spring 2018

volume 82 number 2

THE ENGINEERING DESIGN GRAPHICS Journal

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Table of Contents

Engineering Design Graphics Journal (EDGJ)
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ISSN: 1949-9167

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

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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.

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Message from the Chair

Robert A. Chin, EDGD Chair
East Carolina University

As I close out my tour as your 2017-18 Division Chair, please permit me to remind the Division we are 90 years old—Happy Birthday! According to the spring 1993, special edition issue of the *Engineering Design Graphics Journal*, the Division, as recounted and recorded by William B. Rogers, is 90 years old. Moreover, a transcript of the actions taken to approve the advancement of the Division from what was Committee #19, the Committee of Drawing and Design, can be found in the September 1928 issue of *The Journal of Engineering Education*.

Welcome to the new executive committee members: Nancy Study as the Director of Publications and Editor, *Engineering Design Graphics Journal* Editor; Heidi Steinhauer as the Vice-Chair; and Lulu Sun as the Chair, who rotates in from serving as the Division's 2017-18 Vice-Chair. Lulu and Heidi are Embry-Riddle Aeronautical University faculty members. So I wonder whether this portends the start of another dynasty such as those at Iowa State, North Carolina State, The Ohio State, and Purdue just to name a few.

A special thank you needs to be extended to Heidi Steinhauer for the work she did pulling our annual program together. Please add your thanks to mine when you get a moment.

Norma Veurink and Lulu Sun: thank you in particular for serving as effective bookends supporting me as I negotiated my responsibilities as Chair. Lulu, I hope I will be as supportive of your efforts when you assume responsibility as the Division Chair in June as you have of mine. While I got the basics done, I did neglect getting a few things done or at least started—specifically finding the 2017 ASEE Annual minutes, the disposition of the Orthogonal Medal, the grants Heidi Steinhauer started, and work on the Division by-laws—and that's on me. So, I guess Lulu will be assigning these to me as we get the new fiscal year started.

Regarding the by-laws, we haven't looked at them in over five years. So please consider this a call for assistance to do so. Members, especially new ones, please consider supporting this effort. The executive committee would like your input to leave the Division with up-to-date guidance and guidance that will help us negotiate the next five years. Yes, the membership gets to see them and vote on them before they're deployed.

(continued on page v)

ISSN: 1949-9167

Message from the Chair

(continued from page iv)

Thank you Ted Branoff for riding herd over the various site and program chairs for our annual and mid-year conferences. And thank you Diarmaid Lane for your service to the Division as our director of membership.

In June, Ted and Diarmaid begin their last year as our director of programs and director of membership respectively. Nominations and elections for the two directorships will take place at the end of 2018 and the beginning of 2019 in accordance with our by-laws.

Jennifer McInnis and Lulu Sun, thank you for your efforts as we proceed with the transition to the Division's new website. We're all looking forward with bated breath to its launching: about two months from what I understand.

And AJ Hamlin, our outgoing Director of Publications and *Engineering Design Graphics Journal* Editor, thank you, the reviewers, and your staff for your persistence in getting the second issue of volume 82 (2018) of the *EDGJ* published. It looks like we have the potential to get caught up in very short order given the number of manuscripts in the pipeline. I also understand that much of the credit for the high-quality product that's been produced is owed Nancy Study for bringing aboard Judy Birchman to assist.

Lastly, thank you all for the opportunity to have served.

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Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Message from the Editor

AJ Hamlin, *EDGJ* Editor
Michigan Technological University

This issue of the *EDGJ* is a special issue that contains select digest papers that were presented at the 72nd EDGD Midyear Conference, held in Montego Bay, Jamaica. Thank you to program chairs Sheryl Sorby and Mary Sadowski as well as the site chair Norman Loney for putting on a great event!

I wish to welcome Nancy Study as the Editor of *EDGJ* and Daniel Kelly as the Associate Editor! With Nancy's long history and involvement with the journal, I expect the journal to grow and flourish! As this is my last issue as Editor, I wanted thank everyone again for their support and contributions to the journal especially the Review Board, Raghu Pucha, Judy Birchman, Nancy Study, and Bob Chin for their continued service to the journal. Their help has been invaluable to getting each issue published.

I hope you enjoy this issue!

ISSN: 1949-9167

EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

73rd Midyear Conference – January 2019, Berkeley, California

Site Chair – Dennis Liu

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.

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

The Editor's Award

Congratulations!

Diana Bairaktarova
Virginia Tech

The volume 81 *EDGJ* Editor's Award recipient is **Diana Bairaktarova** of Virginia Tech for her article, "Coordinating Mind and Hand: The Importance of Manual Drawing and Descriptive Geometry Instruction in a CAD-Oriented Engineering Design Graphics Class." Their article was published in the Fall 2017 issue (Number 3)—see http://www.edgj.org/index.php/EDGJ/issue/view/173.

The Editor's Award recognizes the outstanding paper published in the previous volume of the *Engineering Design Graphics Journal* and includes a framed citation and a cash award, which are presented at the ASEE Annual Conference.

The award description can be found at:

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

The past awardees list can be found at:

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

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

The Oppenheimer Award

Oppenheimer Award Recipients

Thomas Delahunty, Lance C. Pérez, and **Presentacion Rivera-Reyes**

The 2017-2018 Oppenheimer Award recipients are **Thomas Delahunty, Lance C. Pérez**, and **Presentacion Rivera-Reyes** of the University of Nebraska-Lincoln for their presentation entitled, “Exploring the Role of Spatial Skill in Electrical Circuits Problem Solving.” Their paper can be found in the *EDGD 72nd Midyear Conference Proceedings* at http://edgd.asee.org/conferences/proceedings.htm

The Oppenheimer Award was established by Frank Oppenheimer to encourage the highest level of professionalism in oral presentations at the Engineering Design Graphics Division Midyear Meeting. This award is funded by a yearly cash award by the Oppenheimer Endowment Fund. The award was presented by Dennis Lieu, at the Awards Banquet of the 72nd Midyear Conference held in Montego Bay, Jamaica.

The award description can be found at:

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

The past awardees list can be found at:

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

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

The Media Showcase Award

Congratulations!

Media Showcase Award Recipients

O’Shane Thompson, Al-Raheem James, Deena-Kay Tomlinson, Ricardo Hunter, Jevais Sterling and Swain Mitchell

The 2017-2018 Media Showcase Award recipients are**, O’Shane Thompson, Al-Raheem James, Deena-Kay Tomlinson**, **Ricardo Hunter, Jevais Sterling and Swain Mitchell,** University of Technology, Jamaica.

The Media Showcase Award is given for he best presentation at the EDGD midyear conference. The EDGD media session is an interactive session at the Engineering Design Graphics Division Midyear Meeting which allows the authors to discuss their topics or demonstrate techniques. The session allows for one-on-one interaction with the audience using display boards and/or computer displays that allow for interactivity or on-screen displays. This format allows authors to display physical props or models that are not as effective in a larger group presentation. This award is funded by a yearly cash award by the Engineering Design Graphics Division.

The award description can be found at:

https://sites.asee.org/edgd/the-media-showcase-award

Engineering Design Graphics Journal (EDGJ)
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A Freshman Engineering Design Graphics Collaboratory

R. E. Barr
University of Texas at Austin

Abstract

This paper briefly reviews the author's experiences over the past four decades in transforming the Engineering Design Graphics (EDG) curriculum. During this time, the field has seen a remarkable evolution from manual drafting to 3-D computer modeling with its many applications to engineering design and analysis. The paper will further discuss the current status of the EDG curriculum at the author's home institution. The current concept is an EDG collaboratory space, in which teamwork and a design project are the overarching theme in which graphics and 3-D modeling fundamentals are taught.

Introduction and Background

Changes in the Engineering Design Graphics (EDG) curriculum over the last four decades have been driven by changes in technology. The drafting machine has been replaced by a computer, and the manual pencil and paper have been replaced by 3-D modeling software. Faculty were aware of solid modeling in the 1980's, but transitioning to solid modeling as the core topic in the EDG curriculum started to accelerate in the 1990's and beyond (Barr, et al., 1994; Ault, 1999; Branoff, et al., 2002; Bertozzi, et al. 2007). A logo shown in Figure 1a was developed to express the author's ideas at that time, and the logo has subsequently been translated into other languages as shown in Figure 1b (Borges and Souza, 2015).

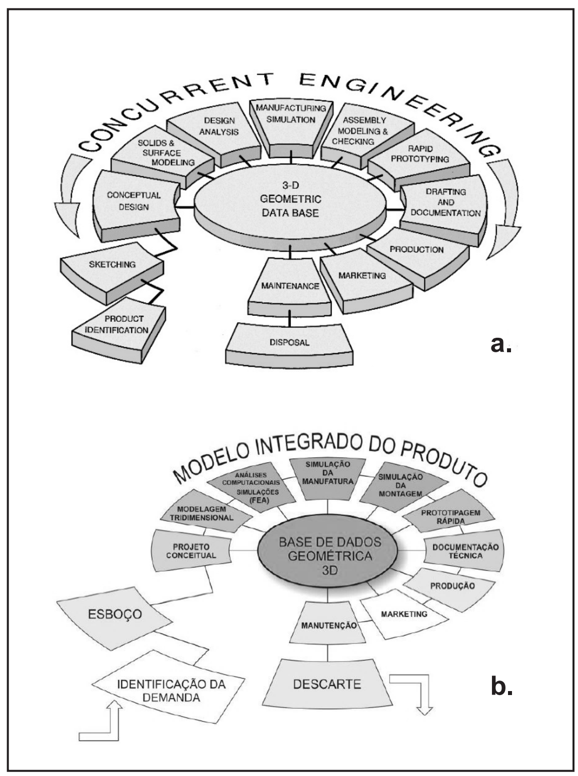

Figure 1. a. Logo to describe 3-D geometric modeling by Barr, et al. (1994) b. Logo translated into Portuguese by Borges and Souza (2015).

As the 3-D modeling paradigm took hold in engineering education, EDG faculty began exploring applications of the model to design projects (Smith, 2003), engineering analysis using finite elements (Balamuralikhrishna and Mirman, 2002; Groendyke and O'Dell, 2002), 3-D animation studies (Lieu, 2004), and 3-D rapid prototyping applications (DeLeon and Winek, 2000). These advances in 3-D geometric modeling further advanced the role of Engineering Design Graphics in

ISSN: 1949-9167

developing modern spatial skills (Sorby, 2005; Connolly, 2009) that are so important in engineering education today.

A triad schematic of the relation between graphics fundamentals, computer modeling fundamentals, and computer model applications has emerged as shown in Figure 2 (Barr, 2012). A group of EDG faculty are currently working to consolidate a graphics concept inventory (Sadowski and Sorby, 2014) which will greatly aid in determining the important graphics fundamentals that should remain in the EDG curriculum (top box of Figure 2).

Authors from Europe and the United States (Danos et al. 2014) recently coined a term "graphicacy," calling for a universal improvement in graphics capability for all students, thus extending EDG principles beyond engineering into everyday society. With the makerspace phenomena on campuses that is spanning all majors, along with the advent of low-cost 3-D printers and new forms of modeling software to run them, the thought of universal graphicacy in society may already be happening.

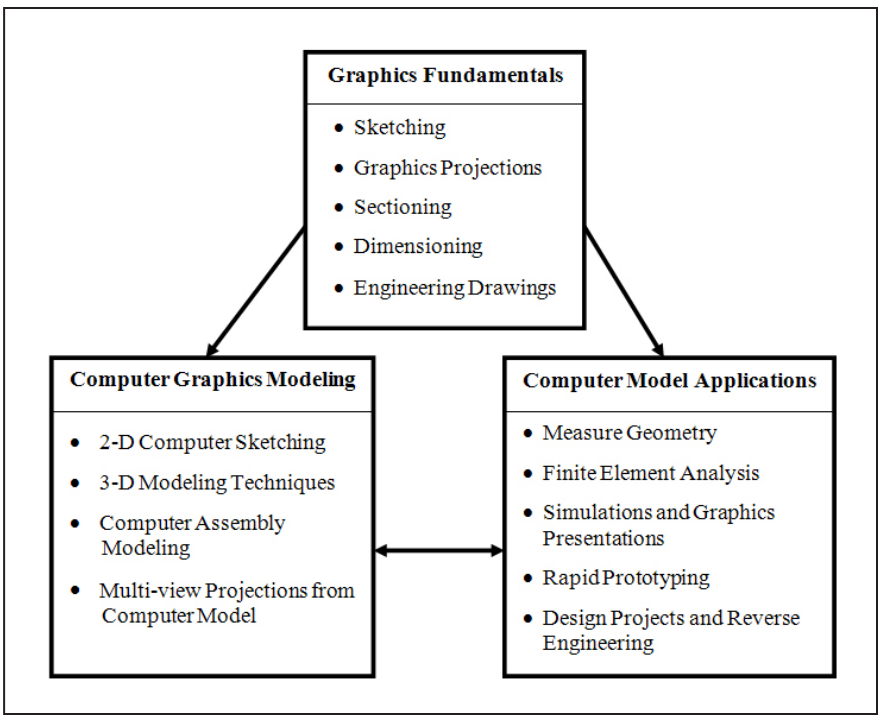

Figure 2. The Engineering Design Graphics Triad for Instruction (Barr, 2012).

Engineering Design Graphics Collaboratory

According to Wikipedia (Wulf, 1993) the word "collaboratory" is used to describe a creative process where a group of people work together to generate solutions to com-

Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

plex problems. In this context, by fusing two elements, "collaboration" and "laboratory", the word "collaboratory" suggests the construction of a space where people explore collaborative innovations. The current space used for Engineering Design Graphics at the author's institution is shown in Figure 3. Old drafting tables and front lecture dais were replaced with flat tables with four chairs surrounding each table, to enable students to interact face-to-face. The instructor's podium is in the middle of the room for facilitation, with projection systems on walls around the room to display key instructional concepts. The university-supplied computers were sent to surplus and replaced with student-supplied laptops running the latest version of SolidWorks. The use of teamwork and a reverse-engineering design project (Barr, et al. 2014) are the overarching theme in which the EDG triad of instruction (Figure 2) is delivered.

Most of our students are freshmen, and it is important to focus on creating an engineering design thinking mindset in the class. To accomplish this design thinking goal, the instructor discusses the four C's (Figure 4) in the context of design. The four C's are a different way of looking at the design process, while helping to develop the crucial inter-personal professional skills that are dearly needed in engineering.

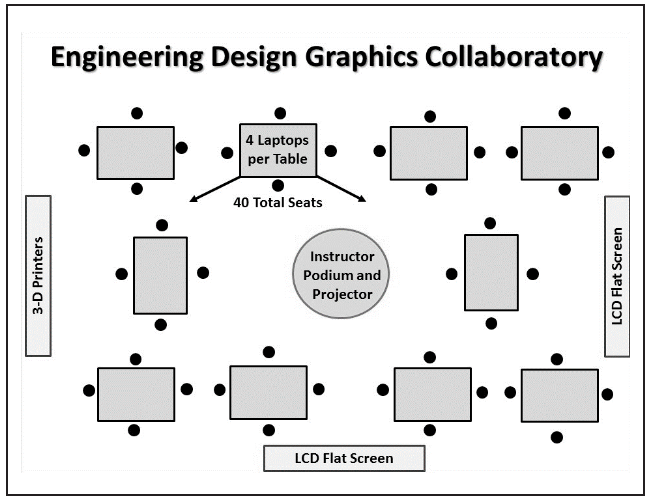

Figure 3. Layout for the EDG collaboratory.

Critical Thinking: You start as a freshman in engineering and in your first engineering course you learn that engineers solve problems. So you need to develop and use critical thinking.

Creativity: As you critically think about the problem, you will come up with many ideas for a solution, some perhaps good and others perhaps a little unusual. So you need to become creative in your thinking to expand the possibilities.

Collaboration: As you try to decide which ideas are best, you find the need to talk to other people about your ideas. Hence you need to collaborate and learn about teamwork to solve complex problems.

Communication: As members of your team start to talk to each other to explain their ideas with words, sketches, and computer images, you find out that effective communication is essential, and is the most important "C."

Figure 4. The Four C's are used to establish a design thinking mindset in the students.

Student Survey

This was the first academic year in which the Engineering Design Graphics course was taught as a collaboratory. The instructional triad shown in Figure 2 served as the

ISSN: 1949-9167

basis for the sketching, computer modeling, and design application exercises used in the course. A student survey of all the topics was conducted to gain feedback from the students. The survey asked students to rank the topics based on how helpful the activity would be in their future engineering career. The responses were on a seven-point Lickert scale, with 7 (extremely helpful), 4 (somewhat helpful), and 1 (not helpful at all). The results of the survey (N = 84) are shown in Table 1 for sketching exercises, Table 2 for computer exercises, and Table 3 for design project exercises. Not surprising, the highest ranked topics pertained to 3-D computer modeling using the popular software SolidWorks. Five of the ten computer topics received scores of 6.00 or higher. Some of the sketching exercises, and in particular isometric sketching, also received good scores. The students also liked the team design project, particularly the 3-D printing aspect of the project.

Discussion and Conclusion

It is gratifying to note that the relationship of graphics to engineering design was ranked very high (score of 6.19). The most important objective of the course was to transition from an historical drafting course, with one-hundred year roots on campus, to a design-centric course. Thus, showing how graphics can contribute to a design project is extremely important. Also, the lowest rated topic was the method of assigning teams (score of 4.79). Experienced faculty might think that using a personality-typing method, such as the MBTI, would be very useful in forming teams. However, these results disprove that thinking. As faculty, we must realize that college freshmen nowadays have other ways of intermixing, socializing, introducing themselves, and finding team partners. The MBTI is a foreign concept.

One final comment was offered by one of the students in the survey. It pertains to the perception that sketching and graphics fundamen-

Table 1
Graphics Fundamentals Through Sketching

Design Sketching: Visualization Techniques	**6.05**
Design Sketching: Isometric Views	**6.02**
Design Sketching: Section Views	**5.89**
Design Sketching: Dimensions	**5.87**
Design Sketching: Orthographic Multi-Views	**5.83**
Design Sketching: Sketching Lines	**5.77**
Design Sketching: Design Features and Modifications	**5.60**
Design Sketching: Oblique Views	**5.51**
Ave.	**5.82**

Table 2
3-D Computer Modeling Fundamentals

SolidWorks: Creating 3-D Parts and Features	**6.54**
SolidWorks: Creating Parts Using Extrusions, Revolutions	**6.52**
SolidWorks: Assembly Modeling and Mating	**6.45**
Loading and Using SolidWorks on Your Laptop	**6.15**
SolidWorks: Kinematic Animation	**6.10**
SolidWorks: Creating Section Views	**5.96**
SolidWorks: Dimensioning Layout Drawings	**5.95**
SolidWorks: Finite Element Analysis, Re-Design	**5.93**
SolidWorks: Mass Properties Analysis, Design Tables	**5.77**
Ave.	**6.15**

ISSN: 1949-9167

tals are less important now during this age of 3-D computer modeling. This student quoted: "The results of the survey will probably show that the class thinks the sketching assignments are less helpful for their careers. However, I believe that the sketching exercises helped me understand 3-D objects and made learning SolidWorks easier." Visualization is the key to good design work and team interaction, and the various forms of graphics projected in the course help to develop this visualization skill. As we move forward into the second year of the EDG collaboratory, student feedback like the ones presented here, will help to further shape and improve the curriculum.

Table 3
Application to Team Design Project

Relationship of Graphics to Engineering Design	**6.19**
Team Project: Printing Rapid Prototypes	**6.15**
Team Project: Oral Presentation	**6.01**
Introduction to Engineering and Teamwork	**5.96**
Team Project: Dimensioned Layout Drawings of Parts	**5.94**
Team Project: Computer Modeling and Mass Properties	**5.88**
Team Project: Final Written Report	**5.85**
Team Project: Project Re-Design	**5.81**
Team Project: Sketching Project Parts and Assemblies	**5.63**
Team Project: Written Proposal	**5.61**
Team Project: Planning Charts and Diagrams	**5.55**
Team Project: Materials and Manufacturing	**5.49**
The MBTI and Assigning Teams	**4.79**
Ave.	**5.76**

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ISSN: 1949-9167

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Adaptive Comparative Judgment for Polytechnic Transformation: Assessment across the Curriculum

S. R. Bartholomew and P. E. Connolly
Purdue University

Abstract

The authors are investigating potential applications of adaptive comparative judgment (ACJ) across numerous environments and learning scenarios within the Purdue Polytechnic Institute as part of Purdue's efforts to transform the undergraduate learning experience. Six courses or program areas were selected for the study, involving a wide variation in subjects, subject matter, and assessment artifacts. The authors anticipate that positive results from these pilot studies will encourage broader and deeper applications of ACJ in the Purdue Polytechnic, across Purdue University, and in other academic institutions. Results from these scenarios will be disseminated in future conferences and scholarly journals.

Introduction

Adaptive Comparative Judgment (ACJ) is rapidly becoming an assessment tool for educational evaluation and learning (Bartholomew, 2017; Bartholomew, Strimel, Yoshikawa, 2017; Hartell, 2015; Seery & Canty, 2017). In the Purdue Polytechnic College we see potential for broad, robust, and potentially-transformative applications of this assessment and learning technique. Previous research has demonstrated that open-ended assessment in STEM-related fields are uniquely situated for the application of ACJ (Kimbell, 2007, 2012a, 2012b).

The Purdue Polytechnic Institute houses six schools/departments consisting of more than 35 program areas. Five program areas or specific courses (shown below) will be piloting the use of ACJ for open-ended assessment and student formative feedback in a college-wide study. The use of ACJ for formative student feedback and assessment and summative project-based evaluation will specifically address the potential for transforming the assessment and learning culture in the Purdue Polytechnic.

Project Overview

The following paragraphs describe each program area or course and the accompanying study methods, design, assessment artifacts, stakeholders, and target outcomes.

Engineering/Technology Teacher Education

The Engineering/Technology Teacher Education department at Purdue University is primarily focused on training future secondary technology and engineering educators in integrated STEM content, pedagogical approaches, and learning theories. Students work in problem-based learning classrooms to develop their content knowledge while applying their learning to classroom applications for secondary students. ACJ will be used for open-ended problem assessment and learning in the core content areas of

ISSN: 1949-9167

the Engineering/Technology Teacher Education program. Students will use ACJ to formatively assess their own, and peer, projects both providing and receiving feedback throughout. This exposure to fellow-student work and the opportunity to differentiate between quality in open-ended design scenarios has already shown promising in terms of student achievement (Bartholomew, Strimel, & Yoshikawa, 2017).

Computer Graphics Technology 11800 - Fundamentals of Imaging Technology

This freshman course provides a foundation for the development and use of raster and vector images for a variety of industries. Full-color images and illustrations are produced using computer technologies, with a focus on both technical and aesthetic aspects. Topics include color theory and perception, surface and lighting analysis, rendering techniques, and technical characteristics.

There will be approximately 50 students in this course using ACJ as part of this study. Four projects will be assessed throughout the semester (approximately 200 artifacts in total) consisting of several file types including PDF, PNG and JPG. The ACJ judges will be the students, instructors, and course teaching assistants. In addition to using ACJ for formative and summative feedback, the resulting rank orders from the students, teaching assistants, and instructors will be compared to identify potential areas of misalignment and necessary emphasis.

Game Development and Design

The Game Development and Design program is designed to produce career-ready graduates who know how to prototype games and game systems and who can evaluate their impact on society. Research areas include the use of games for sustainable energy, therapy and medicine, entertainment, and information visualization. Students take classes in video game design and development, animation, visualization, rendering and programming. As part of this study, students in the Game Development and Design capstone course will be utilizing ACJ for project portfolio assessment in both formative and summative scenarios. Approximately forty students, as well as faculty and industry sponsors, will be acting as ACJ judges for this course. The resulting rank orders will be used to inform both teaching and learning practices.

Transdisciplinary Studies in Technology

The Transdisciplinary Studies in Technology (TST) program is a unique open-ended and competency-based program that enables students to personalize their plans of study by blending areas such as technology, business, and humanities. The emphasis is on hands-on, team-based projects focusing on real world problems. The environment combines individualized learning combined with close mentoring by faculty experts, with resultant artifacts such as an electronic portfolio which documents student ability and mastery of subjects. Approximately 25 students will be using ACJ in formative and final assessment of their portfolios in multi-level (freshman to senior) studio and portfolio

ISSN: 1949-9167

courses. Judges will be the students, their faculty mentors, and invited outside faculty and industry stakeholders. The resulting rank orders will be used to inform competency-based credentialing for the course and student progression.

Theater 35300 - Theater Audio Techniques I

This course (taught in the College of Liberal Arts by a Purdue Polytechnic faculty member) emphasizes a theoretical and practical study of the technical aspects of audio as they relate to theatre. Topics include audio specifications, layout and installation techniques, operation, and maintenance of theatre sound systems. For this study, approximately 18 students (juniors, seniors, and graduate students) will use ACJ for analyzing team projects related to intelligibility under different reverberation times, loudspeaker system design, and CAD drawing layout of physical audio plans.

Design Thinking (Freshman Experience)

Students enrolled in the Design Thinking Freshman Experience course work in teams to solve real-world grand challenges. These open-ended problems, which require creativity, innovation, and teamwork to solve, are framed around design thinking and students work to produce portfolios which demonstrate their mastery of the design process. Students enrolled in these courses will use ACJ as a brainstorming and formative assessment tool throughout the course; as students embark on challenges they will also act as judges in an ACJ session comprised of hundreds of past student projects. This exposure, and opportunity to act as a judge between quality of work, will assist and shape student design thinking and abilities throughout the course.

Conclusion

The goal of this cross-curriculum research study is to test the efficacy and practicality of adaptive comparative judgment (ACJ) as an assessment tool for open ended problem sets across numerous scenarios in technology related environments. The wide variety of variables that are involved include subject matter differences, multiple stakeholders (students, faculty, industry partners), multiple grade levels (freshman to graduate level), artifact types/scope (assignments, projects, portfolios), ACJ purpose (formative learning tool, summative evaluation tool, etc.), individual or team projects, and number of ACJ applications per subset group.

It is expected that the study will yield results that validate the use of ACJ across many environments and scenarios in higher education as both a learning and assessment methodology. Future plans include broader applications of ACJ university-wide at the authors' home institution, and additional collaborative studies at partner institutions. In parallel with this study, the authors are involved in other related research at both the national and international level, highlighting the growing interest in ACJ as a powerful educational resource. Results of this study will be disseminated at multiple conferences and in journals in the technology and education areas.

ISSN: 1949-9167

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Integrating Assessment and Design Activity in Engineering Education: A Proposed Synthesis of Adaptive Comparative Judgement and the CDIO Framework

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Abstract

One of the leading frameworks in engineering education specifically associated with design based competencies is the CDIO framework. This has been incorporated internationally into many institutions offering engineering education courses. Characterized by four unique stages, the CDIO framework affords an ideal scenario to incorporate a continuous assessment model. This paper presents a proposed synthesis between CDIO and Adaptive Comparative Judgement (ACJ). In particular, the opportunity to provide feedback through the ACJ system is theorized to have potentially positive educational effects. As part of a larger study, this approach is in the process of being refined prior to implementation as a pilot study for feasibility which will ultimately be succeeded by large-scale implementation to determine any potentially positive effect sizes.

Introduction

Educational assessment is complex. There are a variety of approaches to assessment such as summative, normative and ipsative, and there are a variety of functions of assessment such as to provide feedback to learners, to act as a diagnostic tool to inform educators, and to serve as a matriculation system for further education. Not only is assessment complex, but it both directly and indirectly through associated actions such as feedback has a high effect size on learning (Hattie, Biggs, & Purdie, 1996; Vaessen et al., 2017). The effects of assessment from both pedagogical and psychological perspectives are well documented with notable attributes being affected such as the learning process (Hattie & Timperley, 2007), assessment related anxiety (Huxham, Campbell, & Westwood, 2012), self-esteem (Betts, Elder, Hartley, & Trueman, 2009), and approaches to learning (Reeves, 2006). It is therefore critical that educators are able to negotiate this space strategically to ensure the educational needs of learners are met without inducing any potential negative outcomes.

One commonly used method to alleviate some of these negative effects created through assessment processes is the adoption of a continuous assessment model (Holmes, 2014). Through the removal of a terminal examination, or at least through the reduction of its weight on overall performance, the pressures perceived by some learners can be

  ISSN: 1949-9167

reduced. There is also comfort in knowing that previous work completed to a perceived high standard is contributing to an overall grade or that future elements of continuous assessment mechanism can reconcile performance perceived to be below a desired standard. Additionally, assessment can be incentivized through the provision of feedback which can positively affect learning gains (Black & Wiliam, 1998) and, if synthesized appropriately into a continuous assessment model, can support student integration into the assessment process further facilitating positive educational outcomes (Nicol & Macfarlane-Dick, 2006). A key goal of the formative process is to advance the learning of the student. Yorke (2003), Orsmond et al. (2000) and Sadler (1998; Sadler 2009), and Black and Wiliam (1998) present the teacher, peers and the student themselves as potential contributors to the formative assessment process and outline the importance of strategic planning for the integration of formative assessment into any learning activity. Black and Wiliam (1998) portray the effectiveness of formative assessment as being dependent on the quality of feedback and the interaction between student and assessor thus highlighting the need for the learner to develop knowledge and skills in the assessment domain. This practice of engaging students with formative assessment cannot be left to chance and therefore learners must be inducted into the process of assessment as learning, developing skills and capacities that are required to be able to function effectively in this space. Failing to recognize this aspect of learning can render even the best teacher/peer feedback as little more than just summative marks or comments on a page. The process of giving and receiving feedback is presented by Nicol & Macfarlane-Dick (2006) and Nicol (2010) as having a significant impact on learners being able to monitor, evaluate and regulate their own learning developing their capacity to make evaluative judgements both about their own and that of others (Boud and Associates, 2010; Sadler, 2009). With the recognition of the positive role assessment can play in the learning process this paper presents an approach to integrating assessment in the CDIO approach in engineering education.

The CDIO Framework for Design in Engineering Education

Not only is the design of an assessment mechanism complex, but it must align appropriately with the evidence that learners create to demonstrate a level of competency. Competencies, broadly defined as an amalgam of cognitive, affective, motivational, volitional, and social dispositions underpinning performance (Shavelson, 2013), are recognized as discipline specific (Zlatkin-Troitschanskaia, Pant, & Coates, 2016) and therefore the context and associated 'content' which forms the basis of a learning experience must be thoroughly understood. The context for which an assessment mechanism is presented for in this paper is design in engineering education. Specifically, the CDIO framework as a model for design in engineering education will be discussed.

Crawley, Malmqvist, Östlund and Brodeur (2014, p.1) define the purpose of engineering education as being "to provide the learning required by students to become successful

ISSN: 1949-9167

engineers – technical expertise, social awareness, and a bias toward innovation". In response to this, they developed the CDIO framework consisting of four stages or activities of the engineering lifecycle which include conceiving, designing, implementing, and operating a design solution (Table 1)

Table 1
Descriptions of CDIO stages (Crawley et al., 2014)

Conceive	Defining customer needs, considering technology, enterprise strategy and regulations, and developing conceptual, technical and business plans
Design	Creating the detailed information description of the design; the plans, drawings and algorithms that describe the system to be implemented
Implement	Transforming the design into the product, process or system, including hardware manufacturing, software coding, testing and validation
Operate	Using the implemented product, process or system to deliver the intended value, including maintaining, evolving, recycling and retiring the system

Under the belief that every graduating engineer should be able to conceive, design, implement and operate complex, value-added, engineering products, processes and systems in a modern, team-based environment, Crawley et al. (2014) designed the CDIO approach with three overall goals: These include educating students who are able to:

1. Master a deeper working knowledge of technical fundamentals
2. Lead in the creation and operation of new products, processes, and systems
3. Understand the importance and strategic impact of research and technological development on society

A critical aspect of the CDIO framework is that despite being designed specifically for the context of engineering education, it is applicable in a broader remit of design education contexts. Arguably, any 'design and make' type task could adopt the CDIO framework, or at least a modified version of it. One of the characteristics of the CDIO framework which makes it so beneficial for engineering design education is the potential that having defined phases affords for assessment practices. As previously discussed, continuous assessment has the potential to alleviate many negative consequences which are created through traditional or terminal assessment practices. It is therefore postulated that incorporating an assessment mechanism which can be used, both validly and reliably, to evaluate the often ill-defined and innovative outputs characteristic of design tasks in education at each stage of the CDIO approach could present a peda-

ISSN: 1949-9167

gogical model with the potential to positively impact students' learning and educational experiences in engineering education and related disciplines. It is also proposed that the involvement of learners in their own assessment has potential in group situations within the CDIO paradigm where soft skills such as leadership and teamwork can be difficult to identify and evaluate by conventional assessment instruments.

Adaptive Comparative Judgement and CDIO: A Proposed Synthesis

The use of Adaptive Comparative Judgement (ACJ) (Pollitt, 2012b) as a method of assessment has been proven to be both valid and reliable in the assessment of design based competencies (Kimbell, 2012; Pollitt, 2012a, 2012b; Seery & Buckley, 2016; Seery, Canty, & Phelan, 2012, Ryan et al. 2017). Based on Thurstone's (1927) *Law of Comparative Judgement*, assessment is carried out by a group of 'judges' making binary decisions on of quality of work evidenced in multiple pairs of portfolios. From a pedagogical and assessment perspective, the use of students as judges has many advantages. Students have been shown to make judgments on quality which align with those of professional educators (Cheung-Blunden & Khan, 2017). Additionally, by incorporating learners into the assessment process they receive immediate feedback on the quality of their work in comparison to their peers. As this is unarticulated, students must develop self-regulatory skills as well as self-appraisal skills in their interpretations of quality. Finally, the ACJ system prompts judges to give feedback on each portfolio they judge. This request sees learners having to articulate their opinions on quality supporting the formulation of their own constructs of capability and also provides a wealth of peer feedback associated with each portfolio which can be made accessible. In addition to being an assessment tool the ACJ process also has statistical data output that can indicate the degree of consensuality of the judges within the decision making process. The ACJ system can record if a judge is at variance with the other judges within the group. A judge outside of acceptable parameters (set by the teacher/awarding authority) is a cause for concern but can now be identified and an appropriate intervention can be actioned. A similar set of statistics is generated for the portfolios that identify work where there was a significant level of disagreement between the judges. Both of these statistics present the opportunity to analyse where there is and is not consensus providing opportunity for analysis, discussion and intervention for those involved in the CDIO process.

Ultimately, this approach has not yet been explored however there are many foreseeable merits which could be achieved through its incorporation into practice. The current proposal is to integrate ACJ within CDIO by hosting a judging session after each stage of the CDIO framework. These sessions would be externally moderated to identify any potential outliers and to screen peer feedback prior to making it available to students. It is well known that students welcome feedback provided it is appropriate and timely, and that continuous assessment has certain advantages. It is hypothesized that incorporating these elements through the synthesis of ACJ and CDIO will have a positive

ISSN: 1949-9167

effect of learning. The next stage of this agenda is to pilot this approach in practice as a feasibility study and to refine associated research questions and hypotheses, which will ultimately be result in the generation of empirical evidence associated with learning effect sizes.

Note: A previous version of this paper was presented at the presented at the 72nd ASEE Engineering Design Graphics Division Midyear Conference Proceedings, Montego Bay, Jamaica, with the title "Assessing Design Activity in Engineering Education: A Proposed Synthesis of Adaptive Comparative Judgement and the CDIO Framework".

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Relationships between Spatial Visualization Ability and Student Outcomes in a 3D Modeling Course

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Abstract

The impact of spatial visualization ability on student outcomes in a freshman-level, 3D modeling class is explored by analyzing connections between students' spatial ability pre- and post-test scores, course grades, and self-reported difficulty of an assignment. Analysis of the results indicate that spatial visualization ability, as measured by the post-test, is strongly correlated with perceived difficulty, exam grades, and overall course grade. Students' spatial visualization scores increased over the semester by an average of 9.4%; however, students with low spatial visualization ability underperform compared to their peers.

Introduction

At Northern Arizona University, the primary engineering graphics course in the mechanical engineering department, ME180: Computer-aided Design, focuses on the use of SOLIDWORKS and does not include activities intended to directly improve spatial visualization. Although spatial visualization ability is expected to impact performance in such 3D modeling courses, there are few studies showing this link. Hamlin, Boersma, and Sorby (2006) found a strong correlation between visualization ability and performance in a 3D modeling class, but students' performance was measured by survey results, not course grades. Branoff and Dobelis (2012) found a correlation between spatial visualization test scores and grades on a single 3D modeling assignment but did not evaluate correlations with other course grades.

Several previous studies (Sorby & Baartmans, 2000; Ault & John, 2010; Islam, Russ, & White, 2013; Study, 2006) have shown clear improvement in spatial visualization ability from 2D engineering graphics classes, but out of the few studies examining the effectiveness of 3D CAD courses (Sorby, 1999; Rodriguez & Genaro Rodriguez, 2016; Connolly, 2009), only Connolly found a statistically significant increase in spatial visualization ability. In this paper, we compare average pre- and post-scores on a spatial visualization test and examine if students' spatial visualization ability is connected to confidence in completing course assignments and success in the course.

Methods

The data for this study was gathered in spring 2017 from three sections (out of six sections total) of ME180, taught by two different instructors. A total of 57 students were

enrolled in these three sections. The students were predominately white/non-Hispanic (52% out of 42 students who reported race/ethnicity) but there was a significant population of Middle Eastern international students (17%) and other minority students (31%). Every week consisted of a 1.5-hour lecture and a 1.5-hour lab. Although the focus was on learning SOLIDWORKS, one week was dedicated to orthographic projections, including sketching exercises. To measure spatial visualization ability, the 30-question Purdue Spatial Visualization Test: Rotations (Guay, 1977), or PSVT:R for short, was administered during the first and last week of the course, with a 20 minute limit.
To assess students' perceptions about the difficulty of a typical homework assignment, a survey (Figure 1), based on that of Hamlin et al. (2006), was administered. The assignment involved reading an engineering drawing, modeling the corresponding 3D object, and creating a drawing for the object in SOLIDWORKS. Students were asked to fill out the optional survey after completing the assignment, which was assigned in the last two weeks of the semester.

1. Before this class, what was your previous 2-dimensional CAD experience?
   Expert user (1) Competent (2) Familiar (3) Very little (4) No experience (5)
2. Before this class, what was your previous 3-dimensional CAD/solid modeling experience?
   Expert user (1) Competent (2) Familiar (3) Very little (4) No experience (5)
3. How did you feel when you started work on the assignment?
   Confident (1) Not worried (2) A little worried (3) Quite worried (4) Overwhelmed (5)
4. How much did you struggle with planning the steps you used to create the object?
   Not at all (1) Very little (2) Some (3) Considerable amount (4) A lot (5)
5. How much did you struggle with the software itself, i.e., having the software do what you thought it should?
   Not at all (1) Very little (2) Some (3) Considerable amount (4) A lot (5)
6. How much time did you spend planning and creating the part for this assignment?
   <20 min (1) 20-40 min (2) 40-60 min (3) 1-2 hrs (4) >2 hrs (5)
7. How much time did you spend creating the engineering drawing for this assignment?
   <5 min (1) 5-10 min (2) 10-15 min (3) 15-20 min (4) >20 min (5)
8. Did you find this assignment difficult?
   Yes No
9. We have encouraged you to ask for help on individual homework assignments when necessary. This help can be from another student, your TA, or your instructor. How much help did you receive from another person(s) in completing this assignment?
   None (1) Very little (2) Some (3) Considerable amount (4) A lot (5)
10. In comparison to your classmates, how easy was it for you to learn SOLIDWORKS?
    Much easier (1) Slightly easier (2) Average (3) Slightly harder (4) Much harder (5)

Figure 1. Survey questions, responses, and response scores.

ISSN: 1949-9167

The correlation between survey results and PSVT:R scores was calculated using Spearman's rank correlation coefficient, r_s, due to the presence of ordinal variables and outliers in the data (Rice, 2007). Spearman's correlation coefficient was also calculated between PSVT:R scores and homework, both exams, and total course score (a weighted sum of attendance, homework, and exam scores). To test the hypothesis that the post-PSVT:R scores would be greater than the pre-PSVT:R scores, a sign test was used, because the data was paired but the distribution was not symmetric. The effect size for the change between pre- and post-scores was calculated using Cohen's *d* (Sullivan & Feinn, 2012). All statistical analyses were implemented in MATLAB.

Results

47 students (11 female) took both the pre- and post-PSVT:R. Scores are shown in Figure 2.

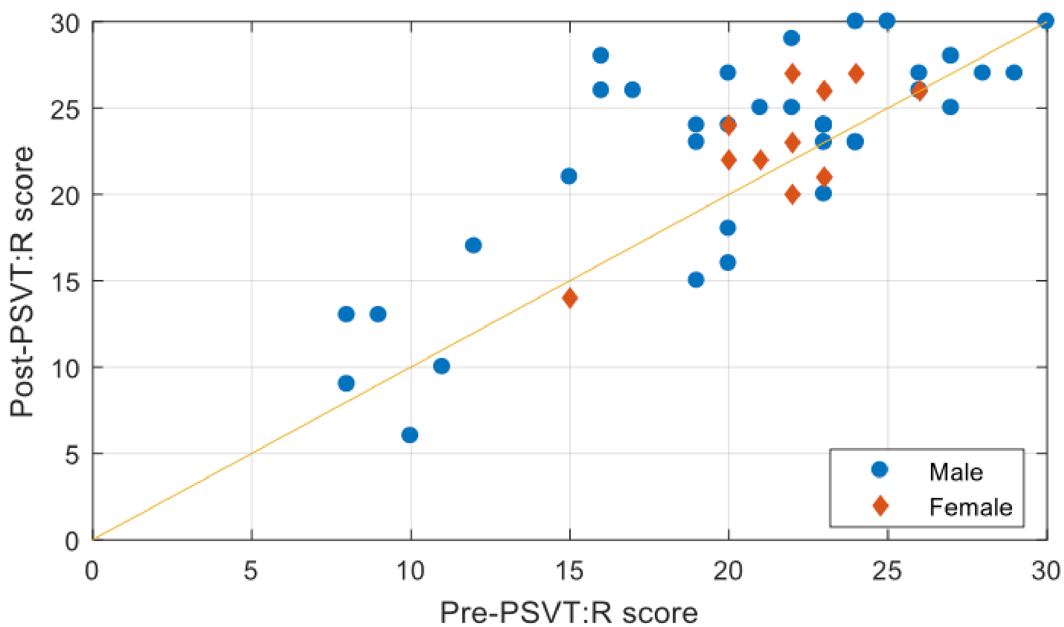

Figure 2. PSVT:R scores. Data above the x=y line indicates an increase in score.

For pre-scores, the average was 20.57, the median was 22, and the standard deviation was 5.37. For post-scores, the average was 22.51, the median was 24, and the standard deviation was 5.72. The increase in average and median scores between the pre-and post-test was 1.94 and 2 points, respectively. We found a statistically significant increase in the median scores from the pre- to post-test (p-value of 0.02 calculated from a sign test). The magnitude of this increase was small to moderate (effect size of 0.36).

Pre- and post-scores of the students were examined to find relationships with students' homework, exams, and total course scores using Spearman's correlation coefficient.

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ISSN: 1949-9167

The post-scores were strongly correlated with both exams and the total course scores, while the pre-scores were only strongly correlated with exam 1, as summarized in Table 1.

Table 1
PSVT:R score correlations (bold indicates statistical significance p<0.05).

	Pre-PSVT:R	**Post-PSVT:R**
Homework	r_s=0.00 (p=1)	r_s=0.24 (p=0.1)
Exam 1	**r_s=0.51 (p=0.0002)**	**r_s=0.61 (p=0.00001)**
Final exam	r_s=0.20 (p=0.2)	**r_s=0.49 (p=0.0004)**
Total course score	r_s=0.22 (p=0.1)	**r_s=0.48 (p=0.0006)**

The total course scores were only weakly correlated with the pre-scores but were strongly correlated with the post-scores. These relationships can be seen graphically in Figure 3.

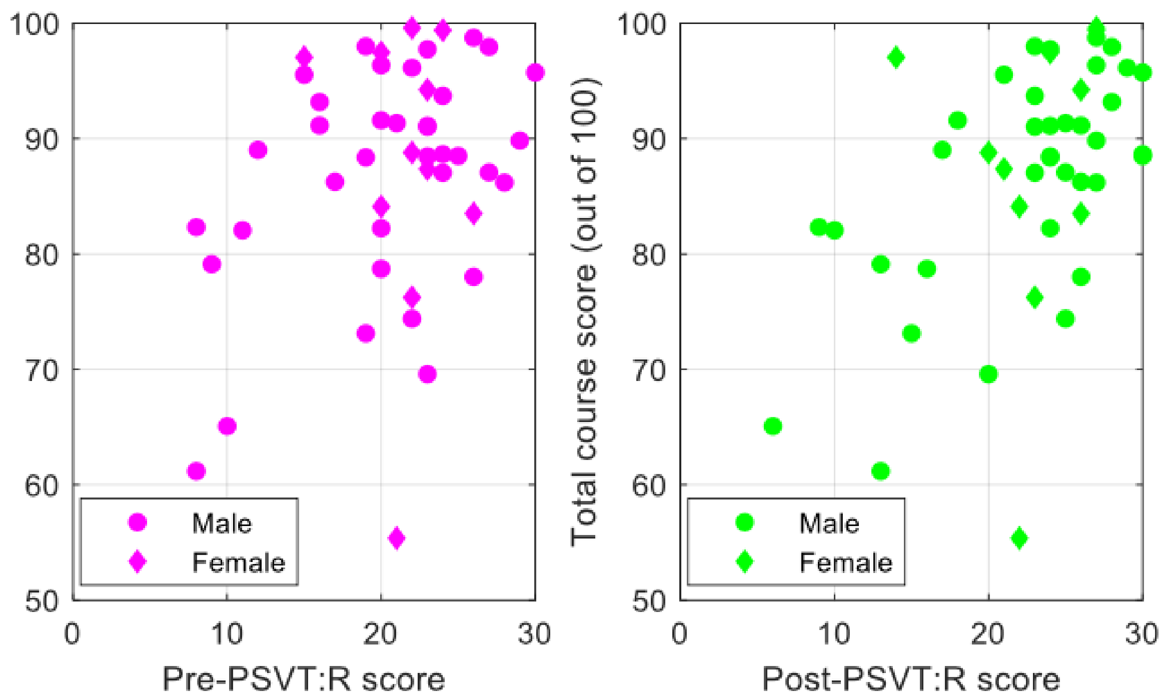

Figure 3. Relationship between PSVT:R scores and total course scores.

ISSN: 1949-9167

Post-scores were also found to be correlated with students' confidence on the homework assignment, as measured by the survey, which was completed by 29 students. We did not identify any statistically significant correlations between the survey responses and the pre-scores. These results are summarized in Table 2. An "average perception," calculated by averaging scores for questions 3, 4, 5, 9, and 10, was found to be strongly correlated with post-scores. Negative correlation coefficients indicate that students with low PSVT:R scores reported a higher level of difficulty.

Table 2
Survey questions and their correlations with PSVT:R scores.

	Pre-PSVT:R	**Post-PSVT:R**
1. Prior 2D CAD experience	r_s= 0.26 (p=0.2)	r_s= 0.07 (p=0.7)
2. Prior 3D CAD experience	r_s= 0.08 (p=0.7)	r_s= - 0.08 (p=0.7)
3. Confidence in starting assignment	r_s= - 0.17 (p=0.4)	**r_s= - 0.65 (p=0.0002)**
4. Ease in planning modeling approach	r_s= - 0.15 (p=0.5)	**r_s= - 0.45 (p=0.02)**
5. Ease of working with software	r_s= - 0.25 (p=0.2)	**r_s= - 0.59 (p=0.001)**
6. Time spent modeling part	r_s=0.06 (p=0.8)	r_s= - 0.15 (p=0.4)
7. Time spent creating engineering drawing	r_s=0.13 (p=0.5)	r_s=0.13 (p=0.5)
9. Amount of assistance required	r_s=0.12 (p=0.5)	**r_s= - 0.38 (p=0.05)**
10. Ease in learning compared to peers	r_s=0.02 (p=0.9)	r_s= - 0.3 (p=0.1)
Average perception (from questions 3, 4, 5, 9, & 10)	r_s= - 0.11 (p=0.6)	**r_s= - 0.61 (p=0.0006)**

Discussion

Analysis of the results showed an average increase in PSVT:R scores that was higher, but of similar magnitude, to that shown in previous studies, as summarized in Table 3.

Table 3
Average PSVT:R scores in CAD courses.

	Pre-PSVT:R	**Post-PSVT:R**	**Change in score (% improvement)**	**Source**
NAU	20.57	22.51	1.94 (9.4%)	
Purdue	23.83	25.30	1.47 (6.2%)	Connolly, 2009
MTU	22.80	23.49	0.69 (3.0%)	Sorby, 1999
WMU	22.43	24.07	1.64 (7.3%)	Rodriguez & Genaro Rodriguez, 2016

  ISSN: 1949-9167

It is difficult to determine the cause of this increase. Sorby, Drummer, Hungwe, and Charlesworth (2005) found that even students who were not enrolled in an engineering graphics class increased their average PSVT:R scores from 21.78 to 23.37 (7.3% improvement) over a semester, possibly because they benefitted from a practice effect of taking the PSVT:R twice in 10 weeks, or because they improved their spatial visualizations skills through taking other technical classes. These factors may have contributed to the gain found in this study, although the practice effect should be less significant here because pre- and post-PSVT:R were administered 15 weeks apart, 150% of the period between tests reported in Sorby et al. (2005). Another possible cause of the increase is that the course content itself helped students improve their spatial visualization ability. Throughout this course, students were frequently asked to interpret 2D engineering drawings and to model the corresponding 3D geometry in SOLIDWORKS. Sketching exercises, though not a major focus, were included in the orthographic projection lesson. Both of these activities, which require students to use their spatial visualization ability to mentally visualize and operate on shapes, may have helped increase PSVT:R scores. Another consideration is that the NAU students started with lower average pre-scores than those reported in other studies; the higher percent improvement at NAU, compared with other institutions listed in Table 3, could be a result of the NAU students having more room to improve.

Interesting correlations between post-scores and student confidence and outcomes were identified. Students who reported high confidence before beginning a modeling assignment and ease completing the assignment tended to have higher post-scores. The correlations between survey responses and pre-scores were much weaker, indicating that students' initial spatial visualization ability, measured months previously, is less related to their perceptions than their spatial visualization ability measured at a similar time to when they completed the assignment.

Similarly, post-scores were found to be more strongly correlated with course outcomes, as compared with pre-scores. Post-scores had a strong positive correlation with both exams but a weak correlation with homework, possibly due to the lack of strict time constraints on homework assignments. Even though homework was weighted at 50% of the total course score, post-scores were strongly correlated with the total score, indicating that low-visualizers tend to struggle in the course as a whole. Although average PSVT:R scores increased, most low-visualizers' post-scores were still low (for students whose scored below 20 on the pre-test, average scores increased from 15.7 on the pre-test to 18.8 on the post-test).

Conclusion

Spatial visualization ability was found to impact student success in this introductory 3D CAD course. Although students who improve their spatial visualization ability tend to achieve more positive course outcomes, the cause and effect relationship of these changes is unclear. Do diligent students succeed in the class because they spend more time on course assignments, working with 2D and 3D shapes, which causes increased spatial visualization ability as a side effect? Or is success in the class directly caused by higher visualization ability? Although this study cannot answer these questions, it is clear from our analysis that students who remain low-visualizers are at a disadvantage: low post-PSVT:R scores were found to be correlated not only with worse course outcomes, but also lower student confidence and higher perceived difficulty. Future research should analyze if sketching-based spatial visualization training or other 3D CAD pedagogical strategies are effective at improving course outcomes for low-visualizers. More work is needed to understand how to best help all students reach their full potential in 3D CAD courses.

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Parallels between Engineering Graphics and Data Visualization: A First Step toward Visualization Capacity Building in Engineering Graphics Design

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Introduction

The definition of visualization in engineering graphics has evolved over the years due in part to extensive research in visualization by the engineering design graphics profession. The literature indicates research in the areas of engineering graphics and the use of visualization has grown from improvement of visualization skills and the development of visualization tools, to the exploration of spatial ability and perception in engineering graphics.

The goals of this paper are three-fold: (1) to provide a high level overview of how the definition of visualization has historically been defined and shaped in engineering graphics, (2) provide an introduction to data visualization as a process, and (3) explore the parallels between the process of visualizing data and the engineering design process as first steps toward visualization capacity building in engineering design.

Literature Review

The literature provides a historical progression from visual literacy to visualization capacity. As seen in Figure 1, the foundation of visualization capacity is visual literacy and perception. Developing competencies in visual literacy and perception along with the ability to articulate ideas in a visual form is the underpinning for understanding the data life cycle and the process of visualizing data. It is important to know data, in its various forms and formats, dictates the type of tool used to visualize the data. The pinnacle of this progression is the ability to apply the competencies gained at each level to transforming data into insight. This section provides a high level overview, and historical review (where applicable), of each of the levels in the visualization capacity building pyramid shown in Figure 1.

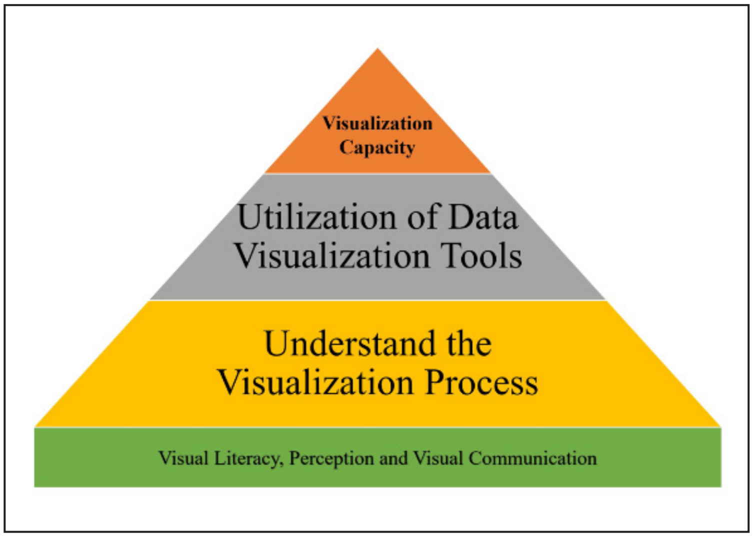

Figure 1. Visualization capacity building pyramid.

ISSN: 1949-9167

Visual Literacy

Many people from very diverse disciplines have attempted to define the concept of visual literacy and as a result those representing the different disciplines and paradigms each interpret visual literacy in a way that reflects their contribution or way of thinking (Avgerinou et al., 1997). The use of and improvement of visualization skills is often thought of as visual literacy. Visual literacy is categorized into three areas: human abilities, teaching strategies and the promotion of ideas (Avgerinou et al., 1997). Broadly defined, visual literacy refers to the skills which enable an individual to understand and use visuals for intentional communication with others (Ausburn & Ausburn, 1978). For engineering graphics, visualization skills for engineering students is referred to as the ability to systematically manipulate objects and coordinate systems and the ability to interpret drawings (Crown, 2001).

Exploration of Spatial Ability and Perception

The history of spatial research in engineering design (described by Miller and Bertoline, 1991), briefly summarized here was spearheaded by Eliot and Smith (1983) who identified three major phases in the development of spatial testing; which in turn led to various theories and research investigations in spatial visualization:

> **Phase 1** (1901-1938): Effort by psychologists to establish and identify the presence of a spatial factor.
>
> **Phase 2** (1938 – 1961) Eliot and Smith (1983) identified two major categories to describe several terms advocated by several researchers at the time to identify spatial factors and how they varied from each other: (1) The ability to recognize spatial configurations; and (2) the ability to mentally manipulate spatial configurations.
>
> **Phase 3** (1961-1982) Studies designed to determine the interrelation of spatial abilities with other abilities and the discovery of various sources of variance in testing spatial abilities.

In 2001, Strong and Smith proposed an additional fourth phase to include the process of establishing computer technology effects on spatial skills and measurement of these skills. A significant amount of research has been done examining the role of spatial visualization ability, orthographic projection and perception in engineering design.
Scholars of engineering design research define visualization in various ways. Kelly (1928), described visualization as the ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and the relative changes of positions of objects in space. French (1951) described visualization as the ability to comprehend imaginary movement in three-dimensional space or to manipulate objects in imagination (pp. 3-4). McGee (1979) defined spatial visualization as the ability to mentally manipulate, rotate,

  ISSN: 1949-9167

twist, or invert pictorially presented visual stimuli. Miller and Bertoline (1991) described visualization as the ability to read and develop orthographic drawings or to solve descriptive geometry problems; that is if a student were able to develop orthographic or descriptive geometry drawings then the student had visualization ability.

Research on the development and assessment of enhancing 3D spatial visualization skills in spatial visualization abilities and work on perception have been extensive. Research in developing spatial skills for engineering students (Sorby, 2009), (Veurink & Sorby, 2014) and spatial training (Martin-Gutierrez, et al., 2013) for students added another dimension to the role of visualization in engineering graphics design. Space constraints prevent a thorough review of this work, however, the contributions to the enhancement of 3D spatial visualization skills and perception have proven to enhance student success, particularly women, in engineering.

Visualization Process

In engineering graphics design, often the term “spatial visualization” is used interchangeably or is combined with the broader terms of “visualization” or “spatial ability” making it difficult to discern the differences between them (Braukmann, 1991). Before exploring the topic of visualization further, it is necessary to explain, in the context of data visualization, what the author means by the term “visualization,” and “visualization capacity building.” Visualization is a process that transforms raw complex data into a visual representation for the purpose of gaining insight into what the data represents without being overwhelming. Visualization aids in explaining complex concepts, analyzing data, discovery, decision making, and storytelling. Data visualization is a process that transforms data from a raw complex state into a visual representation for the purpose of gaining insight (Card et al., 1999) into what the data represents. The process of visualizing data (Fry, 2007) entails seven stages: (1)Acquire - acquiring and providing structure for the meaning of data, (2) Parse – provide some structure for the data’s meaning, (3) Filter – remove all but the data of interest, (4) Mine – apply methods from statistics or data mining as a way to discern patterns, (5) Represent - choosing a basic visual model, (6) Refine – improve the basic representation to make it clearer and more visually engaging and lastly, (7) Interact - adding methods for manipulating the data. The process of visualizing data is iterative. The key is understanding what each stage represents, the tasks to be performed and the skills needed to prepare the data for the next stage, as described in Table 1.

Utilization of Visualization Tools

The field of engineering graphics has developed from the use of drafting table and T-squares to computer aided design drafting (CADD) (Crown, 2001). CADD software, which allows for the manipulation of a reference coordinate system (Crown2001), enhances the ability to visualize ideas (Roberson and Radcliffe, 2009) in engineering graphic design. CADD vendors create 2D and 3D software solutions to aide in the

  ISSN: 1949-9167

design process that allows for realistic renderings and communication of design ideas. 3D graphics software commonly employed in the design industry and for graphics and design teaching (Chang et al., 2016), are often difficult for students with limited "visualization skills" to retain visual information (Carroll, 1993).

Visualization Capacity Building

There is a natural progression from understanding visual content (literacy), understanding visualizing as a process, and the ability to utilize domain specific tools for visualizing data. Visualization capacity is the ability to go beyond generating data to transforming data into insight (Byrd et al., 2016) (Byrd and Cottam, 2016); that is the capacity to go beyond being a data generator to having the ability to apply the data visualization process to disparate data, the skills to apply the appropriate data visualization tool and the know-how to transform data, often difficult to understand, into meaningful insights.

Parallels between Data Visualization Process and the Engineering Graphics Process

The engineering process is specific to each project but generally speaking involves several steps to conceptualize, design and communicate design outputs. An engineering process (adapted from Lieu and Sorby (2015) and internet source) includes: (1) Identify – define the problem, (2) Explore - do background research, (3) Define - specify requirements, (4) Ideate - brainstorm, evaluate and choose a solution, (5) Prototype - develop and prototype solution, (6) Choose - determine final concept (7) Refine - do a detailed design, (8) Present - get feedback, (9) Implement – implement the detailed solution, (10) Test – does the solution work? (11) Iterate/Life Cycle-verify solutions meets requirements, communicate results. An overview of data visualization practices (Fry, 2007) and engineering and scientific practices (NGSS Lead States, 2013) is provided in Table 1.

Table 1
Visualization and engineering processes.

Data Visualization Practices (Fry, 2007)	Engineering & Scientific Practices (NGSS Leads States, 2013)
Acquire the data, provide structure for the data's meaning and ordering it into categories (**Parse**), remove all but the data of interest (**Filter**)	Asking questions and defining problems, obtaining, evaluating, and communicating information
Applying methods to discern patterns (**Mine**), choosing a basic visual model (**Represent**)	Developing and using models, using mathematical and engineering graphics concepts, engaging in argument from evidence
Manipulating the data or controlling what features are visible (**Interact**)	Constructing explanations and designing solutions
Improving the basic representation to make it more visually engaging (**Refine**)	Planning and carrying out investigations

ISSN: 1949-9167

Viewed graphically side-by-side (Figure 2), it is clear to see how stages of the engineering design process logically map to the visualization process described above.

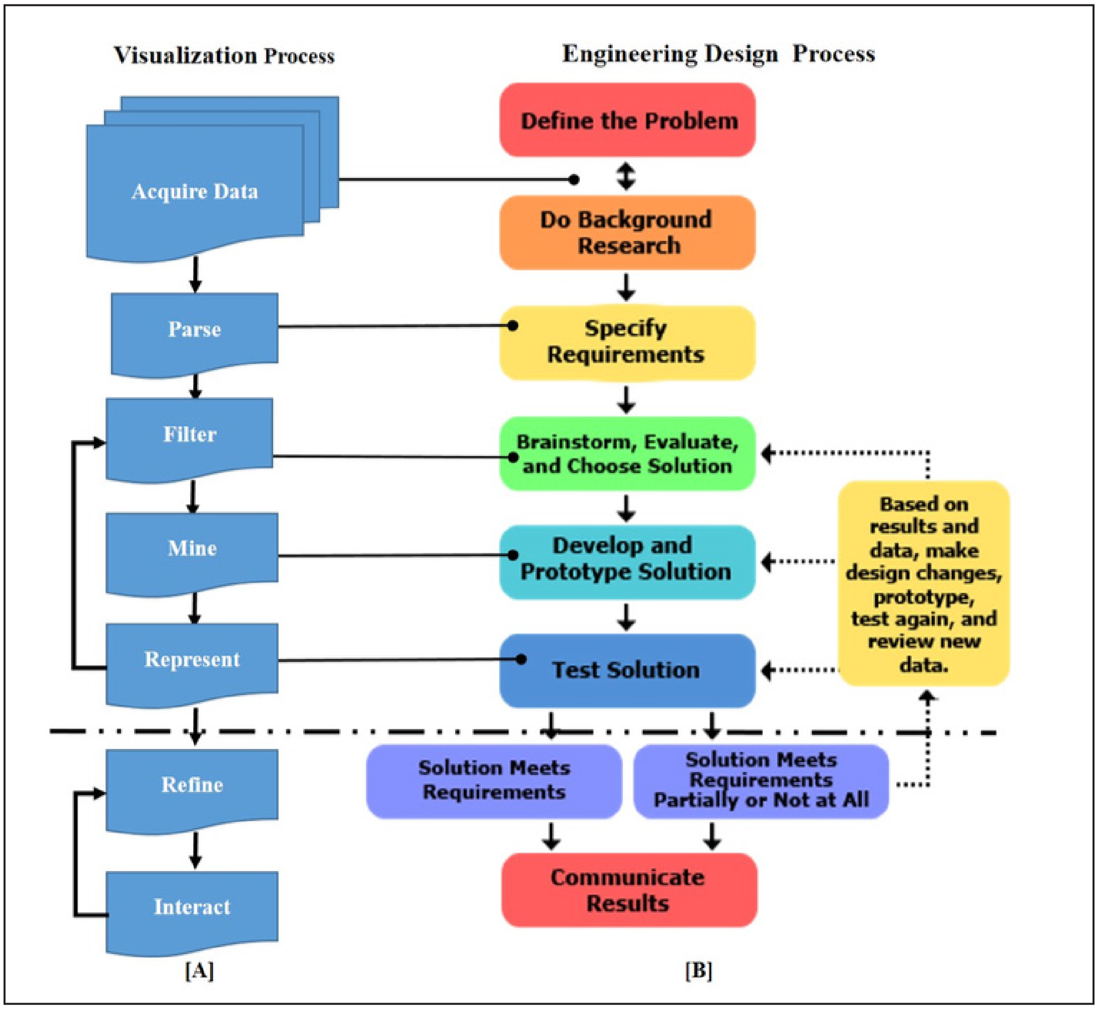

Figure 2. Parallels between visualization and engineering processes. Visualization Process flowchart [A] adapted from "Visualizing Data," by Ben Fry (2007), Engineering Design Process [B] adopted from https://www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-process-steps Last accessed April 8, 2018.

Discussion

The value of visualization is evident. The ultimate goal of the engineering design process is to develop devices where everything fits together and functions properly (Lieu and Sorby, 2015). The goal of the visualization process is to identify patterns and relationships that exist to show how the data features fit together to tell an insightful story about the data. The parallels described above are further strengthened by CAD tools

ISSN: 1949-9167

like Energy3D that has functionality that allows for the reconstruction of activities that can be closely examined using learning analytics, giving researchers considerable flexibility in data mining (Xie et al., 2014). Coupling data visualization with the engineering design process has the potential to further simplify and solidify complex concepts for students. The ability to go beyond being data consumers to having the visualization capacity (Byrd et al., 2016) (Byrd and Cottam, 2016) to understand the entire life cycle of data is a desired skill in workforce development.

Conclusion

There are synergistic parallels between the engineering design process and the process of visualizing data. Despite its many different definitions in engineering design, having an understanding on multiple levels of the role of data and how it is represented throughout its life cycle will better serve students as they explore complex engineering concepts. The data visualization process and the engineering graphics process facilitate four critical areas: (1) collaboration and teamwork, (2) creativity and imagination, (3) critical thinking, and (4) problem solving. This paper has highlighted parallels between the two processes: data visualization and engineering graphics. Research is needed to explore the impact of integrating the data visualizations from the perspective of understanding the data lifecycle, into the engineering design process. On a deeper learning and problem-solving level, more research remains to be done to assess the impact, if any, for students identified as having limited “visualization skills” as well as assess gender differences.

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Exploring the Role of Spatial Skill in Electrical Circuits Problem Solving

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Abstract

Spatial skills have a known beneficiary role in STEM students' academic success. This paper explores data relating to the role of spatial skills in electrical engineering problem solving which is a relatively under researched area. Data indicate a significant association between electrical engineering problem solving and spatial skills and a discussion around their potential causal role concludes the paper.

Introduction

The relationship between spatial skills and successful engagement in Science, Technology, Engineering and Math (STEM) education fields has been widely established and consistently reported. Wai, Lubinski, and Benbow (2009) go as far to state that spatial skill is a better predictor of achievement for STEM students than verbal or mathematical abilities that are commonly focused on in the majority of academic fields. Specific to engineering education, spatial skills have been found to be related to performance in calculus (Sorby, Casey, Veurink, & Dulaney, 2013), mechanical reasoning (Casey, Nuttall, & Pezaris, 2001), electrical concepts (Duffy, Sorby, & Bowe, 2016), and mathematical problem solving (Boonen, Wesel, Jolles, & Schoot, 2014). While it is generally accepted that spatial skills have a key role in STEM learning, their precise role in engineering education is not yet well understood (Delahunty, Sorby, Seery, & Pérez, 2016). More specifically, while some engineering fields such as mechanical engineering have a clear need for evolved spatial talent, it is not apparent whether these abilities play a role in less imagistic engineering disciplines. This paper reports on data gathered in an electrical engineering course and explores the role of spatial skills in solving electrical circuits problems.

Research Method

Students (N=34) from electrical engineering courses within the College of Engineering at the University of Nebraska-Lincoln were recruited to take part in the exploratory study. This sample included both junior (n=20) and sophomore (n=14) students. Students were recruited by email and in person and invited to take part in both an online spatial skills measurement and a voluntary problem solving activity session. The spatial skills assessment instrument was the Mental Cutting Test (MCT), a commonly utilized tool in spatial skills research.

Problem solving tasks included 9 electrical circuits problems and 5 knowledge control problems. These knowledge control problems were to ascertain the level of conceptual understanding, on the part of the students, of the principles required to solve the 9 primary tasks. This allowed the researchers to control for domain knowledge in the analysis

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ISSN: 1949-9167

of the data. Given the established importance of domain knowledge in problem solving performance (Novick & Bassok, 2005), it was important that this variable was controlled to gain a more accurate measure of the relationship between spatial skills and electrical engineering problem solving. These knowledge control tasks were simplified questions that ask the students to state certain fundamentals like Ohm's Law or explain the difference between series and parallel resistors. In addition, students were also assigned a series of mathematical problems (6) as an additional variable to aid in the subsequent analysis by controlling for mathematical problem solving ability.

Electrical Circuits Tasks

The 9 primary tasks were circuits problems taken from the DIRECT 1.1 electric circuits concept test (Engelhardt & Beichner, 2004). These were organized into three categories; 1) Conventional 2) Unconventional and 3) Word problems. The conventional category included three circuits tasks presented in a typical format that students will be familiar with from textbooks. The unconventional category included three tasks where the elements of the problem diagram were manipulated into an unconventional presentation. It is important to note that the intrinsic nature of the problem is not being altered only the presentation. The word problems asked students to solve three circuits tasks presented entirely with a written description. A sample problem and justification for inclusion from each category are presented in Figure 1.

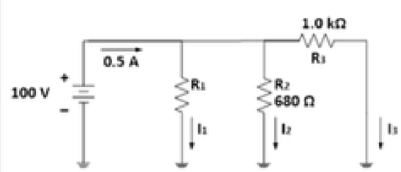
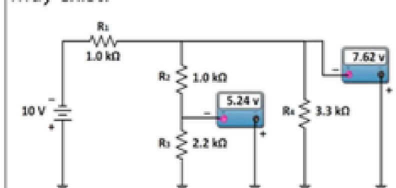
Word Problems	**Conventional Problems**	**Unconventional Problems**
Many types of decorative lights are connected in parallel. If a set of lights is connected to a 110 V source and the filament of each bulb has a hot resistance of 2.2 kΩ, what is the current through each bulb? Why is it better to have these bulbs in parallel rather than series?	*Find the values of R_1, I_1, I_2 and I_3 in the circuit shown in figure below.*  	*Check the meter readings in figure shown below and locate any fault that may exist.* 
<u>Rationale:</u> This style of problem format has been shown to be associated with spatial skill as students are required to construct a representation for the task (Boonen et al. 2014)	**<u>Rationale:</u>** These are problems that students should be most familiar with from textbooks etc.	**<u>Rationale:</u>** Presenting problems in an unconventional format may require students to utilize their spatial cognitive resources to a greater extent given potential unfamiliarity (Domin and Bodner 2000)

Figure 1. Sample task from each task category.

ISSN: 1949-9167

Findings

Performance Overview

Performance on the MCT was varied and the mean score was 50.6% with a standard deviation of 24%. Students performed well on the mathematics problem-solving tasks recording a mean score of 72.9% and standard deviation of 26.8%. Students also displayed a high level of conceptual knowledge recording a mean score of 98% with a standard deviation of 3.4% in the knowledge control questions. In the electrical circuits problems, students performed well with a mean score of 89% and standard deviation of 11.9%. With respect to the categories (Word, Conventional and Unconventional) of electrical circuit problems the mean performances were 93.1%, 96.1% and 79.4%, respectively. Prior to further statistical analysis performance scores for each subset of problems were screened for normality. A Kolmogorov-Smirnov test was utilized to assess statistical normality. The MCT was the only performance measure that displayed normality recording a *p*-value of 0.79. The knowledge control problems (p=0.000), mathematical problems (p=0.001) and electrical circuits problems (p=0.000) all violated assumptions of normality and for that reason a non-parametric approach to the subsequent analysis was adopted.

To determine any significant differences in performance for these categories a Friedman test was conducted as an appropriate non-parametric alternative to a repeat measures ANOVA (Corder and Foreman 2009). A significant difference in performance was recorded across the task groupings (Word, Conventional and Unconventional) $\chi 2$ (2, n=34) = 19.16, p <0.005). Inspection of the median values indicate that students performed similar in the Word and Conventional categories (Md = 100) and poorest in the Unconventional (Md=66.7) category.

Relationship between Spatial Skills and EE Problems

In order to determine if any association exists between performance on the MCT and performance on the electrical circuits problems a partial correlational analysis was conducted. This statistical method was selected in order to control for potential impact caused by conceptual knowledge and mathematical problem solving ability. Partial correlation is a useful technique to assess the strength of a relationship between two variables of interest while controlling for the effect of a third variable (Pallant 2010).

Two separate correlations were conducted between overall scores on the electrical circuits problems and the MCT while controlling for performance scores in the electrical circuits conceptual knowledge control questions and math problem solving. Controlling for the variable of conceptual knowledge, a large significant association was found between performance on the electrical circuits problems and the MCT (r = .521, p < .005). A moderate correlation was found when performance on the math problems was used as a controlling variable (r = .387, p < .05). This indicates that spatial skills, as measured by the MCT, are a contributing variable beyond both conceptual understanding and math-

  ISSN: 1949-9167

ematic problem solving ability for these students. Subsequent standard Spearman *rho* analyses were conducted with the MCT scores and scores in each of the three task categories. This subsequent analysis did not reveal any further associations between MCT scores and performance in the word or conventional categories of tasks. The analysis did reveal an association between MCT performance and the unconventional category of tasks, *rho*=.522, *n*=35, *p*<0.01.

Discussion

The findings of the study address the dearth in the literature regarding the role of spatial skills in electrical engineering curricula. The novel contribution of this study lies in the use of electrical circuits problem solving tasks rather than simple conceptual understanding tasks alone. To the authors' knowledge, this has not been conducted in great detail within the field previously. The findings illustrate the spatial skills, as measured by the MCT, was a contributing variable to students' performance on the electrical circuits problems. This correlation remained significant when conceptual knowledge and mathematical problem solving ability were controlled. This provides empirical support for the role of spatial cognition in the process of solving electrical circuits problems.

It is still unclear as to what exact role spatial ability has in the process of solving these problems, but it is possible that their contribution lie in students' representation of the problem. The data indicate that a significant correlation exists between spatial scores and performance in the unconventional category where students may require enhanced representational competencies to construct an effective problem representation. This is supported in previous work by Pribyl and Bodner (1987) and Bodner and Domin (2000) who found increased involvement of spatial processes when problems are unfamiliar to students. This evidence highlights a potential contribution of spatial processing to the problem representation phase.

A limitation of the current paper is the reliance on correlational data only. This is the common approach to investigating the relationship between spatial skills and academic success and is a useful exploratory approach. However, there is a need to consider deeper investigations into the precise role of spatial cognition in engineering problem solving (Delahunty et al., 2016). This paper controlled for additional variables which adds strength to the approach but future work will incorporate the use of EEG technology (Delahunty, Seery, & Lynch, 2013) and representational analysis as research tools.

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ISSN: 1949-9167

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Using Exploratory Factor Analysis to Build a Self-Efficacy Scale for Three-dimensional Modeling

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Abstract

Research on self-efficacy has provided evidence that it is a moderating factor that positively impacts students' choices to pursue and persist in engineering. Engineering graphics is seen as the preferred method of communication for the profession, yet to date no instrument is available that measures students' self-efficacy as it relates to engineering graphics. This paper discusses an exploratory factor analysis conducted to determine the reliability and validity of a self-efficacy scale designed specific to the domain of engineering graphics. Results from this study provided evidence that the instrument developed is reliable and valid for the investigation of students' self-efficacy as it relates to engineering graphics.

Introduction

Self-efficacy is rooted in Social Cognitive Theory, where theorists and researchers contend that knowledge acquisition directly relates to observing others within their context of social interactions, experiences, and outside media influences (Bandura, 1997). Research has provided evidence that self-efficacy beliefs in engineering disciplines significantly influences engineering students' choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011). Of particular interest in this study are students' self-efficacy beliefs towards engineering design graphics. Engineering graphics is a required area of study for many engineering programs and continues to be the preferred method for the communication of designs and ideas among engineering professionals (Barr, 2013; Branoff, Hartman, & Wiebe, 2002).

However, to date researchers have yet to create and validate a self-efficacy instrument related to engineering graphics. Research proffers that in order to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Bandura, 2006). In this study, we examine the reliability, validity, and underlying factor structure of a self-efficacy scale specific to the domain of engineering graphics.
low-cost 3-D printers and new forms of modeling software to run them, the thought of universal graphicacy in society may already be happening.

Research Questions

The following questions guided this research:

RQ1. Is the domain-specific three-dimensional modeling self-efficacy scale reliable?

ISSN: 1949-9167

RQ2. Is the domain-specific three-dimensional modeling self-efficacy scale valid?

RQ3. What is/are the underlying latent constructs for the items in the domain-specific three-dimensional modeling self-efficacy scale?

Methods

Instrument Development

Development of the three-dimensional modeling self-efficacy scale began with modifying and building upon instruments used in prior studies and grounded in the work of Bandura, especially his *Guide for Constructing Self-Efficacy Scales* (2006). The format of the instrument used in this study closely resembles the evaluation survey created by The New Traditions Project (Denson & Hill, 2010).

It was necessary to modify the scale items to relate specifically to the modeling of three-dimensional objects. Researchers collaborated with subject matter experts (SME) in graphics communication at a large land-grant institution to confirm the existing items were associated with engineering graphics. The SMEs provided comments and feedback, which the researchers incorporated into the scale design. The SMEs and researchers agreed that the resulting instrument measured the desired domain of three-dimensional modeling. In achieving face validity, the instrument provided evidence of measuring the constructs it purported to assess from the perspective of a participant (Weiner & Craighead, 2010). Figure 1 displays the nine-item three-dimensional modeling self-efficacy scale developed for, and used in, this study. Each item uses a seven-point Likert-type scale from “highest level of agreement” to “lowest level of agreement”.

1. I feel that I am good at visualizing/manipulating 3D objects in space.
2. I have confidence in my ability to model 3D objects using computers.
3. I am confident enough in my 3D modeling to help others model 3D objects.
4. I am good at finding creative ways to model 3D objects.
5. I believe I have the talent to do well in 3D modeling.
6. I feel comfortable using 3D modeling software.
7. I feel confident in my ability to create 3D objects in a variety of ways.
8. I feel I can communicate 3D objects to other peers.
9. I always understand what 3D images are trying to communicate.

Figure 1. The three-dimensional modeling self-efficacy scale.

ISSN: 1949-9167

Participants

This study was conducted during a STEM summer camp at a large, southeastern land-grant university. One hundred and one middle and high school students participating in the summer camp took the survey at the end of their weeklong experience. Researchers used the results of ninety-one of the student participants. Students whose answers were considered to be outliers were removed from the study. Examples include students who answered “7” or “1” for each item indicating that they did not read and discern each item.

Requirements for exploratory factor analysis

Prior to conducting the EFA, we evaluated the adequacy of the sample. There are varying opinions in the extant literature on the appropriate sample size required for EFA. There is general acceptance that 100 is the recommended minimum sample size, however, there is evidence that EFA can yield reliable results with a sample as low as 50 for measures of social constructs provided the number of factors is low (de Winter, Dodou, & Wieringa, 2009). The literature also contends that a ratio of respondents to variables should be 10:1 (Yong & Pearce, 2013). We believe the sample in this case (n = 91) is adequate when considering these factors.

Findings

Descriptive statistics and tests for normality (skewness and kurtosis) are displayed in Table 1. Stata 14 was used to analyze the data in this study (StataCorp, 2017).

Table 1
Descriptive statistics and tests for normality for the three-dimensional modeling self-efficacy scale

	M	SD	Skewness	Kurtosis	chi2	p-value
1	4.85	1.52	.01	.95	**6.60**	0.037
2	4.66	1.68	.29	.00	**11.73**	0.003
3	4.15	1.58	.57	.12	2.87	0.238
4	4.68	1.73	.35	.00	**8.54**	0.014
5	5.23	1.47	.00	.30	**9.54**	0.009
6	4.48	1.82	.43	.00	**11.02**	0.004
7	4.59	1.59	.10	.10	5.34	0.069
8	4.40	1.74	.11	.03	**6.55**	0.038
9	4.73	1.70	.01	.86	**7.05**	0.030

Note. Values in bold are significant at $p < .05$ level.

  ISSN: 1949-9167

Reliability

The reliability of the three-dimensional modeling self-efficacy scale was determined using Cronbach's alpha statistic to address our first research question. We determined the nine-item three-dimensional modeling self-efficacy scale to be reliable (α = .81) based on the threshold of .70 (Drost, 2011) with an average inter-item covariance of .87.

Exploratory Factor Analysis

Factorability

Toward investigating the underlying factor structure of the self-efficacy scale and addressing our third research question, we conducted an exploratory factor analysis. The initial step in EFA is to determine the adequacy of the sample. To accomplish this, we used three methods of analysis: examination of the correlation matrix, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity. Table 2 displays the correlation matrix. Analysis of the correlations revealed that all nine items significantly correlated with at least one other item with a minimum coefficient of .30 (Burton & Mazerolle, 2011).

Table 2
Intercorrelations for Items in the 3D Modeling Self-Efficacy Scale

Item	1	2	3	4	5	6	7	8	9
1	–								
2	.38	–							
3	.33	.49	–						
4	.21	.20	.33	–					
5	.22	.22	.24	.39	–				
6	.37	.63	.40	.16	.32	–			
7	.41	.45	.43	.41	.41	.53	–		
8	.32	.27	.40	.40	.31	.23	.50	–	
9	.27	.07	.24	.30	.18	.07	.11	.39	–

Note. Coefficients in bold are significant at $p < .05$ level.

An examination of the Kaiser-Meyer-Olkin measure of sampling adequacy suggested the sample was adequate for factoring (KMO = .80) and Bartlett's test of sphericity was significant ($\chi 2$ (36) = 233.452, $p < .001$) indicating the sample was not an identity matrix.

ISSN: 1949-9167

These two measures combined with the analysis of the correlation matrix, support our contention that the sample is factorable (Burton & Mazerolle, 2011).

Factor determination

Once the factorability of the sample was determined, an EFA was conducted to determine the number of factors underlying the three-dimensional modeling self-efficacy scale. The results of the EFA for the nine-item scale can be found in Table 3.

Table 3
Factor Loadings from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the 3D Modeling Self-Efficacy Scale (9-Item)

	Factor loading			
Item	1	2	3	Communality
1	.54	-.03	.16	.33
2	.64	-.38	.11	.57
3	.62	-.03	.15	.43
4	.51	.34	-.13	.40
5	.49	.14	-.24	.32
6	.65	-.41	-.03	.59
7	.74	-.04	-.21	.61
8	.61	.32	.05	.48
9	.34	.39	.24	.33
Eigenvalue	3.05	.70	.23	
% of Variance		90.41	20.78	7.06

Using Kaiser's criterion, factors with eigenvalues greater the 1.00 were retained (Yong & Pearce, 2013). To confirm this method, we also examined the total variance explained. Factor one explains 90.41 percent of the variance in the sample; greater than our determination criteria of .75. Both methods suggest a single factor structure for the self-efficacy scale. The single factor solution is displayed in Table 4.

ISSN: 1949-9167

Table 4
Single Factor Loading from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the 3D Modeling Self-Efficacy Scale (9-Item)

Item	Factor loading	Communality
1	.54	.29
2	.64	.41
3	.62	.39
4	.51	.26
5	.49	.24
6	.65	.42
7	.74	.55
8	.61	.37
9	.34	.11
Eigenvalue	3.05	
% of Variance	90.41	

Conclusion

The results of the EFA provided evidence that the nine-item scale was a valid and reliable measure of students' self-efficacy as it relates to three-dimensional modeling. In a final determination, analysis of the factor loadings of the scale items indicated that item nine had both a remarkably low factor loading and communality values. As a result, we examined the construction of the item and determined that structurally it was very different than the eight preceding items. This determination led to us removing the item in the final version of the instrument.

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 1
http://www.edgj.org

ISSN: 1949-9167

Differentiating between Spatial Ability as a Specific Rather than General Factor of Intelligence in Performance on Simple, Non-routine Problems in Mathematics

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Introduction

Spearman concluded that performance on any test of mental ability could be explained by several cognitive factors organized hierarchically as one general factor and several subordinate specific factors (Spearman, 1904, 1927). The general factor accounted for the significant amount of inter-correlation between all ability tests for any one individual while the specific factor explained the variation that was unique to each test. While there has been much debate in the literature as to what the specific factors are, with many different combinations of number and type of ability, three abilities — verbal, quantitative and spatial –consistently emerge as playing a dominant role in cognition (Kyllonen, 1996).

While Spearman was quite certain about the existence of ‘g’ he struggled to describe what it was in psychological terms and simply referred to it as a ‘mental energy’ (Spearman, 1904, 1927). Debate has since followed as to what ‘g’ is with one suggestion being that it may be working memory capacity since that can also explain a general aspect of performance across a range of tests (Kyllonen, 1996). Lohman (1993) favors the working memory argument but begins from the observation that tests of spatial ability serve as very good measures of general intelligence and, therefore, if working memory consists of a phonological loop and visual spatial sketchpad, with spatial ability related to the latter component, then spatial ability tests might be excellent measures of ‘g’.

This leads to a conundrum: what should one conclude if a correlation is found between a test of spatial ability and, for example, a test of non-routine problem solving in mathematics? Has one observed an effect related to spatial ability as a specific, lower order factor of intelligence, or to spatial ability as a measure of ‘g’? Given that spatial ability

ISSN: 1949-9167

has been defined as the ability to "generate, retain, retrieve, and transform well-structured visual images." (Lohman, 1993, p. 3), and assuming the non-routine problems in mathematics do not contain any well-structured images, one might conclude the correlation is best explained by spatial ability having revealed 'g' rather than the specific factor. If so, then efforts to improve non-routine problem solving through spatial skills training may be misguided. By analyzing data collected from a sample of engineering students that was administered a test of non-routine problem solving in mathematics the purpose of this paper is to contribute to the discussion as to what spatial ability is and why measures of spatial ability can correlate with other tests that are not overtly spatial in nature.

Research Design

Two math tests were administered to a sample of 115 first year engineering students, 53 from Ohio State University and 62 from Dublin Institute of Technology. One test consisted of six simple word problems and the other of six questions to assess the core competencies needed to solve the problems, e.g. the ability to factories a quadratic equation. Thirty minutes were allowed to complete problems and questions. The Purdue Spatial Visualization Test of Rotations (PSVT:R, Guay, 1976) was administered to each group of students. College entrance test scores from the SAT and ACT tests were chosen as measures of general intelligence and these data were collected from those participants for whom they were available. Previous research suggests that both the SAT and ACT are suitable estimations of general intelligence (Coyle & Pillow, 2008). Unfortunately, the collection of this data was not included in the original research design and, therefore, SAT and ACT math data were available for 35 participants only and ACT English, Reading and Science Reasoning for 31 participants.

The first math test, problem solving, was scored in two ways based on the view that problem solving consists of two phases — representation and solution — with the representation step drawing on linguistic, semantic and schematic knowledge and the solution phase drawing on core competency knowledge (Mayer, 1992). To solve the problem a participant must first represent the problem correctly and then complete the solution phase correctly. The non-routine aspect of the problems surfaced in the representation phase only as the core competencies required for the solution phase in all problems were of a very basic standard.

Results and Discussion

A correlation matrix was created to examine the relationships between each of these variables as shown in Table 1. Correlations were calculated using the maximum number of cases available. Problem score is the combination of representation and solution.

Mathematical ability, as measured by the SAT math and ACT math tests, was found to be significantly related to performance in problem solving but not to problem representation

ISSN: 1949-9167

Table 1
Correlation matrix for all students for whom data were available. The number of cases used is shown in brackets after each correlation value.

	ACT Math	ACT English	ACT Read	ACT SCIRE	Problem score	Problem representation
PSVT:R	.249 (35)	.159 (31)	-.275 (31)	-.180 (35)	.577** (115)	.585** (115)
ACT/SAT Math		-.020 (31)	-.098 (31)	.047 (31)	.441** (35)	.289 (35)
ACT English			.345 (31)	-.006 (31)	-.065 (31)	-.120 (31)
ACT Read				.143 (31)	-.137 (31)	-.111 (31)
ACT SCIRE					-.087 (31)	-.114 (31)
Problem score						.715** (120)

and, relative to spatial ability, with smaller effect sizes. Verbal ability, as measured by the ACT English and reading tests was not found to be related to problem representation or solving. Likewise, the ACT science reasoning test was not significantly related to either aspect of problem solving. It appears that in solving the simple math word problems used in this study, both mathematical and spatial abilities are relevant and that of these, spatial ability has a slightly larger effect size. It is worth noting that the verbal ability level required for the items included in the current study would be considerably lower than the verbal ability threshold requirements for university entry. While this limits an in-depth analysis of the relationship between spatial and verbal ability, research from the last 50 years suggests that these two abilities are typically not closely related (Wai, Lubinski, & Benbow, 2009). In terms of representing the problems, however, only spatial ability was found to be relevant marking it out as separate and distinct from the other two abilities in this thought process.

A significant relationship between math ability and problem solving is to be expected as the problems are mathematical in nature. As tests of mathematical ability, the SAT and ACT have been found to have high reliability and validity and to be very good predictors of success in higher education in the US (Camara & Echternacht, 2000; Powers, Li, Suh, & Harris, 2016). One could regard them as measures of individual abilities and as metrics of general intelligence.

Conclusions

It is interesting to find relationships with problem representation being different for spatial ability on the one hand and SAT/ACT math on the other. SAT/ACT math is significantly related to problem solving but not problem representation whereas the PSVT:R measure of spatial ability is significantly related to both. Problem representation appears to draw on different aspects of cognition compared with the combination of representation and

ISSN: 1949-9167

solution. In this case, therefore, spatial ability appears to measure an aspect of thinking that is not measured by SAT/ACT math tests.

This conclusion is supported by the lack of significance in the relationship between problem solving/representation and the other ACT measures of reading, English and science reasoning. This suggests problem representation is cognitively different to Spearman's 'mental energy' or general intelligence since it is significantly related to only one of the ability tests. Problem representation, as described by the Mayer (1992) model, requires linguistic, semantic and schematic knowledge and the application of this knowledge to a non-routine scenario. The problems used in this study were linguistically and semantically very simple and required no more than common knowledge of these aspects. What these data appear to show is that development of an appropriate schema when representing a problem may draw on spatial ability as a specific cognitive factor rather than as a general factor of intelligence. If so, efforts to improve spatial ability in order to improve performance in mathematics are justified, particularly so in math courses that reward non-routine problem solving.

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Simulations and Manipulatives used to Better Understand Graphics, Statics & Dynamics Concepts

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Abstract

This paper is intended to investigate the merits of adding manipulative devices and solid model simulations to accompany traditional lecture and demonstration materials to a Dynamics course. Based on the successes of Graphics courses using manipulative devices and simulation software to enhance spatial visualization skills in engineering students, a pilot study in a Dynamics course adding a 4-bar linkage mechanism and a NX software simulation was used. A pre-test was administered prior to using the intervention and post test results were collected after. Analysis of the pre- and post- quiz scores showed sufficient improvement in learning to encourage the continued development of more manipulatives and simulations for Dynamics. Recommendations are made to study whether similar methods will impact student learning in Statics courses.

Introduction

Engineering programs often focus on theory and conceptual design, while Engineering Technology (ET) programs typically have an increased focus on application and implementation. Accordingly, Engineering programs require higher-level mathematics, including multiple semesters of calculus and calculus-based theoretical science courses. ET programs, on the other hand, focus on algebra, trigonometry, and basic applied calculus, which are more practical in nature. Most Engineering and ET programs during the freshman year include a Graphics course to familiarize students with the essential spatial visualization skills as well as methods of interpreting engineering drawings and diagrams. In the mechanical field of study, Statics and Dynamics are sophomore-level courses covering a broad spectrum of foundational concepts such as; forces, free body diagrams, equilibrium, friction, moments, displacement, velocity, acceleration, force, work, energy, impulse, momentum, and vibrations. It is well-recognized that graphic interpretation of engineering drawings and diagrams, as well as static and dynamic analysis are fundamental building blocks for many subsequent courses such as Machine Design I and II, Applied Fluid Mechanics, Thermodynamics and Heat Transfer.

Background

In the traditional lecture-based course design, the students take notes on theory and example problems presented by the instructor. The class is usually structured so that the students do assigned homework problems, take exams and quizzes each semester. By teaching the course in this manner, students do not significantly participate in problem solving activities representing real-world applications occurring in the modern engineering/industrial workplace. On the other hand, students are placed in an environment in which they appear to be very comfortable, but not actively participating.

ISSN: 1949-9167

According to Metz et.al. (2011), approaches used at The Ohio State University to teach spatial visualization skills to engineering students utilized manipulative devices such as a set of interlocking building blocks to allow students to depict objects in 3D, and the use of CAD software to rotate 3D objects. The spatial visualization course provided the opportunity for students to improve their performance on the standardized Purdue Spatial Visualization Test – Rotations (PSVT:R) yielding a gain in both semesters administered. This illustrates the point that topics difficult to master such as spatial visualization can result from a lack of experience rather than lack of ability. In practice, Applied Science Education graduate students participating in a 4 credit course, “The Engineering Process” intended for current and future K-12 science and mathematics teachers, yielded very positive results while utilizing these techniques. Students in 2013 (n=20) and 2016 (n=12), using the textbook by Sorby, Manner, Bartmans. “3-D Visualization for Engineering Graphics. Edition: 4th”, and Sorby, C., “Developing Spatial Thinking. Edition: 1st” respectively, were administered the PSVT:R assessment as a pre and post-test. They were assigned problems from the textbook chapters to complete while utilizing “Snap Cubes” as manipulatives and were exposed to the solid modeling software “Tinkercad” to help visualize objects in 3D space. Although the sample size was very small, the results in 2013 yielded an increase of 5% from pre (66%) to post (71%), and in 2016 there was an increase of 12% from pre (63%) to post (75%).

The concepts in statics, particularly the creation of free body diagrams, rely heavily on understanding spatial relationships of objects. Ha and Fang (2015) make the argument that since engineering mechanics requires spatial abilities, which seem to be overlooked by instructors, that they should seek proper instructional and spatial training strategies to help students be successful. The direction that most universities have implemented are to include a prerequisite Graphics course to develop students’ spatial visualization skills. Given that visualization skills are best learned when manipulative devices and solid modeling multimedia software is implemented in conjunction with lecture, demonstration and textbook sketching exercises (Sorby, 2009 & Ardebili, 2006), it suggests that utilizing manipulatives and solid modeling software may help students better visualize application problems in statics and dynamics courses.

Magill (1997) suggests that Dynamics is “one of the more difficult courses engineering students encounter during their undergraduate study.” One reason for this is that Dynamics material has traditionally been taught without discussing the concepts in a meaningful context. It is a complex course requiring both a solid understanding of basic physics and an intuition regarding solution strategies. In other words, dynamics problems are such that a well-defined solution protocol applicable in all cases cannot be provided. An additional difficulty in the context of teaching the course to ET students is that, due to the learning style of the students, the mathematical content of the course is typically simplified, and the emphasis put on practice of application problems.

While some faculty have responded to the inherent difficulties of teaching and learning dynamics by adopting procedural problem-solving methods (Magill, 2011 & Everett,

  ISSN: 1949-9167

1997) , others have applied a variety of active learning approaches in Dynamics and Statics courses (Asokanthan, 1997; Howell, 1996; Jones & Brickner, 1996; and Holzer, & Andruet, 1998). Asokanthan (1997) for example, reports on the use of simulations, physical models, and videos to involve students in the learning process.

Dynamics course Pilot Study

As a result of the successes in Graphics and Statics courses, a pilot study was implemented to test the implementation of both manipulatives and interactive software in a Dynamics course. The Dynamics course meets for 50 minutes thrice a week, on Mondays, Wednesdays and Fridays. The pilot study intent was to assess the effectiveness of using manipulative models and simulations as an integral part of the course conducted in the spring 2015 semester. The in- and out-of-class activities associated with the pilot study lasted approximately two weeks. Details of the pilot study have been reported in Mehendale et al. (2015), and have been summarized in the following paragraphs and the timeline is shown in Table 1.

Table 1
4-bar linkage modeling homework and pre- and post-assessment.

Day-week number	In-class activities	Out-of-class activities
(M-1, W-1, F-1)	Chapter 16: Planar (2-D) Kinematics of a Rigid Body 16.1 Rigid-Body Motion,16.2 Translation, 16.3 Fixed Axis Rotation, 16.4 Absolute Motion Analysis, 16.5 Relative-Motion Analysis : Velocity, 16.6 Instantaneous Center of Zero Velocity	HW 8 16-3,5,7,11,13,23 (sections 16.1,16.2,16.3) 16-41,49 (section 16.4) 16-61,81,88,101 (sections 16.5, 16.6)
(M-2, W-2)	Chapter 16 Q & A Chapter 17 lecture	
(F-2)	First Quiz (pre-assessment) See Appendix A: First Quiz, and Appendix C: First Quiz Solution	4-bar linkage model hw assigned, due (M-3)
(M-3)	Second Quiz given (post-assessment) **See Appendix B: Second Quiz, and Appendix D: Second Quiz Solution**	

The students also had additional time in class to work hands-on with the 4-bar linkage model (See Figure 1) on Friday of week 2. The NX 4-bar linkage model (See Figures 2 & 3) was made available to the students after quiz 1, and the students were surveyed at the time they took quiz 2 to ask (1) whether they used the NX model, and (2) whether they thought it helped them understand the material better. A total of 20 students took quiz 2. The distribution of the answers to the above questions can be seen in Table 2.

ISSN: 1949-9167

Table 2
Student responses to NX model survey.

Question	Responses		Distribution
	Question #1	Question #2	
#1) Did you use the NX model simulation? #2) Did the NX model simulation help you understand the material better?	YES	no response	5
	NO	no response	4
	YES	YES	1
	YES	NO	3
	no response	no response	7

Figure 1. Adjustable 4-bar mechanism used in pilot study.

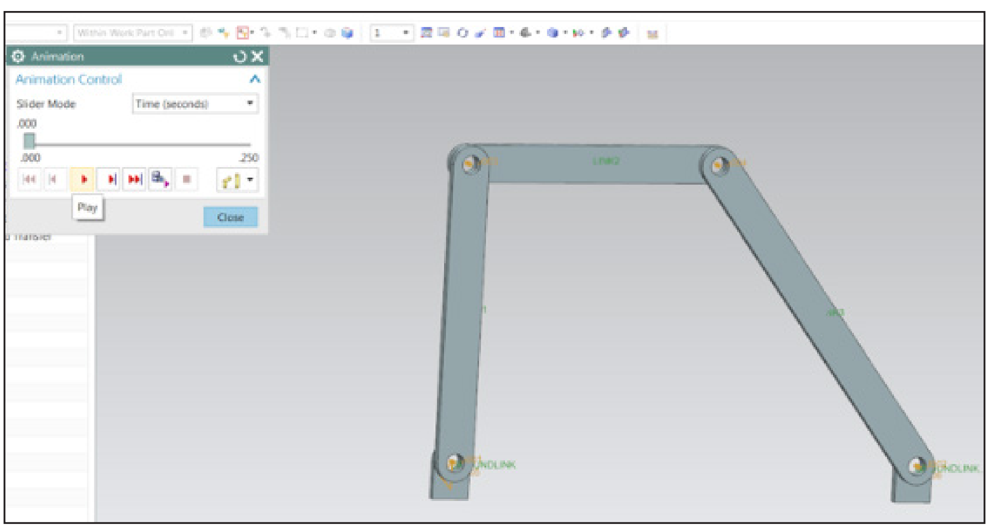

Figure 2. NX 4-bar motion simulation used in pilot study.

ISSN: 1949-9167

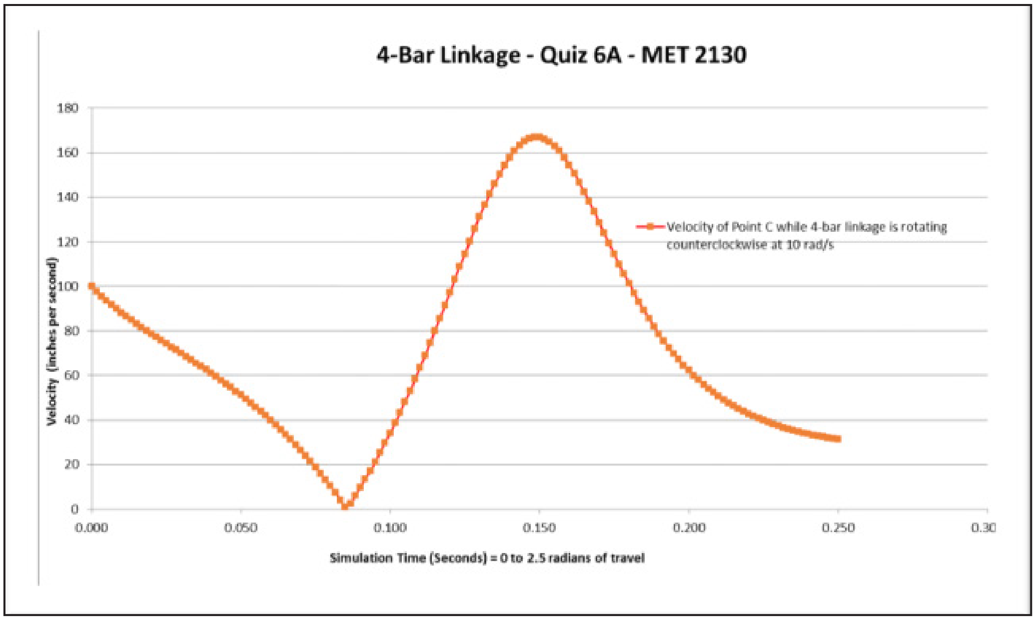

Figure 3. NX 4-bar motion simulation results in Excel graph.

The homework exercise required students to rotate the input linkage of a 4-bar linkage model through a prescribed angle, and then measure the angle of rotation at the output linkage. Specific link lengths L_1, L_2, L_3, and L_4 and angular displacements $\Delta\theta_{in}$ were assigned to each group of students so that the acceleration would be negligible, and thus the angular velocity would be roughly proportional to the angular displacement. It should be noted that the manipulative devices the students worked with were not equipped with instrumentation for measuring the angular velocities ω_{in} and ω_{out} of the input and output links, respectively. For this reason, the students used the angular displacement $\Delta\theta$ as a proxy for the angular velocity ω, which is a reasonably accurate approximation for small angular displacements of the order of about 10–20°. Using this approach, the students were able to calculate the angular velocity of the output link using the approximation: $\omega_{out} \approx \Delta\theta_{out}(\omega_{in}/ \Delta\theta_{in})$. The students were then required to separately verify the measured angular displacements using analysis (using their choice of the instantaneous centers or relative velocity methods).

The second quiz was announced in the previous class, so that any additional studying by the students would be minimal. The first quiz was not returned or discussed until after the second quiz was complete. The second quiz was very similar to the first quiz, with slightly different geometry, and velocities. Again, the students had the option of using either the relative velocity or the instantaneous centers of velocity methods (See Appendices A-D for quizzes and solutions).

ISSN: 1949-9167

Pilot Study Results

Figures 4 and 5 show the corresponding data for the scores of 20 students who participated in the pilot study in spring 2015.

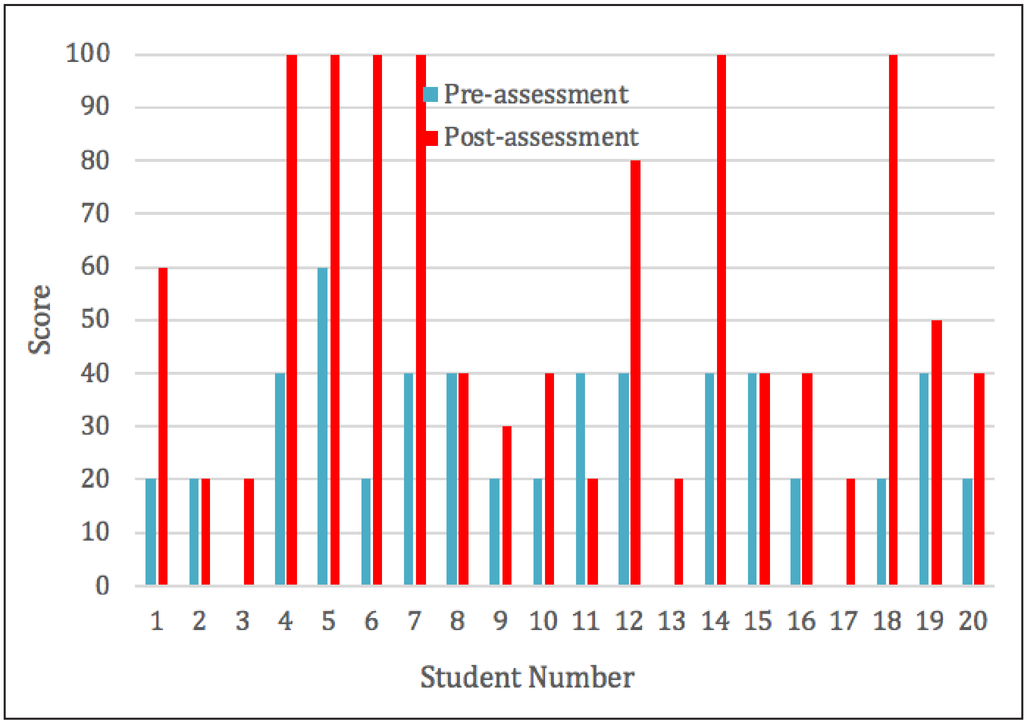

Figure 4. Pre- and post-assessment scores for students in the pilot study.

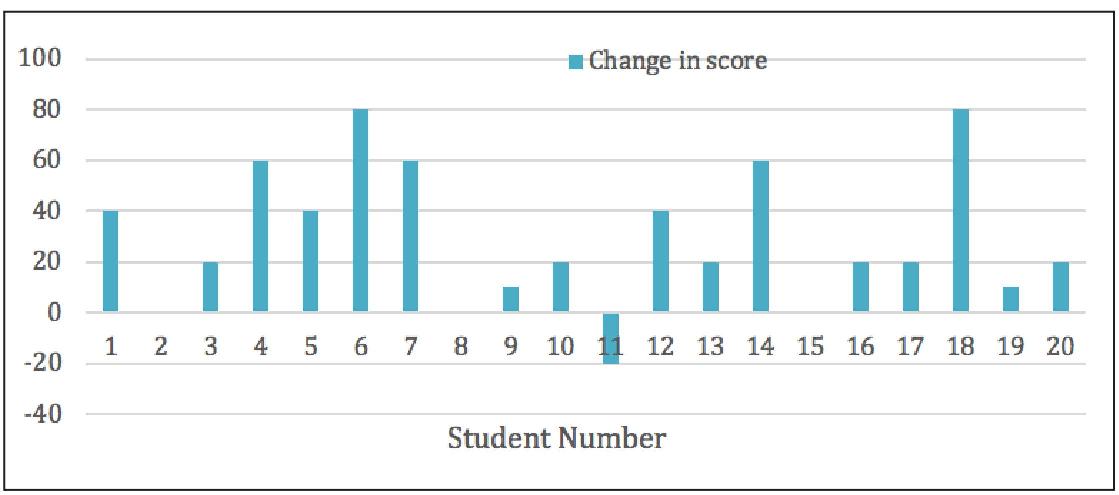

Figure 5. Student score changes resulting from pilot study.

ISSN: 1949-9167

Overall, the assessment data revealed that as a result of being exposed to the exercise with the manipulative models, 80% of the students obtained improved scores, 15% showed no change in score, while the scores of 5% of the students scored poorer.

Pilot Study Conclusions

Given that no additional instruction was provided, other than the 4-bar linkage model homework and NX simulation, the scores on the post-assessment quiz show a fair improvement over the pre-assessment quiz. Attempts were made to avoid any grade improvement solely due to specific studying immediately before the quiz, but improvement in score could still be attributed to the manipulative model experience, and associated analysis homework.

Although the data obtained in the pilot study was limited, analysis of the pre- and post-quiz scores showed sufficient improvement in learning to encourage the continued development of more manipulatives and simulations for Dynamics. Recommendations are to continue the use of manipulatives and solid modeling software activities in Graphics courses. In addition, Statics and Dynamics courses should implement utilization of manipulatives and solid modeling software to help students visualize industry-based application problems. Future research in the Statics course will investigate the impact of using the Pasco “Comprehensive Materials Testing System”, an integrated system for tensile testing that measures both force and position, as well as solid modeling NX software to illustrate textbook problems using Finite Element Analysis static loading solutions.

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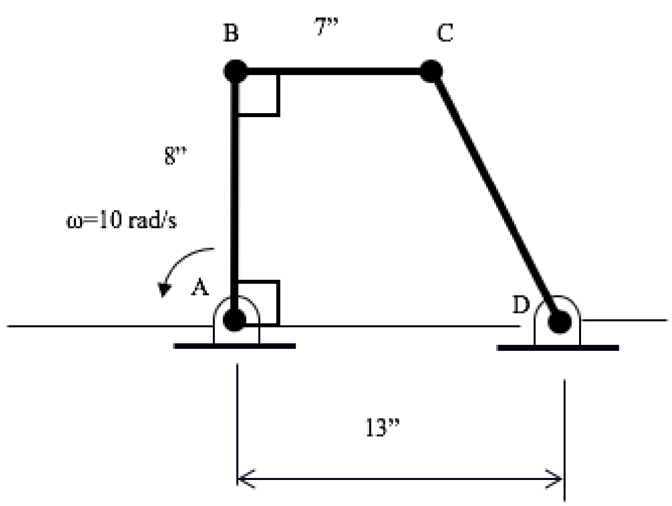
Appendix A: Pilot Study First Quiz

MET 2130 **Quiz 6A** **Name:________________________**

At the instant shown, link AB of the 4-bar mechanism shown is rotating counterclockwise at 10 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link AB is vertical.

What is the velocity of joint C (v_c) at the instant of time shown?



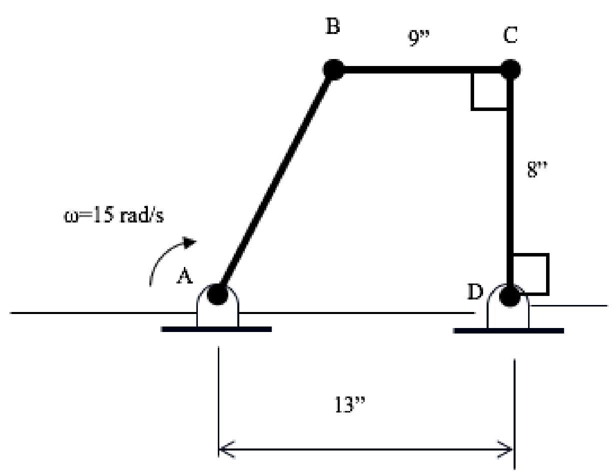
ISSN: 1949-9167

Appendix B: Pilot Study Second Quiz

MET 2130 **Quiz 5B** **Name:**________________________

At the instant shown, link AB of the 4-bar mechanism shown is rotating clockwise at 15 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link CD is vertical.

What is the velocity of joint C (v_c) at the instant in time shown?



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Appendix C: Pilot Study First Quiz Solution

MET 2130 Quiz 6A Name:______________________

At the instant shown, link AB of the 4-bar mechanism shown is rotating counterclockwise at 10 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link AB is vertical.

What is the velocity of joint C (v_c) at the instant of time shown?

Method of ICs

$V_B = AB \cdot \omega_{AB} = (8)(10) = 80$ inch/s

$\tan\theta = \frac{8}{6} = \frac{4}{3} = \frac{(x+8)}{13}$

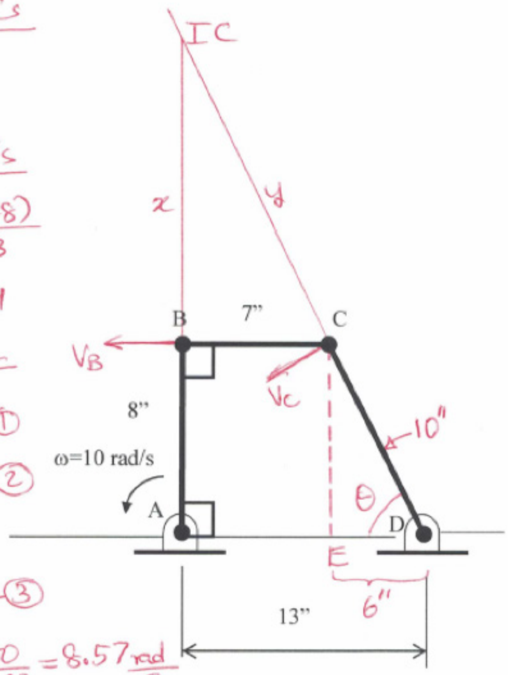
$52 = 3x + 24$

$x = 9.33$ in

$V_c = 10\,\omega_{CD}$ — (1)

$= y\,\omega_{BC}$ — (2)

$y = \sqrt{x^2 + 7^2} = 11.67$ in. — (3)



$\omega_{BC} = \frac{V_B}{x} = \frac{80}{9.33} = 8.57\ \frac{rad}{s}$

From (2) and (3):

$V_c = (11.67)(8.57) = 100$ inch/s

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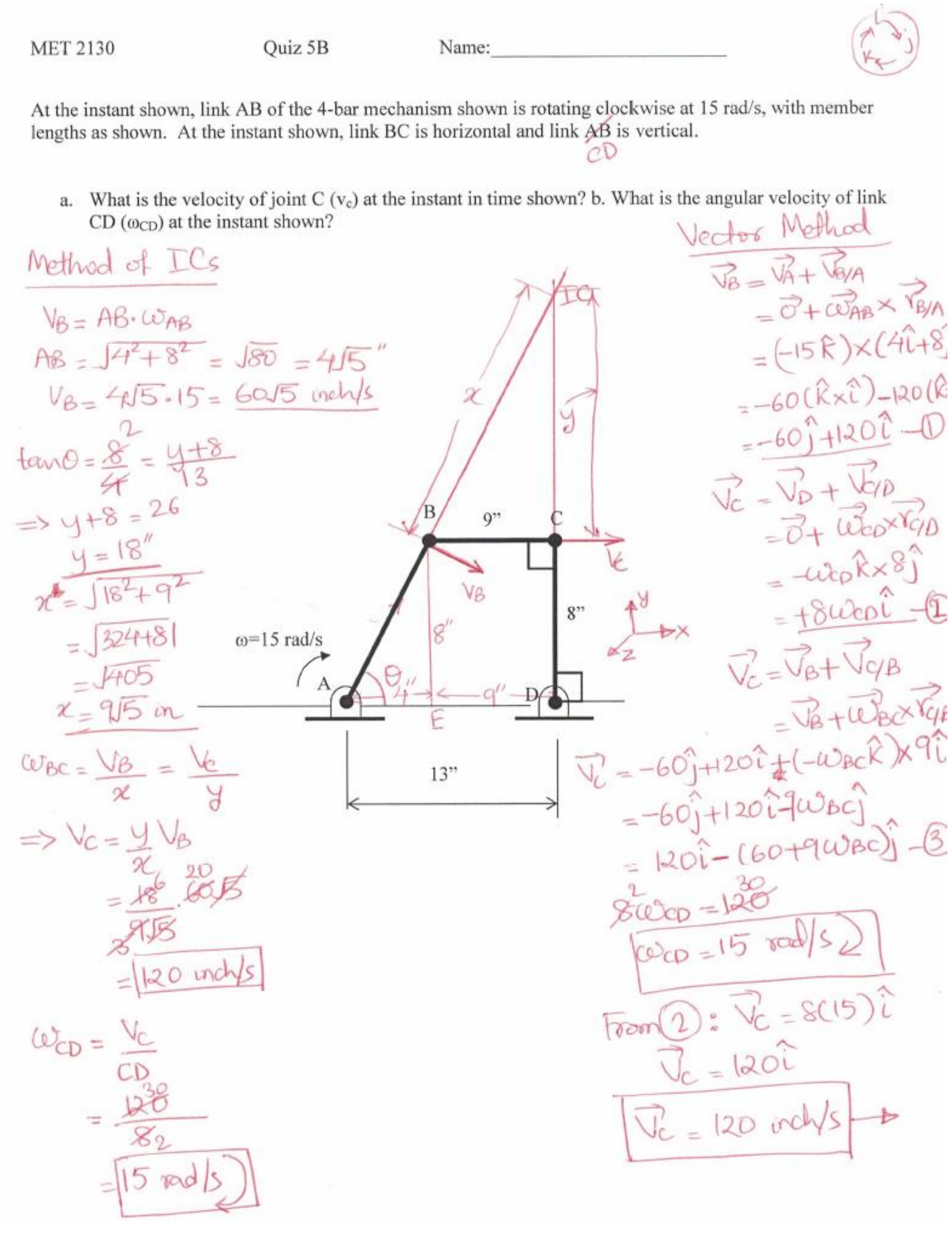
Appendix D: Pilot Study Second Quiz Solution



MET 2130 Quiz 5B Name:________________________

At the instant shown, link AB of the 4-bar mechanism shown is rotating clockwise at 15 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link ~~AB~~ CD is vertical.

a. What is the velocity of joint C (v_c) at the instant in time shown? b. What is the angular velocity of link CD (ω_{CD}) at the instant shown?

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Entrepreneurial Mindset: Integrating Creative Thinking and Innovation into a Graphical Communications Course

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Abstract

Nationwide, leaders in business and industry have increasingly acknowledged the importance of entrepreneurship. Several areas of the country showcase the importance of entrepreneurship such as Silicon Valley in California where a large number of start-up companies in science, technology, engineering and math (STEM) fields are located. To meet the needs of business and industry, institutions of higher education prepare students for future employment by offering rigorous and relevant coursework in areas such as entrepreneurship. Collegiate faculty and staff can use fundamental engineering courses to instill an entrepreneurial mindset – a set of beliefs, attitudes, and behaviors that drive innovation – in their students. This paper will explore an open-ended team project within a freshman-level engineering graphics course in which instructors encourage an entrepreneurial mindset in students. The goal of the course project is to develop engineering students' critical thinking and innovation skills while preparing them for their future professions. An end-of-semester course-wide poster competition allowed students to practice teamwork as well as innovative thinking and communication skills.

Introduction

Future engineering professionals must be prepared to investigate the *Grand Challenges of the 21st Century*, which impact the social, environmental, and economic progress of the world (American Society of Engineering Education [ASEE] Board of Directors, 1999; Byers, Seelig, Sheppard & Weilerstein, 2013; National Academy of Engineering [NAE], 2004; United Nations, 2002a; 2002b). Therefore, engineering students must be taught how to use the knowledge they learn in the classroom to solve real-world problems (Oswald Beiler & Evans, 2014). They should also be taught how to apply nontraditional, creative thinking to address stakeholders' needs (Oswald Beiler & Evans, 2014). If engineering graduates leave their respective universities with an understanding of business principles and entrepreneurship then they will be well-equipped to become future technical innovators.

How can we train engineering students to be more entrepreneurially-minded? To answer the previous question, we used an open-ended team project within a freshman-level engineering graphics course to encourage an entrepreneurial mindset in students. The goal of the course project was to develop engineering students' critical thinking and innovation skills while preparing them for their future professions. An end-of-semester course-wide poster competition allowed students to practice teamwork as well as innovative thinking and communication skills.

ISSN: 1949-9167

Students completed several deliverables for the project. Students submitted preliminary and final reports so instructors could evaluate students' project management ability, innovative ideas, problem-solving approaches, and written communication skills. Students conducted peer evaluations so instructors could determine students' collaboration, leadership, and teamwork skills. Students also gave an oral presentation in teams and received feedback from their instructors. Lastly, after the student poster competition, students completed a preliminary questionnaire to provide insights into their perceptions of the competition and overall project.

Course Curriculum

The freshman-level engineering graphics course was designed to familiarize students with the basic principles of drafting and engineering drawing, to improve three-dimensional (3-D) visualization skills, and to teach the fundamentals of computer-aided design (CAD). Classes met in a computer laboratory twice a week for one hour and forty-five minutes to fulfill the requirements of the three credit-hour semester-long course. To investigate the Grand Challenges of the 21st Century as well as the demand for creative and innovative thinking, students completed an open-ended design project. Students worked in self-selected teams of two to four students. Per the requirements of the project, students designed an existing product and then considered how to improve it. Students received approval from their instructors regarding their design idea along with their innovative and creative methods for solving the problem. Students incorporated sustainability concepts into their design, which involves engineering design feasibility, environmental impact, social and political consideration, and economic and financial feasibility. To address the importance of sustainable design, students were shown example CAD parts or they watched a series of screencasts by Autodesk (2012) that contained real-world examples.

Throughout the semester, instructors served as facilitators to ensure that student projects were completed on time. However, direct guidance was limited to a minimum. Specific class time was dedicated to the project so students could collaborate with their teammates and work on the project. Students were encouraged to think outside of the box and systematically design their project. Before the last day of class, students submitted all project deliverables such as dimensioned drawing sheets, 3-D part models, and PowerPoint slides. On the last day of the class, students wore business casual or professional attire to present their work as a team. Each presentation lasted 8-10 minutes, and was followed by 2 minutes of question and answer time.

Students completed confidential peer evaluation forms in order to evaluate their own performance and that of their teammates. Criteria was considered such as contribution and quantity of work, interaction and collaboration of the team, problem-solving skills and quality of work, time management, and willingness to be a team player. During the oral presentations, students completed a team evaluation for other groups in the class. Crite-

ISSN: 1949-9167

ria were evaluated such as organization, slide content and aesthetics, presentation skills, and team member participation. Students were strongly encouraged to leave comments, as well as recommendations, to support their evaluation. At the end of the presentation, the instructor summarized the student projects and the top two teams were selected to attend the end of semester student poster competition for all sections of the course. Selected student teams made posters and presented their work to students and faculty on campus. During the poster competition, faculty, staff, graduate students, and past student winners served as judges. Different awards such as best poster design, most sustainable design, most sophisticated design, best presentation, people's choice award, and the best of best awards were given to the student teams.

Poster Competition Feedback

Likert scale and open-ended responses from the Spring 2017 semester provide preliminary insight into students' perceptions of the graphics course-wide poster competition. Of the approximately 70 undergraduate engineering students who participated in the Spring 2017 poster competition, 29 students completed a preliminary seven question survey about their overall experience and satisfaction with the event. The 70 student participants presented 11 posters from 11 course sections. Specific demographic information was not obtained for participants in the poster competition but generally students who take the course are first-year engineering students from aerospace, mechanical, and civil engineering departments. As of Fall 2016, undergraduate students from the campus are 54% White, 20% female, 13% international students, 9% multi-racial, 6% Black, 5% Asian, 4% Hispanic, and 33% in-state students with an average age of 21.

Overall, students were satisfied with the organization and execution of the poster competition, as indicated by the following responses to Likert-scale questions. Using a 5-point scale from *poor* to *excellent*, nearly 83% of student respondents rated the poster competition as *very good* or *excellent*. See Figure 1 below for more details.

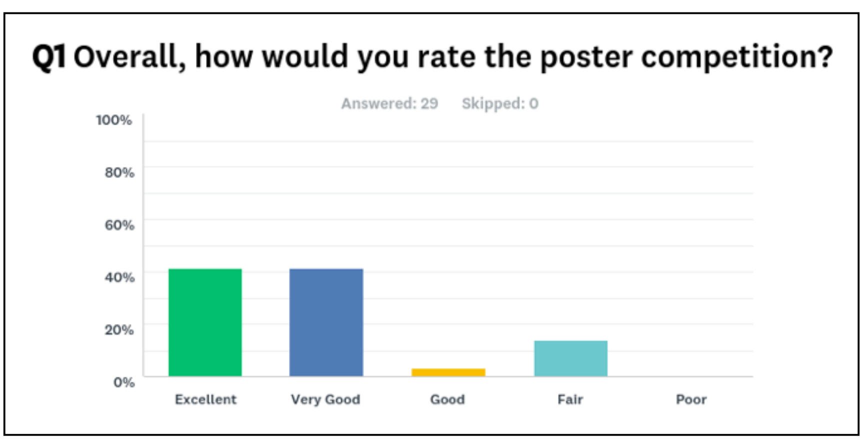

Figure 1. Student responses to survey question about the overall event

In terms of organization, using a 5-point scale from *not at all organized* to *extremely organized*, over 86% of student participants believe the event was either *very organized* or *extremely organized*. See Figure 2 below for more details.

Figure 2. Student responses to survey question about organization of the event

When asked about the length of the two-hour long poster competition, using a 7-point scale from *much too short* to *much too long*, more than 65% of student participants indicated the length of the event was *about right*. See Figure 3 below for more details.

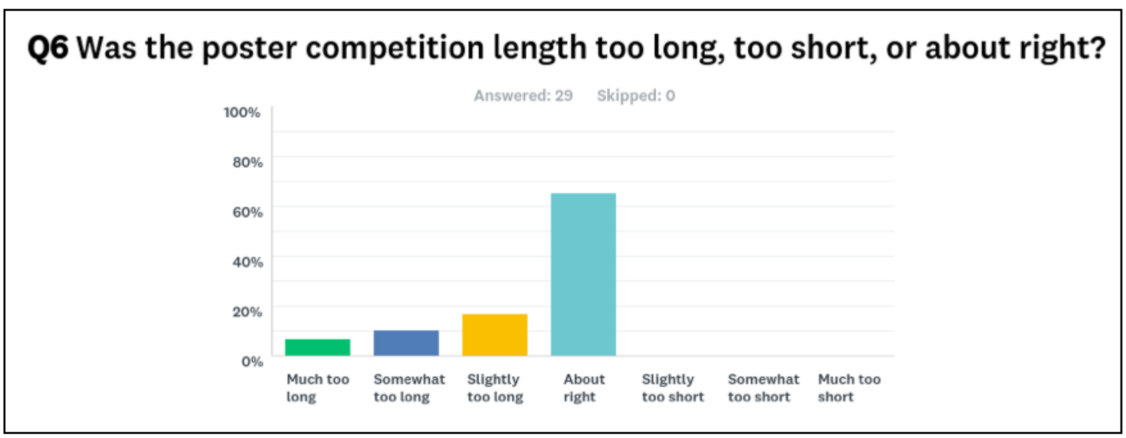

Figure 3. Student responses to survey question about length of the event

Using a 5-point scale from *none of the information* to *all of the information*, over 55% of participants believe they received *most of the information* or *all of the information* they needed before the poster competition. Although, a majority of students felt prepared, the event organizers can certainly focus on ensuring that more students receive the material they need prior to the competition. See Figure 4 below for more details.

ISSN: 1949-9167

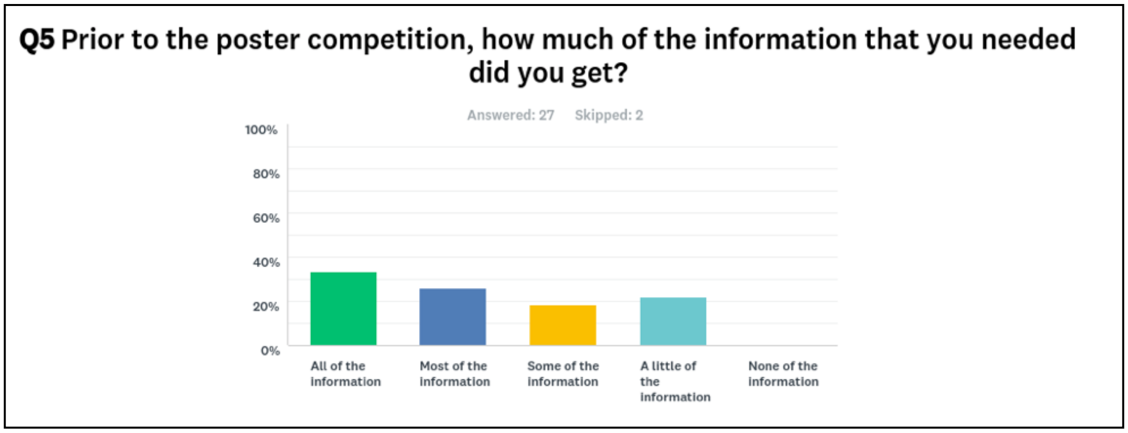

Figure 4. Student responses to survey question about obtaining information needed for the event

While the above Likert-scale survey items mainly focused on structural aspects of the poster competition, open-ended survey items allowed students to reflect on their individual experiences. Students benefited in several ways from their completion of the course project and participation in the poster competition, as evidenced by the following preliminary survey excerpts. In alignment with an entrepreneurial mindset students talked about the creativity and innovation they witnessed by saying they liked viewing “new ideas” and “seeing lots of ideas in one place.” Students also mentioned liking “the diverse selection of posters,” “the application of engineering principles” and “different [design] modifications in each project.” Students mentioned other benefits of the design project and poster competition. Student participants talked about their enjoyment when describing the event as “fun!” and a “fun way to evaluate a project and get good experience.” When describing social interactions with peers and faculty, students said they liked “meeting the other groups and seeing their ideas,” receiving “constructive comments of the judges,” and attending an event that was “open to the public.”

Despite the aforementioned positive reflections, there were aspects of the poster competition that student participants disliked. When reflecting on their experiences, several students complained about “standing” the entire time and not getting “chairs.” Numerous students said we “should have more posters” and they didn’t care for “the fan vote” used to choose an award for the most popular poster. As seen in the Likert-scale survey responses, some students also stated in the open-ended survey items they disliked “the length of the competition” and wanted “more information ahead of time.”

Conclusions

By describing a unique team-based project and student poster competition, this paper highlights an approach for allowing students to focus on innovative thinking while also practicing their teamwork and communication skills (Long and Jordan, 2016). The

ISSN: 1949-9167

open-ended team project offered students an opportunity to learn the type of design engineering that emphasizes environmental, economic, and social responsibility. It also gave students an opportunity to inquire into, collaborate on, design, assemble, and present their work. A preliminary questionnaire was used to assess students' perceptions of the graphics course-wide poster competition and overall project. Preliminary results indicate that the poster competition and overall project provided students with a positive and satisfactory experience, which enabled them to develop and practice critical thinking and innovation skills. Overall, students were able to think "outside of the box" and solve real-world problems, which help to prepare them to ultimately solve challenges within their future companies, country, or even the world (Reid and Ferguson, 2011).

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Evolution of Test Items: From Open-ended to Multiple-Choice

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Abstract

Grading is often a faculty member's least favorite chore, especially in engineering where open-ended problems prevail. For this reason, multiple-choice test items could be a popular alternative for assessing learning and understanding. In addition, most Learning Management Systems allow the instructor to create multiple-choice questions to be scored automatically by the system. The use of multiple-choice items in engineering graphics education could increase efficiency, allowing instructors to focus on other aspects of their teaching rather than spending significant time grading open-ended problems. The authors of the this paper have been involved in a project to develop a Concept Inventory for Engineering Graphics over the past several years. Since Concept Inventories typically consist of multiple-choice items, development of this instrument was reliant on the creation of numerous valid and reliable items. This paper will focus on the process employed in multiple-choice item creation with application to engineering graphics. The process will be illustrated through demonstration of item evolution through several iterations.

Background

According Educational Testing Services, (ETS) there are several key steps that they follow in the creation of a valid and reliable test (ETS, 2017), including:

1. **Define Objectives.** The type of questions to be considered in defining objectives for specific tests are: who will take the test? What skills or knowledge should be tested? What kinds of questions should be included? How long should the test be? What is the level of difficulty for the test?
2. **Form the Item Development Committee.** The responsibility of the committee is to: define the objectives of the test, ensure that test questions are unbiased, determine the test format, develop supplemental materials, write the test questions, and review the test questions.
3. **Writing and Reviewing Questions.** Each question on the test undergoes several iterations until the final format is established. The reviews ensure that there is only one correct answer and that it conforms to the desired test style.
4. **Pretest.** After the questions have been developed, they are pilot tested with a group of individuals who are similar in age and skill level to the desired final testing population. The results from this pilot testing will help to determine the difficulty of each question, any ambiguities in items, or

ISSN: 1949-9167

need for further revision or possible elimination all together. This step also examines distractors to determine if they need to be revised or replaced.

5. **Detecting and Removing Unfair Questions.** ETS then looks at the language as a whole used in the items to ensure that the language is appropriate and non-offensive. In this step, they examine performance by different groups with similar knowledge and skills to ensure items are unbiased and are measuring what they were intended to measure.
6. **Assembling the Test.** In this step, the test is reviewed by experts who were not involved in creating the test, to ensure that the answers are correct and any discrepancies are resolved.
7. **Making Sure that Test Questions are Functioning Properly. Further statistical analysis is** performed on the instrument after administration to ensure its reliability.

Although not all of these steps are applicable to the development of items for a graphics mid-term or final examination (for example, assembling the committee), consideration of these steps could lead to a better, more robust test that actually measures student learning. It should be noted, however, that this is essentially the process used by the Concept Inventory design team as they have worked over the past several years in the creation of the instrument. The team is now in the process of completing Step #7 on this list.

According to Malamed (2010), there are ten best practices for creating accurate multiple-choice test items. Although her rules were written specifically for elearning applications, many are relevant to questions that are being designed for an LMS system as well as for standard in-class administered examinations. The best practices identified by Malamed are:

1. **Items test comprehension and critical thinking, not just recall.** Many engineering faculty avoid multiple-choice testing because they feel that this type of test only assess rote learning and not critical thinking skills. Malamed advises to design items that go beyond this by asking students to interpret facts or evaluate situations.
2. **Use simple sentence structure and precise wording.** Faculty who create multiple-choice items should carefully examine wording to ensure that there is no ambiguity or colloquial expressions that may not translate across cultural groups.
3. **Place most of the words in the question's stem.** This best practice ensure that the answer options are short and not confusing.
4. **Make all distractors plausible.** Wrong answers should be completely reasonable with no "give-away" distractors that hinder your ability to discriminate among test-takers.

ISSN: 1949-9167

5. **Keep all answer choices the same length.** Test-takers might be able to guess the correct answer merely by looking at the length of each choice.
6. **Avoid double-negatives.** Questions that include double-negatives are often confusing to the test-taker. For example, "Which of the following comments would not be unwelcome in a work situation?" could be replaced with "Which of the following comments are acceptable in a work situation?"
7. **Mix up the order of the correct answers.** You should make sure correct answers are randomly located and do not form a pattern.
8. **Keep the number of options consistent.** Typically, each question will have 3, 4, or 5 options. Test creators should decide how many options they will use throughout the test and then stick with it.
9. **Avoid tricking test-takers.** The objective of the test should be to assess learning. Therefore, options that can be interpreted in more than one way or that are too similar to one another should be avoided.
10. **Use "All of the Above" and "None of the Above" with caution.** The option of "All of the Above" encourages guessing and the option of "None of the Above" doesn't really assess what a student knows so these options should be avoided when possible.

Not all of these best practices may be relevant to the creation of multiple-choice items that assess graphics learning; however, test designers may want to keep these in mind as they go about designing accurate tests.

Developing Items for the Graphics Concept Inventory

The technique used to create the Concept Inventory was based on the Assessment Triangle as outlined by Streveler et al (2011); however, the technique described by ETS closely mirrors the process used for individual item development. In the first step outlined by ETS (ETS, 2017), a rigorous process for defining the topics to be covered by the test is advocated. In the case of the Graphics Concept Inventory, a previous project conducted a Delphi study to identify the topics for inclusion on the resulting instrument (Sadowski & Sorby, 2014; Sadowski & Sorby 2015). In the second development step, a team of faculty was assembled with a combined experience of more than 50 years in graphics education. In step 3 of the ETS process, the development team constructed more than 60 open-ended graphics questions. Questions were created to cover all of the topics identified in the Delphi study and were based on the experiences of the design team. A sample open-ended item from this step is shown in Figure 1.

ISSN: 1949-9167

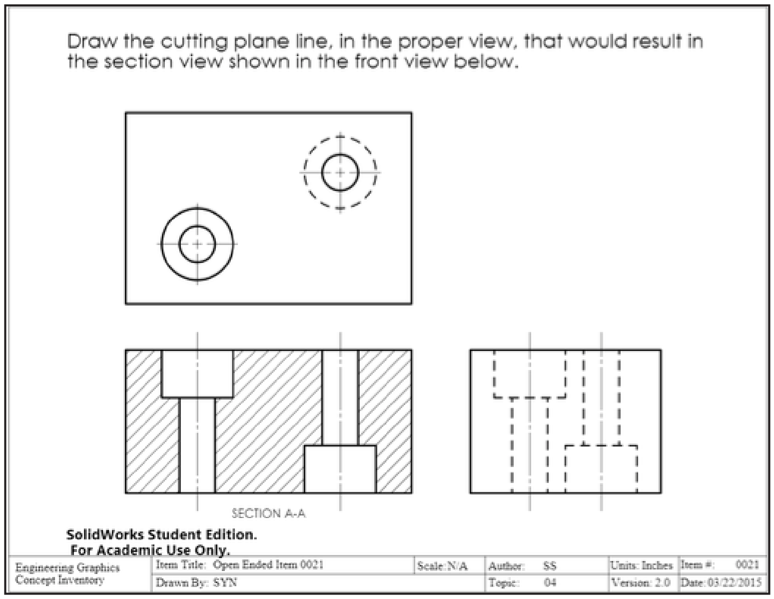

Figure 1. Sample open-ended item from Graphics Concept Inventory.

The item shown in Figure 1 was designed to test conceptual understanding of Offset Section views. In the next step of the Concept Inventory creation, the open-ended items were pilot-tested with students enrolled in graphics courses at three different institutions. The purpose of the pilot-testing was twofold—to determine relative difficulty of the items as well as to develop a battery of student-generated incorrect answers that could eventually be used for distractor creation. Figure 2 shows an incorrect student response to the question from Figure 1.

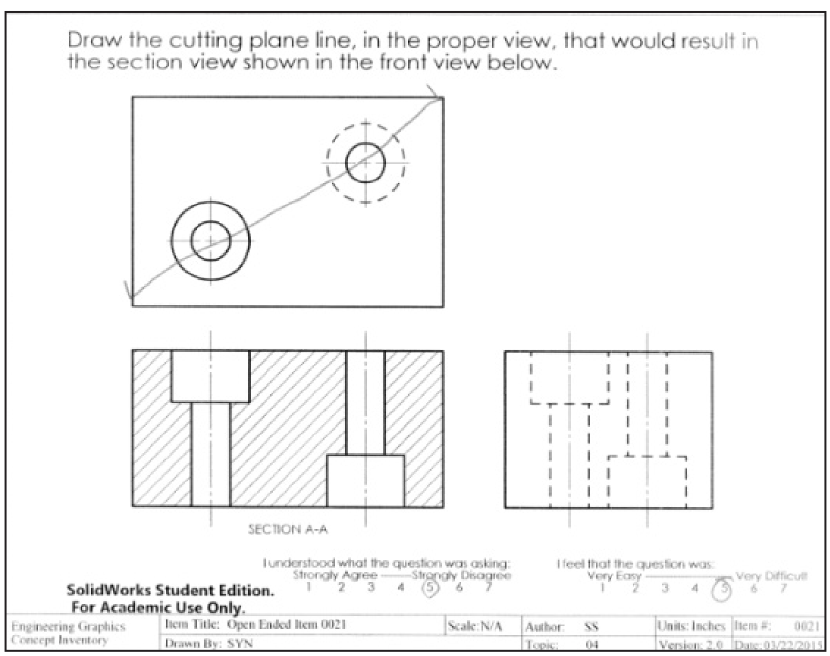

Figure 2. Sample student incorrect response.

ISSN: 1949-9167

For the next step in the Concept Inventory development, distractors were developed that were based on the most popular incorrect student responses to the open-ended problems. Based on the procedure outlined by ETS, steps 5 and 6 were iteratively completed in order to ensure that the test items were behaving appropriately (not too easy and not too hard), were clear and unambiguous (no more than one correct response per item; clearly worded) and there was consistency across items (4 choices per item). The final item for the problem from Figures 1 & 2 is shown in Figure 3.

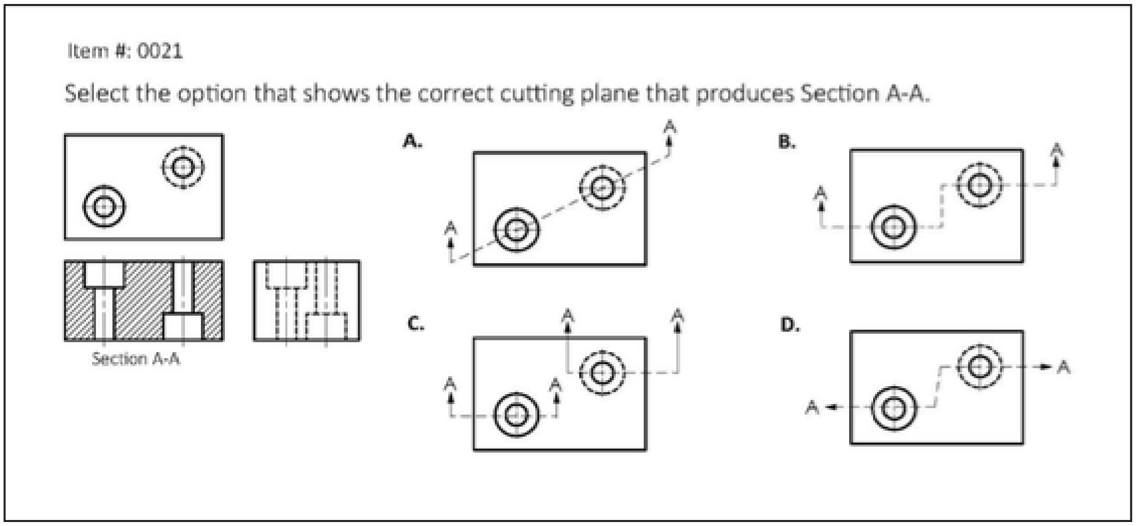

Figure 3. Final Concept Inventory item for the topic of Offset Sections.

The development team is currently completing step 7 from the ETS process by performing a final implementation and statistical factor analysis of data. Results from this final step will be forthcoming.

In the creation of the graphics Concept Inventory, many of the best practices listed by Malamed (2010) were employed. For example, all items on the test include 4 choices with one and only one correct response and three incorrect responses. Items test the ability of students to apply knowledge of graphics to novel problems—no definitions are queried. Distractors were developed from actual mistakes made by students so they likely meet the "plausibility" criteria and none of the questions uses either "All of the Above" or "None of the Above." The test design team labored over stem wording to ensure clarity and precision and since these are graphics items, most of the words are in the stem of the questions.

Conclusions

The need for a Concept Inventory in Engineering Graphics is well-established (Nozaki et al, 2016) and the use of Concept Inventories has been shown to lead to curriculum

ISSN: 1949-9167

innovation in a variety of disciplines (Evans et al, 2003). The Graphics Concept Inventory development team employed best practices from multiple sources in the creation of the items for this instrument. Final statistical factor analysis and hosting options for the instrument are in progress. The process the team members used could be applied to the creation of test items in graphics education as faculty attempt to streamline their grading without compromising the quality of their assessment.

Acknowledgement

The authors gratefully acknowledge the support for this project from the National Science Foundation through grants DUE-1432280 and DUE-1432288. The authors also acknowledge their collaborators on this project: Dr. Ron Miller, Kaloki Nabutola, Dr. Steven Nozaki, Dr. Heidi Steinhauer, and Dr. Nancy Study.

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Engineering Design Graphics Journal (EDGJ)
Spring 2018, Vol. 82, No. 2
http://www.edgj.org

ISSN: 1949-9167

Using Virtual Reality for Community Outreach and Student Recruitment

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Abstract

An antique phone booth was converted into an interactive Virtual Reality (VR) booth to use for potential student recruitment, current student demonstrations, and community outreach. Satisfaction data was collected using a HappyOrNot Smiley Terminal™. In total, 215 users provided feedback on their VR experience over 142 consecutive days. Eighty percent of respondents found their VR experience to be positive (n = 173). A correlation between student recruitment and VR booth use could not be made. However, the booth proved to be effective in displaying student work and has received positive praise from stakeholders (i.e., students, faculty, staff, administration, and community).

Introduction

Recruiting students into engineering technology (ET) programs is difficult. So difficult in fact, that a recent two year study by the National Academy of Engineering (2017), conducted to “shed light on the status, role, and needs of ET education in the United States” (p. vii), concludes that most Americans are unfamiliar with ET as a field of study or a category of employment. If most Americans, which includes parents and the K-12 education system, are unaware, how must post-secondary ET programs compete in student recruiting? The National Academy of Engineering (2017) recommends stronger engagement between K-12 and the leaders of ET programs and new marketing and branding efforts. In line with both recommendations, two faculty members from a leading ET program attempted an innovative multidisciplinary project.

The Proposal

The proposed project was to design and build a VR experience for the lobby of the Purdue Technology Center of Southeast Indiana. The center is home to multiple small businesses and Purdue Polytechnic New Albany (PPNA). PPNA offers a variety of majors focused in engineering technology (ET), such as Mechanical Engineering Technology (MET) and Electrical Engineering Technology (EET), and Computer Graphics Technology (CGT). The proposal consisted of refurbishing and converting a standalone antique phone booth into an interactive VR booth experience. The full restoration included breakdown, cleaning, cosmetic improvements, and VR equipment integration.

In the spring of 2016, the designers proposed the project to administration after positive preliminary discussions with faculty, staff, and building operations. The project was scheduled to begin in May 2016 and final delivery occurring in August 2016. The proposed budget for labor and material was approximately $5,000. The project goals were to use the VR booth for potential student recruitment, current student demonstrations, and community outreach.

ISSN: 1949-9167

Project Details

The VR booth was equipped with the Oculus Rift head mounted display (HMD), Oculus remote, and Oculus sensor (https://www.oculus.com/rift/) (see Figure 1). An Asus G11CD Oculus ready desktop personal computer (PC) (https://www.asus.com/Tower-PCs/G11CD-Oculus-Ready/) powered the system. To allow for external third party viewing and control of the VR experience, the designers installed a touch screen monitor on the outside of the booth (http://www.dell.com/ed/business/p/dell-p2314t/pd).

Figure 1. VR equipment.

To collect usage and satisfaction data of the VR booth a HappyOrNot Smiley Terminal™ (https://www.happy-or-not.com/en/measure/) was utilized (see Figure 2). The designers placed the terminal next to the booth and it collected data 7 days a week from 7AM to 7PM from August 22, 2016 to December 10, 2016. The smiley terminal captured user feedback with universally recognizable four smileys ranging from dark green (very happy) to dark red (very unhappy). The terminal transmitted the collected data via a secure cellular network to a cloud-based reporting service.

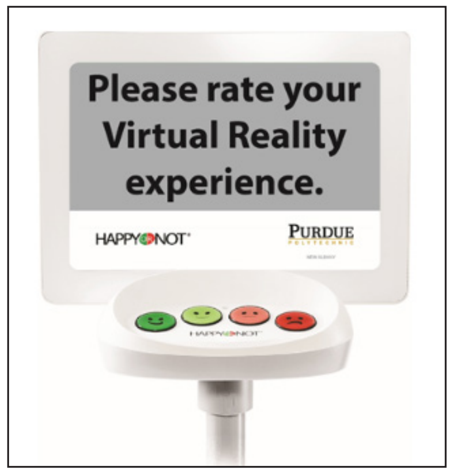

Figure 2. Smiley Terminal.

To promote the VR booth and encourage student involvement in the project, the designers held a poster design contest for current PPNA students (see Figure 3). The contest theme was *visiting other worlds*, and the designers planned to display the winning poster on the outside of the VR booth.

Additional student involvement occurred through the contracting of a CGT student for programming. The task was to design and build a custom VR demo that would highlight the affordances of VR and incorporate a digital replica of the booth to encourage higher levels of immersion. See Durcholz, Webster, and Kopp (2016) for video.

Figure 3. Call for poster contest flyer.

ISSN: 1949-9167

Faculty, staff, and administration would use the final deliverable to demonstrate PPNA student capabilities to potential students and the community.

Results

The refurbishment of the VR booth took approximately 2 months. Final costs were slightly over $4500 (see Figure 4 and Figure 5). See Figure 6 for the winning poster design.

Figure 4. VR booth front.

Figure 5. VR booth side.

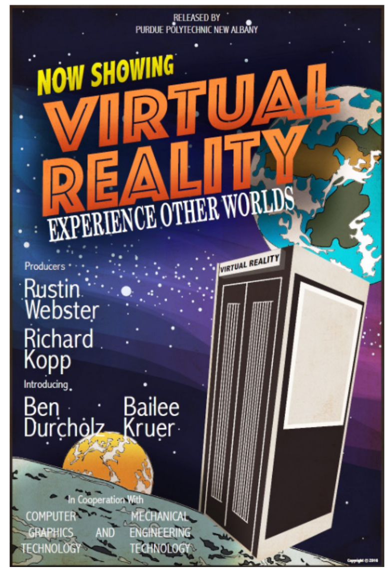

Figure 6. Poster contest winner.

The smiley terminal collected responses from 215 users (see Table 1). Overall, 80% of the respondents rated their VR experience as positive (i.e., dark green or light green smiley) and 20% negative (i.e., dark red or light red smiley).

October was the highest usage month and Tuesday the highest usage day of the week. This is due in part from the increased volume of foot traffic in the building during a community event (i.e., Purdue Pumpkin Chunking Competition) held on campus grounds. See Appendix for monthly, weekday, and hourly distributions.

The contracted CGT student created a VR demo that users experienced sitting down, which helped to reduce the possibility of motion sickness and injury to the user. It had autonomous navigation and heading tracking (orientation and position). See Durcholz et al. (2016) for video.

Table 1
Smiley distribution.

Smiley	Count (%)
	140 (65)
	33 (15)
	19 (9)
	23 (11)

ISSN: 1949-9167

Discussion

HappyOrNot, a global leader in instant customer and employee satisfaction reporting, offered a unique opportunity to collect feedback at the point-of-experience. The designers believe that the smiley terminal encouraged feedback participation over an online survey. The cloud-based reporting portal simplified data collection and analysis.

The designers tried to setup the booths hardware, electronics, and software in a manner that would result in a low maintenance, safe, easy to use, and enjoyable VR experience. The VR booth was unsupervised the majority of the time, thus requiring the display of simple to follow usage instructions. Before entering the VR booth, the designers directed the visitors' attention to the touch screen monitor, which displayed a short instruction list (see Figure 7). Users often ignored the instruction of *return to home*, as the designers often found the booth to be unoccupied and left in the middle of a demo.

Figure 7. VR booth instruction.

To prevent theft, the HMD and remote were secured to the booth walls by a security tether (https://usa.multplx.com/products/jplug_loop). The sensor and PC were secured through refurbishment design efforts, such as built in mounts and anti-tamper connections. Overall, the booth required very little attention from the designers after delivery. However, occasional system updates to the PC operating system and VR software required down periods.

To encourage VR hygiene best practices, individual antibacterial wipes were placed inside the booth. The wipes were anti-static, streak free, lint-free and safe to use on all components. Based on the frequency of needing to reorder additional wipes, the designers believe that most users clean the VR equipment prior to using.

Conclusions

The VR booth has proved to be an effective community outreach tool (Kaufman, 2017) and a medium to demonstrate current students' VR work. However, the designers could not study the effect the VR booth had on student recruitment. To do so, they would need to incorporate the actions of student services, who conduct the majority of student recruiting, and track potential students' use of the VR booth and future enrollment at PPNA after such use.

ISSN: 1949-9167

The declining prices of consumer VR equipment, such as the Oculus Rift and HTC Vive™, present institutions with a new tool for student recruitment and highlighting student work. Integrating such state-of-the-art interactive equipment into antique or unique furniture allows designers and researchers an exciting and unique opportunity.

Appendix

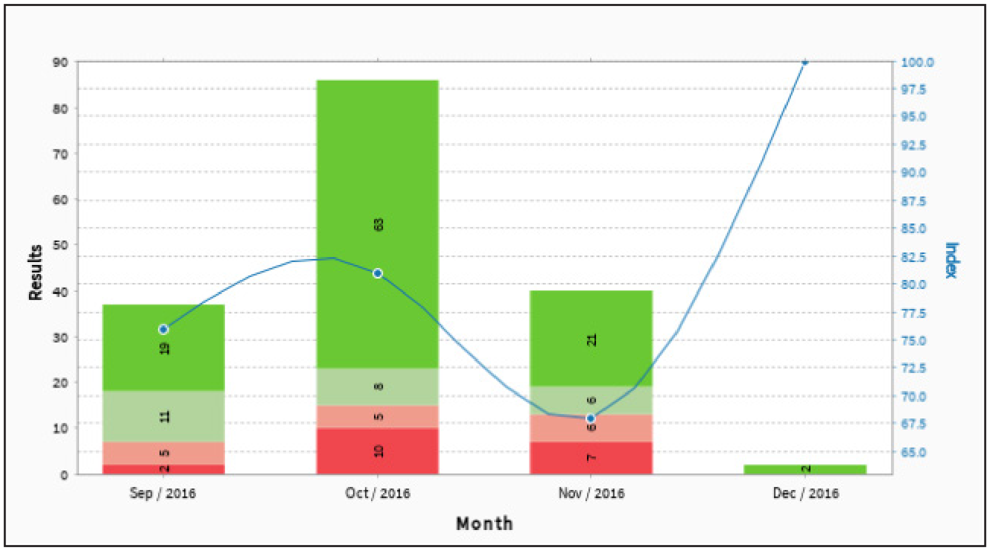

Figure 8. Monthly usage distribution.

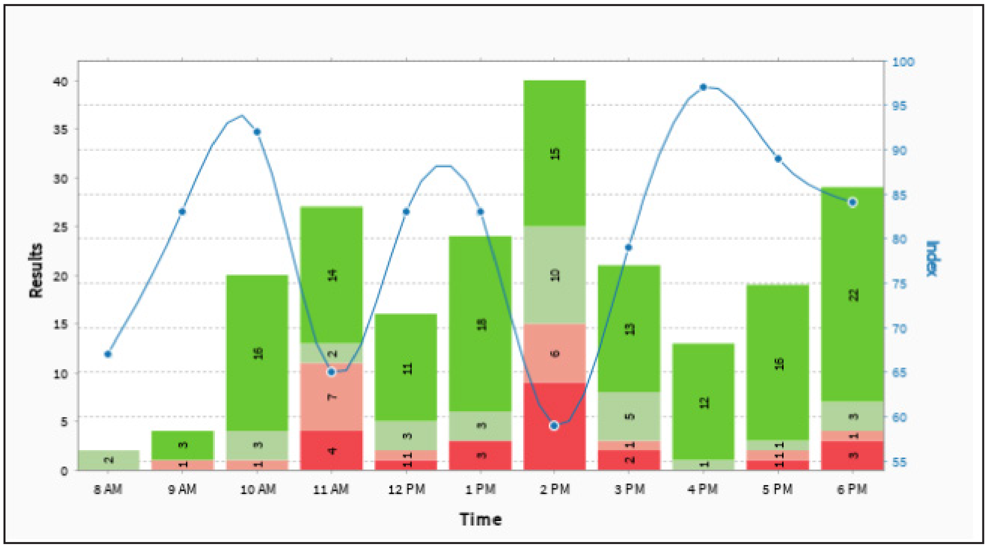

Figure 9. Hourly usage distribution.

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ISSN: 1949-9167

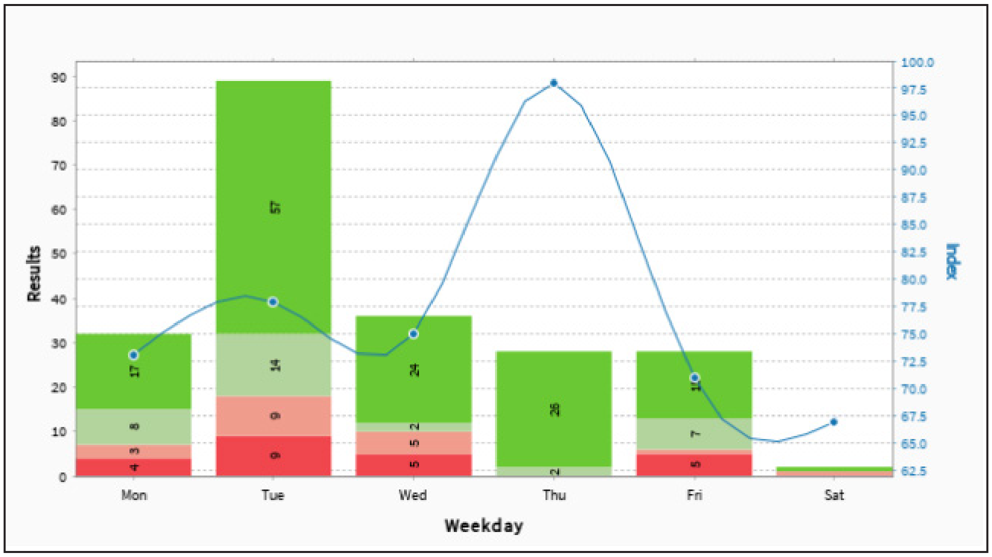

Figure 10. Daily usage distribution.

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