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Editorial Board, Advisory Board, and Review Board

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Message from the Chair

Nancy E. Study
Penn State Erie - The Behrend College

My first "Message from the Chair" took me longer to write than I care to admit. But after multiple drafts and starting over from scratch a few times, I came to one overall conclusion. It's all about perspective; not just the type of perspective we may use when we create and view drawings, but perspective in how we view our students and the ways we teach them, perspective in how we view our careers and our colleagues, and even perspective in how we view this Division. This past June, right after I assumed the duties of Division Chair, I moved 500 miles to take a new job in a new state. The climate is different, both meteorologically and academically. My colleagues are different, my students are different, and even the courses I'm teaching are different. I am back to teaching engineering design graphics in an environment where the content is valued. And now that I've completed my first semester here, I find myself busier than ever, having fun, and looking at many things from a different perspective.

Wait a minute. Did I say I was having fun? Are we as faculty allowed to have fun? Yes, and I believe it's a matter of keeping the right perspective. If you've been at the same job for 10 years or more like I was in my previous position, or even if you've just started a new job, I suggest you take some time and think about how you view that job. When is the last time you seriously thought about how you teach? When was the last time you changed your textbook, revised the way you taught a particular lesson, or added or removed content from a course? How do you view your students and your colleagues? Do you still get excited about preparing for a new semester or teaching a new course? Are you stuck in a rut, or are you having fun? Or are you somewhere in between?

One of the most important benefits I've received as a member of the EDGD, beginning with my first Midyear conference in San Antonio in 2001, is the opportunity to hear different perspectives on teaching and research in engineering design graphics from other Division members who are among the most accomplished and outstanding people in our field. This year the Midyear was hosted by our colleagues in Ireland at the University of Limerick. It was the first time a Midyear was held outside the Continental United States and we as a Division were excited about the opportunity to interact with a wider audience. The theme of the conference was "Universal Graphics – Multiple Perspectives" (there's that word again!) and I believe it was a success in that it met, even exceeded, the goal of bringing a variety of people with a range of experience together to discuss engineering design graphics. Especially for those who could not join us in Limerick, I hope you enjoy the conference papers that are included in this special edition of the Journal. They may just give you a new, perhaps international, perspective and inspire you to think a little bit about how and why you do what you do.

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Message from the Editor

Robert A. Chin
East Carolina University

As Nancy noted in her message, this special issue of the *EDGJ* contains, in addition to the standard fare, the Invited Plenary Panel Discussions papers. The Panel Discussions was one of three parts that comprised 67th Mid-Year Conference. In addition to the Panel Discussions, the conference team also scheduled I2 (Innovations & Ideas) Presentations and Full Paper Presentations. The purpose of the former was allowed authors to use alternative media to engage audience members through short presentations. The purpose of the latter was to allow authors to publish and present their papers in a traditional conference forum. The intent of the Panel Discussions was to promote dialogue among authors in anticipation they would collaborate with one another in future research agendas. For those who were not able to join us at this year's conference, the full proceedings, which include the I2 Presentations summaries, the Full Paper Presentations papers, and the Plenary Panel Discussions summaries, have been posted on the EDGD website at:

http://edgd.asee.org/conferences/proceedings/67th%20Midyear/67th%20Midyear%20proceedings.htm

Special thanks is extended to the Conference Chair, Niall Seery, and the Program Co-Chairs Diarmaid Lane and Sheryl Sorby for their work in delivering the Division's first international venue. In addition, the Journal's review board got a little break. All the papers published in this special issue were reviewed and accepted for publication by the following EDGD members:

Theodore Branoff, North Carolina State University
Donal Canty, University of Limerick
Aaron Clark, North Carolina State University
Frank Croft, The Ohio State University
Seamus Gordon, University of Limerick
Dennis Lieu, University of California, Berkley
Raymond Lynch, University of Limerick
Eddie Norman, Loughborough University
Mary Sadowski, Purdue University
Heidi Steinhauer, Embry-Riddle Aeronautical University, Daytona Beach
Norma Veurink, Michigan Technological University

We look forward to seeing you all in Atlanta for the Annual Conference in June.

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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

68th Mid-Year Conference - October 20-22, 2013, Worcester Polytechnic Institute
Site Chair - Holly Ault

69th Mid-Year Conference - October 2014, Illinois State University
Site Chair - Kevin Devine

Future ASEE Annual Conferences

Year	Dates	Location
2013	June 23 - 26	Atlanta, Georgia
2014	June 15 - 18	Indianapolis, Indiana
2015	June 14 - 17	Seattle, Washington
2016	June 26 - 29	New Orleans, Louisiana
2017	June 25 - 28	Columbus, Ohio
2018	June 24 - 27	Salt Lake City, Utah
2019	June 16 - 19	Tampa, Florida
2020	June 21 - 24	Montréal, Québec, Canada

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

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The Distinguished Service Award

The 2012 Distinguished Service Award (DSA) recipient is Judy Birchman of Purdue University. The DSA is the highest award of merit given by the Engineering Design Graphics Division. It recognizes the significant contributions of the recipient to the Division in terms of leadership, authorship, or support.

[1]

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

The award description can be found at:
http://edgd.asee.org/awards/dsa/index.htm

[2]

A complete list of awardees can be found at
http://edgd.asee.org/awards/dsa/awardees.htm

[1] 2005 DSA recipient, Mary Sadowski (l) introducing the 2012 DSA recipient, Judy Birchman (r). [2] Sadowski (l) and Birchman (r). [3] Birchman delivering her DSA acceptance remarks.

Photos by ***Theodore Branoff***

[3]

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Judy Birchman's DSA Acceptance Remarks
ASEE Annual Conference
San Antonio, Texas, June 10-13, 2012

First of all, I would like to thank the members of the division for choosing to honor me with this award. It means so much to me to be recognized for distinguished service by a group of people that I respect and who's company I enjoy. These meetings of the division are always something to look forward to, knowing that in addition to learning something new, I would get to experience a different part of the country with a fun group of people.

I thought I might share my experience as a graphics educator and a long-time member of this group. Last year, for the first time, Purdue recognized faculty for their years of service to the university—I was recognized for 33 years at the university. It made me think about my career at Purdue and what an experience it has been. Since I started teaching at Purdue, I worked in two different colleges—engineering and technology. Taught in an associate and then a baccalaureate program. Worked under 5 different deans and 4.5 different department heads—one was an interim. I also taught in 3 different programs due to name changes—Engineering Graphics, Technical Graphics and Computer Graphics Technology.

When I started, it was in the Department of Engineering Graphics under Civil Engineering. The department offered an associate degree in Technical Illustration. Later, we moved into what was then the School of Technology and became Technical Graphics and then Computer Graphics Technology. More recently, the School of Technology became the College of Technology.

In addition to these changes, I also experienced a variety curricula changes and teaching assignments over the years. When I first started, I taught graphics classes for the interior design students—orthographic, isometric, perspective, shades and shadows. I was teaching these classes because my undergraduate degree was in interior design. In fact, it was as an undergrad that I first encountered Jon Duff; he was a graduate student at the time. I was working in one of the empty labs, when all of a sudden I hear this voice preceding someone coming into the room, reciting what sounded like a late night show hosts monologue. I thought —Wow, this guy is really excited about graphics! That was my only encounter with him until he came back as a faculty member. I also taught our basic engineering drawing class for a few years. I had a temporary assignment in Creative Arts and then came back to the department and taught classes in design and layout which we were doing manually at the time. Then, after we updated to computers, I moved on to teaching desktop publishing, CAD and eventually interactive multimedia. So although I have been at Purdue for a long time, I feel like I had a variety of careers along the way. The diversity of the curriculum meant that there was always a new challenge—a new class to design, something different to teach or a new software to master.

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The really amazing thing about all of this, however, is that through it all, this division was always a place that I could present and feel at home. So no matter what kind of graphics I was teaching, this group was receptive to my presentations and supportive of my endeavors. All of my different department heads supported my involvement with EDGD, which says a lot about the division and I'd like to thank all of them for their support—Ken Botkin, Jerry Smith (always ready to get us a van and hit the road), Gary Bertoline and my current department head, Marvin Sarapin, who let me attend this meeting at the last minute and even got someone to cover my summer course for a few days.

I credit Jerry with getting me involved with teaching engineering graphics. As an undergrad he was willing to let me take a few independent study courses with him to further my interest in graphics. And when I decided to go to grad school he encouraged me to apply for a graduate teaching assistantship. I appreciate Mary Sadowski and Jon Duff and credit them with encouraging me and collaborating with me throughout my career and involvement with EDGD. We spent many lunch hours discussing classes, the curriculum and what books we were currently reading. I still miss having both of them in the department. There have been many others come through Purdue like La Verne Harris and Nancy Study that have also been colleagues and friends over the years. I would also like to thank my husband who couldn't join us tonight for putting up with me all the times I was stressed out getting ready for conferences.

I am so grateful for all the opportunities I have had to participate in division activities. I always felt appreciated for my efforts and found it easy to work with other members of the division. In addition, I have met so many great people through this division. No matter what type of graphics I am teaching, I always find something to inspire me at the EDGD sessions. Even if it does not directly relate to my class, I get a spark from something—a teaching technique, a new classroom tool or just a new attitude. Being involved with EDGD has been a great experience in every way. Thanks again for this great honor and for the many opportunities to participate, serve, learn and enjoy.

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The Editor's Award

The 2011 Editor's Award recipient is Andrew C. Kellie of Murray State University for his paper entitled Hard Copy to Digital Transfer: 3D Models that Match 2D Maps. His paper was published in volume 75, number 1 of the Journal and can be found at: http://www.edgj.org/index.php/EDGJ/article/viewFile/231/191

The Editor's Award was established to recognize the outstanding paper published in the previous volume of the Engineering Design Graphics Journal. The recognition includes a framed citation and a cash award and is presented during the following Annual Conference.

The award description can be found at http://edgd.asee.org/awards/editors/index.htm

A complete list of awardees list can be found at http://edgd.asee.org/awards/editors/awardees.htm

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Officer Nominees

According to Article IV: Elections and Succession of Officers, Section 1, paragraph 1d of the Division by-laws (http://edgd.asee.org/aboutus/edgdbylaws.htm), not later than February 15, and returnable before March 15, the Secretary-Treasurer shall mail to each member of record (as provided by the Journal Circulation Manager-Treasurer) of the Division a ballot bearing the slate submitted by the Nominating Committee together with additional names presented by petition. A candidate receiving the largest number of votes for the office sought shall be declared elected. The ballot shall be designed to facilitate return mailing and bear the name and address of the chair of the Elections Committee, the Division Vice-Chair.

The Division members that follow comprise the slate of candidates.

Kevin Devine
For Vice-Chair/Chair-Elect
Kevin Devine is an Associate Professor in the Department of Technology at Illinois State University where he serves as the Program Coordinator for their Engineering Technology major. After earning his BS in Industrial Technology in 1984, Kevin spent several years supporting the development of CAD/CAM and NC systems in the aerospace industry. Kevin then earned an MS in Industrial Technology in 1991 and an Ed. D in Curriculum and Instruction in 2003. Kevin has been active in EDGD since 2007 and has been the Division's Membership Director since 2010. Kevin was the recipient of the 2008 Editor's Award from the EDGJ and the 2011-2012 Oppenheimer Award from the EDGD. He is slated to host the 2014 EDGD Midyear Conference at ISU. Kevin is a recipient of Illinois State University's Teaching Initiative Award and he teaches courses in engineering graphics, machining/CNC programming, and industrial automation. His research areas of interest include pedagogy relating to solid modeling, GD&T and industrial robotics.

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Heidi M. Steinhauer
For Vice-Chair/Chair-Elect

Heidi Steinhauer is an Associate Professor of Engineering and Department Chair of Freshman Engineering at Embry-Riddle Aeronautical University. Dr. Steinhauer holds a Ph.D. in Engineering Education from Virginia Tech. She has taught Engineering Graphics, Introduction to Engineering Design, Automation and Rapid Prototyping, and Advanced 3D Modeling at ERAU for 17 years and has been an active member of ASEE since 2005. Dr. Steinhauer is the author of several articles about assessment of spatial visualization, engineering self-efficacy, and engineering education. Her current research interests are in the development and assessment of students' spatial visualization skills, 3D modeling in engineering design, women's self-efficacy and retention in engineering. In 2008, she was awarded the ABET President's Award for Diversity.

Diarmaid Lane
For Director of Membership

Diarmaid Lane received his B. Tech (Ed.) and Ph.D. in Technology Education from the University of Limerick in 2008 and 2011 respectively. He spent six years in the metal fabrication industry developing engineering craft based skills prior to pursuing his studies in technology education. He currently holds a faculty position at the University of Limerick where he teaches engineering graphics courses to undergraduate and postgraduate students of initial teacher education. He was the program chair for the 67th MidYear Conference in Limerick, Ireland in 2012. He has been awarded the EDGD Chair's Award in 2010 and 2011 in addition to the Oppenheimer Award in 2012. His research interests are in the development of spatial cognition through freehand sketching. If elected as an officer in EDGD, his goal would be to promote the recruitment of new members with particular focus on graduate students who could significantly benefit from collaborating with established division members.

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Theodore J. Branoff
For Director of Programs
Ted Branoff, Ph.D. is an associate professor at North Carolina State University. He has been an ASEE member since 1987 and is the immediate past President of the International Society for Geometry and Graphics. Dr. Branoff's research interests include spatial visualization in undergraduate students and the effects of online instruction for preparing teachers and engineers. Along with teaching courses in introductory engineering graphics, computer-aided design, descriptive geometry, and instructional design, he has conducted CAD and geometric dimensioning & tolerancing workshops for both high school teachers and industry.

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Engineering Graphics Educational Outcomes for the Global Engineer: An Update

R. E. Barr
The University of Texas at Austin

Introduction

Graphics has always been the language of engineering and the preferred media for conveyance of design ideas (Booker, 1963). The first record of what appears to be an engineering drawing is a temple plan from 2130 B.C. found in an ancient city in Babylon. From Egyptian times, dated about 1500 B.C., papyrus remnants have been found of drawings that used a grid of straight lines made by touching the papyrus with a string dipped in ink pigment, thus setting the stage for early “drafting” practices. The first written record discussing drafting and the use of geometry for design representation is given by Vitruvius (1914), a Roman builder from the turn of A.D. Vitruvius writes how “an architect must have knowledge of drawing so he can make sketches of his ideas.” In about 1500 A.D., the first record of what could be called related multi-view projections appeared in Renaissance Italy. Some of the engineers and inventors of that time were also famous artists. Drawings left by Leonardo da Vinci were artistic pictorial sketches that resemble axonometric sketching techniques still taught and in use today. In 1795, Gaspard Monge published his well-known treatise on descriptive geometry, which provided a scientific foundation to engineering graphics that lasted for 200 years. During the past century, engineering graphics used different manual tools that made production of orthographic projection drawings easier. Drafting boards, T-squares, triangles, and mechanical pencils were common equipment purchased by engineering students. The development of the computer hailed yet a new era in engineering graphical communication technology. Computer-Aided Design (CAD) systems slowly replaced drawing boards with an electronic tool. By the late 1980’s, it became evident that a new 3-D solid modeling approach would became the core technology for engineering graphics, and the author has spent the last two decades promoting an engineering graphics curriculum based on this 3-D paradigm (Barr, et al., 1994).

Methods

In an effort to attain consensus on educational outcomes for engineering graphics, a survey was conducted amongst engineering graphics faculty. This survey presented a list of potential engineering graphics outcomes affirmed by a literature search of related journal papers (Meyers, 2000; Branoff, et al., 2002; Smith, 2003; Bertozzi, et al., 2007; Planchard, 2007) This resulted in a list of fourteen major graphics outcomes. Figure 1 shows the list of fourteen original outcomes contained in the survey. The survey was conducted twice at ASEE EDG mid-year meetings, in 2004 and again in 2012.

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FOURTEEN PROPOSED EDUCATIONAL OUTCOMES FOR ENGINEERING GRAPHICS

OUTCOME 1: ABILITY TO SKETCH ENGINEERING OBJECTS IN THE FREEHAND MODE.

OUTCOME 2: ABILITY TO CREATE GEOMETRIC CONSTRUCTION WITH HAND TOOLS

OUTCOME 3: ABILITY TO CREATE 2-D COMPUTER GEOMETRY.

OUTCOME 4: ABILITY TO CREATE 3-D SOLID COMPUTER MODELS.

OUTCOME 5: ABILITY TO VISUALIZE 3-D SOLID COMPUTER MODELS.

OUTCOME 6: ABILITY TO CREATE 3-D ASSEMBLIES OF COMPUTER MODELS.

OUTCOME 7: ABILITY TO ANALYZE 3-D COMPUTER MODELS.

OUTCOME 8: ABILITY TO GENERATE ENGINEERING DRAWINGS FROM COMPUTER MODELS

OUTCOME 9: ABILITY TO CREATE SECTION VIEWS.

OUTCOME 10: ABILITY TO CREATE DIMENSIONS.

OUTCOME 11: KNOWLEDGE OF MANUFACTURING AND RAPID PROTOTYPING METHODS.

OUTCOME 12: ABILITY TO SOLVE TRADITIONAL DESCRIPTIVE GEOMETRY PROBLEMS.

OUTCOME 13: ABILITY TO CREATE PRESENTATION GRAPHICS.

OUTCOME 14: ABILITY TO PERFORM DESIGN PROJECTS.

Figure 1. Engineering Graphics Outcomes.

Results

The results of the survey are shown in Table 1 for the 2004 survey and Table 2 for the 2012 survey. Even though the surveys are separated by eight years of on-going

Table 1. Graphics Faculty Outcomes Survey Results for 2004 (N=24).

Outcomes	Rank
Ability to Create 3-D Solid Computer Models	4.75
Ability to Sketch Engineering Objects in the Freehand Mode	4.67
Ability to Visualize 3-D Solid Computer Models	4.46
Ability to Create Dimensions	4.38
Ability to Generate Engineering Drawings from Computer Models	4.33
Ability to Create 3-D Assemblies of Computer Models	4.29
Ability to Create 2-D Computer Geometry	4.21
Ability to Create Section Views	4.13
Ability to Perform Design Projects	3.96
Ability to Analyze 3-D Computer Models	3.71
Knowledge of Manufacturing and Rapid Prototyping Methods	3.42
Ability to Create Presentation Graphics	3.42
Ability to Solve Traditional Descriptive Geometry Problems	2.29
Ability to Create Geometric Construction with Hand Tools	2.13

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Table 2. Graphics Faculty Outcomes Survey Results for 2012 (N=24).

Outcomes	Rank
Ability to Create 3-D Solid Computer Models	4.75
Ability to Sketch Engineering Objects in the Freehand Mode	4.54
Ability to Visualize 3-D Solid Computer Models	4.54
Ability to Create 3-D Assemblies of Computer Models	4.54
Ability to Create Dimensions	4.38
Ability to Create Section Views	4.33
Ability to Generate Engineering Drawings from Computer Models	4.29
Ability to Analyze 3-D Computer Models	4.13
Ability to Create 2-D Computer Geometry	4.08
Ability to Perform Design Projects	4.08
Knowledge of Manufacturing and Rapid Prototyping Methods	3.63
Ability to Create Presentation Graphics	3.46
Ability to Solve Traditional Descriptive Geometry Problems	2.75
Ability to Create Geometric Construction with Hand Tools	2.71

change in the field, the results are very similar. Specifically, the top three highest ranked outcomes are the same for both survey years 2004 and 2012, and come in the same order: 1: Ability to Create 3-D Solid Computer Models; 2: Ability to Sketch Engineering Objects in the Freehand Mode; and 3. Ability to Visualize 3-D Solid Computer Models. Thus, it appears that some stability in the teaching of engineering graphics has arisen after three decades of constant change. These results support the contention in Figure 2 that 3-D solid modeling has become the central theme in most engineering graphics programs. Indeed, four of the top seven ranked outcomes pertain to modern computer tools to generate a graphical image. In addition, several traditional graphics topics (sketching, dimensioning, engineering drawings, and section views) were also ranked high, receiving average rankings above 4.00. On the other hand, the long-standing traditional topics of descriptive geometry and manual geometric construction techniques were ranked low by the respondents. They were the only two topics that received average rankings below 3.00.

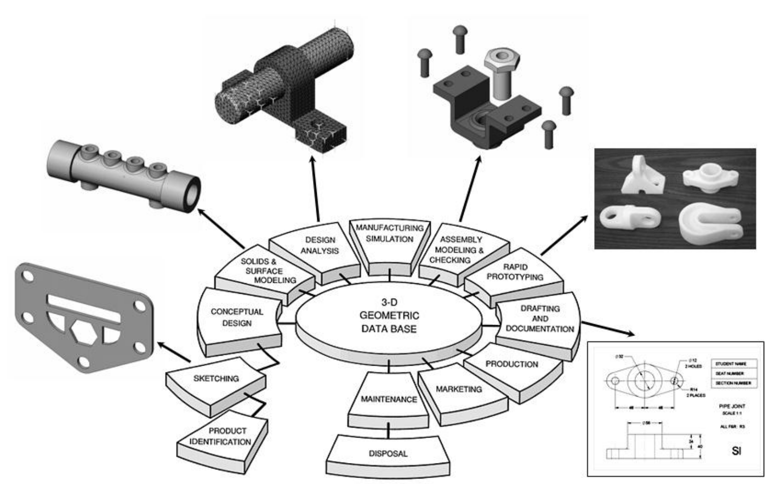

Figure 2.

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Discussion

This paper discusses the formulation of educational outcomes for engineering graphics that span the global enterprise. Results of two repeated faculty surveys indicate that new computer graphics tools and techniques are now the preferred mode of engineering graphical communication. Specifically, 3-D computer modeling, assembly modeling, and model application to design and manufacturing all received significant notices in the survey results. Results of the surveys also show strong sentiment for some traditional graphics topics such as freehand sketching and dimensioning. Thus, modern engineering graphics should focus on three areas of instruction, as shown in Figure 3.

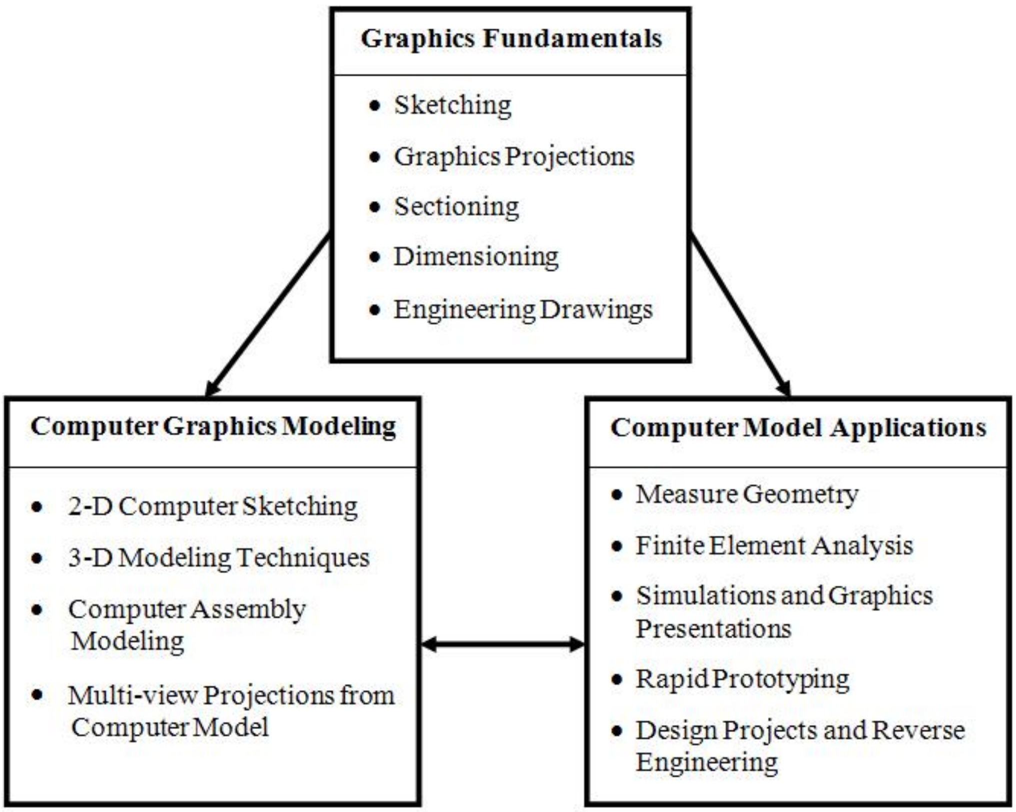

Figure 3.

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Dr. Barr can be reached at rbarr@mail.utexas.edu

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Curriculum Planning for the Development of Graphicacy

X. Danos
University of Cyprus

E. Norman
Loughborough University

Introduction

The ability to imagine a better future and work towards materialising this is 'key' to economic development and technological change. Recent research has highlighted the importance graphicacy has in these developments as well as in our everyday lives; professionally, socially and culturally (Considine, 1987; Stokes, 2002). Graphicacy concerns the ability to communicate through still visual images, such as maps, diagrams, graphs and symbols (Danos, 2012). The cognitive requirements that accompany such skills, e.g. modelling 'in the mind's eye' and critical thinking, support activity in numerous fields. Important 'life skills' are introduced through education from an early age, using policies on literacy, numeracy and articulacy. Graphicacy, however, which is used extensively in the early years and later through school and beyond, has yet to be introduced through a strategic approach (Hope, 2008; Danos, 2012; Anning, 1997; Wilmot, 1999). Currently graphicacy does not explicitly feature in the structured curricula in England; this is similar in many other countries within Europe, the US and Australia, among others (Danos, 2012; Krane & Dyson, 1981; Balchin, 1996). The main reasons for this are believed to be; the low significance attached to graphicacy skills for the development of an intellectually well-balanced human; and the high complexity level involved in analysing and defining the areas of graphicacy, which are both related to a lack of research effort in this area (Danos, 2012; Fry, 1981).

Images are powerful and affect people regardless of their academic, economic, cultural or religious status (Poracsky et.al, 1999). They can educate, inform and inspire; affect perception and decisions; and be used for communicating, learning and recording ideas. Baynes (2011) believes they are fundamental to all peoples and cultures; an intellectual activity that links sensing, feeling, thinking and doing. 'They can be used to effectively model core aspects of future reality which cannot be adequately modelled through language or numbers, such as colour, space, shape, distance and scale amongst others' (ibid:4). The power of images includes these and many more possibilities, as our exposure to more media messages increases. However, young people are given little guidance on how to read, interpret and critically evaluate the images and information they are exposed to (Danos, 2012; Hope, 2008). 'This renders them visually vulnerable and potential victims of a language that can influence and manipulate them' (Considine, 1987, 635).

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Educationalists use visual images as teaching aids, yet little is known about how these are perceived by children with different abilities. There is an emerging need to consider the potential for the development of a graphicacy policy within the curriculum. This paper considers a potential route towards this goal, reporting on research conducted focused on identifying and defining graphicacy; investigating its significance in the curriculum; exploring how children deal with it and ultimately how it can affect their learning (Danos, 2012).

Method

To complete an initial audit of graphicacy in the curriculum, a research tool clearly defining graphicacy was required as part of the research methodology. A number of diverse taxonomies were identified through literature review, covering areas of graphicacy from different aspects. Fry's taxonomy (1974) was the closest one identified relating to the research tool needed for this study; enabling the identification of the still visual images used for teaching and learning. Although being over 30 years old, this taxonomy provided strong foundations for a more modern, up-to-date taxonomy, incorporating images accommodating the technological trends currently available such as coloured 3-dimensional and more complex still images (Figure 1).

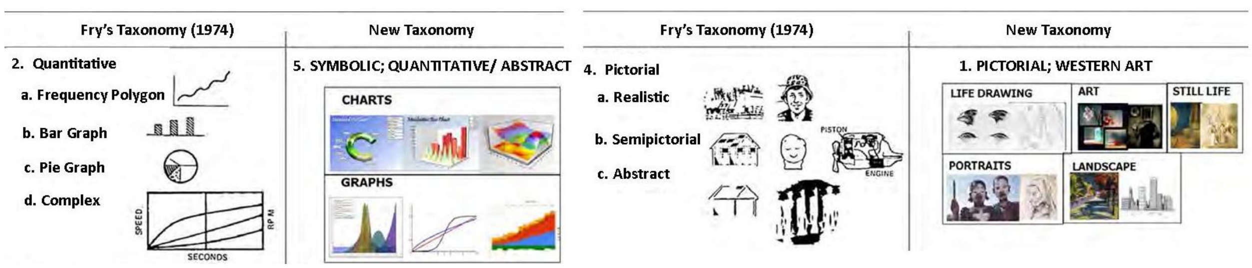

Figure 1. Images from Fry's taxonomy (1974) and Danos' updated version (2012).

The updated taxonomy of graphicacy is considered to be constant work in progress and its effectiveness has been tested in various ways during its development and use. It has been discussed with a number of independent researchers prior its use; and has been validated through an initial study to identify graphicacy use across the curriculum through the analysis of school textbooks in schools in Cyprus, the UK and USA. All the textbooks in an opportunistic sample from 3 schools were analysed. The schools in the UK and Cyprus were for the age range 11-14 and the school in the USA for 16-18. All the subjects for which the teachers agreed to participate in the research were included (the majority, see Table 1). It has been further validated through conference presentations, education publications as well as a formal Delphi study with leading researchers from the UK, Cyprus, Sweden and America.

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Results

Results from the above studies covered in this paper include the new taxonomy developed, as well as cross-curricular links of graphicacy use (Table 1) identified within the 3 schools, in each of Cyprus, UK and the USA and the unexpected and surprisingly similar patterns of graphicacy use across the 3 schools (Figure 2).

Results on progression and development descriptors in graphicacy are also reported. Research explored these in relation to the new taxonomy. A research strategy has been developed to test a number of methodologies to construct progression level descriptors, regarding 5 types or elements of images in 3 different areas of the taxonomy; rendering (graphic arts: still life), symbolic representations (symbolic: abstract), perspective drawing (pictorial: diagrams), star profile (symbolic: quantitative) and portrait drawings (pictorial: western art). Tasks for each area have been designed and pilot-tested during workshops and lessons. The analysis of the results tested different methods of analysis and provided new information for more detailed and exact descriptors of continuity and progression (CaP). A few examples of these are described in this paper.

Discussion

Graphicacy is believed to be used in most subject areas and lessons in schools across the world. The analyses of school textbooks have validated this position and have shown cross-curricular links between the subject areas studied. Hence, although a graphicacy policy would not necessarily introduce anything new, it could potentially develop existing practice. A more structured approach would enable teachers to share information across subject areas, and share common terminology. In other words, teachers will start taking advantage of each other's pedagogy rather than working in isolation.

The tools to develop such a policy have yet to be developed fully, but the overall skeleton structure as well as samples of what can be done, and how, have been completed. This paper describes the essential starting point of an up-to-date taxonomy of graphicacy, and illustrates the next steps of working in particular areas of the taxonomy independently. Through analysis of children's work, continuity and progression (CaP) descriptors have been developed in 5 different areas, which could be used as guidelines during teaching each graphicacy element. Having descriptors in each area of the taxonomy would enable teachers to make comparisons and connections between subject areas, leading towards a systematic and co-ordinated teaching approach.

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Table 1. Inbound graphicacy skills concerning two areas of the taxonomy.

			UK school								Cyprus school														USA school									
Graphicacy elements			Maths	Science	DT	English L.	French L.	Geography	RE	**Out of 7 subjects**	Maths	Biology	Chemistry	Physics	DT	Art	English/ French/ German L.	Greek	Geography	History	Music	ICT	RE	**Out of 13 subjects**	Calculus	Geometry	Biology	Chemistry	French/ German L.	ICT Java	History	Art	**Out of 8 subjects**	**Out of 28 subjects over 3 schools**
PICTORIAL	Graphic arts	Art	X		X					2				X	X	X		X		X	X		X	7					X		X	X	3	12
		Life drawing			X					1							X						X	2									0	3
		Landscape								0						X			X			X	X	4									0	4
		Portraits	X							1						X								1									0	2
		Still life		X	X					2						X								1									0	3
	Drawings	Drafts			X					1						X								1									0	2
		Sketching	X	X	X					3				X	X		X							3	X				X		X		3	9
		Drawing	X	X	X	X		X	X	6	X	X	X	X	X		X			X	X	X		9	X		X	X	X	X			5	20
		Architectural			X					1										X	X		X	3	X	X							2	6

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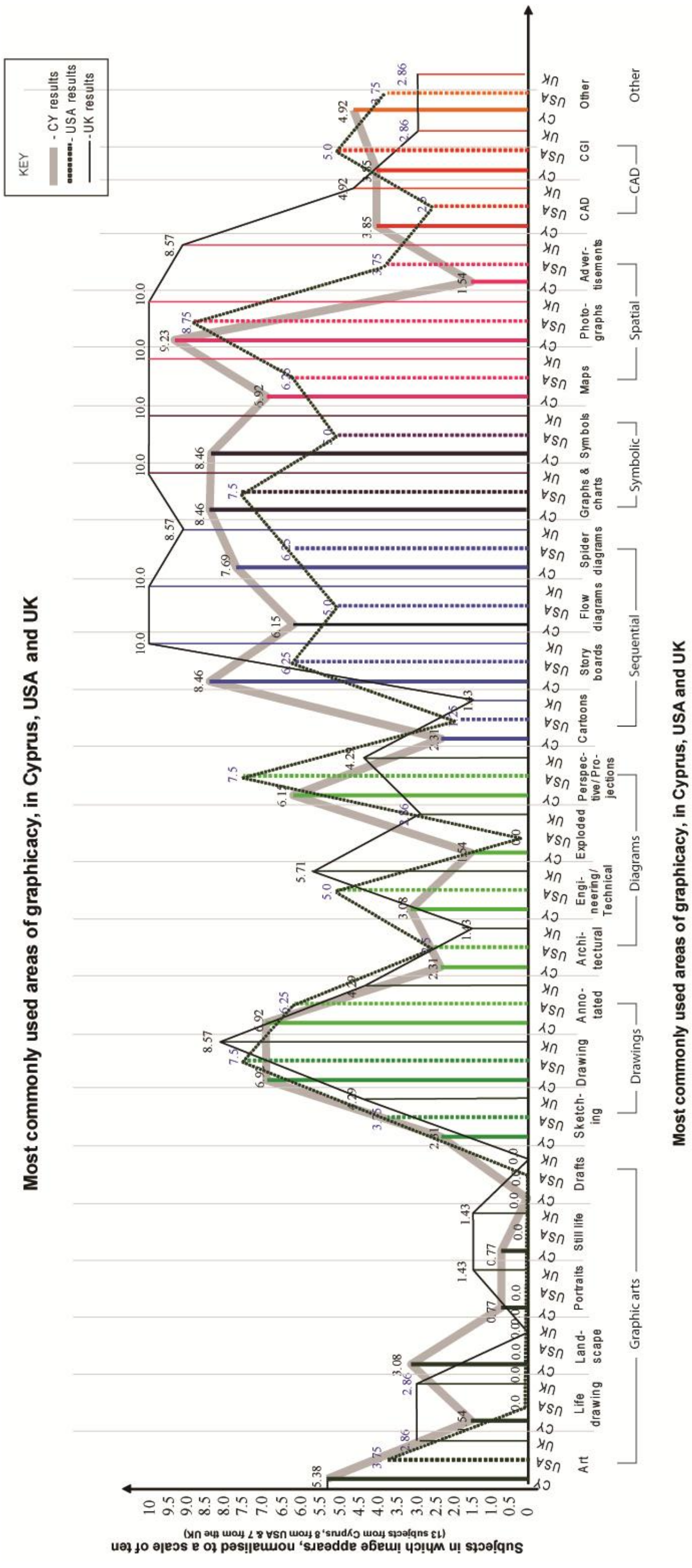

Figure 2. Comparison of patterns of graphicacy use in 3 schools.

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Dr. Danos can be reached at xdanos@gmail.com, Dr. Norman can be reached at ewlnorman@gmail.com

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Engineering Graphics Courses in the Light of the National Qualifications Framework

R. A. Górska
Cracow University of Technology, PL

Introduction

In recent years major changes have been introduced into the system of higher education in the common European Higher Educational Area (EHEA). On account of the Bologna Process the EHEA is leading to greater compatibility and comparability of the systems of higher education and is making it easier for learners to be mobile and for institutions to attract students and scholars from other continents.

In 2011, the Law of the Higher Education (Dz.U. No 84, poz.450) in Poland has implemented the 'National Qualifications Framework' (NQF) which assumes that the education in each of the EU countries is transferable and that every student gets the right, with no further conditions, to continue his/her studies in any other country within the community. The main assumption of the NQF is to develop and/or to re-construct the curricula by defining and taking into account the **learning outcomes** (Próchnicka et al., 2010). According to the NQF new curricula must be implementing **competence orientation** into programs. The **qualifications** necessary for contemporary graduates have been defined and classified in order to eliminate the content, which is no longer up-to-date, from the curriculum. The main advantage of these re-defined curricula in terms of learning outcomes is their transparency. Basically, the method 'bottom-up' has been implemented for the existing curricula reconstruction while the method 'top-down' was used to create new modules and subjects. The deadline for delivery of the new definitions of curricula at Polish universities has been set for October 1st, 2012.
The main assumptions for the curriculum construction according to the NQF are as follows (Report, 2010):

1. **educational objectives** are uniquely defined for a **major** (faculty), a **field**, a **specialty**, or a **subject**;
2. **learning outcomes** are classified in terms of various types of education: generic, field, and specific; **they** have been divided into three categories (EQF_LLL08a, 2008): **knowledge**, **ability** and **competence**.
3. **framework qualifications** have been classified (EQF_EHEA05a, 2005) into three cycles when the students are able to: **demonstrate knowledge** and **understanding** in a field of study; are able to **apply knowledge** and understanding to their work and vocation; have the ability to **gather and interpret relevant data**; can **communicate ideas**, i**nformation**, problems and have the **learning** skills. The NQF defines three various cycles of qualifications: level I – relates to qualifications received after

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graduation from the 1st level of studies (Bachelor degree, engineer); level II – completion of studies at the 2nd level (MSc), Level III – graduating from the PhD study level.

All these guidelines are crucial both in context of determining the syllabuses of newly designed subjects and re-modeling the existing programs. In this paper we describe two graphics courses: 'Technical Drawing'(TD) and 'Descriptive Geometry' (DG) which belong to a freshman level studies in Poland. Modifications introduced to the courses have directly resulted from the NQF recommendations.

Syllabuses and the Educational Objectives

The educational objectives for two of the mentioned graphics courses have been listed in Table 1. At the faculty of Civil Engineering, Cracow University of Poland, the total number of hours carried out in a classroom as a face-to-face instruction equals 30 for each of the DG and TD courses, while the workload resulting from the ECTS points respectively corresponds to 90 (for DG) and/or 60 (TD- regular studies) hours—see Table 2. The part of work includes studying online (blended) instruction. Both design projects and online content study is done at home individually by each student. This is especially important to the students who study in a system of 'distant' (extramural) studies, which in practice means that the classroom instructions are delivered during the sessions over the weekend days every second week.

Table 1. Educational objectives for graphics courses*.

Descriptive geometry course	Technical drawing course
Introduction of basic representation methods used in engineering practice in order to graphically describe three-dimensional (3D) objects on a two-dimensional (2D) plane.	Introduction of basic principles and terminology used for preparation of technical documentation in accordance with applicable standards. Designations and dimensioning on architectural and building drawings are introduced.
Introduction of the methods used in order to correctly read 2D technical drawings and to restitute spatial models in a 3D space.	Introduction of basic principles and terminology used for preparation of **reinforced** structures
Introduction to theory on spatial relationships between the planar and spatial elements of 3D constructions.	Introduction of basic principles and terminology used for preparation of **metalwork** structures.
Development of spatial visualization abilities.	Introduction of basic principles and terminology used for preparation of **wood** constructions.

* http://newsyllabus.pk.edu.pl/

Definition of the Learning Outcomes for Graphics Courses

The final evaluation of the performance on the graphics course consists of a few components. These are: 1) evaluation of the design projects delivered in a form of

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Table 2. TD and DG courses: Balance between classroom hours and students' individual work.

	Type of Activity:	Number of hours assigned to activity			
		DG: Regular studies	**DG: Distant Studies**	**TD: Regular Studies**	**TD: Distant Studies**
Contact-hours	Classroom hours (lectures & labs)	**30**	**30**	**30**	**30**
	Office hours	**7**	**5**	**0**	**0**
	Partial and Final Exams	**3**	**0**	**0**	**0**
Self-study	Self-study hours	**10**	**15**	**5**	**15**
	Results' elaboration	**0**	**0**	**0**	**0**
	Project's elaboration	**30**	**30**	**25**	**35**
	Online-content studies Moodle	**10**	**10**	**5**	**10**
Overall number of hours assigned to a subject		**90**	**90**	**60**	**90**
ECTS		**3**	**3**	**2**	**3**

monochrome printouts and completed into a file-folder (DG & TD) accompanied with the attached CD of the recorded drawings – this is only the case for the TD course, 2) two partial and one final test completed at the end of the course (DG & TD), 3) practical exam on the skill of using the CAD system (TD). Some examples of students' projects have been shown in Figures 1 and 2.

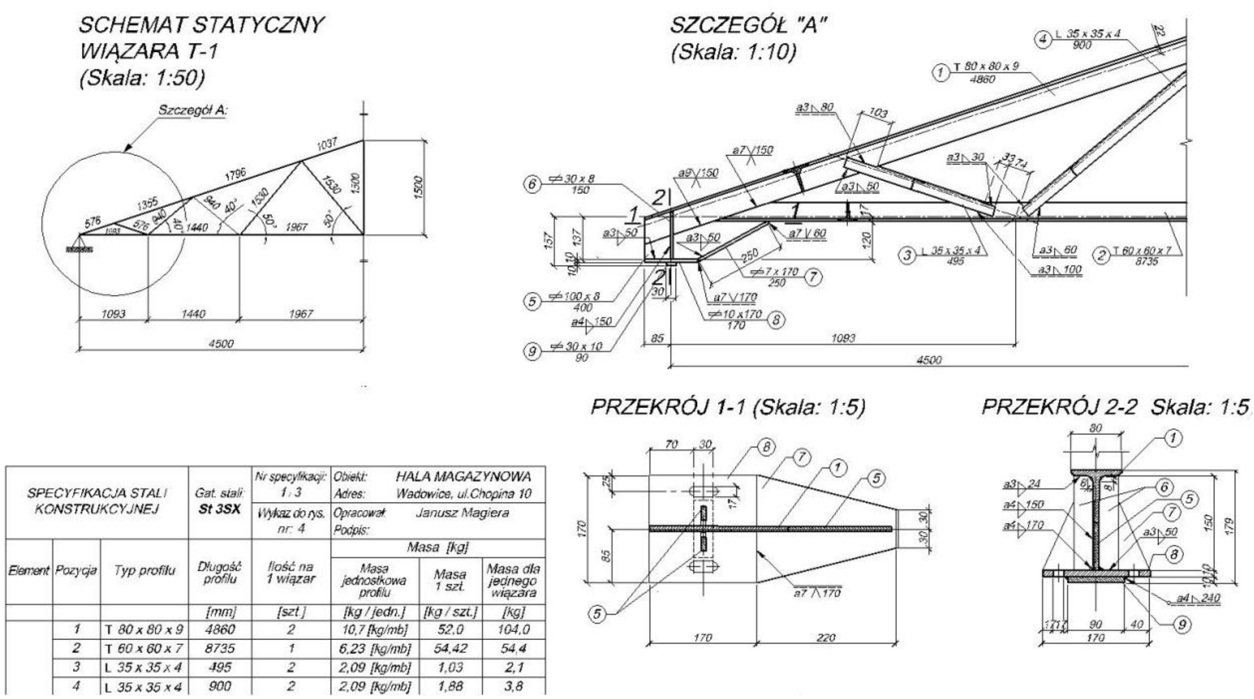

Figure 1. Example of a welded steel truss assignment – welds' designation.

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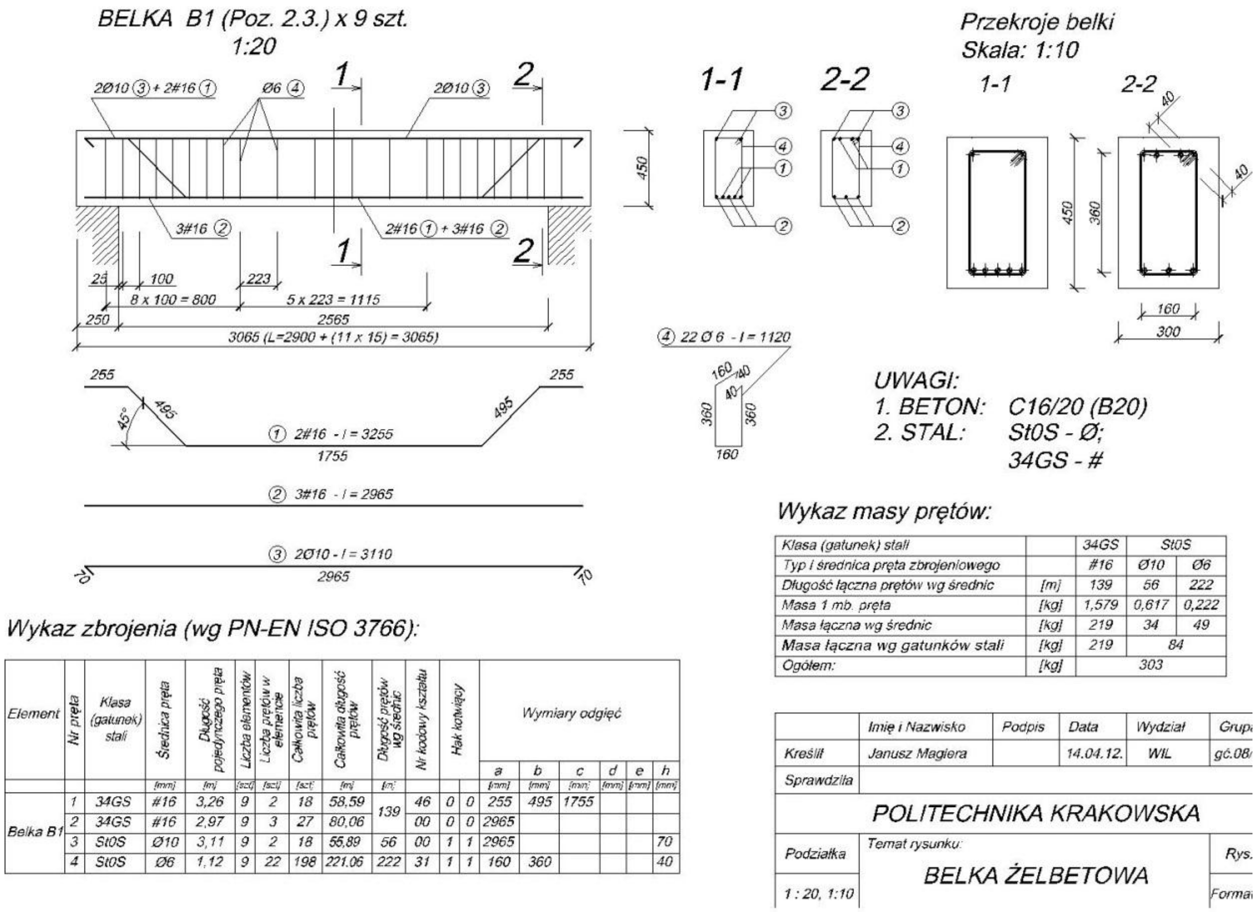

Figure 2. Example of a reinforced concrete structure: Beam and Bill of materials

The expected learning outcomes must undergo evaluation and verification after the course has been completed in context of the planned educational objectives. It is worth noticing that ‘Descriptive geometry’ courses stay alive within the programs for architecture and civil engineering at most universities in Poland, while they have disappeared or were changed into graphics courses at other technical faculties in Poland. As a **learning outcome** of both a graphics and a descriptive geometry courses one can identify development and fostering knowledge, abilities and competence. The student will be able to:

1. effectively communicate engineering concepts and problem solutions for civil engineering design both in a teamwork and in the interdisciplinary communities,
2. create technical documentation, i.e. to provide representations of 3D constructions on a 2D media, and to be able to read technical drawings of the designed constructions, i.e. to restitute planar drawings into a 3D space, according to related drawing standards and conventions of engineering graphics,
3. develop spatial thinking and spatial imagination.

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Prerequisites for the courses listed here are: basic knowledge of planar and spatial Euclidean geometry, planar geometric constructions and basic planar theorems, properties of spatial solids (descriptive geometry) and knowledge of major projection methods used for structures' representation (technical drawing). Schematic drawings, assembly drawings, working drawings and detailed drawings will be done and specified at various degrees of accuracy.

Reports

After completion of the course, an anonymous survey has been conducted among the students and then used to evaluate the impact of various teaching methods on the learning habits of our students. The survey included the following questions:

1. Did you use the online instructional material when you studied DG and/or TD content?
2. What is your instructional preference?
3. What is your preference for AutoCAD instruction?
4. What type of interactivity do you prefer: student-teacher or student-student when you study a specific content?

Figure 3 shows some data which was derived after evaluation of the survey. Forty students from the distant study course completed the survey. We can conclude that the on-line material delivery was the one most preferred by the students. However, in terms of AutoCAD instruction delivery the students preferred both face-to-face demonstrations during the meetings and written instructions which were uploaded to the Moodle system. What is interesting, the use of AutoCAD help has turned out not to be a means commonly used by the students.

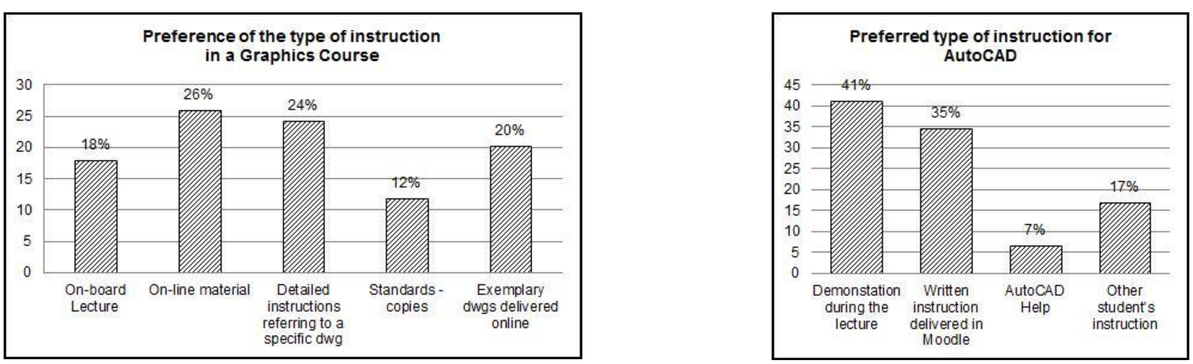

Figure 3. Preference of the type of instruction for the a) graphics course, b) AutoCAD

Figure 4 provides evidence on the activity of students during the semester course. The activity has risen at the times preceding the tests.

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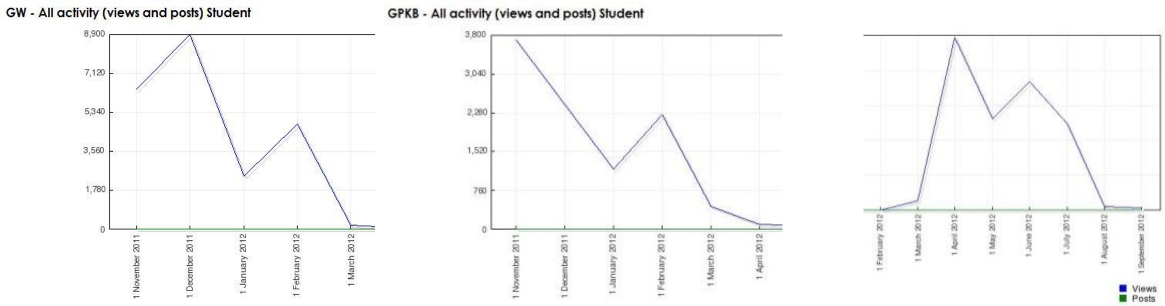

Figure 4. Reports on activity in DG course: Regular studies (left) and Distant courses (middle), TD - summer semester (right).

Conclusions

The article describes the rationale for introduction of the NQF into graphics courses teaching. New requirements set up by the NQF have caused a revision of the curricula at all universities in Poland. Much stress has been put on the load of knowledge, abilities and competences, which resulted in re-formulation of the courses. Delivery of the online content for the undergraduate engineering graphics (DG and TD) instruction in a form of blended courses for over 3 years has been beneficial to the students and it complies with a model of a student-centered education.

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Dr. Górska can be reached at rgorska@pk.edu.pl

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Use of Technology Solutions to Improve CAD Instruction

Holly K. Ault
Worcester Polytechnic Institute

Alister Fraser
Parametric Technologies Corporation

Introduction

Engineering Graphics curricula have changed dramatically in the past three decades. In the past, students in nearly all engineering disciplines were instructed in manual drafting and descriptive geometry. Students spent many hours “on the board”, and this training enhanced the students’ graphics communication, design and visualization skills (Connolly, 2009; Mohler, 2006). With the advent of CAD in the 1980s, graphics instruction shifted to use these new computational tools. CAD instruction shifted to focus on procedural knowledge, i.e. the ability to use the ‘features and functions’ of any given CAD tool. These curricular changes have been driven by industry’s desire to increase productivity, at the expense of developing good design skills (Brown, 2009). In addition, accreditation agencies in the US have eliminated graphics from their list of required skills for all engineering disciplines (ABET, 2012). As a result, a majority of universities often find it difficult to devote a significant amount of time to CAD instruction in the curriculum. Despite this, increased product complexity and challenges in modern product development means that an understanding or awareness of these technologies is a necessary skill for engineering graduates (Branoff et al., 2002). However, effective use of CAD systems requires the development of declarative and strategic knowledge such as selection of solid modeling alternatives and use of modeling constraints (Chester, 2007; Menary, 2011; Rynne and Gaughran, 2012).

This paper explores the use of a web based Learning Management System (LMS), coupled with Pro/FICIENCY, a PTC (2012) technology designed to automate the assessment of student assemblies, parts and drawings, in an attempt to make more faculty and student time available to focus on strategic knowledge and conceptual understanding that may be more relevant to a wider engineering degree. This paper records student perceptions of using an LMS to understand basic CAD competencies and identifies that there is a lack of conceptual assessments available to adequately understand the impact on their wider education.

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Method

The advanced CAD course at WPI is an elective course for juniors and seniors in mechanical, manufacturing and aerospace engineering. The 3-credit hour equivalent course includes 14 one-hour lectures and 14 two-hour lab periods. It is expected that students have taken the introductory 3-credit CAD course and are familiar with solid modeling methods and strategies as well as basic drawings and assemblies. The introductory course is taught using SolidWorks (2012). However, the advanced course utilizes a different software tool, PTC Creo (2012), so the first few classes and labs are devoted to “getting the students up to speed” on the new software and reviewing solid modeling fundamentals, which many of the students have forgotten since taking the freshman course. The remainder of the course covers advanced design and analysis topics such as mechanism design, rapid prototyping and finite element analysis. Students are assessed using modeling exercises, online multiple choice and short answer quizzes, and two or three project activities.

Typically, the lectures cover conceptual material such as modeling strategies, constraint theory, mechanism design, and structural analysis fundamentals. Lab modeling exercises were based on tutorial texts such as (Toogood, 209; Kelley, 2008). Students would complete the textbook tutorials during the lab period with instructor and teaching assistant (TA) present to answer questions, and then complete one or more similar exercises for lab homework, to be checked off by the TA during the following lab period. Experienced lab proctors were available to answer questions during open lab hours outside of class time.

In the case of student work, Pro/FICIENCY can be deployed in conjunction with web based learning management system in an effort to automatically assess variations and mistakes in the modeling methods prescribed by the instructor. The quizzes and parts can be corrected and graded automatically to provide feedback to the students, thus enabling the lab activities to reflect the “inverted classroom” strategy (Gannod, 2007; Lage et al., 2000; Steif, 2009; Toto and Nguyen, 2009; Young, 2012). In this course offering, only the online quizzes were utilized; students were required to complete the tutorial and quiz before lab. During the lab periods, the students were then given more challenging parts to model, which had previously been assigned as homework for the labs. With the inverted classroom strategy, the instructor and teaching assistant were available to assist the students with the more difficult modeling exercises during the lab period. In most cases, these exercises could be checked off during the same lab period.

Results

Upon completion of the course, students were queried to evaluate their perceptions of the use of the LMS tutorials. This is an excellent pool of students to survey, as they used the textbook tutorials for their introductory CAD course, and thus were able to make a good comparison between the two instructional methods. Twenty-three students

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completed the survey. In general, about 2/3 of the students stated that they always completed the tutorials before the associated lab session (Figure 1). This is not totally consistent with the data collected from the LMS system, which suggests that the students were not as diligent as they claimed.

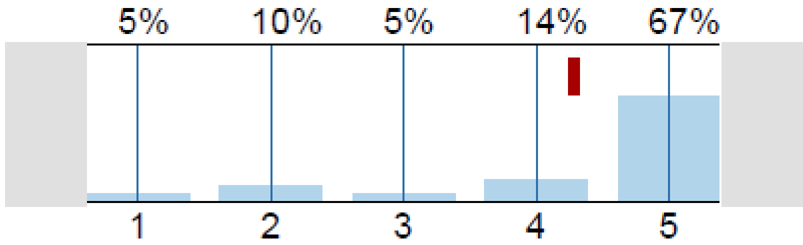

Figure 1. Student completion rate for online tutorials, n=22 (1=Never, 5=Always).

Students rated the LMS tutorials as average, however, three-fourths of the students stated that they would **not** prefer a tutorial text over the LMS online tutorials (Figures 2 and 3). The reasons for this preference were not investigated. This topic will be explored further in future course offerings.

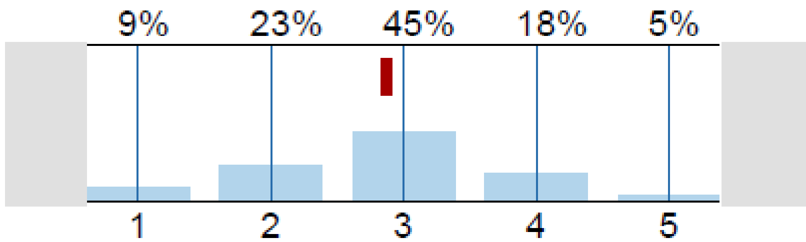

Figure 2. Student rating of online tutorials, n=23 (1=Poor, 5=Excellent).

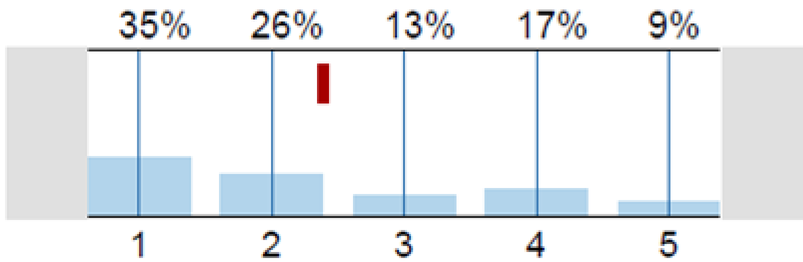

Figure 3. Student preference for textbook tutorials, n=23 (1=Strongly prefer online tutorial, 5=Strongly prefer textbook).

Forty percent of the students felt that the online tutorials helped them to be more productive during the lab periods (Figure 4), and another quarter of the students felt that there was no difference between the online and text-based tutorials in terms of productivity. A significant number of students (39%) expected that they would use the vendor website during the coming year to access additional tutorials for further learning

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(Figure 5). Most likely these were juniors who plan to use the CAD software for their capstone design projects.

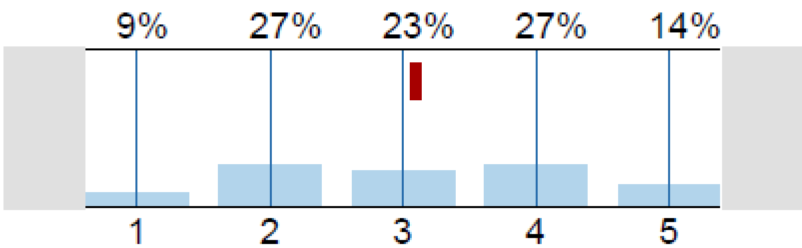

Figure 4. Student measure of online tutorials' ability to increase lab productivity, n=22 (1=Poor, 5=Excellent).

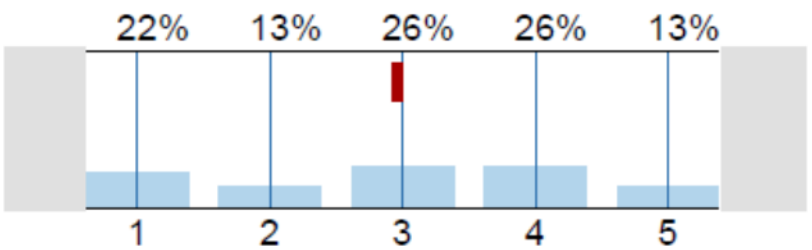

Figure 5. Student prediction to use online tutorials after course end, n=23 (1=Highly Unlikely, 5=Definitely).

Conclusions

Our preliminary results suggest that use of the LMS was successful and resulted in similar outcomes as compare to the use of tutorial texts. Furthermore, students preferred the online learning system, and recognized advantages to be able to access the learning modules for more advanced topics later in their academic program. Future work will focus on the use of the model checking software to reduce instructor grading time and provide feedback to students on modeling strategies.

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Dr. Ault can be reached at hkault@wpi.edu, Mr. Fraser can be reached at afraser@ptc.com

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Using the Continuum of Design Modelling Techniques to Aid the Development of CAD Modeling Skills in First Year Industrial Design Students

I.J. Storer
Loughborough University

R.I. Campbell
Loughborough University

Introduction

Industrial Designers need to understand and command a number of modelling techniques to communicate their ideas to themselves and others. Verbal explanations, sketches, engineering drawings, computer aided design (CAD) models and physical prototypes are the most commonly used communication techniques. Within design, unlike some disciplines, visualisation tools, whether 2D or 3D, are an essential part of the communication process, particularly with clients. Many of these tools have modelling techniques at their heart. Students first encounter these techniques at school, typically as part of their Design and Technology education, where they tend to be delivered as part of a linear design process with project work progressing through the techniques one after the other. This rather artificial way of working is driven more by the need for assessment than a desire to reflect professional practise. As such, many students enter higher education with a limited view of how these techniques should be used in combination. In addition, the range of modelling techniques presents a steep learning curve for the students at the beginning of their studies. To continue to treat them as stand-alone tools with no integration between them merely adds to the difficulty. The authors report on efforts at Loughborough Design School (LDS) to provide an easier route to mastering these modelling techniques and using them to support each other.

Method

The key to this integration is recognising that within each modelling technique, similar behaviours are used, such as describing volumes, cross sections and proportions. The modelling media may change (e.g. sketching on paper, CAD, physical prototyping) but the fundamental process behind the shape description remains the same. Typically, these techniques are taught as separate activities, often by different educators in different sequential modules, and the students are then required to choose the most appropriate technique for design activity themselves. At LDS, the first year Design Practice 1 (DP1) module applies lessons learnt from design practice in industry (Storer, 2005) and teaches several modelling techniques in parallel. Its aims are to provide the students with an introduction to form analysis and creation through two “design and build” projects, with a focus on using modelling techniques as a continuum and not as a

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sequential process. Cross referencing between the techniques is encouraged and similarities in thinking and execution are highlighted. Sketching in DP1 is taught using similar form description methods to the way a CAD package creates surface geometry. Elevations, sketching planes, and critical cross-sections are used to describe product form when sketching, directly relating to both engineering drawing conventions and CAD methodology. Existing products are analysed to determine how the surface geometry has been created (most likely in a CAD system) and how to describe it on a 2D sheet of paper. Following on from this, as part of their second semester assignment, all 130 students were asked to create an external product form around a given set of internal components. They were required to both sketch the form and translate it into a foam model. They were also given the option of using 3D CAD to complement their manual techniques. Iteration between the different media was encouraged.

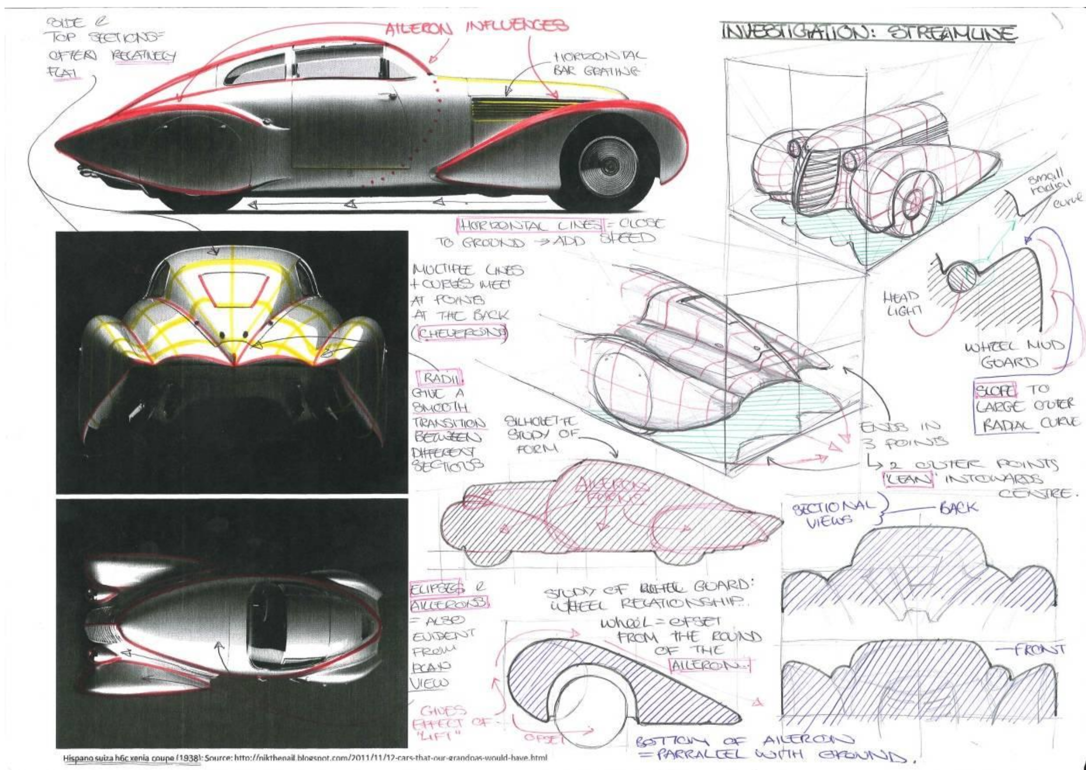

Figure 1. Example of student's identification of key cross-sections in an existing product.

Results

The expected outcome was that students would develop a competence in 3D shape analysis and the transformation into 2D profiles. This should enable them to create analogous 3D CAD and physical models more quickly, making use of the cross-sections they have identified. In order to assess the effectiveness of the approach, the authors inspected the drawing and modelling outcomes of all the students to identify how often the technique of key cross-section identification and creation had been used. It was found that the vast majority (> 90%) of the students had grasped the concept of key cross-sections and were able to identify these on images of existing products (see Figure 1 for an example image analysis). Again, virtually all of the students became very competent in iterating between 2D sketches and a 3D foam model, where they would derive the key sections from their model, re-sketch the shape they wanted and modify the foam accordingly (see Figure 2 for an example of sketch-foam iteration).

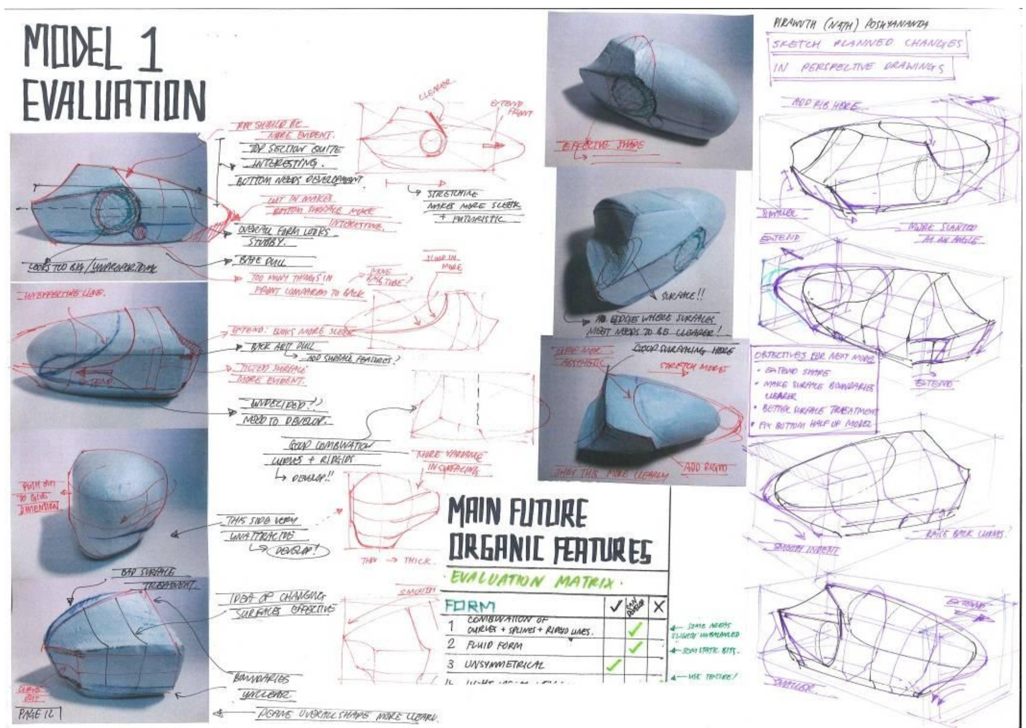

Figure 2. Example of student's iteration between sketches and foam model.

When it came to 3D CAD modelling, only a small proportion of the students (less than 10%) took the opportunity of using this technique to support their manual activities. The main reasons given for this were time constraints and a lack of confidence in using CAD. Those students who did use CAD showed a clear ability at "importing" their 2D sketches into CAD but not necessarily the ability to convert these into the same organic form created in their foam model. For example, Figure 3 shows a rather "box-like" radio design created from a number of key sections taken from the original design. Even so, the geometric complexity of the design created is impressive, for a first year student.

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Figure 3. Example of student's CAD model derived from key sections.

Discussion and Conclusions

The literature offers many opinions on the importance and teaching of sketching and it remains a key visualisation technique, despite the increasing use of 3D modelling tools. There are numerous approaches to the teaching of sketching from freehand artistic through to prescriptive isometric. Many of these techniques will have originated before CAD modelling had even been invented, let alone entered common use in higher education. Therefore, they will typically give little consideration as to how the 2D sketch would offer an accelerated route to creating a 3D model. There are some exceptions to this, e.g. where the decomposition of the human body into 2D profiles as shown in the books of Andrew Loomis (Loomis, 1943), (Loomis, 1956). If the analogies between various modelling techniques are to be shown to students, it will be necessary to change the way some, or all, of these techniques are taught. The inherent flexibility of sketching means that it is easier to modify the way it is taught rather than recreate on-line CAD tutorials or change engineering drawing standards. This is the route that was followed at LDS and the results achieved to date are promising, particularly in relation to 2D images and 3D physical models. However, when it comes to CAD modelling, the ability to identify and even create key sections is not enough. As previously observed by Rynne et al (2010), placement of sketches must be done correctly and must be accompanied by adequate surface or solid modelling skills to achieve a complete model. Nevertheless, the ability to correctly identify the key sections does give students a good start to their CAD modelling process. This study will be followed-up through examination of the students' CAD skills in the second year of the course (when they learn surface modelling), to ascertain the continuing effect of the design modelling techniques they have learnt.

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Dr. Campbell can be reached at r.i.campbell@lboro.ac.uk

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The Relationship between Spatial Visualization Ability and Students' Ability to Model 3D Objects from Engineering Assembly Drawings

T. J. Branoff
North Carolina State University

M. Dobelis
Riga Technical University

Introduction

Universities have eliminated many courses in engineering graphics and descriptive geometry over the last 30 years and typically replaced them with a single course that is focused on solid modeling and engineering design (Branoff, 2007; Clark & Scales, 2000; Meyers, 2000). The reduction in the number of courses seems to be true internationally. CAD instruction appears to be the main focus of engineering graphics courses that remain in the curriculum, but faculty have many opinions about what is essential when preparing students for careers in engineering and design (Dobelis, Veide, & Leja, 2008; Han, Zhang, Luo, & Luo, 2010; Kise, Sekiguchi, Okusaka, & Hirano, 2008; Kotarska-Bozena, 2008; Suzuki & Schroecker, 2008; Szilvási-Nagy, 2008; Wang & Hao, 2010). With the increase in focus on 3D modeling, are students still able to read and interpret engineering drawings well? Is this ability to read engineering drawings related to spatial visualization ability?

Spatial abilities have been used as a predictor of success in several engineering and technology disciplines (Strong & Smith, 2001). In engineering graphics courses, scores on spatial tests have also been used to predict success (Adanez & Velasco, 2002; Leopold, Gorska, & Sorby, 2001). Other studies have shown that some type of intervention, whether a short course or a semester long course, can improve spatial abilities in students who score low on tests in this area (His, Linn, & Bell, 1997; Martín-Dorta, Saorín, & Contero, 2008; Sorby, 2001).

For this study, the primary research question was, how well do current engineering and technology students read engineering drawings, and is there a relationship between reading engineering drawings and spatial visualization? Can students take the information given on an assembly drawing, visualize or interpret each part, and then create 3D models of the parts in a constraint-based CAD system? Is their ability to do this related to scores on a standard spatial visualization test?

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Method

Participants

During the Fall 2011 semester, sixty-eight students in two constraint-based modeling courses participated in the study. One course was offered at North Carolina State University in Raleigh, North Carolina and the other course was offered at Riga Technical University (RTU) in Riga, Latvia. Both courses covered engineering graphics standards and conventional practices and advanced SolidWorks modeling and drawing techniques.

There was a near equal distribution of the participants between the two universities; however, there was a much higher percentage of females at Riga Technical University (29.4%) than at North Carolina State University (4.4%). A majority of the participants were in their third year of studies (52.9%), but there was also a fair amount of students in their final year (45.6%).

The participants from Riga Technical University were all enrolled in a Biomedical Engineering program (51.5%). A majority of the participants from North Carolina State University were either from Mechanical/ Aerospace Engineering (14.7%) or from Technology Education (19.1%).

Instruments

Modeling Test – Figure 1 shows the modeling test used in this study. Only overall dimensions and a few other dimensions required for installation were given, including thread designations and sizes. All of the information about the form and size of the parts had to be determined from the given views and sections and scaled with the use of a metric ruler. To measure the students' understanding of the assembly drawing, students were required to model the individual parts using 3D solid modeling software.

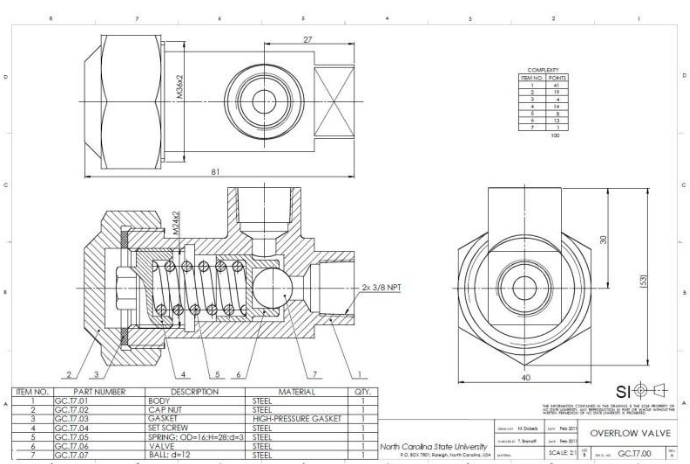

Figure 1. Modeling Test Drawing.

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PSVT:R – The Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) was used to measure students' spatial visualization ability (Guay, 1997). Engineering graphics faculty have used the test since the late 1970s to measure the construct of spatial visualization (Branoff, 2000; Connolly, 2009; Sorby, 2006; Sorby & Baartmans, 2007; Yue, 2008).

Students were administered an electronic version of the PSVT:R within the Moodle learning management system. One class during the semester was dedicated to a practical exercise in reading assembly drawings. After the lecture, students were given the rest of class to model as many parts as possible. Later in the semester students were given the test assembly drawing and asked to model as many parts as possible during the 110 minute class period. Once the data was collected, the researchers evaluated all of the models produced by the students based on the rubrics pilot tested in the spring 2011 semester (Branoff & Dobelis, 2012). The assessment rubric spreadsheet was created to account for model accuracy and time required to model each part.

Results

The data were examined to see if there were identifiable differences in the means between the scores on the modeling test and the scores on the PSVT:R. Tables 1 and 2 display the descriptive statistics for scores on the PSVT:R and the modeling test. Figures 2-3 display scatterplots for these data to provide a visual representation.

Table 1. Scores on the PSVT:R.

School	N	Mean	SD	Min	Max
RTU	35	25.71	5.044	7	30
NC State	33	25.85	3.154	16	30
TOTAL	68	25.78	4.203	7	30

Table 2. Scores on the Modeling Test.

School	N	Mean	SD	Min	Max
RTU	35	53.03	20.792	9	86
NC State	33	47.33	24.757	1	93
TOTAL	68	50.26	22.811	1	93

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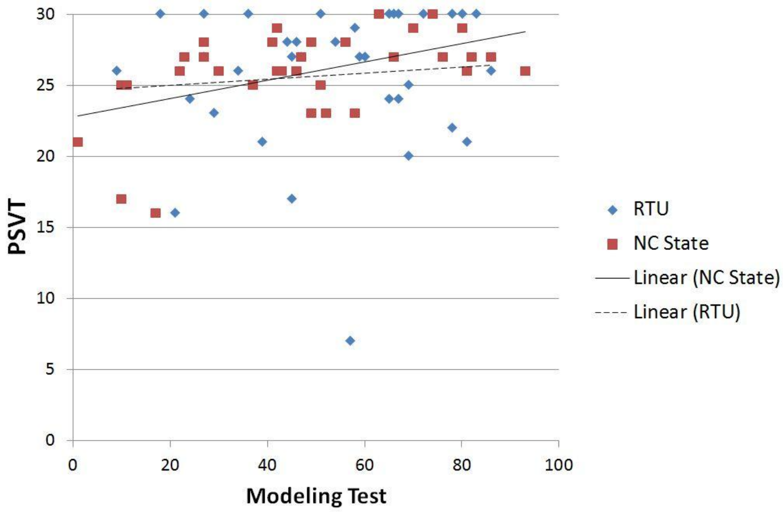

Figure 2. Modeling Test & PSVT:R by School.

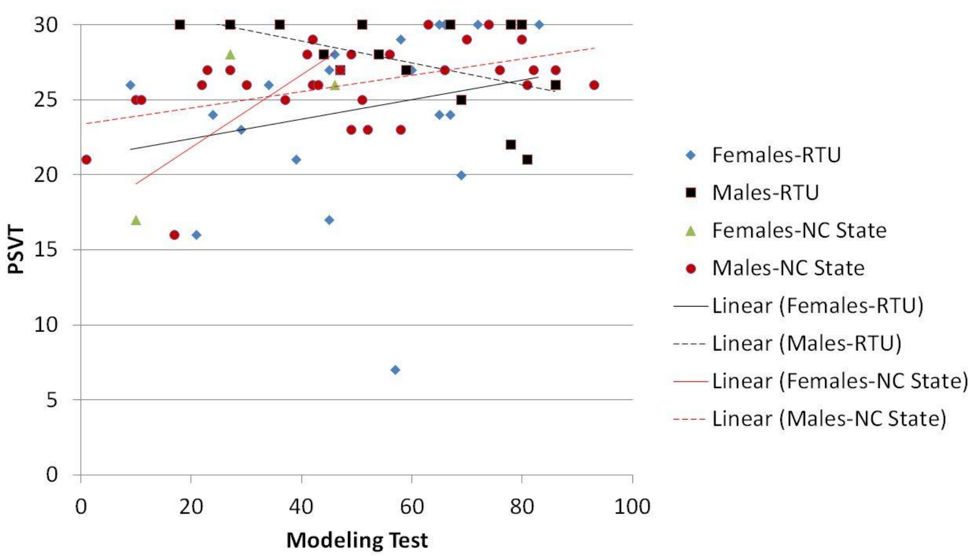

Figure 3. Modeling Test & PSVT:R by Gender.

The scatterplots for the data display a relationship between the PSVT:R and the modeling test. It appears that students who score higher on the modeling test also tend to score higher on the PSVT:R. The scatterplots also reveal some outliers in the data. The standard deviations of the data show that the scores on the modeling test were much more spread out than the scores on the PSVT:R.

The main research question for this study was "is students' ability to interpret and model information from an assembly drawing related to their spatial visualization ability?" Since the data do not meet the assumptions of parametric tests, a non- parametric

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Spearman's Rho was used to test the hypotheses. The analysis revealed a significant correlation between scores on the PSVT:R and scores on the modeling test ($\rho = .258$, $\alpha = .033$).

Discussion

The analysis of the data revealed that there is a significant correlation between students' scores on the PSVT:R and their scores on the modeling test. This makes sense since the interpretation of the information in an assembly drawing requires one to mentally manipulate the two-dimensional information given in the drawing, visualize the part in three-dimensions, and then break down the geometry for so it can be reconstructed in the 3D modeling program. One must be cautious not to assume that a high score on the PSVT:R will assure a student will perform well on the modeling test. The scatterplots revealed a positive correlation between the two variables, but they also show many outliers.

The main research question for this study was whether a relationship exists between reading engineering drawings and spatial visualization ability. In this study students who scored higher on the PSVT:R tended to score higher on the modeling test. Although other factors such as symbol recognition and understanding standards and conventional practices influence how well students read engineering drawings, it appears that spatial visualization ability plays a significant role it how well they visualize part geometry.

One of the main concerns for conducting future studies is the ability to scale-up to handle more students. Although the rubric used in the pilot study and in this study delivered accurate assessments of the students' modeling abilities, the time required to assess student work was very high. This potentially could prevent other faculty from using the instrument. The researchers plan on investigating alternative methods for accurately assessing student models such as automated programs for gathering the desired data from the models.

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Dr. Branoff can be reached at ted_branoff@ncsu.edu, Dr. Dobelis can be reached at Modris.Dobelis@rtu.lv

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Correlation Between a Student's Performance on the Mental Cutting Test and Their 3D Parametric Modeling Ability

H. M. Steinhauer, Ph.D.
Embry-Riddle Aeronautical University

Introduction

Engineering graphics has historically been viewed as a challenging course to teach as students struggle to grasp and understand the fundamental concepts and then to master their proper application. The emergence of stable, fast, affordable 3D parametric modeling platforms such as CATIA, Pro-E, and AutoCAD while providing several pedagogical advantages, such as the interaction with a dynamic solid model, have also created a few new instructional challenges, such as clarifying the connection between the fundamental engineering graphics concepts and the overarching concepts of robust, parametric 3D solid modeling.

3D parametric modeling platforms offer students the opportunity to manipulate a completed solid model in space – enabling them to actually see views of the model not readily available in a traditional engineering drawing, helping them to build their conceptual modeling frameworks. However, simply completing 3D models does not properly develop spatial visualization skills (Hamlin et al., 2006), the theory of parametric modeling must be thoughtfully integrated into the curriculum so it scaffolded by spatial visualization theory. One of the more common assessment instruments for spatial visualization is the Mental Cutting Test, (MCT). There has been a little research on the relationship between the MCT and modeling ability /maturity, specifically the organization and order of the specification tree/model browser of 3D solid models. This paper presents the results of such a study. 219 first-year engineering students participated, a significant relationship was found between high performance on the MCT and 3D modeling ability.

Method

A study was conducted at Embry-Riddle Aeronautical University in the fall of 2011 to investigate the correlation between a student's performance on the MCT and the quality of their 3D modeling structure. This research comprised 219 students enrolled in the introductory graphical communications course, EGR 120.

Students were asked to complete two common modeling assignments for this study, Figure 1. The first was given during the initial week of modeling instruction and the second was given during the fifth week. The solid models were chosen for several factors. The first model, the image on the left, had several elements, the two concentric

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holes, the three rounded ends, and the elongated hole on the top vertical surface, which would quickly reveal the level of modeling maturity and understanding. The second model, the image on the right, incorporated the original features plus several new elements - the raised boss, the embedded, elongated cylinder, the centered, lower channel, and the finishing fillets. The models were given as part of the students' regular assignments; only the course instructors knew these assignments were to be part of this study. The specification tree of each model was evaluated closely to determine the maturity of the modeling approach and structure.

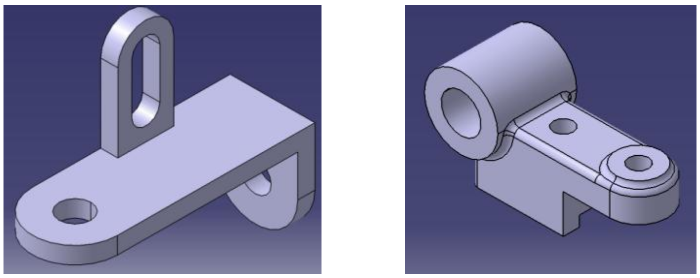

Figure 4. Two Common Solid Modeling Projects.

Figure 2 shows two example specification trees for the first CAD model. The one on the left denotes a lower level of understanding as the model is divided into three distinct pieces and all detail features, such as the corner fillets and holes, are embedded in the base sketches. This structure is indicative of a cursory understanding of the software, as many of the direct modeling commands (hole, pocket, and tri-tangent fillet) were not utilized. This approach does not lend itself well to assembly integration, modification, or revision and is often plagued with waterfalling update errors.

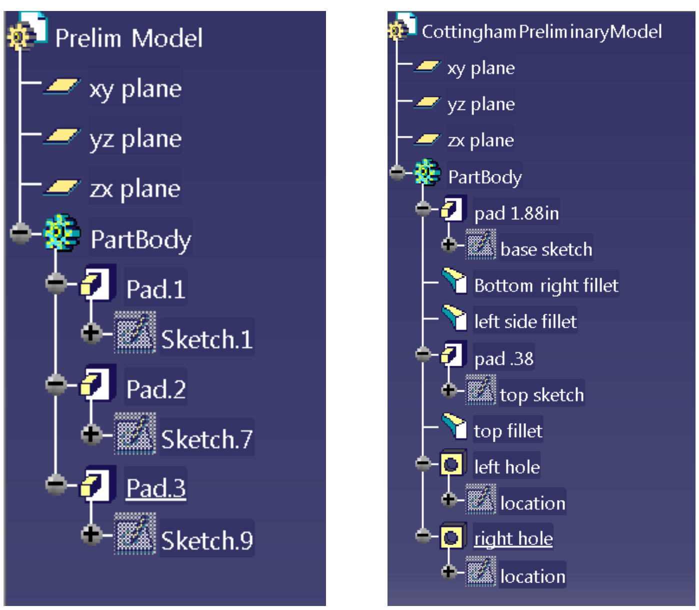

Figure 5. Example Specification Trees.

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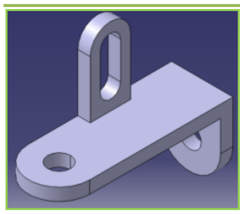
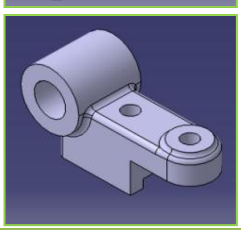
The structure specification tree on the right with its ordered detail elements of the solid model as features (hole and tri-tangent fillet) instead of sketch elements indicates a much deeper understanding of modeling and organization. The specific order is another indication of the deep understanding of the modeling process and how to best leverage it, note the tri-tangent fillets were placed before the concentric holes which reduced the required number of placement constraints for the holes.

Results

Correlations between student scores on the MCT (n= 219) and the individual modeling projects were calculated using SPSS 20 and are shown in Table 1. There was a statistically significant medium correlation between the MCT pre-score and both solid modeling projects. Table 2 presents the correlation factors between student performance on the MCT and the five sections of the rubric. For all findings statistical significance of $p < 0.05$ is denoted by * and $p < 0.01$ is denoted by **.

Table 1. Correlation between Pre-Test Score and Two Modeling Projects.

	MCT (n = 219)
	r = 0.32*
	r = 0.36**

Results from the rubrics were recorded for both of the common modeling assignments. Values for each of the sections of the rubric were input as numerical values. A Principal Component Analysis, PCA, was performed on the rubric section scores using SPSS 20. With this analysis, multipliers for each section of the rubric were obtained so that the composite score for each student on a particular rubric could be determined. Use of these multipliers accounted for more than 50% of the variability between the rubrics. Correlations were computed between the rubric scores, the model scores, and the MCT score and are presented in Table 2.

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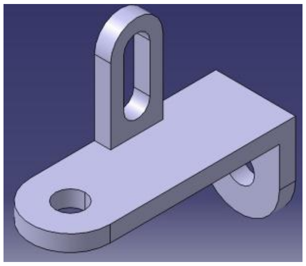
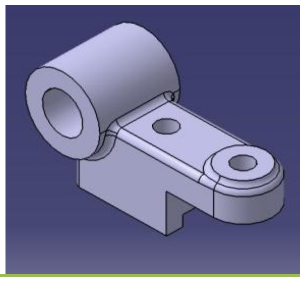
Table 2. Correlation Factors between Solid Models and MCT Score.

Solid Models	Rubric	MCT
	**First Solid Model**	
	Approach	r = 0.3933*
	Structure	r = 0.1865*
	Accuracy	r = 0.4182**
	Robustness	r = 0.2457**
	Creativity	r = 0.2108*
	**Second Solid Model**	
	Approach	r = 0.3001**
	Structure	r = 0.1782*
	Accuracy	r = 0.3910*
	Robustness	r = 0.2994**
	Creativity	r = 0.3654*

Discussion

The correlation factors in Table 1 are between student performance on the MCT and overall grade for each model. Both of the modeling projects had a medium positive correlation with the MCT, indicating that students who performed better on the MCT had more mature 3D modeling frameworks than those students who did not perform as well on the MCT. These findings support Feng, X., Morgan, C., & Ahmed, V. (2004) theorized connection between the MCT and modeling ability, Hamlin et al.'s (2006) and Tsutsumi's (2010) previous research which also suggest the MCT may be a better predictor of students' 3D modeling skill than the more commonly used PSVT:R, the Purdue Test of Spatial Visualization: Rotations. This may be because the MCT requires students to identify the 2D cross section of a provided part while the PSVT:R requires to students to identify the proper orientation of a solid, of these two tasks the MCT more closely relates the theory and approach of solid modeling.

The correlation factors presented in Table 2 are between student performance on the MCT and the five sections of the rubric. There was significant relationship between performance on the MCT and the each of project sections. Approach is defined by shape of the base, or first sketch, the measured correlations are .3933* and .3001*. Structure is measured by the organization and detail included in the specification tree, the reported correlations are .1865* and .1782*. Accuracy is measured by comparing the final model dimensions to the provided handout, the reported correlations are .4182** and .3910*. Robustness is indicated by the type of constraints placed in the base sketch and the associations in the subsequent detail sketches, the measured correlations are .2457** and .2994**. Creativity is indicated by selection of modeling commands and the order in which they are executed; the reported correlations are .2108* and .3654*.

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These results support the findings of Hamlin et al. (2006) where they found a correlation between the MCT and the capability to learn and use 3D modeling software. These findings are also supported by the presented results in Tsutsumi's (2010) work. These results may be indicative of the close relationship between the skills measured by the MCT and creating solid models, both require the ability to discern the correct 2D profiles associated with a solid model.

The literature does suggest a connection between the MCT and 3D modeling ability, and it appears that this research has identified the same association. However, little of the previous research has included a detailed and structured analysis on the specification tree as a measure of modeling approach. Instead much of the published literature has compared other factors against student performance on the MCT. This is the first time this type of analysis has been conducted.

It appears that performance on the MCT may be an effective predictor of student success in 3D modeling. Certainly an area of future research would be a deeper investigation into students' modeling frameworks and their performance on the MCT.

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Dr. Steinhauer can be reached at steinhah@erau.edu

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Comparison of Spatial Skills of Students Entering Different Engineering Majors

N. Veurink
Michigan Technological University

S. A. Sorby
The Ohio State University

Introduction

Spatial skills have been shown to be important to success in an engineering curriculum, and some question if poor spatial skills prevent students from entering STEM fields or if students with weak spatial skills avoid engineering disciplines believed to highly spatially-oriented. Towle et al., (2005) found that an engineering student's score on a spatial task was directly correlated with their belief in their ability to complete the task. Betz and Hacket (1981) found that a person's self efficacy was related to their career choice processes and that there was a lack of complete correspondence between a student's perception of ability and measured ability to successfully pursue various careers. They also found that males equally believed in their abilities to succeed in both traditional and non-traditionally male occupations while females had a lower self-efficacy in their abilities to succeed in traditionally male careers such as mathematics and engineering than in their abilities to succeed in traditionally female careers. Veurink and Hamlin (2011) found that freshmen students entering engineering disciplines that are perceived as more spatially oriented such as mechanical engineering had higher averages on a spatial test than students entering engineering disciplines that are perceived as less spatially oriented such as environmental engineering. However, in the 2011 Veurink and Hamlin study, the numbers of students in some of the engineering majors were quite low. This study builds on the previous study by comparing spatial test scores of freshmen engineering students over a 14-year time period.

Since 1993, Michigan Tech has given freshmen engineering students the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Guay, 1977) in order to identify students with low spatial skills as potential candidates for a spatial training course. From 1993 to 1999 primarily Mechanical, Civil, Environmental, Biomedical and Geological engineers were administered the PSVT:R. From 2000 on, all engineering majors were given the spatial test. This study compares the PSVT:R scores by engineering discipline, and by gender in each discipline, of Michigan Tech freshmen engineering students who matriculated between 1996 and 2009.

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Results

Table 1 compares the average PSVT:R and Math ACT scores for freshmen engineering students by major. The math ACT scores are shown as a study conducted by Parolini (1994) showed there is a link between math ACT and PSVT:R scores. For this study, a correlation of 0.35 was found between PSVT:R and Math ACT scores for all students, and this correlation was highly significant ($p < 0.0001$). Students in Environmental and Geological Engineering have the lowest average PSVT:R scores, while students in Electrical, Computer, and Mechanical Engineering have the highest average scores. The table also shows that although the Environmental Engineering students have the lowest average PSVT:R score, they do not have the lowest average Math ACT score. Nor do the Mechanical Engineering students, with the highest average PSVT:R score, have the highest average Math ACT score.

Table 1. Comparison of average student PSVT:R score out of 30 possible points by engineering major.

Major	Average PSVT:R Score	Average Math ACT score
Environmental	21.7 (n=366)	27.0 (n = 340)
Geological and Mining	21.8 (n=102)	26.3 (n=96)
Biomedical	22.3 (n=544)	27.9 (n=515)
Chemical	23.3 (n=730)	28.4 (n=711)
Civil	23.4 (n=980)	26.8 (n=951)
Undecided	23.4 (n=2260)	26.4 (n=2179)
Materials	23.8 (n=124)	28.3 (n=114)
Electrical	24.0 (n=718)	27.6 (n=658)
Computer	24.2 (n=641)	27.9 (n=590)
Mechanical	24.4 (n=2969)	27.3 (n=2855)

Since some of the engineering disciplines have a higher percentage of females than other disciplines, and studies have shown that females often have less-developed spatial skills compared to males, Tables 2 and 3 break the above comparison down by gender and show where there are significant differences in the PSVT:R scores among

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the engineering majors. Correlations between PSVT:R score and Math ACT score were also found for the two gender groups. The correlation between PSVT:R score and Math ACT score was 0.432 for females and 0.35 for males. Both correlations were highly significant (p<0.0001).

Table 2. Comparison of average *male* student PSVT:R score out of 30 possible points by engineering major.

Major	**Average PSVT:R Score**	**PSVT:R scores significantly different than Materials students?**	**Average Math ACT score**	**Math ACT scores significantly different than Materials students?**
Geological and Mining (GEO)	23.3 n=68 s=5.15	Yes	26.9 n=64	Yes
Environmental (ENV)	23.6 n=184 s=4.35	Yes	26.7 n=171	Yes
Biomedical	23.8 n=283 s=4.47	Yes	28.0 n=268	Yes
Civil	23.9 n=794 s=4.41	Yes	26.8 n=771	Yes
Undecided (EUN)	24.1 n=1867 s=4.20	Yes	26.3 n=1799	Yes
Chemical (CHEME)	24.3 n=519 s=4.15	No	28.5 n=505	No
Electrical (EE)	24.4 n=651 s=4.42	No	27.7 n=597	Yes
Computer (COMP)	24.5 n=602 s=4.28	No	28.0 n=557	Yes
Mechanical (ME)	24.7 n=2704 s=3.85	No	27.4 n=2598	Yes
Materials (MSE)	25.0 n=93 s=4.27		28.8 n=86	

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Table 3. Comparison of average *female* student PSVT:R score out of 30 possible points by engineering major.

Major	Average PSVT:R Score	PSVT:R scores significantly different than Civil students?	Average Math ACT score	Math ACT scores significantly different than Civil students?
Geological and Mining (GEO)	18.9 n=34 s=4.60	Yes	25.0 n=32	Yes
Environmental (ENV)	19.8 n=182 s=4.60	Yes	27.3 n=169	No
Computer (COMP)	19.8 n=39 s=5.94	Yes	26.3 n=33	No
Materials (MSE)	20.2 n=31 s=5.46	No	26.8 n=28	No
Undecided (EUN)	20.2 n=393 s=5.48	Yes	26.5 n=380	No
Electrical (EE)	20.3 n=67 s=5.67	No	26.9 n=61	No
Biomedical	20.7 n=261 s=4.75	No	27.8 n=247	Yes
Chemical (CHEME)	20.7 n=211 s=4.58	No	28.1 n=206	Yes
Mechanical (ME)	21.0 n=265 s=4.93	No	27.0 n=257	No
Civil	21.3 n=186 s=4.56		26.9 n=180	

Discussion

Mechanical and civil engineering are typically considered to be highly visual engineering fields, and the above data show that males in Mechanical Engineering have the second highest average PSVT:R score of the males. Females in Civil Engineering have the highest spatial skills, while females in Mechanical Engineering have the second highest average PSVT:R score of the females. Electrical, Computer, and Environmental Engineering are often considered to be less visually oriented than other engineering disciplines, and females in those disciplines do have lower PSVT:R scores than females

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in all other disciplines except Materials Engineering and those undecided on an engineering major. Male Environmental Engineering students have the second lowest PSVT:R scores of the males.

The greatest differences between the males and the females are that females in Civil Engineering appear to have stronger spatial skills than females in all other engineering disciplines while males in Civil Engineering have the fourth lowest average PSVT:R score of the males. Female Materials Science and Engineering students have the fourth-lowest PSVT:R scores of the females, while the male MSE students have the highest PSVT:R average of the males.

In general, for both males and females, the students in engineering majors with lower PSVT:R scores also had lower Math ACT scores, although exceptions did occur. These exceptions and the correlations found between Math ACT and PSVT:R scores show that other factors contribute to spatial ability. However, this correlation could explain why male Electrical and Computer Engineering students had higher PSVT:R scores than males in disciplines considered to be more visually oriented.

It should be noted that the scores reported here are for first-year engineering students who completed the test before enrolling in any college courses. They are not really “mechanical engineers” per se, since they graduated from high school only three months prior to taking the test. So, in reality, this study attempts to measure whether students with high spatial ability are *attracted* to fields where high spatial ability is a requirement. Thus it appears that for women, well-developed spatial skills are particularly important in order to be attracted to fields which are perceived to be highly spatial (civil and mechanical); whereas, for men, this does not seem to be as critical. What is interesting is that the students going into Geological Engineering, both male and female, have the weakest spatial skills. Geological Engineering is one of the most highly demanding spatial career options, yet it is unclear that students understand the spatial demands they will face as geological engineers.

Another factor that could be contributing to the fact that students who declare Mechanical Engineering as their major seem to have higher PSVT:R scores than students who declare other engineering majors could be that these students engaged in activities as children thought to help develop skills more frequently than did students who expressed an interest in other, less spatially demanding, engineering fields. For example, taking mechanical drafting and CAD courses in middle and high school has been shown to predict better developed spatial skills, and it could be that students interested in Mechanical Engineering have participated in these courses at a higher rate than those who declare a major of geological or environmental engineering.

Conclusions

Through this data analysis, it is apparent that people with higher spatial ability are typically attracted to spatially demanding careers. What is not clear is whether helping

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students improve their spatial skills at an earlier age will also lead to increased enrollment, especially for young women, into these spatially demanding fields. It should also be noted that even though the spatial skills of students who declare, for example, environmental engineering as a major are lower than those who declare mechanical engineering, the spatial skills are likely still higher than those who would declare psychology as a college major. All engineering fields are spatially demanding and students in all engineering disciplines require well-developed spatial skills—it just appears that some disciplines are more spatially demanding than others.

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Dr. Veurink can be reached at norma@mtu.edu, Dr. Sorby can be reached at sorby.1@osu.edu