more information.

Thanks our immediate past chair, Bob for leading our bylaws revision. The revised version after the Executive Committee meeting will be presented to the Division at our business meeting on Monday, January 7th, 2019.

Our new website is https://sites.asee.org/edgd/. We are still in the middle of the migration. Eventually we want to use old domain name http://edgd.asee.org/ to direct you to our new website. Our website offers a great source of division information.

Last but not least, thank you all, EDGD executive committee members for your continuous dedication, support, and contribution. I look forward to working with all of you throughout another prosperous year.

Hope you enjoy this Fall issue of the *Engineering Design Graphics Journal* and see you at our 73rd Midyear Conference in January 2019!

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Message from the Editor

Nancy Study, *EDGJ* Editor
Penn State Behrend

This issue of the *EDGJ* is the last in the format of three publications, Fall, Spring, and Winter, each year. Beginning in 2019 with Volume 83, we will have one Volume per year with articles published as accepted and Messages from the Editor and Division Chair coinciding with the Midyear and Annual Conferences. I'm sure it will be a learning curve for all of us on the Journal Staff, and I want to thank Bob Chin, Judy Birchman, and AJ Hamlin for helping me immensely in the process of taking over the duties of Editor, and Daniel Kelly for agreeing to be the Associate Editor. And I would also like to thank you all for entrusting me with this job. I will do my best to lead the *Journal* in a positive direction.

Thank you for reading and please consider submitting your work to the *Engineering Design Graphics Journal.*

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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

73rd Midyear Conference – January 2019, Berkeley, California

Site Chair – Dennis Lieu

Program Chairs – Tom Delahunty and Daniel Kelly

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	
2021	June 27 - 30	Long Beach, California	
2022	June 26 - 29	Minneapolis, Minnesota	
2023	June 25 - 28	Baltimore, Maryland	

If you’re interested in serving as the Division’s program chair for any of the future ASEE annual conferences, please make your interest known.

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The Distinguished Service Award

Nancy E. Study
Penn State Behrend

The 2018 Distinguished Service Award (DSA) recipient is **Nancy E. Study** of Penn State Behrend. The DSA is the highest award of merit given by the Engineering Design Graphics Division. It recognizes the significant contributions of the recipient to the Division in terms of leadership, authorship, or support.

The awardee is recognized with a framed citation or plaque, which is presented by the Division Chair or their delegate at the Annual Conference Awards Banquet. Following the presentation, the recipient may address those assembled.

The award description can be found at:

http://edgd.asee.org/awards/dsa/index.htm

A complete list of awardees can be found at:

http://edgd.asee.org/awards/dsa/awardees.htm

Photos from Theodore Branoff

Engineering Design Graphics Division Chair, Bob Chin,
presenting the DSA plaque to Nancy Study.

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The Distinguished Service Award

Judy Birchman's Introduction of DSA Recipient Nancy Study
ASEE Annual Conference
Salt Lake City, Utah, June 26, 2018

Greetings from Judy Birchman! I wish that I could join you for this occasion, but I was unable to attend due to a scheduling conflict. I want to thank Bob Chin for agreeing to read my message today.

The Distinguished Service Award is the highest honor bestowed upon an EDGD member. It is awarded to a person who is excited to teach graphics and share what they have learned in the classroom with their peers through their research and scholarship. This person also contributes to the success of the division through their participation in its activities and through service to the division.

I am pleased to announce this year's recipient of the EDGD Distinguished Service Award is Nancy Study from Penn State Behrend. Congratulations Nancy! Nancy has been an active member of EDGD since she joined the division. In the division, she is known for her enthusiasm and participation. I remember the first time Nancy visited me in my office when she became a grad student at Purdue. She was excited, friendly and showed a desire to be a part of the graphics community. She returned to Purdue for her PHD, because she just couldn't stay away!

Once Nancy graduated and became a faculty member, she and I roomed together at the midyear and annual conferences. After the day's activities, we enjoyed many conversations about the presentations we saw—what we liked and how it could impact what we did. We exchanged the inevitable stories about our students—and it always showed how much Nancy cared about her students and their success. She shared her love of graphics with her students so that it was a positive experience for them and included them in industrial projects to enhance their graphics experience. Likewise, when volunteers were needed to work with young girls in STEM workshops, Nancy was always willing to volunteer.

Nancy has been a contributor to the division in many ways. She has presented papers on numerous occasions at the midyear, annual and international graphics conferences. She has also collaborated with other division members in presenting joint papers. She has contributed to the division by presenting her research and likewise joined other members in research projects relevant to the EDGD members. Through her participa-

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tion, she has won the division’s Oppenheimer Award for best presentation at a midyear meeting and the Editor's Award for best paper in the *Journal*.

Lastly, she has served the division for many years in many different capacities. She has been the Associate Editor of the *EDG Journal* for two terms. She was also Circulation Manager and Treasurer of the *Journal* for two terms. When she volunteered for this job, we knew she was dedicated to the division, as previously, it had been a career-long, if not longer job! This year, she will take over as the Director of Publications for the *Journal*. She has also served as both Vice-Chair and Chair of the division.

Nancy has served the division in both formal ways as well as informal ways. Formally, by volunteering and serving on committees and in leadership positions within the division. Informally, by her participation in all division activities as well as representing the division in her publications, research, teaching and outreach to the community and industry.

Congratulations Nancy for all your contributions to the division and for being a friendly and enthusiastic colleague to many of us in the division.

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The Distinguished Service Award

Nancy Study's DSA Acceptance Remarks
ASEE Annual Conference
Salt Lake City, Utah, June 26, 2018

It's an incredible honor to be here in the room with so many people who have been friends and mentors through the years. Engineering graphics became my field of choice because I knew being an art major was probably not something that was going to make me a decent living, pre-med quickly bored me, then I thought about how interesting my shop classes were in high school, especially drafting, and how much fun I'd always had working with my Dad on his projects. He was in special ops in the military and after that always worked mechanical or machinist or maintenance sorts of jobs. And he was always building and fixing things around the house, everything from plumbing, to lawn mowers, to cars and trucks and tractors, to electronic things. And I knew I could do much worse than grow up to be like my Dad. He was always supportive of me and my pursuits, even if they didn't quite fit the mold of what all the rest of the girls my age were doing.

Being a professor was never high on my list of possible careers when I was younger. I first started teaching completely by accident. Long story shorter, I found out when I arrived at the Purdue campus to start my Masters that they'd made a mistake when they sent me a letter saying I'd been awarded an assistantship so instead of having school paid for, I owed them something along the lines of $10,000. I was freaking out, just a tiny bit. I went to see Dennis Depew, who was chair of the Department of Industrial Technology at the time, and explained my situation. He asked what my background and interests were, then took me down the hall to meet Jerry Smith the chair of Technical Graphics, who hired me on the spot as a TA. He took a huge chance on me that I'll never be able to thank him enough for.

Whilst working on my Masters I TA'd for Judy Birchman, Mary Sadowski, Bill Ross, Gary Bertoline, and Craig Miller and grew to love teaching. I graduated, left Purdue, and Indiana, and worked for about five years teaching, doing CAD work for a city utility company, and also quite a bit of facility planning and construction drawings for various companies and individuals. Then I decided I wanted to have a full time career as a professor and that I needed a PhD, as you do. Here's a hint, don't buy a brand new F-150 XLT with all the toys and options, and then decide a few months later to quit your job and go back to school! It makes balancing your finances a bit dodgy. Anyway, I emailed Gary Bertoline who was the department chair of Computer Graphics at Purdue at the time and told him I was thinking about coming back to school, but had some concerns about paying for it. He told me that if I wanted to come back to school,

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not to worry, that he'd find a way to help me pay for it, and he did. So I either worked as a graduate instructor, or helped out in the CGT advising office, or both, and was eventually hired as a visiting assistant professor, and that paid for my school. So I'm very thankful for Gary's assistance in not only giving me a job, but being on my graduate committee, and serving as an advisor and mentor in the years since. And there are a lot of you in this room who have been mentors and friends over the years; Sheryl Sorby, Ted Branoff, Frank Croft, Bob Chin, Dennis Lieu, and I'm going stop naming names because I know I'll leave people out.

But as important as teaching is to me, currently my job title indicates I am a teaching professor – which means teaching is my primary job, and I do some research and service on the side – I almost left teaching altogether six years ago. Before I moved to the land of lake effect snow that is Erie, PA (a record 198.5 inches last year!!!!), I had a job where, as much as I loved teaching, and enjoyed my students, and knew I was making a difference to them, the work environment was, to put it mildly, a bit not good. Many of you know the stories, and for the sake of time and decency, I'll leave them out. I was selectively applying to different jobs around the country, but nothing had worked out, either I wasn't right for the place or the place wasn't right for me. Some turned me down, and I turned some down. And even with the awesome support of the people in this Division, I'd made the decision that at the end of that academic year, I was leaving my job, no matter what. I had enough side jobs consulting and writing to keep me going for a while, and my backup plan was to move to northern Michigan, help my extended family on their farms, maybe teach at the local community college if anything opened up, and take a break from it all. But then, my friend, and a Division member, Kathy Holliday-Darr told me she was retiring and that I should apply for her spot. I did, was interviewed, and was hired. From day one, it's been great. Even the weather.

And now we're on to the advice portion of this speech. To those of us "elders" in the crowd, being a mentor, along with being a champion for engineering graphics, is so important. Engineering graphics is a field that many in engineering education see as perhaps not as important as courses in topics like statics, or thermodynamics, or materials. But as I tell my students on day one of their first freshman engineering graphics course, nothing in this room could be built without a model and/or a technical drawing. What we do is the foundation of design and production. So support your colleagues who teach these courses, support our field in your department. Mentor and support young colleagues so that when we retire, we're confident we will be replaced with someone who will take up the charge for the field of engineering graphics. Make sure basic concepts are addressed and standards are implemented in the graphics courses. I get so much positive feedback from my School of Engineering's industry

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partners who hire our students as interns because most of their interns from other schools cannot do CAD work, cannot read drawings, and don't know anything about GD&T, and those from our programs have those skills. Tell new colleagues about our division, encourage them to come to not just the Annual conference, but to our Midyear meetings.

I remember my first Midyear meeting in San Antonio, TX in 2000. I had co-authored a paper with Judy Birchman, and I was overwhelmed, especially by meeting people whose papers I'd read and whose books I'd used both in class and for research, but also amazed by how friendly everyone was, how supportive they were of little old me as a lowly grad student. And everyone hugged, that was different. I believe it was Alice Scales who I first heard compare our Midyear meetings to a family reunion. And as someone who just attended a reunion of the crazy bunch that is the Study family, I can attest to the truth in that. I know I wouldn't be where I am if it weren't for the mentorship, collaboration, and most of all, friendships that have come out of being a member of this Division. So please continue your support of our colleagues and our field, and keep up the good work of mentorship and collaboration. Because of members of this Division I have authored and co-authored papers, co-authored textbooks, consulted on grants, received excellent teaching advice, always had a sounding board, and even had the opportunity to cross another continent off the list of those I've visited, thanks to Holly Ault for giving me the chance to visit Australia. If any of you are going to be in Africa or Antarctica, and are willing to host a visitor, I'm game! Those are the only two continents I've yet to set foot on.

And last, but definitely not least, thanks to everyone in this room, and to those who couldn't attend, and all the previous DSA winners who came before me. Thank you from the bottom of my heart for everything through the years, and thank you for honoring me with the Distinguished Service Award.

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A Cognitive Approach to Spatial Visualization Assessment for First-year Engineering Students

Cheryl Cohen
Illinois Institute of Technology

Diana Bairaktarova
Virginia Tech

Abstract

First-year engineering (FYE) students are routinely screened for spatial ability, with the goals of predicting retention in the major and identifying those who need supplementary spatial instruction. Psychometric tests used for such screenings are often domain-general measures that lack diagnostic information to inform remedial instruction. A new approach to spatial screening is to use measures that assess performance on authentic engineering tasks while accounting for the cognitive processes that underlie spatial thinking. We tested the utility of a relatively new spatial visualization test (the Santa Barbara Solids Test; SBST) to characterize individual differences in performance among FYE students with low mental rotation scores. The internal reliability and predictive validity of the SBST were previously demonstrated in sample populations with average spatial skill. One hundred and forty-one FYE students with low mental rotation scores completed the SBST and an engineering drawing task before instruction. We investigated the internal reliability of the SBST, patterns of performance and the validity of the test to predict performance on the drawing task. Through item analysis, we deleted problems that contributed to low internal reliability. Performance means were normally distributed. There were small significant positive correlations between the drawing task and SBST total score and subscales. The SBST shows promise for diagnosing difficulties and strategies demonstrated by students who are challenged by spatial visualization. We suggest applications of the SBST to support remedial spatial instruction.

Introduction

First-year engineering (FYE) students are frequently screened for spatial abilities, with the goals of predicting who will persist in engineering programs and identifying those who might benefit from supplemental spatial instruction (Maeda, Yoon, Kim-Kang, & Imbrie, 2013; Sorby & Baartmans, 2000; Veurink et al., 2009). The remediation of spatial thinking is particularly critical in the first year of an engineering program, as many FYE students enter the university with low spatial ability (Duffy et al., 2015; Garmendia, Guisasola, & Sierra, 2007; Maeda, Yoon, Kim-Kang, & Imbrie, 2013; Nagy-Kandor, 2007; Veurink et al., 2009). Although there is literature demonstrating a male advantage on some spatial tasks, (Baenninger & Newcombe 1989; Bergvall, Sorby, & Worthen, 1994; Voyer, Voyer & Bryden, 1995), a number of studies confirmed that sex differences in performance can be greatly reduced by changing the testing environment, changing testing instructions, and reassuring women about their spatial abilities skills prior to testing (Sorby, 2009; Moe, 2009; Sorby & Veurink, 2010).

Engineering educators typically use *spatial visualizatio*n tests to screen FYE students for spatial ability. The construct of spatial visualization is defined in the psychometric litera-

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ture as the ability to comprehend, encode and transform three-dimensional visuospatial forms in multi-step processes (Carroll, 1993). Component processes of spatial visualization include encoding a three-dimensional stimulus, constructing a visuospatial representation from perceptual input, mentally rotating a three-dimensional image, switching one's view perspective, and comparing a visual stimulus to one in working memory (Carroll, 1993; Hegarty & Waller, 2005).

There is no definitive spatial visualization test. Engineering educators use a variety of assessments, including the Purdue Spatial Visualization Test: R (PSVT:R: Guay, 1976), the Mental Cutting Test (CEEB, 1939) the Revised Minnesota Paper Form Board Test (Pearson, 2011), and the Differential Aptitude Test (DAR; Bennett, Seashore, and Wesman, 1973) to screen FYE students for spatial ability (Maeda, Yoon, Kim-Kang, & Imbrie, 2013). The standard and most widely used assessment of spatial skills in engineering education is the PSVT:R, Several studies provide evidence that there are sex differences in performance on the PSVT:R (Miller & Bertoline 1991; Hsi et al. 1997; Sorby & Baartmans 2000; Humphreys, Lubinski, & Yao 2003; Webb, Lubinski & Benbow 2007; Sorby 2009).

While useful in identifying students who would benefit from remedial spatial instruction, most of the above mentioned tests are limited in their value to support remedial spatial instruction. There are a number of reasons for these limitations. Many standardized spatial tests were developed out of the factor analytic tradition with the goal of measuring skills that likely to predict performance in skilled trades and crafts. Consequently, these traditional psychometric spatial ability tests use domain-general stimuli that bear little resemblance to authentic engineering tasks.

In many spatial tests, 3D objects are represented by pictorial views of axonometric drawings, mostly with isometric projections (Yue, 2007). Isometric projections distort the visible dimensions of the objects. These distortions may contribute to students' misconceptions of the spatial properties of the figures, thus comprising the validity of the tests to measure students' actual spatial abilities (Yue, 2007).

Finally, tests that have historically been used to screen for spatial ability lack subscales to identify difficulties faced by students who are challenged by spatial visualization tasks. While useful in predicting performance in skilled trades, the design of many psychometric spatial tests does not reflect current theories of cognitive processes that account for performance in spatial tasks.

Applying Cognitive Theory to Spatial Assessment: The Santa Barbara Solid Test (SBST)

A new approach to spatial assessment in STEM domains is to measure performance on authentic tasks with instruments that are designed to capture individual differences in

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performance, as understood by cognitive psychology theory. We investigated the utility of a relatively new spatial visualization test (Santa Barbara Solids Test) to identify the challenges and problem-solving strategies of low-spatial FYE students on a task that contributes to performance in many areas of engineering (Duesbury & O'Neill, 1996; Hsi, Linn & Bell,1997; LaJoie, 2003; Ha & Brown, 2017), the ability to represent the two-dimensional cross section of a three-dimensional geometric figure.

The 30-item multiple-choice Santa Barbara Solids Test assesses the ability to identify the two-dimensional cross section of a three-dimensional object. The test was designed to reflect cognitive theory that accounts for variability among normal populations in the capacity to mentally form and manipulate visual images (Hegarty & Waller, 2005). Sources of this variability are understood as differences in the capacity of a cognitive system called *visuospatial working memory* to create and transform visuospatial representations (Baddeley, 1992). Visuospatial working memory is one component of Baddeley's *information processing system* of memory, which describes how humans encode, transform and retain new information (1992). Images that have been encoded and processed in visuospatial working memory can subsequently be stored in a system called long-term memory. Images that have been stored in *long-term memory* can subsequently be retrieved and added to new spatial information in visuospatial working memory.

There is experimental evidence for natural variability in the ability to form mental images and to retain visuospatial information while transforming images (Carpenter et al., 1999; Just & Carpenter, 1985; Lohman, 1988). There is also evidence for individual differences in the ability to change one's view perspective of objects or scenes (Hegarty & Waller, 2005; Kozhevnikov & Hegarty; 2001). Individuals who are less able to form and transform visuospatial images, or who lack experience with such transformations, will consequently have a decreased store of visuospatial images available to access from long-term memory.

To capture aspects of performance that might result from normal variation in visuospatial working memory, items in the SBST vary along two hypothesized dimensions of difficulty: geometric structure and orientation of the cutting plane. The first dimension of difficulty is the structural complexity of the test figures, two-dimensional images of three-dimensional solids, rendered with perspective cues and shadows to suggest depth. There are three levels of geometric structure in test figures: simple, joined and embedded figures. Simple figures are primitive cones, cubes, cylinders, prisms and pyramids. Joined figures consist of two simple solids attached at their edges. Embedded figures are composed of one simple solid enmeshed inside another. The use of primitive geometric solids at the lowest level of proposed difficulty is motivated by research that holds that the most elementary recognizable three-dimensional forms are primitive solids (Biederman, 1987; Pani, Jeffries, Shippey & Schwartz, 1996).

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The second dimension of difficulty is the orientation of the cutting plane intersecting the test figure. Mental transformations of objects with axes oblique to the environmental frame of reference are more difficult to perform than mental transformations of objects whose main vertical axes are orthogonal to the environment (Appelle, 1972, Rock, 1973, and Pani, Zhou & Friend, 1997). Thus, the test incorporates two cutting plane orientations: orthogonal (horizontal or vertical) and oblique to the main vertical axis of the test figure.

Fig. 1 shows examples of each geometric structure and each cutting plane. Fig. 1a is a simple figure with an orthogonal (horizontal) cutting plane. Fig. 1b is a joined figure with an orthogonal (vertical) cutting plane. Fig. 1c is an embedded figure with an oblique cutting plane. Each test item shows a criterion figure and four answer choices (Fig. 2).

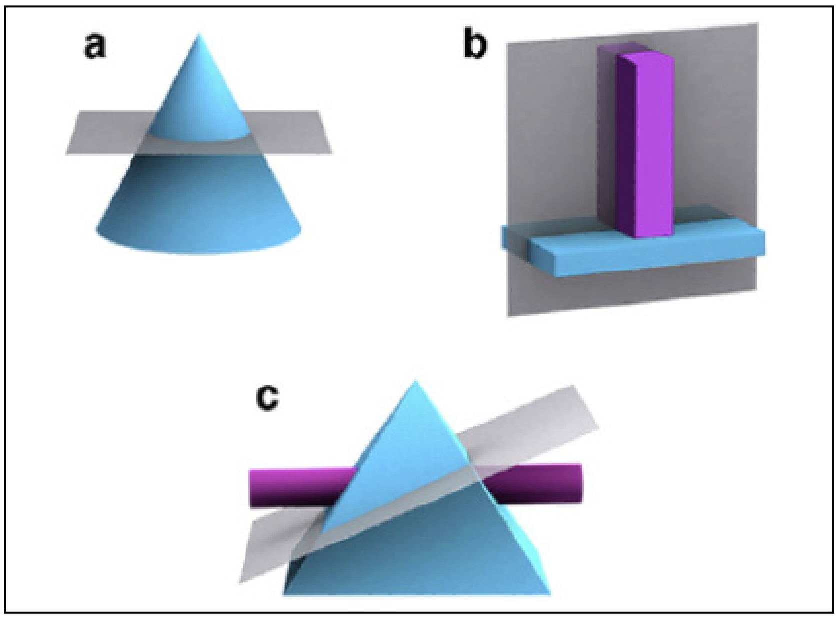

Figure 1. Santa Barbara Solids Test figures varied along two parameters: Geometric structure and orientation of the cutting plane. The above figures are: a) simple figure with an orthogonal cutting plane; b) joined figure with an orthogonal cutting plane; and c) embedded figure with an oblique cutting plane.

The authors of the SBST initially hypothesized that complex (joined and embedded) problems would be more difficult than simple problems because of the added visuospatial working memory resources need to form and transform visual images of in complex objects (Cohen & Hegarty, 2007). However, sample populations of non-engineering science students (Cohen & Hegarty, 2007; 2012) with normal distributions of spatial ability scored significantly higher on complex (joined and embedded) problems than on simple problems, suggesting that SBST subscales were amenable to analytic strategies that did not rely solely on the use of mental imagery. For example, as shown in Fig. 2, the answer choices to embedded problems allow participants to compare the size and location of internal and external structures and to use analytic strategies to eliminate incorrect answers. In contrast, the answer choices to simple problems are single, monochromatic shapes.

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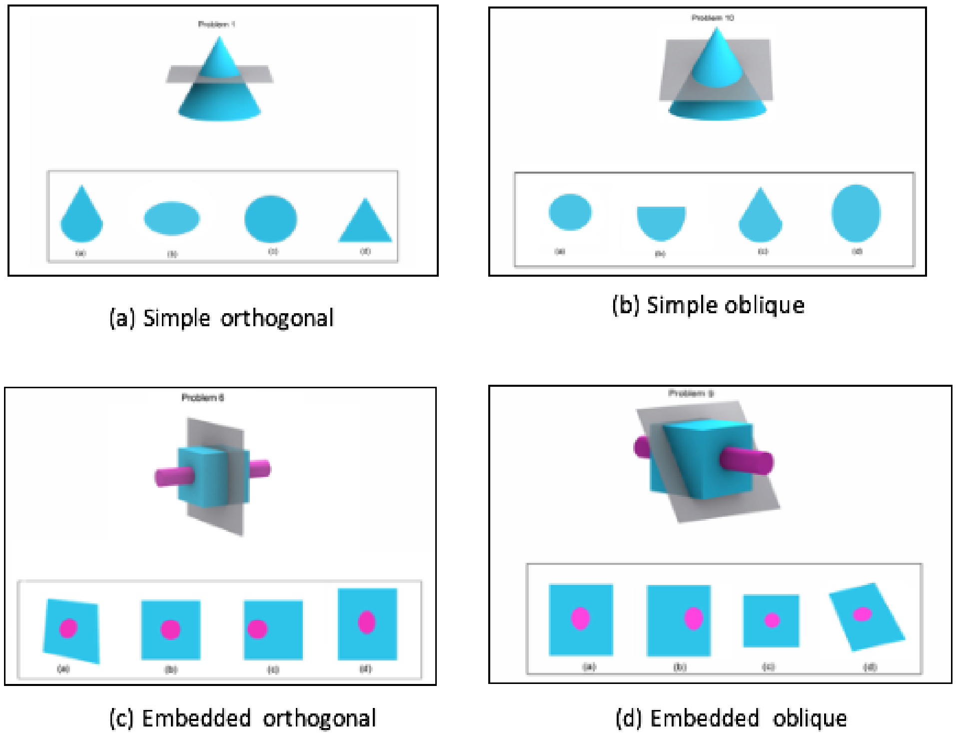

Figure 2. Four categories of problems on the Santa Barbara Solids Test. The participant is asked to identify the two-dimensional shape that would result when the criterion figure is sliced by the indicated cutting plane. Correct answers are: 1(a) Simple orthogonal: answer c; 1(b) Simple oblique: answer d; 1(c) Embedded orthogonal: answer b; 1(d) Embedded oblique: answer a.

The interpretation that participants can use non-imagistic strategies on spatial visualization test problems is consistent with literature describing a continuum of strategy use, ranging from purely imagistic to analytic strategies, both within and between individual (Gluck & Fitting, 2003; Hegarty, 2010). In their review of spatial strategy use on mental rotation and other psychometric spatial tests, Gluck & Fitting (2003), found that purely imagistic strategies were associated with robust working memory capacity, and that the use of analytic strategies increased with the complexity of test items. Emphasizing the importance of adaptive spatial thinking in STEM domains, Hegarty (2010) described the ability to flexibly switch between purely imagistic and analytic strategies as a valuable component of spatial thinking.

The internal reliability of the SBST, as measured by Cronbach's alpha, was previously demonstrated in (Cohen & Hegarty, 2007; 2012), and for a sample population of sophomore civil, mechanical and aeronautical engineering students enrolled in mechanics of materials classes at five U. S. colleges and universities (Ha & Brown, 2017). As

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there were no floor and ceiling effects in these samples, the difficulty of the SBST was deemed to be appropriate for undergraduate non-engineering students with normal distribution of spatial skill and for engineering undergraduates.

The SBST shared moderate significant positive correlations with an aggregate spatial visualization measure in Cohen & Hegarty (2007; 2012). Its validity in predicting performance on the Mechanics of Materials Concept Inventory (MMCI) was demonstrated in Ha & Brown (2017). The MMCI assesses the ability to visualize and analyze the distribution of stress loads on cross sections of inclined planes (Richardson, Steif, Morgan, & Dantzler, 2003). For civil engineering students, the SBST accounted for 53% of the variance in performance on the MMCI and up to 31% of the same variance for mechanical and aerospace engineering students (Ha & Brown 2017).

Given the evidence that the SBST was an appropriate and predictive tool for measuring the spatial abilities of liberal arts and engineering undergraduates, we investigated the benefits of using the test to characterize the performance of students previously identified with low mental rotation scores, as measured on the PSVT: R. Our first research goal was to determine if the difficulty level of the SBST was appropriate for a population of undergraduate engineering students with below average spatial abilities. The second research goal was to investigate the utility of the test in identifying difficulties and strategies demonstrated by this population. After reporting our results, we consider the implications of our findings and suggest how the SBST might be used to inform remedial spatial visualization instruction.

Present Study

Method

Participants

One hundred and forty-one FYE students (males= 79; females= 62) participated in the study. All had previously scored 18 or less on a pre-semester PSVT: R screening, placing them the lower 60% of a distribution of 1,651 incoming freshmen at a large public university. All students had voluntarily enrolled in an introduction to spatial visualization class.

Materials

Santa Barbara Solids Test (Cohen & Hegarty, 2012). The Santa Barbara Solids Test (SBST) consists of 30 multiple-choice figures. Three levels of geometric structure and two types of cutting planes are distributed evenly across the 30 figures: simple figures (10 items) are primitive geometric solids: cones, cubes, cylinders, prisms and pyramids. Joined figures (10 items) are two simple solids that are attached at their edges or faces, but do not intersect, along one face. Embedded figures (10 items) consist of one simple solid enmeshed inside of another. In joined and embedded figures, each simple solid is

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a distinct color. Fifteen of the test items are bisected by plane that is orthogonal (parallel to or at a 90 degree angle) the figure's main vertical axis, and 15 figures are bisected by an oblique cutting plane. There was no time limit. Participants took 5-8 minutes to complete the test.

Purdue Spatial Visualization Test: Rotations (PSVT: R; 1976). In the Purdue Spatial Visualizations Test: Rotations (PSVT: R) participants are asked to choose which of four answer choices is rotated in the same direction and to the same degree as a criterion figure. Test figures are black and white line drawings of truncated blocks. Participants have 20 minutes to complete 30 figures. The maximum score is 30. Figure 3 shows a sample problem from the PSVT:R).

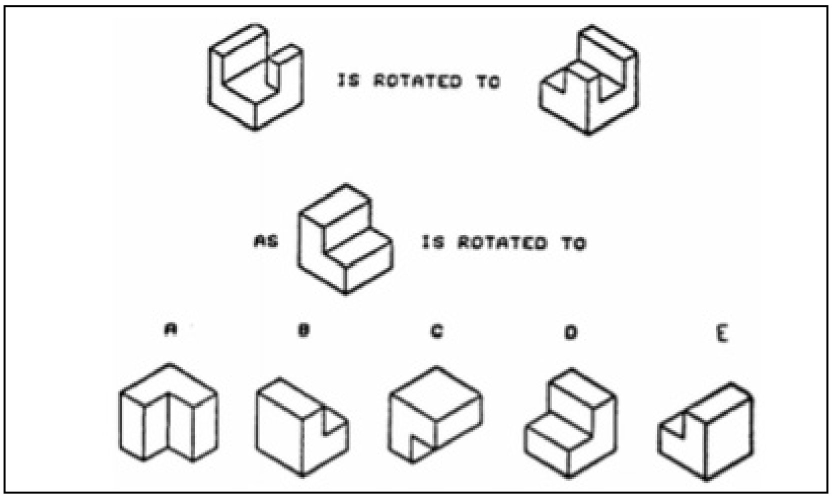

Figure 3. A sample problem from the Purdue Spatial Visualizations Test: Rotations. Participants are asked to choose the multiple-choice option that represents the indicated rotation of a criterion figure.

Sectional Drawings (Srivasavan, Smith & Bairaktarova, 2016). Students completed six drawing problems. As shown in Figs. 4 (a -b), each problem was a black and white drawing, without shading, of a simple, symmetrical mechanical object, with an indicated cutting plane. (Drawing 4b is the correct answer template for this problem. Drawings 4c-4e are three student drawings of this problem.)

The instructions read:

> Draw a two-dimensional sectional view of the object at the indicated cutting plane. To visualize how the section would look, make an imaginary cut through each object and remove the portion of the object between your point of view and the cutting plane line. Arrows at the end of the cutting plane line indicate the direction of the cut. Use hatch marks to indicate cut surfaces of the mechanical object.

Students were given 15-minutes to complete 6 drawing problems.

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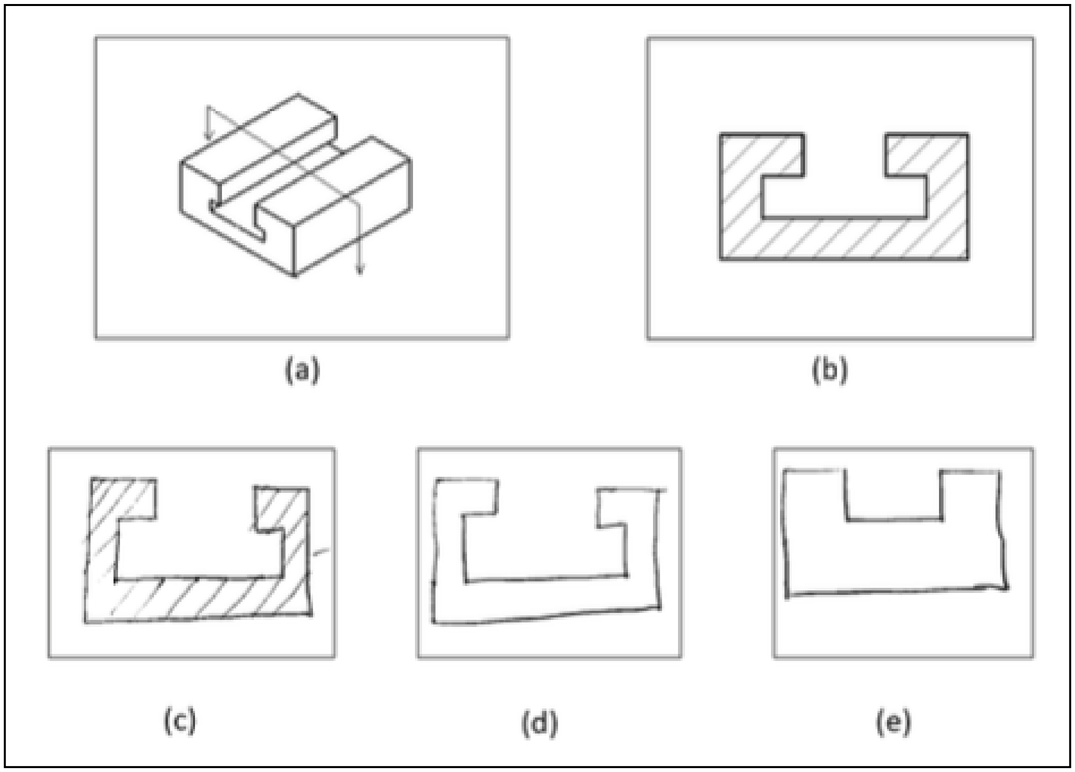

Figure 4. Examples of (a) sectional drawing problem; (b) correct answer template; and (c)-(e) student drawings of the given problem. Drawing (c) earned 5 points; drawing (d) earned 4 points (hatching was absent); and drawing (e) earned 3 points (hatching and structural features of section are absent).

Procedure

Participants completed the PSVT: R prior to the first day of instruction. During the first week of class of the semester, they completed the SBST and the Sectional Drawings.

RESULTS

Participants were eliminated from the dataset if their total score on the SBST (as proportion correct) was ≤ .25, which represents chance performance on a four-answer multiple-choice test.

Internal reliability

Satisfactory internal reliability, as measured by Cronbach's alpha, was initially found for the entire test (α=. 69) and orthogonal (α = .74) subscales. Cronbach's alpha for the remaining subscales (simple, joined, embedded and oblique) was at or below α=.43. We conducted item analyses to identify problems that contributed to low reliability, resulting in the removal of five problems (#s 3, 25, 26, 27 and 30) from the scored items. Notably, each of the five removed problems had oblique cutting planes. Two of the removed

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problems (27 and 30) had means lower than chance; three of the five removed problems had standard deviations of .50 and above, indicating high variability. One problem each was removed from the simple and joined subscales, and three problems were removed from the embedded subscale. After removing problems that contributed to low internal reliability, the resulting number of problems by subscale were: orthogonal = 15; oblique = 10, simple = 9, joined = 9, embedded = 7; total score = 25. Cronbach's alpha for the reconstructed scales were: simple (α =.63); joined (α=.62); embedded (α = .64); oblique (α=.65), and total score (α =.82).

Using the remaining 25 problems, we computed descriptive statistics for the SBST, determined the relative difficulty of its scales and subscales, and investigated the validity of the test to predict performance on the sectional drawing task. The results should be interpreted with some caution, as the deletion of five problems from the original test design results in an unequal distribution of problems across scales. Within the orientation of cutting plane scale, there were 15 orthogonal problems and 10 oblique problems. Within the geometric structure scale, there were 9 simple problems, 9 joined problems, and 7 embedded problems.

Descriptive statistics

Table 1 gives descriptive statistics for the SBST (total score and subscales). On average, students answered less slightly more than half of the 30 problems correctly, indicating that this test was challenging for students whose PSVT: R scores were at the lower end of a distribution of FYE engineering students. Subscale means ranged from *M* =.41 (SD= .26) for oblique figures to *M*=.65 (SD = .20) for orthogonal figures.

Table 1
Performance means and standard deviations, Santa Barbara Solids Test (total and subscales) for sample population of low-spatial FYE students enrolled in a remedial spatial visualization class, n = 141

	M	SD	Range
All figures (25 items)	.56	.20	.16 - 0.92
Simple figures (9 items)	.48	.23	.00 - 0.89
Joined figures (9 items)	.58	.21	.00 - 0.89
Embedded figures (7items)	.62	.25	.00 - 1.00
Orthogonal figures (15 items)	.65	.20	.20 - 0.93
Oblique figures (10 items)	.41	.26	.00 - 0.90

The mean PSVT: R score on the, which was administered as a screening measure before beginning of the semester, was .49 (*SD* = .09). The range for the PSVT: R was

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.03-.60. The distribution of PSVT: R scores was negatively skewed (skewness = - 1.54, *SE* = .20). As class enrollment was limited to students with PSVT: R scores of ≤.60, the upper limit of the range and the skew are artifacts of the enrollment policy.

Relations among the subscales and their relation to the PSVT: R

As presented in Table 2, correlations among the five SBST subscales were medium to large (cf., Cohen, 1992) and statistically significant. Using the Bonferroni approach to control for Type I error across the 10 correlations, a p value of less than .005 was required for significance. The correlations indicate that the subscales of the SBST (orthogonal, oblique, simple, joined and embedded) measure a common ability or skill.

Table 2
Bivariate correlations among the subscales of the SBST and the PSVT: R

	Subscales				
	Simple (9 problems)	Joined (9 problems)	Embedded (7 problems)	Orthogonal (15 problems)	Oblique (10 problems)
Joined	.54**				
Embedded	.63**	.56**			
Orthogonal	.76**	.79**	.84**		
Oblique	.80**	.71**	.66**	.67**	
PSVT: R	n.s.	n.s.	n.s.	n.s	n.s

***p*<value is significant at the .01 level

There were no significant correlations between the SBST (total score and subscales) PSVT: R. This contrasts with previous studies (Cohen & Hegarty, 2007; 2012), which reported a significant positive correlation between the SBST and a summary spatial visualization measure that included a mental rotation test. A possible explanation for the absence of a correlation between the SBST and the PSVT:R is the ceiling effect on the PSVT:R (participants had scores of < 18).

Patterns of performance

To determine patterns of performance by subscale, we conducted a 2 (plane) x 3 (geometric structure) within-subjects, repeated measures analysis of variance (ANOVA) on 25 problems of the SBST. Figure. 5 shows relative performance by subscale.

We conducted a 2 (orthogonal, oblique) x 3 (simple, joined, embedded) repeated measures within-subjects analysis of variance (ANOVA) to determine the contribution of orientation of the cutting plane and geometric structure to performance on the SBST. There was a significant main effect of cutting plane orientation, $F(1, 140) = 225.80$ $p<.001$, partial eta-squared = .62. Performance was significantly higher on orthogonal

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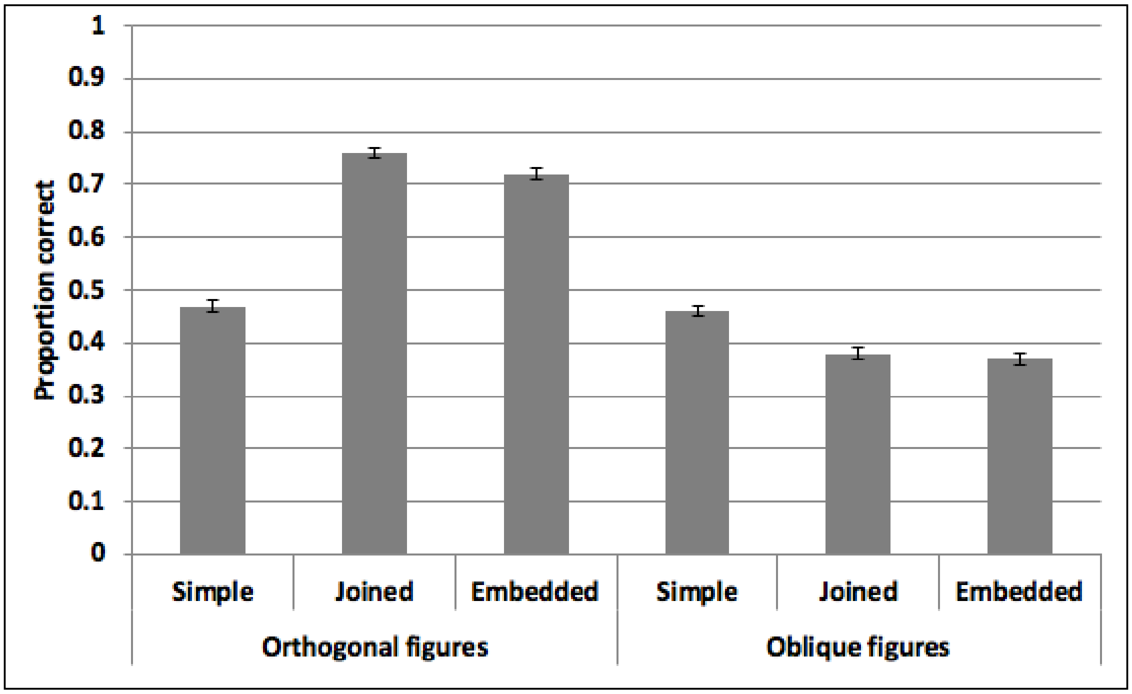

Figure 5. Mean performance on SBST (n=141), showing interactions of geometric structure (orthogonal, oblique) with cutting plane (simple, joined, embedded). Error bars represent +/- one standard error.

figures (*M* = .65, *SD* =.20) compared to oblique figures (*M* = .40, *SD* =.24). Participants scored significantly higher on joined orthogonal problems, compared to joined oblique problems, *t* (140) = 18.13, *p*<.001 and on embedded orthogonal compared to embedded oblique problems, *t*(140) = 15.87, *p*<.001. There was no significant difference between the means of simple orthogonal and simple oblique problems. The comparative difficulty of oblique compared to orthogonal figures is similar to that seen with undergraduate non-engineering students (Cohen & Hegarty, 2007; 2012).

There was a significant main effect of structure, *F* (2, 139) = 13.56, *p*<.001, partial eta-squared = .01. Across orientation of cutting plane, the highest performance was on embedded (*M*=.62, *SD* = .25), followed by joined (*M*=.58, *SD* = .21) and simple figures (*M* =.48, *SD* = .23). The means of embedded figures were significant higher than that of joined figures, *t* (140) = 2.25, *p* = .03, which, in turn, were significantly higher than the means of simple figures, *t* (140) = 5.71, *p*<.001. These results suggest that the extra spatial information available in complex figures (joined and embedded), conveyed an advantage, compared to the singular monochromatic shapes lacking internal detail in simple figures. Furthermore, the significantly higher means on embedded, compared to joined problems, suggests that visual information describing the relative size and location of internal vs. external structures in embedded figures conveyed a greater advantage than the visual cues describing the size and location of adjacent structures in joined figures.

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There was a significant interaction between plane and structure, *F* (2, 280) = 60.42, *p*<.001, partial eta-squared = .30. For orthogonal figures, highest performance was on joined figures (*M* =.76, *SD* =.32) , followed by embedded figures (*M* = .72, *SD* =.33) and simple figures (*M* = .48, *SD* =.26). There was no significant difference between the means of joined orthogonal and joined embedded figures, which were combined into an aggregate variable (complex orthogonal). The results of a t-test showed that the means of complex orthogonal figures were significantly higher than the means of simple orthogonal figures, *t* (140) = 16.01, *p*<.001.

For oblique figures, the pattern differed. For oblique figures, highest performance was on simple figures (*M* = .46, *SD* = .22), followed by joined oblique (*M* =.38, *SD* =. 16) and embedded oblique (M = .37, SD =.18) figures. There was no significant difference between the means of joined oblique and embedded oblique figures, which were combined into an aggregate variable (complex oblique). The results of a t-test showed that the means of simple oblique figures were significantly higher than the means of complex oblique figures, *t* (140) = 2.36, *p* <.01. This pattern was similar to that seen in Cohen & Hegarty (2012), but differed from those seen in Ha & Brown (2017), in which there was no significant difference between the means of orthogonal and oblique problems, and a significant advantage on joined problems and simple problems, compared to embedded problems.

Relationship between the SBST and Sectional Drawings score

Two mechanical engineering graduate students independently scored each student's set of six sectional drawings on a scale of 1-5, using the coding scheme shown in Table 3 (Srivasavan et al., 2016). See Fig. 4 for examples of a sectional drawing, the answer template, and three student drawings. Based on the rubric in Table 3, drawing (c) earned 5 points, drawing (d) earned 4 points (one point was deducted for missing hatching); and drawing (e) earned 3 points (one point each was deducted for missing hatching and missing structural features).

Cohen's kappa, a measure inter-rater reliability for the scoring was (α = 0.89), indicating satisfactory reliability. The mean sectional drawing score (as proportion of total points received across 6 drawings) was .51, SD=.13 (range =.20 -.98). There were no significant differences in the sectional drawing score by sex.

Table 3
Coding scheme for sectional drawings

Criteria	Points
Student attempted to draw the section.	1
Outline of sectional shape is correct	1
Cutting plane perspective is correct	1
Hatch marks are correct	1
Other structural features are correct	1
Total	5

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We found small significant positive correlation between the drawing score and total score of the SBST, $r = .25$, $p<.01$. There were also significant positive correlations between the Drawing Score and the simple ($r =.31$, $p<.01$), embedded, ($r =.22$, $p<.05$, orthogonal ($r =.21$, $p<.05$), and oblique ($r = .26$, $p<.01$) subscales. These significant positive correlations, though modest, suggest an association between test subscales and the skills required to visualize and draw sections of mechanical objects.

Discussion

In summary, we determined that the SBST is an appropriate and useful tool for characterizing the spatial visualization challenges and strategies demonstrated by FYE students whose mental rotation scores were in the lower 60% of a distribution of their peers. The 30-item multiple-choice test assesses the ability to identify the two-dimensional cross section of a three-dimensional object. Previous studies with non-engineering undergraduate students demonstrated significant positive correlations between the SBST and an aggregate spatial visualization measure (Cohen & Hegarty, 2007; 2012).

As measured by Cronbach's alpha, the internal reliability of the SBST for this sample was initially below acceptable levels. After deleting five problems that contributed to low internal reliability, we determined that the remaining 25 problems exhibited satisfactory internal reliability for the total score, and for each subscale of the test (orthogonal, oblique, simple, joined and embedded).

The SBST was challenging for this sample of FYE students with low mental rotation scores. The total (M= .56, SD = .20) and subscale scores across 25 problems were lower proportionally than the means seen in samples of undergraduate science students and sophomore engineering students (Figure 6) on the 30-problem version of the test. There was no floor effect in our sample, and the means of students' total and subscale performance provides latitude for measuring gains after instruction. We conclude that this test represents an appropriate level of difficulty for FYE students previously identified has having low spatial ability.

We found small significant positive correlations between the sectional drawing score and the total score of the SBST. We also found significant positive correlations between the sectional drawing score and four of the five test subscales. These correlations, although modest, add to previous evidence (Ha & Brown, 2017) supporting the SBST's validity to predict performance on authentic engineering tasks. The sectional drawings were completed during the first week of the remedial spatial visualization class, before students received instruction in orthogonal and sectional views that would contribute to their understanding of the task. We hypothesize that the shared variance in these measures reflects a range of skills, including imagistic and analytic strategies.

We did not find significant correlations between the sectional drawing score and the PSVT:R. These results contrast with those of Branoff and Dobelis (2013) who found in

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a sample of *n* =34 students a significant positive correlation between the PSVT:R and a modeling task (p = .50, α = .000). Branoff and Dobelis also found a significant positive correlation between modeling task and the MCT, (*p* =.70, α = .003) and a significant positive correlation between the PSVT:R and the MCT (*p* = .49, α = .003). Their modeling task was far more complex than ours, as it required participants to use 3D software to model a machine part from an multi-view assembly drawings accompanied by a list of parts. Additionally, their population (*n* = 34) was considerably smaller than ours (*n* = 141) and represented a different population: primarily male, junior-level students who were enrolled in a constraint-based modeling course.

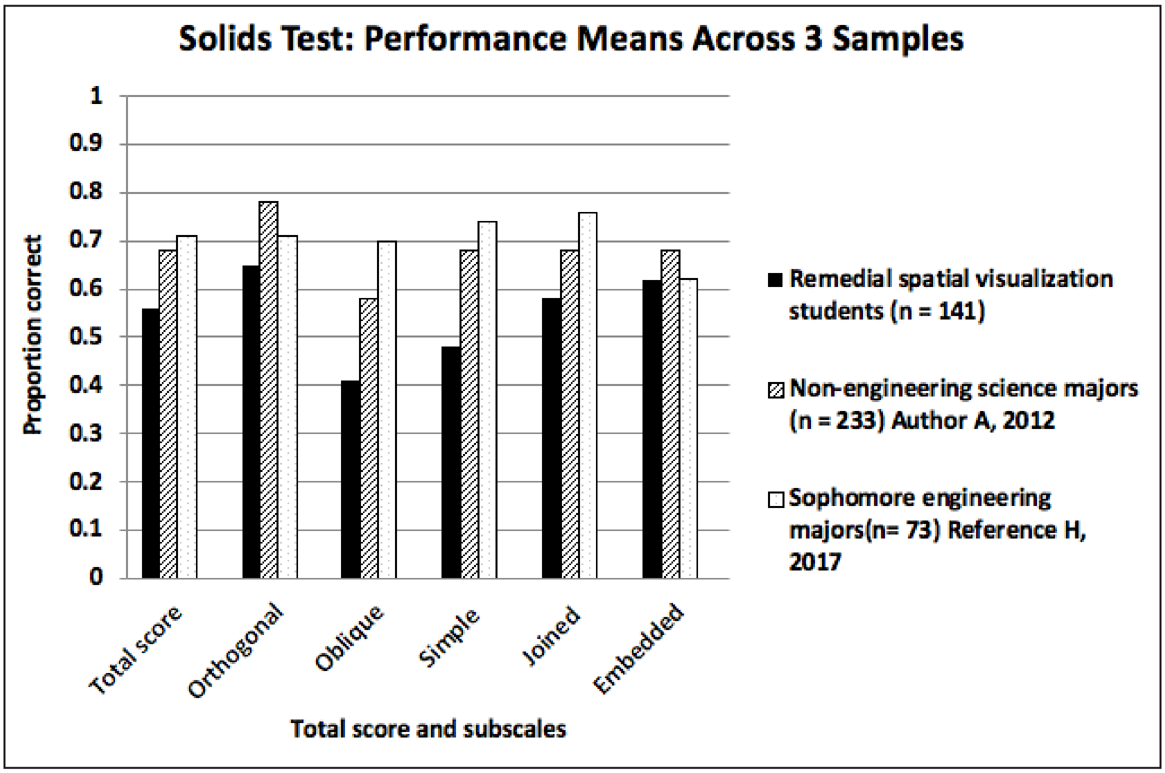

Figure 6. Mean performance on the SBST for three populations: remedial spatial visualization, non-engineering science majors and sophomore engineering (mechanics of materials) students. For the remedial spatial visualization students, scores reflect performance on 25 problems. Scores for the non-engineering and engineering students reflect performance on 30 problems.

Patterns of performance among the subscales of the SBST revealed both similarities and differences to patterns seen among non-engineering undergraduates. As in (Cohen & Hegarty, 2007; 2012), the means of oblique figures were significantly lower than the means of orthogonal figures, across geometric complexity (see Fig. 6). This result is also consistent with literature that predicts difficulty among participants of average spa-

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tial skill in the interpretation of oblique sections (Appelle, 1972, Rock, 1973, and Pani, Zhou & Friend, 1997). It is notable that Ha & Brown (2017), reported that sophomore engineering students performed equally on orthogonal and oblique problems.

Simple orthogonal figures were significantly more difficult than complex orthogonal figures (joined and embedded), a pattern also seen with participants with average spatial skill. As simple figures offer no visual clues, such as relative sizes and placement of interior and exterior shapes, that can be leveraged in analytic strategies, we interpret the relative difficulty of simple, compared to complex, orthogonal problems as evidence of participants' challenge in forming and manipulating visual images. We therefore suggest that performance on the simple scale of the SBST can be interpreted as a reflection of competency in forming and manipulating visual images. This diagnostic information could be applied to remedial spatial visualization instruction by providing to students with low scores on the simple scale more experience manipulating physical or virtual simple geometric solids and observing the shapes of their orthogonal and oblique sections.

In addition to diagnosing challenges in creating and manipulating visual images, the relative difficulty of simple orthogonal, compared to complex orthogonal, problems suggests that participants were successful in using analytic strategies to solve complex orthogonal, but not oblique, problems. Examples of analytic strategies that are commonly applied to spatial visualization test problems are *task decomposition*, rule-based reasoning, and feature matching (Hegarty, 2010). Task decomposition refers to the process of mentally subdividing a complex visuospatial array into separate components in order to reduce demands on visuospatial memory. *Rule-based reasoning* refers to the application of heuristics to the solution of spatial problems. *Feature matching* refers to the comparison of visible features, such as angles, shapes, colors and spatial relationships (e.g. above, below, adjacent, etc.) to determine congruency, or matches, between among whole objects and their parts.

Although the present study does not provide information about *which* strategies participants used on complex orthogonal figures, we hypothesize that SBST answer choices are amenable to analytic strategies. For example, a participant could decompose each answer choice in Fig. 2c into two shapes and evaluate each shape separately. Individuals with memories of previous experience sectioning cubes and cylinders could retrieve that information and predict that the outside shape of Fig. 2c would be a square, and the inside shape would be a circle. The participant could use feature matching to compare the distance between the intersections of the cylinder with the cube in the test figure with the relative placement of the circle inside the square in the answer choices.

Our participants had lower means on complex, compared to simple, oblique problems (Fig. 4), suggesting that they were unable to use either imagistic or analytic strategies on complex oblique figures. This pattern is consistent with that seen in sample popula-

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tions with average spatial skill (Cohen & Hegarty, 2007; 2012). Given that oblique sections are challenging for participants with average spatial skill, and that the ability to use visual imagery is associated with more robust visuospatial working memory, this result is not surprising. We recommend that future studies investigate the benefits of providing explicit instruction in spatial strategies to students.

Our participants anecdotally reported finding some test figures ambiguous in their depiction of three-dimensional space. Ambiguity regarding the spatial extent of the test figures could have contributed the high variability and lack of internal consistency of the oblique test figures. We plan to investigate the perceived ambiguity of test figure and to redraw deleted problems for future test administrations. (Anecdotal information regarding the possible ambiguity of test figures was not collected or reported in previous studies).

Regardless of the artfulness of lighting, there will always be some ambiguity inherent in representing a three-dimensional problem in two dimensions. The test figures were created in a three-dimensional modeling program using linear perspective cues, lighting and shadows. However, some spatial information remains ambiguous in the two-dimensional representation of a three-dimensional figure. In addition to fixing the ambiguity of problematic items as identified by item analysis, there are other ways to address this problem in future research. Participants could be shown small 3D physical models of figures during test administration. Another possible solution is to adapt the test to an augmented or virtual reality display in which participants are allowed to rotate the figure to observe their shapes in three dimensions.

Conclusions

Spatial reasoning is crucial to success in engineering. The development of a cognitive approach to assess of reasoning early on in engineering coursework and providing remedial training to those students that test low in initial assessments is crucial to students' persistence and success in engineering. Our work demonstrates how a relatively new spatial visualization measure can effectively characterize performance on authentic engineering tasks while accounting for the cognitive processes that underlie spatial thinking. In our study, the SBST showed promise for diagnosing difficulties and strategies demonstrated by students who are challenged by spatial visualization. We suggest applications of the SBST to support remedial spatial training by including in spatial reasoning instruction, strategy learning and achieving fluency with solid geometrical shapes.

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Spatial Working Memory and Neural Efficiency in Mental Rotations: An Insight from Pupillometry

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Abstract

Spatial ability, particularly the cognitive capacity for mental rotations, is a critical component of human cognition. Proficiency with mental rotation tasks is linked with educational performance in various Science, Technology, Engineering, and Mathematics (STEM) disciplines, and with more general tasks such as real world wayfinding. Spatial working memory (SWM) is posited as a fundamental psychological construct associated with mental rotation ability. Through the adoption of pupillometry, this study aspired to investigate the potential role of SWM within mental rotation performance. The results of this study unexpectedly illustrated that mental effort decreased as item difficulty increased. It is posited that learning may have occurred during the initial easier tasks facilitating an increased efficiency in cognitive processing associated with SWM storage during the more difficult mental rotations tasks.

Introduction

Spatial ability is well established as a core cognitive faculty for humans (Johnson & Bouchard Jr., 2005). Proficiency in this domain has been shown to result in an increased likelihood for success in various disciplines associated with Science, Technology, Engineering, and Mathematics (STEM) (Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). It is also associated with the more general task of real world wayfinding (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). However, spatial ability as a construct is multidimensional, consisting of a variety of cognitive factors (Carroll, 1993). The capacity to mentally rotate abstract stimuli is a specific ability within this faculty which is widely recognised for its particular importance in human cognition (Maeda & Yoon, 2012).

Investigations into spatial ability and particularly mental rotations have revealed a gender difference favouring males (Linn & Petersen, 1985; Lippa, Collaer, & Peters, 2010).

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In attempts to understand the rationale for this difference, numerous explanatory factors have been proposed including genetics, hormones, brain structure and functions, previous experience with toys, games, activities and training, gender role identity, and confidence in spatial abilities (Doyle, Voyer, & Lesmana, 2016). By virtue of their postulation as explanatory factors for the gender difference, these factors are therefore considered as general factors involved in the cognitive action of mental rotations or in its development. Working memory capacity has also been identified as a factor inherent to mental rotations and has been shown to account for the common variance between genders (Kaufman, 2007). When considering the findings of Heil and Jansen-Osmann (2008), which illustrated males as preferring a holistic strategy and women preferring a more analytical piecemeal approach, the role of spatial working memory (SWM) in mental rotations becomes increasingly interesting as the concept of mentally storing the image of an abstract stimulus through the various stages of the rotation is posited as a core process within this ability.

Cognitive load and spatial working memory in mental rotations

Items within mental rotation tests commonly involve the presentation of a target rotation which includes an abstract stimulus presented in an initial state and in a goal state. A second item stimulus is then presented in an initial state. The objective is to apply the rotation(s) presented through the target stimulus to the item stimulus and select the correct goal state from a selection of potential solutions (e.g. Guay, 1977). It is posited within this study that SWM is a critical psychological mechanism inherent within this process. SWM can be defined as “the system of psychological processes and representations that underlie our ability to remember the locations of objects in the world, for short periods of time” (Dent & Smyth, 2006, p.529). This short period of time refers to a period of seconds, differentiating it from the iconic memory which has a span of approximately half a second (Delvenne & Bruyer, 2004). SWM is also recognised as having a capacity and temporal limitation which restricts the amount of visual and/or spatial information which can be contained within it and for how long it can be retained without rehearsal (Cowan, 2001; Miller, 1956; Peterson & Peterson, 1959). These findings ultimately led to the conception of cognitive load theory which describes how mental effort can be induced by tasks relative to working memory limitations (Sweller, 1988). In the context of mental rotations, particularly where multiple rotations or steps are required, it is posited that the spatial information pertaining to the stimulus position will need to be stored briefly prior to subsequent rotations. In addition to this, further storage is posited to be required for remembering the target sequence of rotations, and for the comparison between the target stimulus’ state with the potential solution stimulus after various steps.

Hypothesis

Just and Carpenter have shown that in the mental rotation of 2-dimensional stimuli, pupil dilation, an indicator of mental effort, increased monotonically relative to an increase in angular disparity (Just & Carpenter, 1995; Just, Carpenter, & Miyake, 2003). This work also showed that pupil size changes were more substantial for low visualizers. From this they posited that the demand on spatial resources was more for low visualizers than for high visualizers. Considering this postulated role of SWM in mental rotations, it is hypothesised that participants with lower levels of spatial ability will need to exert a greater amount of mental effort during a 3-dimensional mental rotations task than people with higher levels of spatial ability. It is also hypothesised that the magnitude of this variance will increase as item difficulty increases where item difficulty is classified by number of rotations and number of axes of rotation. The work conducted by Sorby (2009) has established that mental rotation ability can be developed, however the psychological mechanisms underpinning this development are relatively unknown.

Method

Approach

There are multiple approaches to measuring mental effort or cognitive load including self-report measures, dual task analyses, behavioural measures, neurological measures, and physiological measures (Brünken, Plass & Leutner, 2003). Kahneman (2011) considers pupil dilation as probably the best index of cognitive load as it reflects the current rate of mental effort expenditure. Strengths of pupillometry include its non-invasive nature and that it provides a continuous estimate of the intensity of mental activity (Laeng, Sirois, & Gredebäck, 2012). All cognitive effort causes pupil dilation (Kahneman & Beatty, 1966) with this dilation reflecting an overall working memory capacity utilisation (Just et al., 2003). This infers that pupil dilation can be used to indicate overall cognitive functioning in a particular task (Van Der Meer et al., 2010). This inference is supported by research showing increased pupil dilation relative to increased task difficulty (Nuthmann & van der Meer, 2005; Raisig, Welke, Hagendorf, & van der Meer, 2007). However, the allocation of cognitive resources is not solely dependent on task difficulty but also on the level of engagement (Ahern & Beatty, 1979; Van Der Meer et al., 2010). Therefore, it is important that pupillometric methodologies are designed and subsequent data is interpreted with this consideration. As this study purported to examine SWM in mental rotations, based on this research, pupillometry was adopted as the principle method of investigation.

Participants

This specific study using pupillometry was part of a larger study examining the effects of cognitive strategies on spatial ability performance. The cohort consisted of 2nd Year undergraduate Initial Technology Teacher Education (ITTE) students (N = 85) of which 80 were male and five were female, however not all participants engaged with this particular part of the study. The low representation of females in the cohort is reflective of the gender distribution in technology education in Ireland where the study was conducted. Initially, the Paper Folding Test (PFT) (Ekstrom, French, Harman, & Derman, 1976) was

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administered to the full cohort (N = 85) as it is a valid measure of a general visualization (Vz) factor often used as a representative measure of spatial ability (Carroll, 1993). The results of this test were used to stratify the cohort into quartiles (Q1 ≤ 9, Q2 10 - 11, Q3 12 - 14, Q4 15 - 20). The cohort for this part of the study (n = 16) which involved the use of pupillometry comprised of four participants from each quartile to ensure a range of spatial ability levels was represented. Considering the low number of females in the full cohort, it was not possible to include adequate representation of females in this part of the study. Additionally, in order to control for potential variances based on biological factors, participants age, sex and handedness were controlled for (Piper et al., 2011). The study cohort who engaged with the pupillometry aspect (n = 16) consisted of all male undergraduate students, had a mean age of 20.19 with a standard deviation of 0.75 (min age = 19, max age = 21), and were all right handed.

Method

Psychometric Tests

In addition to the PFT, the Shape Memory Test (SMT) (Ekstrom et al., 1976) as a measure of SWM and the Ravens Advanced Progressive Matrices Test (RAPM) (Raven, Raven, & Court, 1998) as a measure of fluid intelligence were also administered. These tests were selected as additional variables to investigate their potential role in mental rotations tasks.

Stimuli for Pupillometry Tasks

The stimuli for this study included the 30 items from the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) (Guay, 1977) and 30 experimental items based on those within the PSVT:R. The PSVT:R was selected as it is a psychometrically sound measure of mental rotations (Maeda, Yoon, Kim-Kang, & Imbrie, 2013) whereby the items systematically increase in difficulty as more rotations are added and the geometry becomes more complex (Branoff, 2000). All items in the PSVT:R contain abstract stimuli. Initial items require a mental rotation of 90º about one axis and progress to more difficult items requiring a rotation of 90º about one axis followed by another rotation of 180º about a second axis. Thirty experimental items were also included which were designed based on the items included in the PSVT:R. The experimental items contained common real life objects in place of the abstract stimuli found in the standard PSVT:R. The familiar nature of the stimuli was the only variance in the experimental items as all rotations were designed to correspond those within the standard test.

Implementation

All testing was conducted individually with participants. Initially the psychometric tests described above were administered in paper and pencil format. The order of administration was varied for each participant to avoid inducing an order bias. After all paper and pencil tests were administered, participants engaged with the mental rotations test items

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electronically. Test items were displayed on a monitor and pupil dilation was recoded using the Tobii X120 system. The Tobii X120 system tracks both eyes, has a sampling rate of 120 Hz and a spatial resolution of 0.2º. Participants were seated with their heads resting on a chinrest 65 cm in front of the monitor. Participants were evenly distributed between one of two test conditions (Figure 1) with two participants from each quartile being assigned to each. Following an explanation of the test instructions participants completed two sample items from each type of stimulus to ensure that the data from

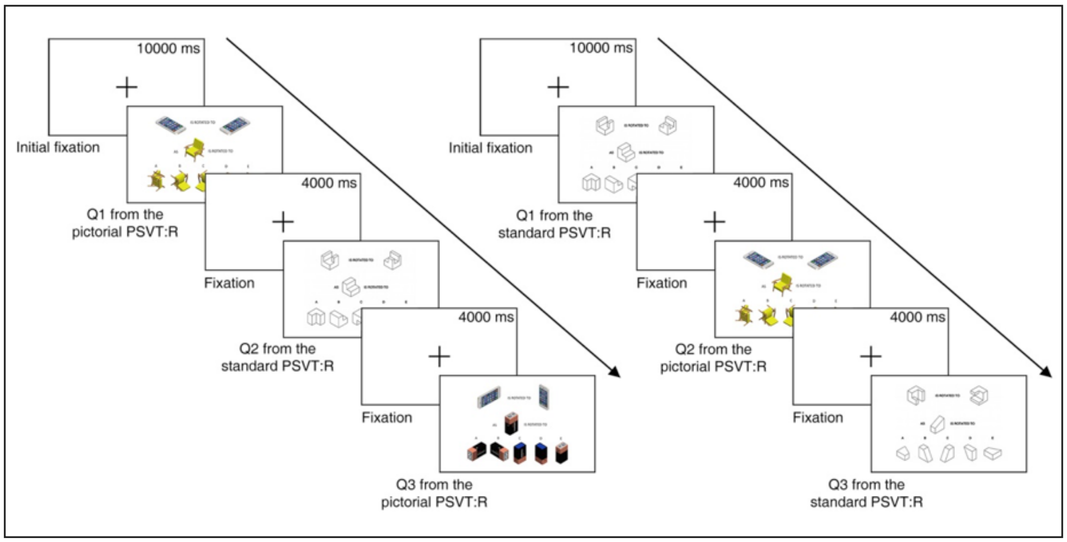

Figure 1. Illustration of test condition one (left) and condition two (right). Items in this figure are sample items not included in the actual tests.

initial items wasn't skewed by the novelty of the experience. Both tests were then preceded by a 10000 ms fixation period. For test condition one, even numbered items from the standard PSVT:R were mixed with the odd numbered items from the experimental pictorial version. For test condition two, odd numbered items from the standard PSVT:R were mixed with even numbered items from the experimental pictorial version. There was no time limit placed on participants when answering any test item. A 4000 ms fixation period was placed between each item. All participants answered 30 items, 15 from the standard version of the PSVT:R and 15 from the experimental version.

Results

A Spearman's correlation analysis was conducted to identify any relationships between performance in the psychometric tests and mental effort exerted in the mental rotations items as measured by the participants' pupil dilation (Table 1). No statistically significant correlations were observed between pupil dilation indices and performance in the psychometric tests. Statistically significant moderate correlations were observed between the performance in the mental rotation items and both the PFT ($\rho = .574$, $p < .05$) and RAPM ($\rho = .547$, $p < .05$). Furthermore, a statistically significant strong correlation was

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Table 1
Correlation matrix indicating Spearman's rho (ρ) correlations (n = 16)

	PSVT:R Dilation	Pictorial PSVT:R Dilation	Mental Rotation Performance	PFT	SMT
Pictorial PSVT:R Dilation	.956**				
Mental Rotation Performance	-.003	-.006			
PFT	.043	-.007	.574*		
SMT	-.095	-.133	.382	.435	
RAPM	.135	.072	.547*	.471	.774**

Note. PFT = Paper Folding Test. SMT = Shape Memory Test. RAMP = Ravens Advanced Progressive Matrices. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

observed between the RAPM and the SMT (ρ = .774, $p < .01$) and a statistically significant very strong correlation was found between participants average pupil dilation in standard and pictorial mental rotation items (ρ = .956, $p < .01$). Due to the low sample size and resulting low statistical power, these correlations should be considered with caution.

Further analysis of the pupillometry data was conducted to examine mental effort over time as the item difficulty increased. For this part of the analysis, due to the different items administered to participants, four separate datasets were created. These included the standard PSVT:R items from test condition one, the experimental PSVT:R items from test condition one, the standard PSVT:R items from test condition two, and the experimental PSVT:R items from test condition two. Each dataset contains the results from eight participants. The results of this analysis are presented in Figure 2.

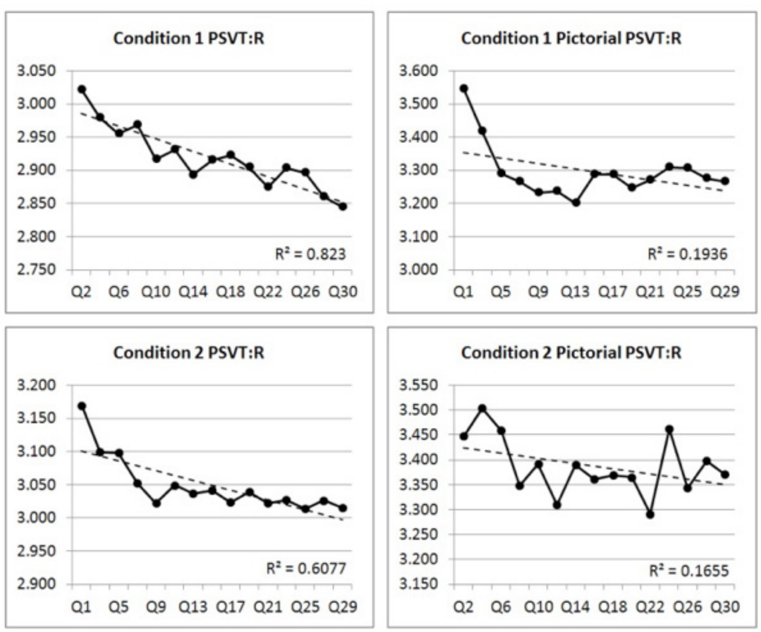

Figure 2. Average pupil dilation for items in each test condition. Vertical axes indicate pupil dilation in millimetres (mm) and horizontal axes indicate test item numbers.

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Figure 2. Average pupil dilation for items in each test condition. Vertical axes indicate pupil dilation in millimetres (mm) and horizontal axes indicate test item numbers.

The results of Figure 2 illustrate negative trends in each circumstance indicating that in general, as item difficulty increased, exerted mental effort decreased. As the difficulty level increased with each item, it was hypothesised that the required mental effort would also increase. Therefore, a more detailed analysis was conducted for the results from each participant. The results of this analysis are presented in Figure 3 (standard PSVT:R items) and Figure 4 (experimental items) respectively.

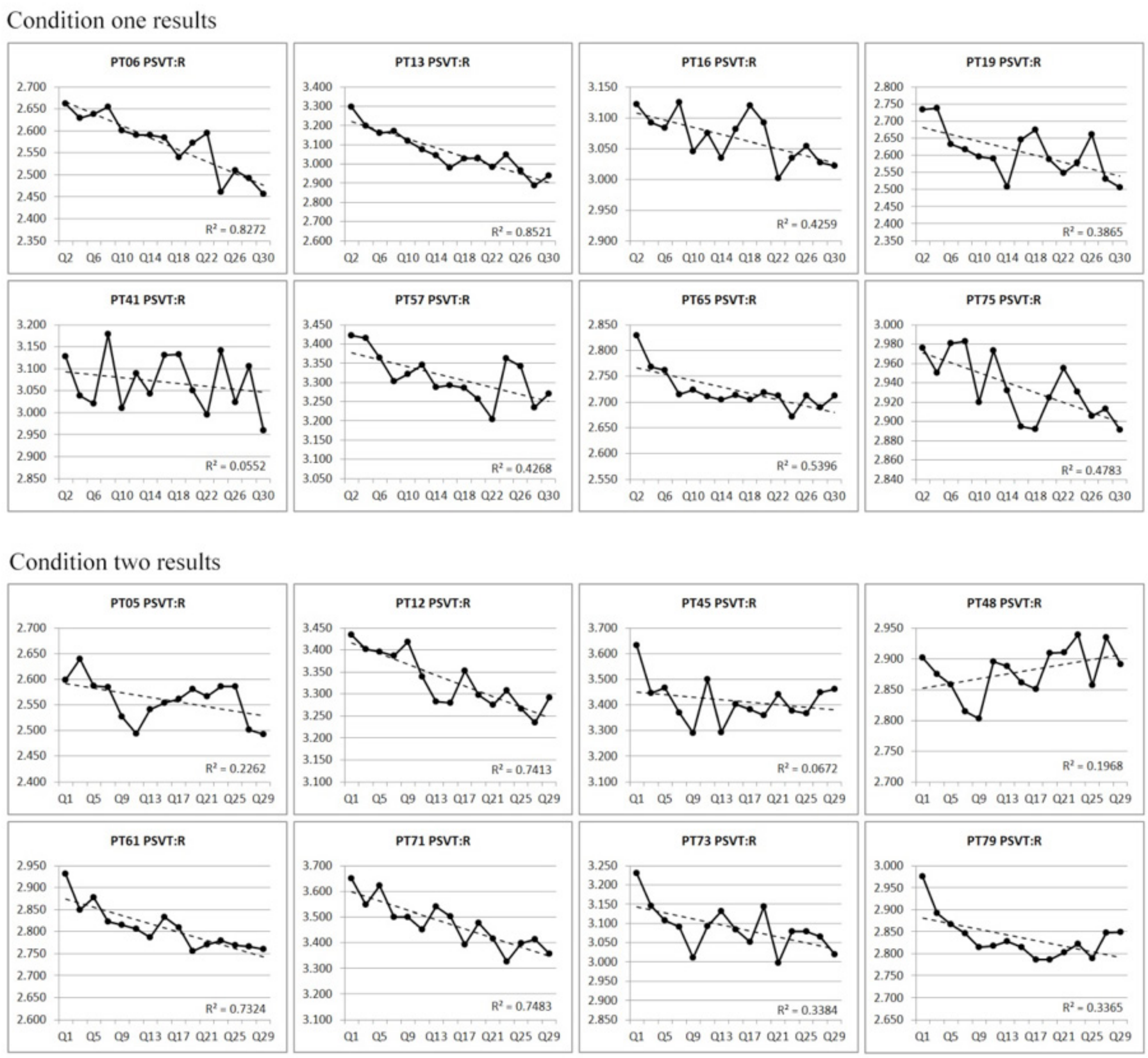

Figure 3. Pupil dilation results for each participant for the standard PSVT:R items. Vertical axes indicate pupil dilation in millimetres (mm) and horizontal axes indicate test item numbers.

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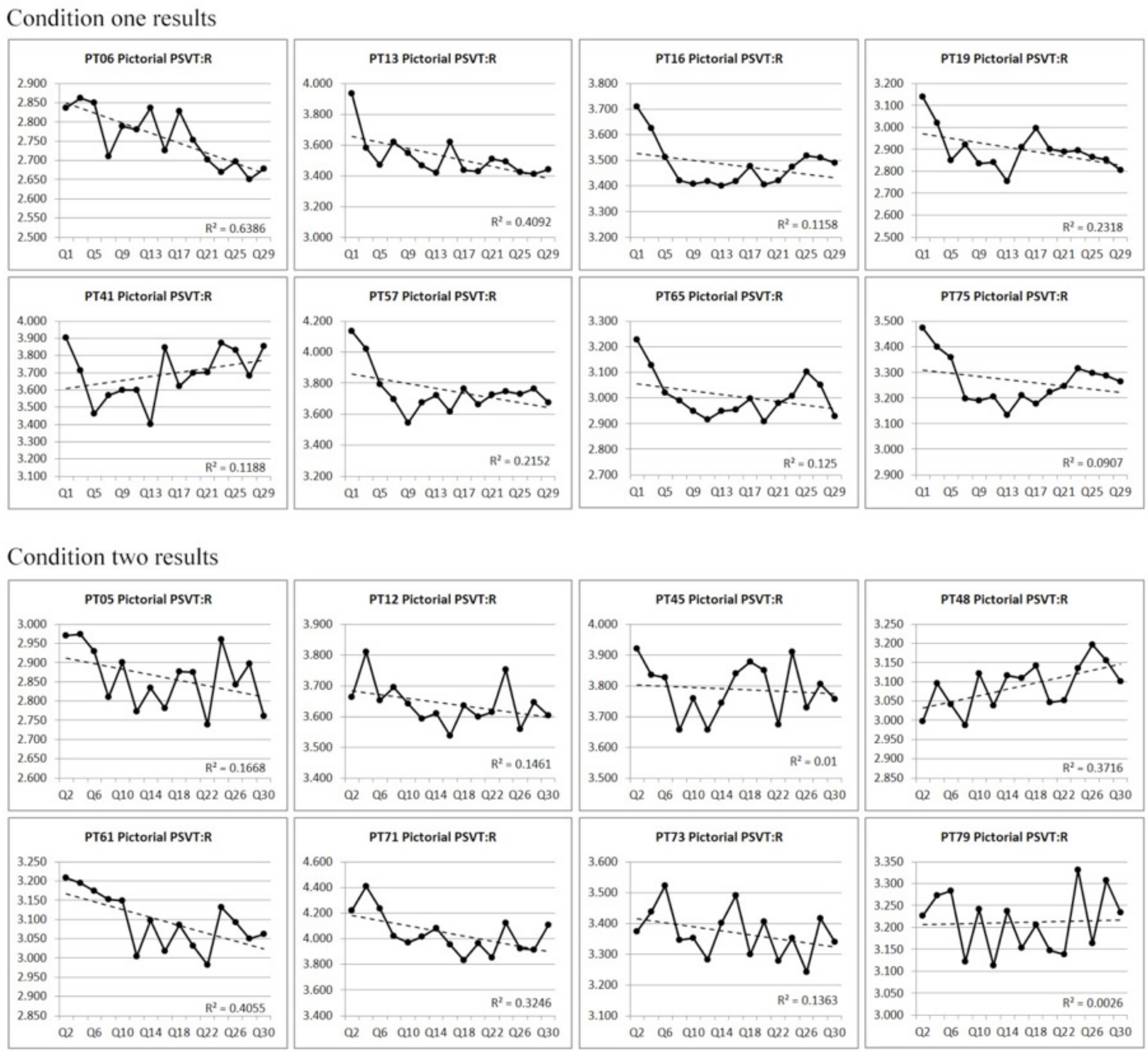

Figure 4. Pupil dilation results for each participant for the experimental PSVT:R items. Vertical axes indicate pupil dilation in millimetres (mm) and horizontal axes indicate test item numbers.

As can be observed from Figure 3 and Figure 4, 28 out of the 32 results from individual participants illustrate a negative trend in mental effort exerted over time despite item difficulty increasing. In addition to this, when comparing the R^2 values for the trends between individual students effort on the standard and experimental items, in 14 of the 16 cases the R^2 values are higher for the standard PSVT:R items containing the abstract stimuli.

Discussion

The results of this study were unexpected especially considering the work of Just and Carpenter (Just & Carpenter, 1995; Just et al., 2003). The study aspired to investigate a hypothesis predicated on the assumption that as item difficulty increased, mental effort

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associated with SWM would also increase relative to the demands of the task. However, the results illustrate a negative trend indicating that despite an increase in item difficulty, exerted mental effort tended to decrease over time. It is possible that the negative trends exist as a result of increased boredom or disengagement over time during the test. However, if this were the case it would also be expected that performance would decrease as a result or that there would be a low level of reliability. The decreasing trend is observable from the initial items however performance scores (M = 18.938, SD = 5.323) suggest that sufficient effort was exerted to perform well until at least the middle of the test and the reliability of the test was high (α = .795) indicating that participants didn't resort to guessing in order to finish the test quickly. The time taken by participants to complete the test was short (M = 9.48 min, SD = 3.48 min) considering the standard 20 min time limit. Therefore, while it is plausible for boredom, disengagement, or reduced enthusiasm to have caused the negative trends, these variables did not affect participants enough to impact substantially on performance. The relationship between these and related emotions with test taking behaviour requires further investigation to make more precise inferences on these results.

The results of this study do however align with the neural efficiency hypothesis which suggests that intelligence is a function of how efficient the brain works and not how hard it works (Haier, Siegel, Tang, Abel, & Buchsbaum, 1992). Evidence of neural efficiency illustrates that a decrease in cognitive effort can be found subsequent to learning or training. In this study, early items may have provided an opportunity for such learning to occur reducing the mental effort associated with SWM storage as this process became more efficient. However, the idea that such efficiency could develop so quickly throughout the first number of test items is surprising and warrants further inquiry to determine if this is the case.

In addition to further enquiry being warranted for the potential development of neural efficiency in SWM and mental rotations, another question emerges from these results associated with performance. If the mental effort required to engage in more difficult questions is lower than previous and easier questions, suggesting more cognitive resources are available to engage in the task, why is performance poorer in these questions? Woodman and Vecera (2011) illustrate that accessing object features in the visual working memory degrades the representations of other stored objects. The increased number of rotations in more difficult questions may require more continued access to object features and therefore despite the rotation seemingly becoming more efficient, the degrading of the target rotation may be the reason people get the harder items incorrect. This would explain why the apparently reduced effort required doesn't result in increased performance.

With respect to the differences between the abstract and familiar stimuli, R^2 values were typically higher for the standard items. This is likely due to it being a validated instrument. It is interesting however that the results from the items with familiar stimuli show a similar trend as these items were experimental and not statistically validated prior to this

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study. Unfortunately, mental effort could not be compared between the types of stimuli due to luminance difference in the items. Further work is warranted where this variable is controlled to examine if the familiarity of the stimuli affects the required mental effort. In relation to potential differences, Mayer, Kim, and Park (2011) have shown that abstract or novel stimuli are more easily encoded in the working memory and therefore the hypothesis may be generated that less mental effort will be needed in mental rotation tasks with abstract rather than familiar tasks. Alternatively, familiar objects may be able to be retrieved from long-term memory storage rather than needing to be encoded into the SWM which may facilitate an easier mental rotation.

Conclusion

Considering that mental rotation ability is a strong predictor of educational success in STEM, it is paramount that a causal explanation for this phenomenon is determined to facilitate the scientific development of associated pedagogical approaches and training interventions. Determining more clearly the role of SWM in mental rotations would aid in identifying its underlying cognitive processes and knowing these would aid establishing why this ability is related to STEM performance. Additionally, as mental rotation ability can be trained, it may be possible to enhance such interventions through the incorporation of working memory training and increase the effect size that can be obtained both in terms of increasing spatial ability capacity and STEM performance. Finally, if it is the case the either a strategy can be developed in the initial test items or that a degree of efficiency can be achieved making more mental resources available in more difficult items, this has implications for research aiming to adapt the PSVT:R and potentially other related tests. Shortening these tests for pragmatic reasons may affect the strategies used by test takers if sufficient time is not available at the beginning prior to more difficult items affecting their psychometric properties.

Note

The preliminary results of this study were presented at the 72nd ASEE Engineering Design Graphics Division Midyear Conference in Montego Bay, Jamaica.

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Effects of Light Reflection on Spatial Visualization Ability and implications for Engineering Technology Students

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Abstract

Results from a number of studies indicate that the type of light generated by the reflection on the surface of different types of surfaces can influence the spatial visualization ability; however, research provides inconsistent results. Considering this, a quasi-experimental study was conducted to identify the existence of statistically significant effects on spatial visualization ability as measured by the Mental Cutting Test and Sectional View drawing ability due to the impacts of light reflection. In particular, the study compared three types of light reflection; mirror, specular and diffuse and whether a significant difference exists among engineering technology students. According to the results of this study it is suggested that the type of light reflection provides statistically significant differences.

Introduction

In the natural world, the way we see objects is a consequence effect result of how the objects interact with the environment and its lighting. The world is illuminated by two types of light: Direct or Indirect. Direct light occurs from a specific light source (e.g. the sun, a lamp, overhead lighting), this is referred to as *local illumination*. When light is transmitted by bouncing off of other surfaces (e.g. a crack in a door, body of water) it is referred to as an indirect light source (Autodesk, 2015a).

When light waves strike an object it may be absorbed, reflected, or refracted. In our natural world light may also be transmitted by an object based on its transparency, color, and the material of which it is constructed (Autodesk, 2015). Absorption occurs when light stops at an object's surface appearing dark or opaque, it does not reflect or refract light. Reflection occurs when light bounces off of the surface and an equal angle as the incoming light waves (e.g. glass or mirrors). Refraction occurs when light bends at an angle and goes through an object (Autodesk, 2015b).

It is clear from the research presented in this paper that lighting on an object's surface plays a critical role in how an observer sees and mentally processes its properties. This study was designed specifically to determine the effects of light reflection on spatial visualization ability for engineering technology students as its measured by the Mental Cutting Test (MCT) and sectional view drawings.

Effects of Light Reflection in Learning

Reflection occurs when light bounces off of the surface of an object. Three types of reflection have been identified: mirror, specular, and diffuse (see Figure 1). Mirror reflec-

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tion can be one of two types: concave or convex. Mirror reflection occurs in two distinct ways. First, concave mirrors (e.g. inside curve of a spoon), reflects in a straight line inward to a focal point with each light ray reflecting at the same angle as it hits the surface. Second, convex mirrors curve outwards (e.g. outside of a ball), and parallel rays of light strike the mirror and reflect outward giving a wider field of vision. (see Figure 2).

Specular reflection occurs when light reflects at the same angle as it hit the surface (e.g. smooth and shiny surfaces such as glass, water, or metal. Alternatively, diffuse reflection occurs when light hits an object with a rough surface and reflects the light in many different directions.

Light reflection in learning has an impact on the way a learner sees the object. Veiling reflection in particular is glare caused by reflection of light on a bright surface such as computer screens and whiteboards in a classroom setting. A study conducted by Fotios & Parnell (2009) suggests that veiling reflection causes a reduction in the contrast of character-to-background on computer screens and whiteboards which reduces legibility and in some cases causing contents to become completely unrecognizable.

Research conducted by Fleming, Dror, & Adelson (2003) indicate that people evaluate object characteristics more accurately under natural illumination rather than artificial light sources. Neuroimaging studies have supported the non-visual effects of light (time and intensity) on performance during cognitive tasks by regulating neu-

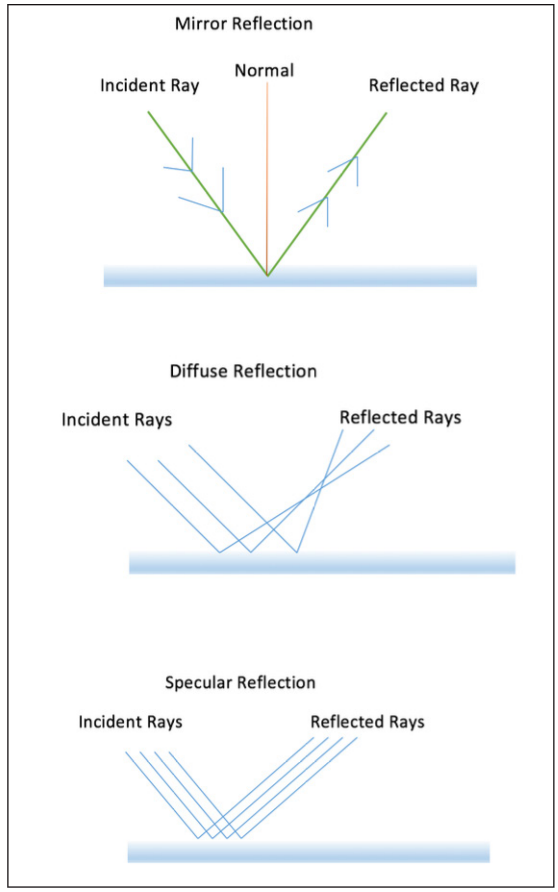

Figure 1. Three types of reflection.

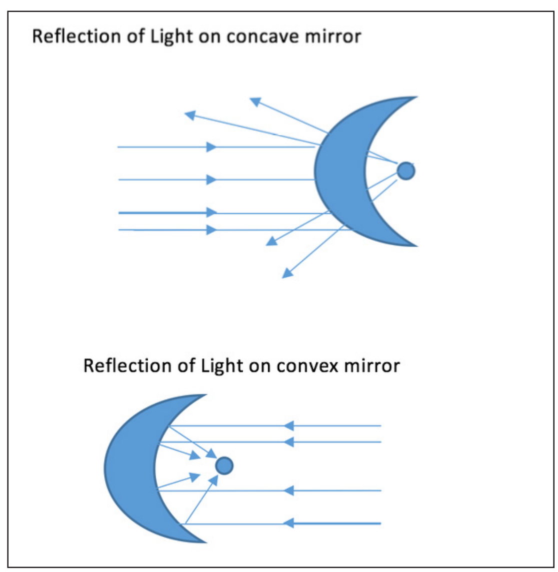

Figure 2. Mirror reflection.

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ral activity (Vandewalle, Maquet, & Dijk, 2009). Furthermore, the non-visual effects of light on mood regulation and long-term memory has been confirmed by the activation of amygdala and hippocampal activation during tasks that are associated with these functions (Vandewalle, Balteau, Phillips, Degueldre, Moreau, Sterpenich, Albouy, Darsaud, Desseilles, Dang-Vu, Peigneux, Luxen, Dijk, & Maquet, 2006; Vandewalle, Gais, Schabus, Balteau, Carrier, Darsaud, Sterpenich, Albouy, Dijk, & Maquet, 2007).

Spatial Ability

Spatial ability may be described as a range of cognitive thinking skills which allow learners to relate within an environment (Hegarty & Waller, 2004). Spatial ability allows learners to shape and store mental representations of objects in order to mentally manipulate and rotate models (Carroll, 1993; Höffler, 2010). Höffler, 2010 also described this ability as independent from general intelligence. An historical perspective suggests that spatial ability has had a significant role in science including the discovery of DNA structure as well as Einstein's theory of relativity (Newcombe, 2010; von Károlyi, 2013).

Spatial skills performance is considered the gatekeeper to success in many STEM disciplines (Science, Technology, Engineer, Mathematics) (Bogue & Marra 2003; Contero, Company, Saorin, & Naya, 2006; Mohler, 2008; Sorby, 2009; Miller & Halpern, 2013; Sorby, Casey, Veurink, & Dulaney, 2013). Undergraduate engineering students in particular have numerous competencies required to achieve success in engineering programs. These essential and fundamental competencies are critical to the retention and success of students in all engineering programs. In fact, research suggests a positive correlation between spatial ability and completion of degree requirements for engineering technology students. (Brus, Zhoa & Jessop, 2004; Sorby, 2009; Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002). Furthermore, individuals with a higher level of spatial ability performance may have a broader array of strategies in spatial task problem solving (Gages, 1994; Orde, 1996; Pak, 2001; Lajoie, 2003).

Spatial Visualization

Spatial visualization is also referred to as "spatial ability" and the terms may often be used interchangeably (Braukmann, 1991). Spatial visualization of an object involves the cognitive manipulation of an object through a series of alterations (Ferguson, Ball, McDaniel, & Anderson, 2008). McGee (1979), defines spatial visualization as "the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object" (p. 893). Strong & Smith (2001) refer to spatial visualization as "the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint" (p. 2).

The importance of enhancing spatial visualization ability has been a focus for engineering education researchers, industry representatives, and the U.S. Department of Labor who have all initiated a demand for a focus in these skills most specifically in engineer-

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ing and technology students (Ferguson, et al., 2008). In addition, in the past twenty years conference proceedings and journal articles have reflected a fundamental focus on these skills in engineering education (Marunic & Glazar, 2013; Miller & Bertoline, 1991). As part of this initiative to improve spatial ability in students, many environmental factors have been considered with lighting being one of the lesser variables studied.

Spatial Ability and Light Reflection

The human eye contains cone cells and function to provide sharpness, detail, and color vision. Studies have shown that the amount and distribution of lighting has an impact on the level of performance in work and learning environments (Mott, Robinson, Walden, Burnette & Rutherford, 2011). Lighting in classroom environments has been found to be related to student learning in a variety of ways (Winterbottom & Wilkins, 2009). Although daylight is the preferred lighting situation, teachers prefer to have more control over lighting in classroom settings (Schreiber, 1996). As daylight changes throughout the day due to constant changes in the sun and weather, a more controlled lighting sequence may ensure a consistent environment throughout the day. (Ho, Chiang, Chou, Chang, & Lee, 2008).

The relationship of varying light directions and shadows plays a fundamental role for a learner to visualize and comprehend the characteristics of an object's shape and surface (Watteeuw, Hameeuw, Vandermeulen, Van der Peere, Boschloos, Delvaux, Proesmans, Van Bos & Van Gool, 2016). With the use of computers and other types of classroom mediums in engineering learning labs, it is important to consider light reflection and glare as a potential road block in spatial ability learning.

Research Question and Hypothesis

To enhance the body of knowledge related to light reflection for spatial visualization ability, the following study was conducted. The following was the primary research question:

> Will the different types of light reflection; mirror, specular and diffuse significantly change the level of spatial visualization ability; as measured by the MCT and sectional drawings, for engineering technology students?

The following hypotheses were be analyzed in an attempt to find a solution to the problem:

> H_0: There is no effect on engineering technology students': a) Spatial visualization ability as measured by the MCT and b) ability to sketch a sectional view drawing, due to the different types of light reflection; mirror, specular and diffuse.

> H_A: There is a significant effect on engineering technology students': a) Spatial visualization ability as measured by the MCT and b) ability to

sketch a sectional view drawing, due to the different types of light reflection; mirror, specular and diffuse.

Methodology

A quasi-experimental study is an investigation that possesses all of the elements of a true experiment except that "subjects are not randomly assigned to groups" (Pedhazur & Pedhazur- Schmelkin, 1991, p. 277). In a quasi-experimental design, the researcher must identify and separate the effects of treatments from the effects of other factors which affect the dependent variable (Pedhazur & Pedhazur- Schmelkin, 1991). Quasi-experimental designs are used in natural settings with naturally occurring groups where the researcher has some control over the conditions of the experiment, and where full control is not desired or possible. (Hank & Wildemuth, 2017). The lack of control over the experiment due to the absence of random assignment is what sets quasi-experimental design apart from true experimental designs (Hank & Wildemuth, 2017). Campbell and Stanley (1963) describe quasi-experimental designs as those studies that are designed "where better design are not feasible" (p. 34). A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the spring semester of 2017.

Using a convenience sampling approach and lacking the element of random assignment to treatment or control the researchers felt that the quasi experimental design was the most appropriate one to use . The study was conducted in an Engineering Graphics course offered as part of the Engineering Technology program. The research design methodology is shown in Figure 3. Using a convenience sample, there was a near equal distribution of participants between the three groups.

The engineering graphics course emphasized hands-on practice using 3D Autodesk inventor software in the computer lab, along with the various methods of editing, manipulation, visualization, and presentation of technical drawings. In addition, the course included the basic principles of engineering drawing/hand sketching.

The three groups ($n1$=39, $n2$= 35 and $n3$=38, with an overall population of N = 112) were presented with a visual representation of an object (visualization). All three groups ($n1,n2,n3$) received a different version of the same 3D printed model. The main difference was the finish quality of the surface (glossy, semi glossy and ruff), in order to represent the three different kinds of light reflection (mirror, specular and diffuse). Please see Figure 4. Since light reflection was used as a part of the study treatment, and to prevent bias for students using glasses or contact lenses, all participants were exposed into the three different light reflections represented by different models and were asked to report whether they could clearly see or not. No students were identified as having difficulty seeing within the spectrum of the light reflections used in this experiment.

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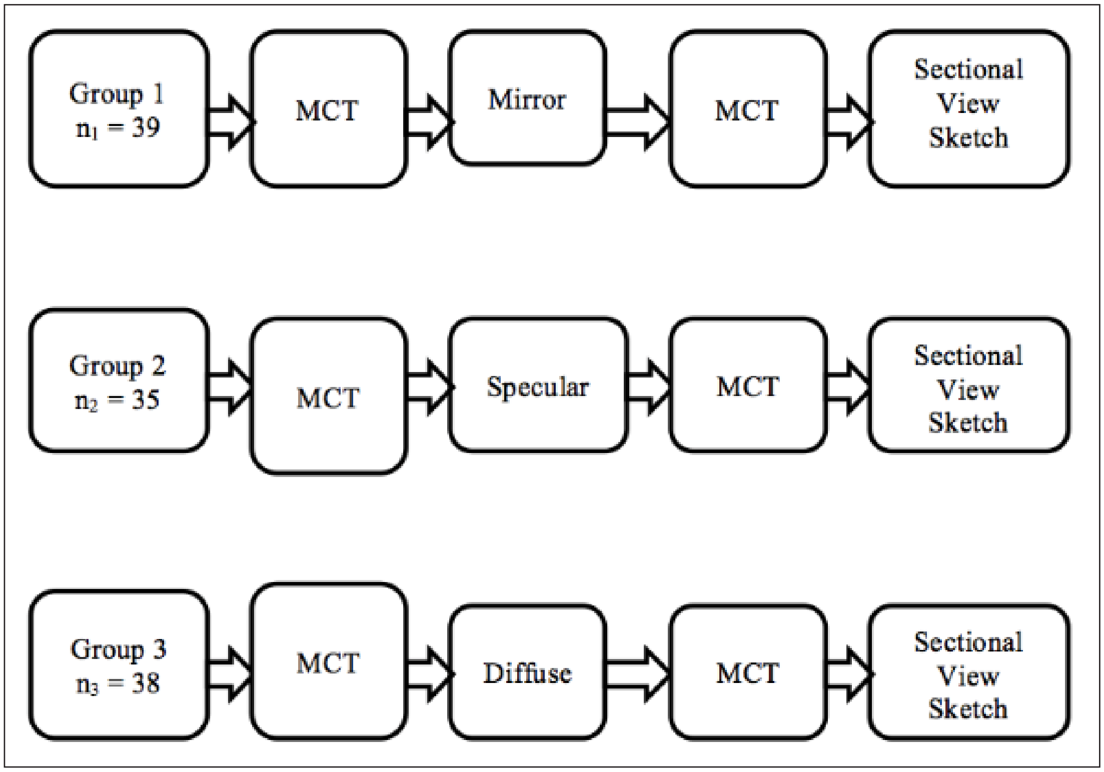

Figure 3. Research design methodology.

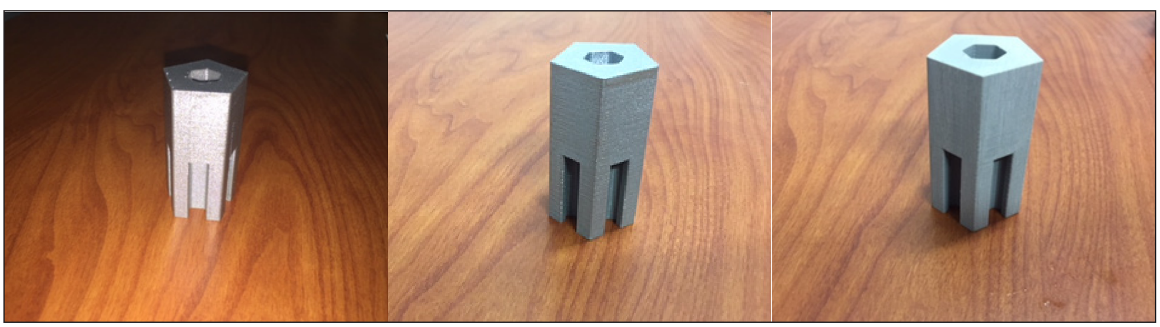

Figure 4. Three types of surface; glossy, semi glossy and ruff.

In addition, all groups were asked to complete the Mental Cutting Test (MCT) (CEEB, 1939) instrument, 2 days prior to the completion of the sectional view sketch in order to identify their level of visual ability and show equality between the three groups. The MCT was not used to account for spatial visualization skills in this study. The only purpose was to establish a near to equal group dynamic based on visual ability, as it relates to Mental Cutting ability. According to Nemeth & Hoffman (2006), the MCT (CEEB, 1939) has been widely used in all age groups, making it a good choice for a well-rounded visual ability test. The Standard MCT consists of 25 problems. The Mental Cutting Test is a sub-set of the CEEB Special Aptitude Test in Spatial Relations and has also

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been used by Suzuki (2004) to measure spatial abilities in relation to graphics curricula (Tsutsumi, 2004).

As part of the MCT test, subjects were given a perspective drawing of a test solid, which was to be cut with a hypothetical cutting plane. Subjects were then asked to choose one correct cross section from among 5 alternatives. There were two categories of problems in the test (Tsutsumi, 2004). Those in the first category are called *pattern recognition problems*, in which the correct answer is determined by identifying only the pattern of the section. The others are called *quantity problems*, or *dimension specification problems*, in which the correct answer is determined by identifying, not only the correct pattern, but also the quantity in the section (e.g. the length of the edges or the angles between the edges) (Tsutsumi, 2004).

The three groups were asked to create a sectional view of the pentagonal cylinder (see Figure 5). Sectional views are very useful engineering graphics tools, especially for parts that have complex interior geometry, as the sections are used to clarify the interior construction of a part that cannot be clearly described by hidden lines in exterior views (Plantenberg, 2013). By taking an imaginary cut through the object and removing a portion the inside features could be seen more clearly. Students had to mentally discard the unwanted portion of the part and draw the remaining part. The rubric used included the following parts: 1) use of section view labels; 2) use of correct hatching style for cut materials; 3) accurate indication of cutting plane; 4) appropriate use of cutting plane lines; and 5) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points. This process takes into consideration that research indicates a learner's visualization ability and level of proficiency can easily be determined through sketching and drawing techniques (Contero, et al., 2006; Mohler, 1997). All students in all groups were able to approach the visualization and observe from a close range.

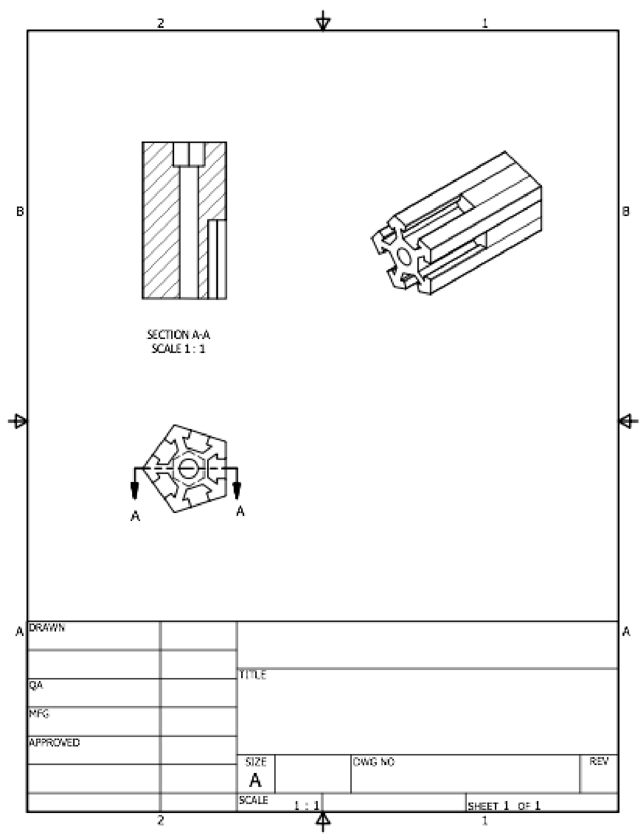

Figure 5. Sectional views of the pentagonal cylinder.

Data Analysis

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instru-

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ment prior to the treatment to show equality of spatial ability between the three different groups. The researchers graded the MCT instrument, as described in the guidelines by the MCT creators. A standard paper-pencil MCT pre and post were conducted, in which the subjects were instructed to draw intersecting lines on the surface of a test solid with a green pencil before selecting alternatives. The maximum score that could be received on the MCT was 25. As it can be seen in Table 1 for the pre-test, *n1* had a mean of 22.622, *n2* had a mean of 23.839, and *n3* had a mean of 23.983. As far as the post-test *n1* had a mean of 23.489, *n2* had a mean of 23.993, and *n3* had a mean of 24.180.

Due to the relatively low numbers of the participants and the fact that we did not have random samples, a non-parametric Kruskal-Wallis test was run to compare the mean scores for significant differences, as it relates to spatial skills among the three groups. The result of the Kruskal-Wallis test, as shown in Table 2, was not significant $X^2 = 1.102$, $p < 0.576$.

Table 1
MCT Descriptive Results

Light Reflection	***N***	***Mean pre-test***	***Mean post-test***	***SD pre-post***	***SE pre-post***	***95% Confidence Interval for Lower Bound pre-post***	***Mean Upper Bound pre-post***
Mirror	39	22.622	23.489	3.532	.693	22.428	23.497
Specular	35	23.839	23.993	3.142	.592	23.124	23.692
Diffuse	38	23.983	24.180	3.391	1.252	22.941	24.639
Total	112	23.814	23.887	4.050	2.537	22.831	23.942

Analysis of Drawing

The second method of data collection involved the creation of a sectional view sketch drawing. As shown in Table 3, the group that used the specular model ($n = 35$), had a mean observation score of 3.632. The groups that used the mirror model ($n = 38$) and the diffuse model ($n = 39$) had lower scores of 3.249 and 3.532, respectively (see Table. 3). A Kruskal-Wallis test was run to compare the mean scores for significant differences among the three groups. The result of the Kruskal-Wallis test, as shown in Table 4, was

Table 2
MCT pre and post-test Kruskal-Wallis H test Analysis

Light Reflection	***N***	***DF***	***Mean Rank***	***X^2***	***p-value***
Mirror	39	2	23.482	1.102	.576
Specular	35		23.289		
Diffuse	38		23.029		
Total	112				

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significant: X^2= 1.502, $p < 0.0029$. The data was dissected further through the use of a post hoc *Steel-Dwass* test. As it can be seen in Table 5, the post hoc analysis shows a statistically significant difference between the mirror vs. specular model ($p < 0.053$, d = 0.190, Z=2.532) and the specular vs. diffuse model ($p = 0.004$, $d = 0.381$, Z=2.421).

Table 3
Sectional View Drawing Descriptive Results

Light Reflection	***N***	***Mean***	***SD***	***Std. Error***	***95% Confidence Interval for Lower Bound***	***Upper Bound***
Mirror	39	3.532	.395	.132	3.532	4.064
Specular	35	3.632	.405	.125	4.522	4.523
Diffuse	38	3.249	.459	.142	3.294	3.028
Total	112	3.633	.551	.218	3.782	3.871

Table 4
Sectional View Kruskal-Wallis H test Analysis

Light Reflection	***N***	***DF***	***Mean Rank***	***X^2***	***p-value***
Mirror	39	2	23.841	1.502	.0029*
Specular	35		23.342		
Diffuse	38		23.642		
Total	112				

* Denotes statistical significance

Table 5
Sectional View Drawing Steel-Dwass test Results

	Light Intensity (1 vs. 2 vs. 3)	*Score Mean Diff.*	*Std. Error*	*Z*	*p-value*
2 vs 1	Mirror vs. Specular	0.190	0.192	2.532	0.053*
2 vs 3	Specular vs. Diffuse	0.381	0.164	2.421	0.004*
3 vs 1	Diffuse vs. Mirror	0.301	0.184	1.422	0.510

* Denotes statistical significance

Discussion

This study was conducted to determine whether the different types of light reflection; mirror, specular and diffuse, significantly change the level of spatial visualization ability;

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as measured by the MCT and sectional drawings, for engineering technology students. It was found that the different types of light reflection provided statistically significant higher scores; therefore, the hypothesis that there is an identifiable amount of effect on engineering technology students': a) Spatial visualization ability as measured by the MCT and b) ability to sketch a sectional view drawing, due to the different levels of light reflection; mirror, specular and diffuse was accepted.

The fact that two of the groups gained statistically significant advantage when exposing the drafting model in different types of light reflection could suggest that important details on the drafting model can be hidden during light reflection conditions. Previous studies suggested a positive correlation between light reflection and intensity and oral reading fluency performance among middle schools students and learning in general (Mott, et al., 2012). The literature also supports that color and light intensity could positively effect on cognitive performance, and the level varies across different groups such as female or male students (Knez, 1995).

The effects of direct and indirect lighting as well as its reaction to an object (absorption, reflection, or refraction) have an impact on how one mentally processes the appearance of an object. Xiao & Brainard (2008) offered the hypothesis that an observer integrates luminance and chromaticity across an object as they synthesize the spatial average of light. However, data did not support this simple hypothesis rather the observer's visual scheme offsets for the physical effect of light (or gloss) so that the appearance of the object is supported in relation to what would be predicted. Furthermore, an object's composition (the material it is made up of) creates a wide range of optical properties (Fleming, Dror, & Adelson, 2003). Different materials will "reflect, transmit, refract, disperse, and polarize light to different extents and in different ways" (Fleming, et al., 2003, p. 347). This results in the reflectance properties of an object's surface becoming its most critical optical properties (Fleming, et al., 2003).

The results of this quasi experimental study suggest that light reflection conditions could affect learning in a positive way. More specific, a particular light reflection type (mirror) could enhance learning; however, this conclusion it is based only on the results of a small pilot study, therefore, additional studies need to be conducted in order to strengthen this conclusion.

Limitations and Future Plans

In order to have a more thorough understanding of the effects on spatial visualization ability and the effects of light reflection for models used by engineering technology students, it is imperative to consider further research. Future plans include, but are not limited to:

- Repeating the study using a larger population to verify the results

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- Repeating the study using a different population such as mathematics education, science education, or technology education students
- Repeating the study by comparing male versus female students
- The short timeframe of treatment was not long enough to influence on spatial visualization or student's ability to create the rotational view

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Developing a Scale to Investigate Student's Self-Efficacy as it Relates to Three-Dimensional Modeling

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Introduction

Binkley et al. (2012) contends that the economy and workplace for the 21st Century will not lie in the routine tasks of the past, instead emphasis will be put on the ability of students to communicate, share and use information to solve increasingly complex problems. This is especially true of individuals who chose to pursue careers in the sciences, technology, engineering, and mathematics (STEM). For many engineers and technologists, at the heart of this exchange of information is the ability to model, design, and fabricate complex objects using the latest three-dimensional modeling software. Yet, for many students tackling this authoring software begins with their own perceived ability to complete said task. Eccles et al. (1983) seminal research revealed that students' belief about their ability to complete a task is inextricably linked to their previous experience and other socialization factors. To better understand how different experiences impact students' belief about their abilities, it is imperative to design, test and validate instruments with the ability to provide insight into students' belief in their ability to complete a task within a given domain or self-efficacy. In an effort to address the lack of instruments designed to measure students' self-efficacy as it relates to three-dimensional modeling, researchers conducted a study with the intent to develop, test and validate such an instrument.

With more and more middle and high school STEM courses using of computer-aided design (CAD) software (a central component of engineering graphics education) to enhance instruction and incorporate 21st-century skills in the classroom (Katsioloudis & Jones, 2015; Schoembs, 2016), the effect of these programs on non-cognitive constructs such as self-efficacy represents a dearth in the contemporary literature. Technology and engineering curricula such as Project Lead the Way (PLTW) and Engineering by Design (EbD) both explicitly use CAD as part of their courses and the inclusion of engineering skills and concepts in the Next Generation Science Standards (NGSS) is increasing students' exposure to CAD in the general education classroom (Schoembs, 2016; Standish, Christensen, Knezek, Kjellstrom, & Bredder, 2016). It is also becoming more common to see Makerspaces and Fablabs in K-12 schools, adding to the need for students to have at least a basic understanding of three-dimensional modeling and using CAD software.

The availability of CAD software has increased as well. Web-based software such as Tinkercad and Onshape provide free CAD access on any computer. Programs such as

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SketchUp can be used free with some limitations whereas full version access to the industry-standard Autodesk suite of CAD programs is available to students and teachers. The growing prevalence of, and access to, CAD software in K-12 classrooms warrants study into factors that impact student learning and success.

A review of the extant literature on three-dimensional modeling and spatial skills reveal previous studies that have identified factors that impact student success in engineering graphics however much of their focus is on operational tasks that help build students' skill level such as sketching (Sorby, 1999a). Studies have also noted the impact of having students work with hand-held models and given voice to the ability of student's spatial ability to predict success in three-dimensional modeling (Sorby, 1999b). However, few studies have investigated the ability of affective measures to predict student success in three-dimensional spatial and visualization skills. The dearth of research investigating the impact of affective constructs on student success in three-dimensional modeling can in part be attributed to the lack of valid and reliable instruments that measure these constructs.

The goals of this study were to develop a valid and reliable instrument for the purpose of measuring students' self-efficacy as it relates to three-dimensional (3-D) modeling. Currently, there is not an instrument available that measures students' self-efficacy as it relates to three-dimensional modeling. Based on Bandura's Social Cognitive Theory, self-efficacy is a construct that has been measured in education for the last forty years (Bandura, 1977). Those familiar with measuring this construct are aware of its domain specificity. Bandura (2006) argues that, "there is not all-purpose measure of perceived self-efficacy" (p. 307). Sherer et al. (1982) offers that self-efficacy has been primarily thought of as a task-specific belief. Hence, in order to effectively measure self-efficacy as it relates to three-dimensional modeling, a scale must be developed specifically related to this domain. This approach is support by Sherer et al. (1982) who asserts that when dealing with specific behaviors, more direct behavioral measures will increase the accuracy of the measurement. Bandura (2006) helps bring this point home by proffering that self-efficacy scales must be tailored to activity domains in order to assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain. In this study researchers present the results of a pilot study conducted for the purpose of testing the reliability of a scale design to measure students' self-efficacy as it relates to three-dimensional modeling.

There was one research question guiding this study;

1. Is the newly developed instrument for measuring students' self-efficacy as it relates to three-dimensional modeling a reliable instrument?

To answer this question researchers tested the newly developed self-efficacy instrument with middle school and high school students. In the next section, the researchers pres-

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ent a literature review in an effort to situate this study within context of the most current literature on self-efficacy and measuring three-dimensional modeling.

Literature Review

Self-Efficacy

Self-efficacy refers to the confidence in one's ability to successfully complete a given task in order (Bandura, 1977, 1997). Self-efficacy is rooted in Social Cognitive Theory, which holds that knowledge acquisition is directly related to observing others within their context of social interactions, experiences, and outside media influences (Bandura, 1988). A student's self-efficacy levels help mediate their behavior. Their behavior, in-turn, influences their academic outcomes. Self-efficacy is also of importance due to its ability to be a powerful contributor to students' decision to choose a career in the STEM fields as well as a predictor for success in these fields (Zeldin, 2008).

Self-efficacy has also been shown to be positively associated with performance among engineering graphics students (Metraglia, Villa, Baronio, & Adamini, 2016), and has been identified as having a significant impact on the educational outcomes and persistence in academic settings (Bandura, 1997; Lent, Brown, & Larkin, 1984; Pajares, 1996). Self-efficacy has also been shown to be a predictor of achievement and persistence among engineering students (Loo & Choy, 2013; Ponton, Edmister, Ukeiley, & Seiner, 2001). In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains has been found to increase the self-efficacy beliefs of engineering students significantly and, by extension, their choices to pursue and persist in engineering careers (Fantz, Siller, & Demiranda, 2011).

There is a growing body of evidence that self-efficacy plays a significant role in predicting student outcomes and persistence in engineering education classes. In a pair of studies, (Lent, Brown, & Larkin, 1986) found associations between self-efficacy and academic outcomes. In the latter study, the use of hierarchical regression analysis suggested that self-efficacy beliefs contributed a significant amount of unique variance toward the prediction of student academic outcomes (Lent et al., 1986). In the 1986 study, two different self-efficacy scales were used with one being general and the other domain-specific. These two scales were not significantly intercorrelated supporting the contention that assessments be domain-specific and have clear construct validity (Bandura, 2006). Vogt, Hocevar, & Hagedorn (2007) also confirmed previous research findings that self-efficacy levels are strongly associated with academic outcomes.

In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains has been found to significantly increase the self-efficacy beliefs of college engineering students and, by

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extension, their choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011). The greatest contributing factor to a student's self-efficacy levels are mastery experiences (Bandura, 1997) which engineering graphics courses provide opportunity for through hand-on experiences and project-based assignments. Research has consistently supported the assertion that in order to have to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Lent et al., 1986; Zimmerman, 2000).

In engineering education, a student's self-efficacy levels have been demonstrated to be a predictor of achievement and persistence (Loo & Choy, 2013). In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains has been found to significantly increase the self-efficacy beliefs of college engineering students and, by extension, their choices to pursue and persist in engineering (Fantz, 2011). The greatest contributing factor to a student's self-efficacy levels are mastery experiences (Bandura, 1997) which engineering graphics courses provide opportunity for through hands-on experiences and project-based assignments. Research has consistently supported the assertion that in order to have to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Lent, 1994; Sherer, 1982).

Three-Dimensional Modeling

The development of a scale to measure self-efficacy must clearly define its respective domain; in this case three-dimensional modeling. Students most often encounter modeling in engineering design challenges through hands-on experiences. Often, this end product is modeled before final production for testing and evaluation commences. A model can be a tangible prototype, simulation, or procedure. This study is concerned with graphical model representations. It is vital that this study clearly differentiates graphical modeling from other forms of modeling. A graphical model is principally representational. This particular model is usually shared among design team members in order to solidify the details of the design. This design will take on dimensions and interfaces will be defined. At this point in the design process feasibility is often determined. Therefore, this model contains dimensions, clear specifications, and more accuracy. This model may be termed hard-lined, as it is more concrete in its form (MacDonald, Gustafson, & Gentilini, 2007). A graphical model is one that is typically — though not always — generated with some form of software on a computer. This allows for simulation and testing transitioning into other models for analysis.

Although scales for self-efficacy exist for engineering and engineering education, there are currently no existing domain-specific scales for engineering graphics or three-dimensional modeling. To this end, we are concerned with students' ability to model objects in a three-dimensional space and the development and psychometric analysis of a domain-specific instrument intended to measure three-dimensional modeling self-efficacy.

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Methods

The survey instrument framing this study was developed by modifying and building upon instruments used in prior studies. Specifically, the scale was grounded in the work of Bandura, especially his "Guide for Constructing Self-Efficacy Scales" and his Self-Efficacy Beliefs of Adolescents (Bandura, 2006). The format of the instrument used in this study closely resembles the evaluation survey created by The New Traditions Project. Marat (2005) developed an instrument that measured mathematics self-efficacy for students learning in a multicultural environment of which the results are provided in *Assessing Mathematics Self-efficacy of Diverse Students from Secondary Schools in Auckland*. Using existing questionnaires and literature that examined the intended constructs, an instrument was drafted by the researchers.

In this instance, it was necessary to modify questions so that they related specifically to the modeling of three-dimensional objects, which was a focus of the instrument. In order to achieve face validity for self-efficacy scales, Bandura (2006) contends that self-efficacy scales should measure what they purport to measure. Face validity was seen as an appropriate method of validity and is viewed as a proven measure of the quality of a test and can be verified statistically (Bandura, 2006). The face validity, which details a scale's adherence to a cogent construct, is achieved only after a reasonable level of agreement exists among raters (Nevo, 1985). Researchers for this study collaborated with subject matter experts (SME) in graphics communication at a research one institution in an effort to modify the existing items to better measure the desired construct. It is imperative that researchers secure SMEs with similar backgrounds and more importantly, a displayed expertise in the domain of functioning.

Researchers were able to secure three experts in the field who each touted over a decade of experience in teaching engineering design graphics at the secondary and tertiary level, experience designing state curriculums focused on engineering design graphics and experience in designing and validating psychometric scales. Each expert reviewed the formative instrument individually and provided comments in regards to the appropriateness of the items as they related to the construct of interest. Items that were considered problematic and did not achieve face validity were removed or revised based on recommendations from the SEMs. The final instrument was returned to the experts for their final approval. The resulting instrument, according to face validation, measured the desired constructs that framed this particular study. The final instrument was not decided upon until consensus had been met amongst the subject matter experts and the researchers.

Pilot Test

Participants were 101 middle school and high school students who were participating in a mathematics, science, and engineering Summer camp held at a research-intensive

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university in the Southeast. The results reported are from 91 participants. Ten (10) of the surveys collected were deemed invalid and were not used in the study.

Results

The resulting instrument was a nine-question questionnaire that was devised to measure students' self-efficacy as it relates to modeling three-dimensional objects (see appendix). Each question was a 7-point Likert type item from "highest level of agreement" to "lowest level of agreement." In order to understand whether the questions all reliably measure the same latent variable (self-efficacy to model three-dimensional objects), Cronbach's alpha was run as a test of internal consistency.

The reliability of the test was evaluated using Cronbach's alpha statistic. Stability, based on test-retest, indicates the degree to which scores on the same instrument are consistent over time. To evaluate the reliability coefficient the scores of the pilot test were correlated. Values ranging from 0.70 to 0.95 are considered to be sufficient to consider an instrument reliable (Drost, 2011).

Results from reliability tests yielded a Cronbach's Alpha of .7 or higher for all nine (9) items in the self-efficacy survey and the overall Cronbach's Alpha for the scale is .815 indicating a high level of internal consistency.

Table 1
Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Square Multiple Correlation	Cronbach's Alpha if Item Deleted
Q1	36.85	73.601	.451	.222	.804
Q2	37.12	69.302	.559	.488	.791
Q3	37.70	69.432	.586	.377	.788
Q4	37.09	70.414	.489	.332	.800
Q5	36.53	73.685	.464	.268	.803
Q6	37.33	68.638	.536	.508	.794
Q7	37.28	67.799	.655	.512	.780
Q8	37.43	68.615	.560	.408	.791
Q9	37.17	75.037	.330	.223	.819

Conclusions/Discussion

Spatial visualization is viewed by many in the engineering graphics community as the "most fundamental" aspect of engineering graphics communication (Katsioloudis, 2014). Subsequently, this suggests that the ability to model objects in a three-dimensional space particularly for students aiming to pursue careers in STEM areas is paramount.

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The research is clear when discussing the relationship between self-efficacy and students' participation in STEM related tasks however there is little to no research which looks at the relationship between students' self-efficacy and its relationship with student outcomes.

This research begins a thematic endeavor for the authors focused on the investigation of different methods of assessment for students in engineering graphics and visualization courses. To improve pedagogical practices within the classroom adequate measures must be developed in order to support teaching practices. The results from this study will inform further investigation into students' self-efficacy as it relates to three-dimensional modeling. The literature is demonstrative in its assertion that an instrument to measure self-efficacy would need to be domain specific (Bandura 1997, Sherer et al., 1982). Results from this study provided evidence that the scale developed was a reliable instrument. Further research includes targeting a larger sample population in an effort to perform an exploratory factor analysis on the eight remaining items.

The literature is replete with visualization tests for the measuring of students' three-dimensional modeling ability. Yet, little research links students' spatial visualization ability and their ability to persist, and complete a task. Self-efficacy has been shown to be a predictor of success and persistence in STEM fields, particularly for students from underrepresented populations (Zeldin, 2008). Designing experiences and activities that positively impact students' self-efficacy can potentially help attract underrepresented students to STEM areas. Yet, it is a nebulous task when attempting to determine experiences that positively impact students' self-efficacy. Developing measures that can accurately pinpoint and isolate this domain-specific construct will provide instructors with tools necessary for evaluating the value and impact of their lessons and activities. As instructors look for innovative ways of engaging their students, it may behoove of them to direct their attention to more affective measures.

Although the instrument was able to achieve face validity according to the SMEs, more nuanced investigations are needed in order to achieve content or construct validity. For self-efficacy scales to be effective it is imperative that they are domain specific. Bandura (2006) proffers that initially, self-efficacy scales should have face validity, but they should also display discriminant validity and predictive validity as well. Researchers suggest that self-efficacy beliefs should be distinguishable from related constructs such as self-esteem, and outcome expectations (Bandura, 2006). However, tests of this nature were outside the scope of this research study. In furthering the development of the self-efficacy scale, the researchers are interested in conducting an exploratory factor analysis in an effort to ensure the homogeneity of the constructed items.

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