Gender Differences in Spatial Visualization Among Rural and Urban Populations

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Abstract

Women are underrepresented in STEM despite ongoing work. One area that might be a factor in the underrepresentation of women in engineering is large gender difference in spatial skills. The purpose of the research presented here was to explore if gender differences exist between rural and urban middle school students. Well established spatial visualization tests were used to collect data that was then analyzed using an ANOVA. Findings suggest that some differences do exist.

Background

Women continue to be underrepresented in most engineering disciplines. Achieving equal representation is not only important for social justice reasons but also in addressing the grand challenges of the future. One factor that is likely to contribute to women being unsuccessful in engineering programs pertains to their spatial skills. Spatial skills of females continue to lag behind their male counterparts, a key aspect of engineering education (e.g. Leopold, Sorby, & Gorska, 1996; Linn & Petersen, 1985; Medina, Gerson, & Sorby, 1998; Sorby, 2009; Sorby, Casey, Veurink, & Dulaney, 2013; Veurink & Sorby, 2011; Wei, Chen, & Zhou, 2016). Spatial skills refers to the ability to conceptualize real and imagined spatial relationships including being able to mentally manipulate, organize, and reason about these relationships. Spatial skills have been found to relate to gender equity within a country - countries where women are treated more equitable have better spatial abilities compared to countries where women are treated less equitably (Lippa, Collaer, & Peters, 2010). Additionally, spatial skills have been found to differ across socioeconomic (SES) groups, with significantly lower spatial skills found among low SES groups compared to students from high SES groups (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005).

Most studies have focused on urban populations when studying the spatial skills of students from different groups (SES status, gender etc.) but few have compared differences between students in rural and urban populations. Rural populations are unique in the sense that they are often of lower SES status but they also may have greater opportunities to develop spatial skills through their environment (outdoor play, stay-at-home parent, etc) compared to their urban counterparts. Students from rural areas are 32.2% less likely to pursue post-secondary education compared to non-rural youth (Byun, Meece, & Irvin, 2010). By understanding the spatial skills of rural youth, targeted STEM interventions can be adapted with these findings in mind to help attract more rural youth to post-secondary STEM degrees.

Purpose

The purpose of this research is to examine if differences exist between males and females from rural and urban locations in their spatial skills. Due to environmental factors, we hypothesize that both male and female students from rural locations will perform statistically significantly higher on spatial tests compared to their counterparts in urban locations.

Methods

The data used in the analysis presented here was collected in 18 middle schools from seven states (Texas, Michigan, Georgia, Colorado, Ohio, Tennessee, and Alabama) in rural and urban areas within the United States. To be considered rural, the school had to be located in an area with a population of less than 50,000 residents. A majority of the students were of white/non-Hispanic race/ethnicity.

A total of four tests of ten problems each were administered. The tests used here have been shown to be valid for people as young as 7th grade (Hungwe, Sorby, Molzan, Charlesworth, & Wang, 2014). These tests are widely known in the engineering graphics education community and are:

- Purdue Spatial Visualization Test: Visualization of Rotation (PSVT:R) (Guay, 1977).
- Differential Aptitude Test: Space Relations (DAT:SR) (Bennett, Seashore, & Wesman, 1973).
- Mental Cutting Task (MCT) (CEEB, 1939).
- Modified Lappan Test (LAP) (Lappan, 1981).

Data collection occurred sometime in the second semester (~March of 2016 and 2017) of grade 7. Testing was spread out over at least two class periods by the math or science teacher at each respective school.

Responses were analysed using IBM SPSS where both descriptive statistics and an ANOVA was used to test the differences between genders in urban and rural locations relative to their performance on the spatial skills tests. The sample size varied as shown

in Table 1.

	DAT	PSVT	LAP	MCT
Rural Male	766	766	714	710
Rural Female	694	694	648	640
Urban Male	636	624	328	314
Urban Female	636	624	291	287

Table 1. Sample size for each of the four groups and across the four tests

Results

Means obtained in this analysis are presented in Table 2 and explained in the following sections. Letter superscripts in Table 2 indicate where statistically significant differences were found. For example, if superscripts are the same, then no statistical differences were found between these two groups. Likewise, if superscripts are different, a statistical difference is present.

For the DAT:SR, differences were statistically significant between Male Rural, Male Urban, and Female Urban, with Male Rural students scoring the highest. Female Rural students were not statistically different than any of the other three groups for this test. No differences were found between Male Urban and Female Urban students on the DAT:SR test. Effect size was small or minimal ($\eta = .07$) (Cohen, 1988; Vaske, 2008).

For the PSVT:R, differences were statistically significant between Male Rural students and the three other groups, with Male Rural students scoring highest. Effect size was between small or minimal and medium or typical ($\eta = .16$).

The results from the LAP test showed statistically significant differences between Male Rural and the other 3 groups, with Male Rural students scoring higher. No differences were found between Female Rural - Male Urban and Urban Males - Females. The effect size was between small or minimal and medium or typical ($\eta = .17$).

Table 2. Gender and Location relating to performance on spatial skills tests

	Male	Female	Male	Female	E value	n velve	Eta (η)
	Rural	Rural	Urban	Urban	<i>F</i> -value p	<i>p</i> -value	effect size
DAT ¹	4.59 ^a	4.31 ^{a,b}	4.24 ^b	4.24 ^b	4.16	.006	.07
PSVT ¹	4.27 ^a	3.56 ^b	3.56 ^b	3.32 ^b	22.91	< .001	.16
LAP ¹	3.23ª	2.71 ^b	2.49 ^{b,c}	2.33°	20.51	< .001	.17
MCT ¹	2.77ª	2.74ª	2.37 ^b	2.24 ^b	10.28	< .001	.13

¹Means are on a 10-point scale with 1 point being awarded for each correct answer. Means with different letter superscripts in each row are significant at p < .05 based on Tamhane's T2 post-hoc test for unequal variances. ^{a,b,c} superscripts indicate where the statistically significant differences were found.

Results from the MCT test showed statistically significant differences between Rural and Urban students (both for male and females) with rural students scoring higher on the test compared to their urban counterparts. The effect size was between small or minimal and medium or typical (η = .13). Overall, Rural Males performed statistically better than Urban Males on all spatial skills tests.

No statistically significant differences were found between Male and Female Rural students on the DAT and MCT. Male Rural students performed statistically significantly higher on PSVT and LAP in comparison to the other three groups.

The hypothesis is partially accepted as males from rural locations performed significantly better on spatial skills compared to males and females in urban locations but the same was not always true for rural females.

Conclusions

The results lead us to two potential explanations. First, a rural location has a greater impact on male students compared to female students as the data showed that rural males outperformed urban males and females on all spatial tests. Conversely, statistical significance for rural females outperforming urban males and urban females was found on one test (MCT). This could suggest that rural females are not experiencing the rural environment in a similar manner that rural males are. For example, rural males might be assisting in farm work while rural females may not be included in these activities.

Our findings indicate that the spatial skills of rural and urban students vary between genders in some cases. Future work will examine if the trend found here persists into grades 8 and 9. Additionally, we plan to examine the impact of a spatial curriculum intervention on rural and urban students to see if the impact varies by gender or by school location.

Understanding if these differences in spatial skills narrow or widen into high school and ultimately university will assist in developing interventions earlier in a student's education and help prepare students for entering engineering programs. Improving the spatial skills of all students could contribute to a greater diversity of engineering students by not eliminating students from an early stage. Additionally, understanding the spatial skills of rural students can help provide more targeted interventions that are aimed at STEM participation.

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Material Dissemination of the Biewald Orthographic Visualization Battery

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Abstract

The Biewald Orthographic Visualization Battery (BOVB) represents a reliable instrument for use in engineering graphics education. Analysis of the BOVB indicates that there is evidence of predictive validity for academic outcomes when used as both a pre- and post-test. This paper provides the engineering graphics education community with an analysis of the instrument and the online location to access the assessment and the collaborative dataset intended for open access for researchers and practitioners. **Keywords:** spatial visualization, engineering graphics, assessment, engineering education, persistence

Introduction

Spatial skills have long represented a major component in a variety of STEM fields and have been demonstrated to have predictive validity within engineering graphics (Sorby & Baartmans, 2000), a predictor of interest in, academic persistence, and career success within science, technology, engineering, and mathematics (STEM) disciplines (Wai, Lubinski, & Benbow, 2009; Torpey, 2013; Author), and recently, to have statistically significant associations with broad-scale score measures in English Language Arts (Rutherford, Karamarkovich, & Lee, 2018). STEM professionals tend to demonstrate skills significantly higher levels of spatial ability as students than their peers (Lubinski, 2010).

Several measurement instruments frequently used in engineering education include the Mental Rotations Test (MRT), the Mental Cutting Test (MCT), the Revised Minnesota Paper Form Board Test (RMPFBT), the Differential Aptitude Tests: Spatial Relations (DAT:SR), and the Purdue Spatial Visualization Tests: Visualization of Rotations (PVST:R; Author). It has also been demonstrated that spatial ability is malleable and can be improved with training (Uttal, Miller, & Newcombe, 2013; Sorby, 2009). The assessments listed above, as well as many

others not mentioned here, measure differing constructs within the broader scope of spatial ability. The Biewald Orthographic Visualization Battery (BOVB) adds to that list, an assessment that measures a student's ability to visualize three dimensional orthographic shape.

During a recent mid-year meeting of the Engineering Design Graphics Division (EDGD) of the American Society for Engineering Education (ASEE), a "new" assessment of spatial ability was unveiled with the promise that it would be openly disseminated to the engineering as well as providing a digital platform from which researchers and educators can contribute to, and access, a repository of collaborative data for analysis and comparison.

The Biewald Orthographic Visualization Battery

The 80 items of the BOVB are contained in two separate forms, each with 40 items. These items contain two views of an orthographic projection and ask the participant to select the correct missing view from a collection of four possible answers or indicate that they do not see a solution in any of the four choices. Figure 1 shows a sample of three items from the BOVB.





Figure 1. Sample Items from the Biewald Orthographic Visualization Battery.

Correlational Analysis. Analysis of the BOVB taken by 146 engineering graphics undergraduate students showed statistically significant associations with final exam and course grades when the BOVB was used as a pre-test (Form A) and a post-test (Form B). The analysis also showed a strong statistically significant correlation between the pre- and post-test versions. The correlation coefficients are displayed in Table 1.

	BOVB Pre-Test	BOVB Post-Test	Final Exam Grade	Final Course Grade
BOVB Pre-Test				
BOVB Post-Test	0.72***			
Final Exam Grade	0.32***	0.37***		
Final Course Grade	0.25**	0.28**	0.69**	

Table 1. Correlation Analysis for the Biewald Orthographic Visualization Battery

Note.*p<.05; **p<.01;***p<.001

Reliability. The reliability of the BOVB scale was determined using Cronbach's alpha. Based on the stated threshold of .70 (Drost, 2011), the BOVB is reliable (α = .88) with an average inter-item covariance of .03.

Means Testing. A t-test was conducted to compare the pre- and post-test mean scores for the engineering graphics students. The post-test scores (M = 25.10, SD = 7.91) on the BOVB was significantly higher than the pre-test scores (M = 19.09, SD = 8.02) by 6.02 points; t(230) = 5.76, *p*

< .001. These results, combined with the significant correlation between the BOVB and final exam and course grade, provide evidence that the BOVB may be a potential predictor of academic performance in an introductory engineering graphics course.

Regression. A simple linear regression analysis was performed to examine whether the score (pre and post) on the BOVB was predictive of final exam scores. The final exam score was analyzed rather than the final course grade due to the strong positive correlation of the exam with course grade, the weaker correlation of the assessment to the final course grade than the final exam, and the exam being a more consistent measure of engineering graphics knowledge than the course grade with multiple independent factors such as homework completion that could not be controlled for in this study.

The score on the BOVB pre-test explains approximately 10% of the variance in the final exam scores, $R^2 = .10$, F(1, 114) = 13.33, p < .001, and is positively and

significantly related a student's final exam grade, b = .37, t(114) = 3.65, p < .001. For every item a student gets correct on the BOVB pre-test, we can expect them to score .37 percent higher than the mean final exam score. Similarly, the score on the BOVB post-test accounts for approximately 14% of the variance in the final exam scores, R^2 = .14, F(1, 114) = 18.03, p < .001, and is positively and significantly related a student's final exam grade, b = .43, t(114) = 4.25, p < .001. For every item a student gets correct on the BOVB post-test, we can expect them to score .43 percent higher than the mean final exam score.

Conclusion

The BOVB is a reintroduction of an instrument developed nearly 50 years ago that was seemingly lost to history. Analysis of the BOVB provides evidence that the use of the assessment in undergraduate introductory engineering graphics courses may have predictive validity for a student's score on the final exam and course grades. Although more study and analysis is warranted, the BOVB may be (in whole or in part) an appropriate instrument for the identification of students who may be struggling with the course content particularly within the context of orthographic projection. This intention of this paper and release of the BOVB to collect more data for analysis and share that data with the broader engineering graphics community to encourage collaboration among researchers and practitioners.

As part of the reintroduction of this assessment, the authors of this paper deemed it appropriate to rename the *Visualization Test of Three Dimensional Orthographic Shape* (Biewald, 1969; 1971) to the *Biewald Orthographic Visualization Battery* in honor of the original developer and to ensure proper accreditation be given if/when adjustments are made to the assessment in the future. Dr. Biewald gave the authors explicit permission to reintroduce the assessment and make it publicly available. It will be publicly available for use as of the publication of this paper as part of the Connecting STEM Project.

To access the BOVB and the collaborative research dataset, visit the link below: https://bovb.connectingstem.org

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Student Design Projects to Improve Spatial Visualization Ability

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Abstract

In this digest, we describe student design projects for which interactive demonstrations will be provided during the Media Showcase event. We present examples of projects designed to help future students improve their performance in an introductory engineering graphics and visualization class. Projects include "X-treme Blocks," designed for students who struggle with visualization from coded plans, a set of 3D models and a matching isolation box to help students visualize 2D projections from 3D objects, and the game "Ortho-Slap," which helps student practice mental rotation skills for interpreting orthographics multi-view drawings in a fast-paced, fun environment.

Introduction

In the freshmen-level engineering graphics class at the University of California, Berkeley (E25: Visualization for Design), students complete a group design project. When Engineering Graphics was a 3-unit class, the main project deliverables were a complete set of working drawings produced in CAD. More recently, the material was split up, so that the freshman class could focus more on sketching, visualization, and multiview drawing interpretation skills in a 2-unit class, and 3D solid modeling was moved to a separate 2unit sophomore level class, during which the students output working drawings from within a solid modeling program. Therefore, a new emphasis for the group design project in the freshman class was tried, without any working drawings deliverable: each group was tasked with designing and prototyping something that could be used by future students in the class to improve their learning. This design objective had the advantage/disadvantage that the students understood their target users well because they were their own target users; thus (advantage) they could generate their own user needs, but (disadvantage) they did not get the first-hand experience discovering how much actual user needs (Ulrich and Eppinger, 2015) tend to differ from what engineers believe them to be. Another advantage, however, was that their own classmates could be the subjects for a user testing day where the groups could get feedback and improve their designs.

Motivation

Engineering traditionally has a low retention rate due to the difficulty of certain aspects of the engineering curriculum. At the same time, the demand for engineers is high, due to their technical problem solving skills (Markopoulos, 2015). This indicates an urgency to retain as many motivated students as possible. Student engagement, confidence in one's abilities, and academic success directly impact retention rates in engineering (Bandura, 1989). The design project implemented in E25 at UC Berkeley aims to improve student's academic success, confidence, and engagement through the development of learning tools that can be used by future students.

The purpose of many of the student design projects was to aid in the process of visually converting between 3D objects and either pictorials or two-dimensional 2D views. This will help future students as they develop the spatial visualization skills needed to succeed in engineering classes and eventually as engineers (Allam, 2009). The ability to create 2D orthographic projections of 3D objects is one of the fundamental components of spatial visualization (Sorby, 1999). These design projects address the reality that student visualization abilities vary widely (Milne, 2014).

Sample Projects

Many groups took advantage of a student Makerspace on campus to prototype their projects. Others had access to personal 3D printers. Three exemplars are presented in the following sections.

Example 1: X-treme Blocks

The "X-treme Blocks" group designed a set of modular blocks -- in shapes of extruded squares, triangles, and quarter circles -- in which they embedded magnets to make it easy to build structures corresponding to coded plans such as for the exercises in Chapters 2 and 3 of the Lieu and Sorby engineering graphics textbook (2017).





Figure 1: X-treme Blocks, a set of modular blocks



Figure 2: (a) Coded plan visualization exercise and *(b)* X-treme Blocks visualization of coded plan

Figure 2 (a) reproduces one of the more challenging coded plan visualization exercises from Lieu and Sorby (p. 3-42, 2017). The photo of the X-treme block visualization to its right in Figure 2 (b) looks at first glance almost like an Escher drawing of an impossible object, due to the alignment of non-coplanar faces. The blocks allow the students to experiment with inventing other examples with other sorts of coincidences. The clear plexiglass base (also containing embedded magnets) allows students to experiment with more challenging worms-eye views as well as the more familiar birds-eye viewing angle.

Example 2: Multiview Multipurpose Models

The Multiview Multipurpose Models group designed more geometrically complex blocks to aid students who struggle to visually "flatten" what the eye sees as a 3D object when they are asked to produce corresponding 2D orthographic views. 3D objects viewed by the eye are subject to size and shape distortions caused by location and orientation of the viewer. For the project, this group designed a set of five white 3D objects (Figure 3) that all fit inside the same cubic geometry bounds. The objects were fabricated on a 3D printer, and then the edges were marked with a black Sharpie, which makes them stand out clearly. A black bounding cube (the "view-plane isolation box") that the objects can slide in and out of was also constructed.



Figure 3: Set of 3D objects (in white with black highlighted edges) that fit into bounding box (black)

The isolation box and edge highlights are helpful learning aids for several reasons. When the 3D object is placed in the box, it is easier for students to adjust their viewing angle so that they are looking straight into the box (viewing direction perpendicular to the corresponding 2D viewing plane). In this head-on view, the object shape is closer to an orthographic projection, reducing the shape distortion for viewers. Aligning a light with the viewing direction can help eliminate shadows. In addition, the sides of the isolation box block the side surfaces of the object, which otherwise give perspective cues when the viewing angle isn't perfect. Furthermore, with the high-contrast Sharpied edges, viewers are less likely to rely on interpreting changes of orientation between adjacent faces to recognize where edges are located. With the orientation less salient, the projected shape of faces is easier to visualize. Eliminating 3D cues that are distracting in this context should be helpful for converting complicated 3D objects to multiview drawings, allowing the viewer to focus on the shape of a single planar face at a time.

Example 3: Ortho-Slap

The "Ortho-Slap" group designed an ingenious, competitive game designed around rolling a "die" of a rather non-standard shape. Overall, it has six "sides" it could land upon, but each has a different orthographic projection when hidden lines are considered. Players each have a set of cards corresponding to these projections, including both the hidden and center lines on each view. The original prototype is shown below (Figure 4).



Figure 4: Original prototype of "Ortho-Slap"

For a "solitaire" version of the game, a student rolls the "die" and lays out the cards in appropriate unfolded-glass-box position, based on how it lands, as shown above left. But the real fun is the competitive version, where after the "die" is rolled, students compete to be the first to slap down the card corresponding to the view facing "top," in the correct orientation. With the sturdy 2nd prototype from a 3D printer (Figure 5), the card can be slapped down right on top of the "die," and there are no ties because one player's card is clearly the one that made it onto the die first (though sometimes incorrectly chosen or oriented; the other players help to judge).



Figure 5: Second 3D printed prototype of "Ortho-Slap" with set of projection cards

Other students really enjoyed playing this fast-paced game the following semester; one written comment was that "It was surprisingly fun!" The top mental rotator in the student group that invented the game (right) challenged the professor to a game, where adrenalin

ran high. (She barely managed to pull of a win, much to her relief but to the obvious disappointment of the student.)

Discussion and Future Work

For a second iteration of the X-treme blocks, one change we would make is to choose a plastic filament and/or 3D printing process that allows for a matte finish. When teaching engineering students who have such a wide range of art backgrounds, it is our practice to only teach students about simple diffuse shading that is dependent only on surface orientation and surface normal, omitting specular highlights that vary with the eye position. The shiny finish of the current blocks picks up specular highlights, so that could be confusing for students trying to shade their sketches using only the diffuse shading rules.

The ortho-slap concept would be a fun inspiration for a design exercise in a 3D solid modeling class. One complaint from students learning solid modeling is that for typical homeworks and labs, they are always given designs and then they just have to reproduce them in CAD, rather than designing anything themselves. Designing alternate ortho-slap die geometries would be a fun exercise that would incorporate both visualization skills to design something that had six unique projections, but also incorporate analysis of moments in order to design a fairly weighted die. (Or perhaps they want to design an unfairly weighted one, so that students could beat their professors more often by being able to predict which side is most likely to land facing up!)

"Fun" and "play" were characteristics of many of the most successful projects. Gamification (Kapp 2012), the integration of games into non-traditional contexts, has been used a teaching technique in a variety of contexts. Games give participants immediate feedback and provide a way to practice concepts in a fun environment. Empirical results from previous studies are limited, but it is theorized that gamification will increase student interest,

motivation, and ability to learn difficult concepts (Markopoulos, 2015). The results of this design project support that conclusion. Overall, projects that were games were among the most popular, gaining lots of interest and feedback from the testers. Gamification may have as promising a future in higher education as in K-12.

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Use of Decision-Tree Approach for Identification of Dominant Predictive Factors in Standardized Visualization Testing

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Abstract

Predictive analytics is a subject that has become useful in forecasting behaviors and performances, which could be of benefit when attempting to predict the students' performance on a visualization standardized test. Predictive analytics uses a variety of algorithmic approaches, being decision-tree one of them, and an approach that has been recognized for its applicability and the fact that its outcomes can be represented graphically. Decision-tree is considered an approach that generates a model based on the probabilities extracted from the data being analyzed.

Some initial modeling using a small dataset has been reported, and results were obtained based on performance (i.e., minimum overall score on standardized visualization test – PSVT:R) and demographics (i.e., four characteristics were analyzed – status, gender, ethnicity, CAD experience). The objectives pursued for this report are twofold:

i) increasing the size of the dataset being utilized in the model building and validation phases, and compare the new results for performance predictions to the ones previously reported, ,and

ii)establishing predictive parameters based on grouping and trends of the performance data, in order to attempt to define common predicting factors.

The ultimate goal of these studies is to have objective information that can help in the definition of specific academic interventions in course content or in content delivery.

Introduction

The topic of predictive data analytics has received substantial attention in the recent past due in part to its potential to provide a competitive advantage in a globalized economy, which has resulted in the almost imperative need for focused or customized services, thus deriving in this global trend of collecting and analyzing all kinds of data. Most of the attention and applications of this concept relate to consumer sciences, but the applicability of predictive data analytics has extended to processes and trends analysis, which has more direct relation to engineering and manufacturing. Data analytics is considered a generic term used to refer to a set of quantitative and qualitative approaches that are applied to provide the basis for some decision making (Big, 2017). Specific objectives that are being pursued when using data analytics are increase in productivity, additional business profit, or expected performance or behavior (Data, 2017).

Predictive data analytics is primarily utilized to establish an expected performance, specifically in academics besides the administrative tasks like enrollment and satisfaction of students, it was extensively used in technical applications, but not in pedagogical studies where the objective is to establish an expected academic performance or behavior, such as spatial visualization skills. There is a variety of tests that have been applied to measure spatial visualization skills of students (Strong 2002, Yue 2008), and there are numerous studies that have collected and analyzed information regarding demographics, spatial visualization skills, and academic performance (Prieto 2009, Sorby 1999). Of interest are studies where spatial visualization skills have been linked to abilities to do engineering and technology work, and subsequent studies that have provided a relationship between those skills of students and their performance in engineering courses, particularly for engineering graphics and design courses (Sorby, 2005). Similarly, there are reports that indicate the value in improving visualization skills when looking at the performance in learning in technology and engineering courses Koshevnikov, 2006), indicating improvement of such skills as the complexity of the problem increases (Titus 2009) which is the basis for looking at performance in a standardized test such as Purdue Spatial Visualization Test with Rotations (PSVT:R) (Guay, 1977).

This study reports on the application of a predictive data analytics approach to spatial visualization scores with the objective of establishing dominant predictive questions that define expected high performance. The data utilized in this study is from the PSVT:R. The goal is to have information that helps in directing interventions to be implemented for development of spatial visualization skills.

Methodology

Scores for each of the questions in the PSVT:R test where utilized as dataset. The test was administered to students taking introductory engineering graphics courses, and the results were collected for a previously reported study (Rodriguez, 2016a). This study

focuses on identifying the answers for each one of the 30 questions in the PSVT:R test and the final total score (maximum of

30) as potential dominant factors, no demographic data is utilized even though it was collected. Similarly, a new parameter is introduced, 'top performer,' which is used as defined as the prediction criterion, being top performer indicates that the total score in the test is equal or above a given value.

The software used in this study is RapidMiner, a commercially available data analytics software that has the option to analyze and visualize datasets applying different approaches, thus comparing results. Because the objective of this study s to identify dominant factors (i.e., questions) that predict high level of performance, the Decision-Tree approach has been applied. This approach has been identified has a good general purpose technique, with acceptable reliability in predictions, and it is a technique that provides graphical output that is very helpful in following the predictive model developed (Best, 2017). A decision-tree is a tree like collection of nodes that defines a decision on specific parameters to a class or an estimate of a numerical target value (i.e., final test score). Each node represents a splitting rule for one specific Attribute (i.e., answer to each test question). This approach reduces the error in an optimal way for the selected criterion (top performer) (RM, 2017).

Results

The dataset for this study consisted of 156 test records. As indicated before, this dataset was collected at two different institutions, and they have no statistically significant difference by being from two campuses (Rodriguez, 2016b). A total of 152 records were used for the machine learning stage where the prediction model is being built, the rest of the records were used for validation of the prediction model generated by the decision-tree approach.

The first objective is to increase the number of records in the dataset being used for model building. The dataset used here is almost 6 times the size of the dataset used in the previous pilot study (Rodriguez, 2018), and the previously reported result indicating that Q22 is the dominant factor when specifying a top score of 25 or higher (Figure 1). Interesting situation is that such dominant factor is not the same one when the top score is modified, which takes us to the second objective, and important issue is that only question answers are being used for the predictive model.



Figure 1. Decision tree for two different datasets. Small n=27, large n = 152.

For the generation of predictive models to identify dominant factors, ten decision-tree models were generated for top scores ranging from 21 and above to 30. The dominant factor(s) for each case are reported in Table 1. As it can be observed, the primary dominant factor is not a single one for the tested range, it varies from Q23 at the lower end (scores 21 to 23), to Q30 for the high end (scores 29 and 30), with different primary dominant factor for the scores in between.

It is of interest to relate these results to previously reported results that extract dominant factors in the standardized test, in particular a study by Ernst 2017 where a factor analysis is performed, indicating the need to consider at least three principal components (factors) to have an acceptable level of inclusion of data variance. Performing a Factor Analysis (FA) on the dataset utilized in this study it renders similar result of requiring at least three factors to have an acceptable level of the data variance explained, as seen in the Scree graph in Figure 2. There is no match in terms of the specific test questions considered as principal components by the FA, and the ones identified as dominant predictive parameters, which is expected given the nature of the two studies, but indicating the need of performing a clustering approach to have better agreement (Farias 2017).

Test Score+	21	22	23	24	25	26	27	28	29	30
% as Top Performer	73	73	73	50	46	35	23	12	8	4
1 st DominantQuestion	<mark>23</mark>	<mark>23</mark>	<mark>23</mark>	<mark>12</mark>	<mark>22</mark>	<mark>27</mark>	<mark>29</mark>	<mark>29</mark>	<mark>30</mark>	<mark>30</mark>
2 nd Dominant Question	19	19	19	19	10	17	27			
3 rd DominantQuestion						2				

Table 1. Summary of Dominant Factors for Top Performers



Figure 2. Scree plot for Factor Analysis of the dataset used in this study.

Conclusions

Predictive data analytics approaches provide a valid insight when looking for dominant factors that will help define possible pedagogical interventions, as is the case in this study. For the dataset utilized there is a good agreement in terms of the type of factors (i.e., question number) that define top performance in a standardized skill visualization test. Given the design of the PSVT:R, more involved manipulations are indicative of higher performance by the student. Comment is that only the first dominant factor in the predictive model is considered, and in such case there are two models that do not follow the expected trend (i.e., for scores of 24 and 26), which indicates that further investigation is required.

Regarding the parameters for this study, one issue is that even when a larger dataset has been utilized, it might need to have a substantially larger set for better generation of predictive models. A second issue is the possible use of a different predictive analytics approach, this is a field that is constantly being improved and there might be a 'better trap' out there already. Both of these issues are currently being considered.

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A Comparative Analysis of Gender and the Impact of Mathematics Achievement on Spatial Visualization Ability in Engineering Technology Students

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Abstract

The purpose of this study is to determine if there is a relationship between spatial visualization ability and mathematics performance based on gender for 300 freshmen students in an introductory engineering design graphics course. SAT and ACT mathematics scores will be analyzed versus an initial pre-test using the Purdue Spatial Visualization Test: Rotation (PSVT:R). Based on previous studies, evidence supports a strong correlation between higher mathematics achievement and spatial visualization ability. In addition, prior research has indicated that gender has been a factor in performance with males outperforming their female counterparts in spatial ability. It is expected that male students continue to possess a higher level of spatial ability correlated with math performance compared to their female peers.

Introduction

This study will be conducted beginning August, 2018. Preliminary results will be presented at the EDGD mid-year in January.

Spatial Ability: Research suggests that spatial ability is the "gatekeeper" to admission and achievement in STEM (Science, Technology, Engineering, Mathematics) education (Uttal, Meadow, Tipton, Hand, Alden, Warren & Newcombe, 2013; Newcombe, 2010; Kell, Lubinski, Benbow & Steiger, 2013; Miller & Bertoline, 1991; Sorby & Baartmans, 2000). Cultivating spatial abilities has been shown to support development and achievement in mathematics and science (Keller, Washburn-Moses & Hart, 2002; Olkun, 2003; Robichaux, 2003; Shea, Lubinski & Benbow, 1992).

Spatial ability is the capacity to formulate and retain mental representations of given stimuli allowing learners to relate within a given environment (Carroll, 1993; Höffler, 2010, Hegarty & Waller, 2004). This ability is a critical component for success in many STEM fields including engineering and technical fields such as mathematics and even the medical field. Developed spatial reasoning is recognized as "the most fundamental and

rewarding part of engineering graphics instruction" (Contero, Company, Saorín & Naya, 2006, p. 472). Spatial ability skills are considered to be an important predictor for achievement in controlling objects and interacting with computer-aided design (Norman, 1994). Research has suggested that there are positive correlations between spatial ability and retention of technology and engineering students' ability to complete degree requirements (Brus, Zhoa & Jessop, 2004; Sorby, 2009; Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002).

Spatial Visualization: Spatial visualization is often synonymous with "spatial ability" and "visualization" (Braukmann, 1991) involving the mental alteration of an object through a sequence of modifications and is suggested to be a key element for success in engineering coursework (Ferguson, Ball, McDaniel, & Anderson, 2008). McGee (1979) defined spatial visualization as the "ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object" (p. 893). Strong & Smith (2001) went on to define it as "the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint" (p. 2). There are many factors suggested through research that may have an impact on spatial ability. These factors include, but are not limited to environmental influences such as culture, social, gender and stereotype, developmental and educational factors (Mohler, 2008; Mann, Sasanuma, Sakuma, & Masaki, 1990; Belz & Geary, 1984; Tracy, 1990; Harris, 1978). Educational factors such as problem solving skills specifically used in mathematics influence spatial ability performance (Clements & Battista, 1992; Mislevy, Winersky, Irvine, & Dann, 1990; Michaelides, 2002; Wheatley, Brown, & Solano, 1994; Heitland, 2000; Robichaux & Guarino, 2000). Descriptive geometry, orthographic views, and three-dimensional modeling have been used as a means to improve the spatial abilities of learners (Martín-Gutiérrez, Gil, Contero & Saorín, 2013).

Spatial Visualization and Engineering Education: Spatial visualization is perhaps one of the most critical skills lending itself to success in engineering coursework and ultimately in the workforce. Spatial thinking, specifically spatial visualization is perhaps one of the most distinctive characteristics for engineers to possess. It is used as a means for documenting concepts and design modeling, and communicating these concepts and models to others (Condoor, 1999). More generally spatial visualization encompasses the mental alteration of an object through a sequence of adjustments, and considered a key factor in the success of engineering students (Ferguson, et. al, 2008).

Mathematics Education. Mathematics is an essential subject required in the early years of education relying on psychological factors such as self-confidence, motivation, and most importantly working memory which is considered to be the most significant cognitive element (Kyttälä, Aunio, Lehto, Van Luit, & Hautamäki, 2003; Cornoldi &

Lucangeli, 2004; Middleton & Spanias, 1999; Casey, Nuttall & Pezaris, 1997). Working memory controls, regulates and processes information to conduct the cognitive tasks associated with mathematical processing (De Smedt, Janssen, Bouwens, Verschaffel, Boets & Ghesquière, 2009). Research has shown significant evidence that visuo-spatial ability is critical for the development of mathematical skills as working memory is also a key factor in the development of spatial skills (Agus, Mascia, Fastame, Melis, Pilloni & Penna, 2015; Van Garderen, 2006; Heathcote, 1994; Van Garderen & Montague, 2003).

Spatial Ability and Mathematics: The correlation observed between spatial and mathematical ability suggest the importance of spatial ability in problem solving specifically as a significant factor in the success of many STEM fields (Bogue & Marra 2003; Contero, et. al., 2006; Mohler, 2008; Sorby, 2009; Miller & Halpern, 2013; Sorby, Casey, Veurink, & Dulaney, 2013; Grandin, Peterson & Shaw, 1998; Keller, Wasburn-Moses & Hart, 2002). Since spatial visualization is directly correlated with problem solving ability (Carter, LaRussa, & Bodner, 1987), mathematics becomes a significant factor in understanding how spatial skills are developed through achievement in mathematics. Research has suggested that there is a relationship between spatial ability and mathematics (Casey, et. al., 1995; Geary, 2011; Mix & Cheng, 2012; van der Ven, van der Maas, Straatemeier & Jansen, 2013; Tosto, Hanscombe, Haworth, Davis, Petrill, Dale, Malykh, Plomin & Kovas, 2014; Sella, Sader, Lolliot & Kadosh, 2016). Research interest has existed since the mid-1900's and has been supported by research identifying the possible concurrent development of spatial ability and mathematics performance (Casey, Nuttall, Pezaris, & Benbow, 1995; Casey, et. al., 1997; Ganley & Vasilyeva, 2011; Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, & Chang, 2014). Rohde & Thompson (2007) found spatial ability to moderately correlate with raw SAT-M scores at the age of 18, and an important predictor of mathematics performance after controlling for working memory, general intelligence, and processing speed. However, the key guestion remains whether or not there is a unique and exclusive link between the two (Rutherford, Karamarkovich & Lee, 2018). There are several reasons for exploring the relationship between mathematics achievement and spatial visualization ability. Spatial ability and high achievement in mathematics are critical factors for student success in STEM fields including mathematics and engineering education. A link between these two disciplines further substantiates the importance of problem-solving as a key skill for success in both areas as well as STEMrelated fields. However, as observed by Uttal, et al. (2013), there may be a "Catch 22" regarding spatial ability in early STEM education. Students lacking achievement in mathematics as well as spatial ability face significant challenges affecting performance in STEM-related majors.

Spatial Ability and female students: A significant body of research has been

conducted on the performance of females enrolled in STEM-related majors. Much of the research conducted over the past several decades indicates that females lack adequate spatial ability and thus perform at a lower level than their male counterparts (Linn & Petersen, 1986; Masters & Sanders, 1993; Sorby, 2009; Voyer, Voyer & Bryden, 1995;). However, more recent research is finding that female students are more skilled than in the past due to perhaps changing technologies and the digital age (Sorby & Veurink, 2010).

Research Question and Hypothesis

To complement the body of knowledge related to female students in mathematics and spatial ability, the following study was conducted.

The following was the primary research question:

Is there a difference between freshmen engineering technology male and female subjects' mathematics performance and its effect on spatial visualization ability?

The following hypotheses will be analyzed to determine the solution to the research question:

H₀: There is no correlation between mathematics performance and spatial visualization ability between male and female students as measured through the PSVT:R and freshmen SAT and ACT mathematics scores.

H₁: There is a significant correlation between mathematics performance and spatial visualization ability between male and female students as measured through the PSVT:R and freshmen SAT and ACT mathematics scores.

Methodology

To perform the comparative analysis, a quasi-experimental study was performed during the fall of 2018. Subjects for the study were enrolled in an engineering design graphics course as part of the course requirements for the Engineering Technology program. This course focuses on basic principles in engineering design including drawing/hand sketching, dimensions, and tolerance. The engineering design graphics course also emphasizes practice through a hands-on environment using 3D AutoCAD software, as well as editing, manipulation, visualization, and presentation of technical drawings.

A population of 300 freshman students was used as a convenience sample. Using the Purdue Spatial Visualization Test (PSVT:R), students were asked to complete a pretest the first week of classes to measure their initial spatial ability. Upon completion of the pre-test, students SAT and ACT mathematics scores were assessed to determine if mathematics scores correlated with performance in spatial visualization ability and if the study's population revealed a difference between male and female subjects. Data for SAT and ACT mathematics scores were provided by the university's assessment administrators.

Results

A Pearson's correlation was used to determine the association between PSVT:R pre-test scores and SAT and ACT scores between male (N= 230) and female (N=70) subjects. The maximum score on the PSVT:R was 36, 800 for the SAT and 36 for the ACT. Scores for male subjects reveal a mean of 17.72 for the PSVT:R, 651.63 for the SAT, and 29.10 for the ACT (Table 1). No correlation was found between the PSVT:R pretest and the SAT, p = .079, p > .05 (Table 2), or the ACT, p = .262, p > 0.5 (Table 2).

Scores for female subjects reveal a mean score of 17.91 on the PSVT:R, 648.26 for the SAT, and 30.04 on the ACT (Table 3). A statistically significant correlation was identified for the female population for the PSVT:R and SAT, p = .000, p < .05, however no correlation was found between the PSVT:R and the ACT, p = .941, p > .05 (Table 4).

	Ν	Mean	SD	
PSVTPre	230	17.72	3.360	
SAT	230	651.63	67.095	
ACT	230	29.10	3.262	

Table 1

Male Descriptive Results

Table 2

Male Pears	son Correlation			-
		PSVTPre	SAT	ACT
PSVTPre	Pearson Correlation	1	.116	.074
	Sig. (2-tailed)		.079	.262
	Ν	230	230	230
SAT	Pearson Correlation	.116	1	.293
	Sig. (2-tailed)	.079		.000
	Ν	230	230	230
ACT	Pearson Correlation	.074	.293	1

Sig. (2-tailed)	.262	.000	
Ν	230	230	230

Table 3

-emale Descriptive Results							
	Ν	Mean	SD				
PSVTPre	70	17.91	4.187				
SAT	70	648.26	71.334				
ACT	70.	30.04	2.590				

Table 4

Female Pearson Correlation

		PSVTPre	SAT	ACT
PSVTPre	Pearson Correlation	1	.412	009
	Sig. (2-tailed)		.000	.941
	Ν	70	70	70
SAT	Pearson Correlation	.412	1	.274
	Sig. (2-tailed)	.000		.022
	Ν	70	70	70
ACT	Pearson Correlation	009	.274	1
	Sig. (2-tailed)	.941	.022	
	Ν	70	70	70

To find if a statistically significant difference existed between male and females, the $Z_{OBSERVED}$ test was used. The $Z_{OBSERVED}$ for the SAT was .529, since -1.96 < .529 < 1.96 there is no statistically significant difference between male and female subjects. The $Z_{OBSERVED}$ for the ACT was .471, since -1.96 < .471 < 1.96, there is no statistically significant difference between male and female subjects.

Conclusion

This study was conducted to determine a relationship based on gender between spatial ability in freshmen engineering students in an introductory engineering design graphics course. Past studies in the field have historically revealed that male subjects typically outperform their female counterparts in spatial ability and mathematics. This study compared the PSVT:R pre-test with SAT and ACT scores for male and female subjects finding no statistically significant difference between the two genders. Furthermore, it should be noted that a statistically significant correlation was identified for the female population for the PSVT:R and SAT. These findings suggest that female subjects may in

fact be improving in spatial ability and mathematics performance where historically they have been less successful than their male counterparts. The findings also support Sorby & Vuerink, 2010 where female students are more skilled than in the past due to the changing technology landscape and the digital age.

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Using Solid Models to Visualize Concepts in Engineering Mechanics

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Abstract

Students often struggle to understand basic concepts in core engineering mechanics courses such as strength of materials, dynamics and kinematics. With professors from these courses acting as project clients, teams of two to four students in an advanced CAD course provided a suite of in- class demonstration tools using either finite element analysis or mechanism simulation. Topics in strength of materials included Saint Venant's principle, Poisson's ratio, beam bending and neutral axis, axial elongation of a tapered shaft, combined loading, superposition, and torsional loading. Kinematics and dynamics demonstrations were based on simulation of dwell mechanisms, cognates, Ferguson's paradox, spherical and spatial linkages, and a double pendulum. The advanced CAD students gained valuable experience in using CAD software simulation tools, but also reinforced their understanding of basic engineering concepts. The faculty teaching these topics will be able to use these new demonstration tools in their core engineering classes in the upcoming semester.

Introduction

Engineering educators have increasingly noted that students lack conceptual understanding of basic engineering mechanics. Students achieve passing grades in their basic engineering science courses by completing problem sets using algorithmic processes, but fail to understand the significance of their calculations, making it difficult for them to apply their knowledge to new situations (Montfort et al., 2009). Educators have developed concept inventory assessments to evaluate student misconceptions in basic mechanics courses such as statics, strength of materials and dynamics (Richardson, 2004), but little work has been done in upper level courses such as kinematics and dynamics of machinery (Canfield, Hill and Zuccaro, 2016). Misconceptions may arise from previous everyday experiences, and are difficult to overcome with traditional lecturing and textbook examples. Educators are currently developing computer simulations and/or hands-on active learning tools to help students overcome these misconceptions (Deliktas, 2011; Fraser et al., 2007; Newcomber, 2015;

Self et al., 2008). Most of this work is focused on introductory courses in physics and engineering science (statics, strength of materials and dynamics).

In spite of these efforts, students still retain deep-seated misconceptions that can hinder their success in upper level courses (Brown et al., 2018). Roman philosopher Seneca proclaimed that *docendo discimus* ("by teaching, we learn") (Crispo, 2015). By partnering with engineering professors in the basic mechanics courses, students in an upper division CAD course were tasked with preparing visual representations to explain these basic mechanics concepts, thereby enhancing their own understanding of these basic concepts while also providing useful tools for the engineering instructors.

Methods

The Advanced CAD course at WPI is intended for upper division mechanical engineering students who have completed an introductory solid modeling course as well as the mechanics sequence. Many of the students have also taken the kinematics and machine design courses. The course objectives are to improve the students' solid modeling skills and introduce them to various analysis tools such as dynamic simulation and finite element modeling. Although students use SolidWorks in the introductory CAD course at WPI, the Advanced CAD course is taught using Creo due to its more robust analysis capabilities.

Structural analysis using the FEA simulation application in Creo uses wither part or assembly models from the standard modeling application. Loads, constraints and materials are applied in the simulation application; mesh generation is automatic. Students do not need to understand details of the numerical solution methods or mesh generation to use the package, although some guidance from the instructor is necessary when questions arise or models fail due to problems with selection of constraints and interpretation of results.

Kinematic and dynamic modeling in Creo is relatively straightforward. Assembly models are created in the standard modeling application, but utilize pre-defined kinematic joints. The assembled linkages are then opened in the mechanisms application to apply loads, driver motors, springs, dampers, and other dynamic elements, as well as special constraints such as cams, slots and gears. Interference or collision detection within the analysis is optional, but requires significantly more computation time. The application is capable of analyzing either fully determinate (0 DoF) models, or forward dynamic solutions based on the equations of motion.

Topics suitable for simulation using finite element analysis included simple loading conditions (axial, bending), torsion, combined loads and superposition, St. Venant's principle, Poisson's ratio, and stress concentrations. For example, students in strength of

materials courses have difficulty understanding the concept of the stress tensor as exhibited by the distribution of forces in bending beams. Typical homework problems involve calculation of bending stresses and displacements, but the scalar values calculated do not provide students with a more holistic view of the tensor qualities of the stresses and the distribution of stress and displacement throughout the beam. Instructors in these courses requested visual images to demonstrate these concepts.

Instructors also asked for dynamic simulations of dwell mechanisms, cognates, Ferguson's paradox, double pendulum and planetary gears. For example, cognate linkages are presented using static images in many kinematics texts (Norton, 2011; Waldron, Kinzel and Agrawal, 2016). Any fourbar linkage has two cognate linkages which generate identical coupler curves, as shown in Figure 1. These cognate linkages can be used in design applications requiring motion along a specific path. The cognate linkage may provide more convenient ground pivot locations, but because the link lengths and driving link are different, the cognate may not satisfy the Grashof condition and/or the velocity of the coupler point along the identical coupler curves differs even though the cognates may be Grashof crank-rocker linkage. Dynamic simulations would enable the students to grasp these differences in linkage behavior.

Cognate Linkages



Figure 1. Cognate fourbar linkages with identical coupler curves (blue). The linkage on the left is a non-Grashof linkage. The linkages in the center and on the right are both Grashof crank-rocker linkages wherein the shortest green link can be motordriven, but have different velocity profiles along the coupler curve (adapted from Ampofo, 2018).

Students were provided with a list of various topics that had been proposed by instructors in the strength of materials, kinematics and machine design courses. Teams of 2-4 students selected one of these topics, consulted with the sponsoring instructor regarding the desired content, reviewed their modeling strategies for the simulation with the CAD course instructor, and prepared a demonstration and course handout materials for use by the sponsoring instructor during the two- week project time frame.

Results – Stress Problems

Five teams each produced multiple FEA simulations to illustrate various classical stress analysis problems which could be found in standard textbooks, and that the instructors had identified as representative of difficult problems for their students.

Even а simple axial loading problem, as shown in Figure 2, holds the potential for significant learning. The CAD students were challenged to identify the proper boundary and loading conditions that would simulate the textbook problem. Whereas the textbook shows a fixed base and point load, when these boundary conditions are applied, the model does not show the uniform stress distribution one would expect from the textbook example. St. Venant's principle is evident in the higher, non-uniform stresses at both the load and base. The simulation requires a combination of partial constraints and free motion in the x, y, and z directions at the ends and a distributed load along a region at the center of the beam. Under these conditions, the model is able to duplicate the textbook example and also shows lateral displacements caused by the Poisson effect. A similar analysis is conducted as a lab exercise earlier in the course, with a compressive axial load at the end of the beam. Results of the lab exercise are shown in Figure 3.



Figure 2. Textbook problem for statically indeterminate axial load (Hibbler, 2003).



Figure 3. FEA analysis of simple axial loaded beam with fully constrained end (left) and partially constrained end (right). Note that the more complex constraint set is needed to simulate the uniform stress distribution of the textbook example.

More complicated models were used to demonstrate stress concentrations in notched beams (Figure 4). These simulations were intended to accompany physical models made from acrylic that could exhibit the stress bands using a polariscope (photoelasticity).



Figure 4. FEA model of beam showing stress concentrations at a notch

Other student teams studied torsion and superposition. All of the FEA teams prepared a class handout with visuals from the stress analysis for instructor use. Two of these teams also provided animations of the deformed models.

Results – Dynamics Problems

Nine teams elected to create dynamic simulations using the mechanism modeling application in the CAD system. Challenges faced by the students included selection of proper constraints at the connections (joints) between the parts in the assembly, designing Grashof mechanisms that could demonstrate the desired principles, and working with 3D linkages. Table 1 lists student models of linkage and gear mechanisms and materials provided to the instructors. Note that the simulations were used to create videos demonstrating the motions within the mechanism; class handouts also included plots of the kinematic properties such as linear and angular position, velocity and acceleration of various points and bodies.

Торіс	Deliverables	Thumbnail Image
Cognates	Class handout with Roberts diagrams, two .mpg videos	
Double Pendulum	Class handout, .avi file, working mechanism model for student and instructor use	
Dwell Mechanisms	Class handout, two working mechanism models for instructor demonstrations	

Ferguson's Paradox	Class handout, working demonstration model, video	
Spatial Six- bar Mechanisms (2 teams)	Working models, videos	
Spherical Fourbar	Working model, video	
Stamping Mechanis m	Working model, video	
Walking Tribot	Working model, video. This model was created as a research tool for robotics faculty, not for classroom demonstration.	

Discussion

Student response to the selected projects were overwhelmingly positive. Although several teams expressed some frustration with the challenge of duplicating the textbook examples and designing functioning mechanism models, they felt that this was a valuable learning experience. The course objectives do *not* include strengthening their understanding of basic mechanics and machine design concepts. This project enhanced their understanding of the basic principles in mechanics and kinematics, while also providing an opportunity to deepen their knowledge of the simulation applications in the solid modeling system. Some representative comments from their final reports include:

- This project gave the team valuable experience in conducting finite element analyses as well as provided a useful review in topics of stress analysis.
- In this projected we learned an extensive amount about FEA modeling as well as axial loading calculations.
- Through this project we were able to practice our finite element analysis skills as well as further improve our understanding of basic stress analysis principles. Visualizing what direction certain components of stress act in is something that is extremely confusing even for students who have already taken (strength of materials). In each loading scenario we had to be mindful of what types of stresses were acting on the beam and what the best way to display them would be.
- Overall, our team very much enjoyed this project. All four of our team members became much more proficient using the simulation application.
- We come away from this project with a better understanding of how to build, constrain, and analyze mechanisms to accomplish specific tasks.
- Overall the project was an interesting way of applying what we had learned in the course and taking it one step further.

Conclusions

These student comments demonstrate that the use of carefully selected FEA simulations enhances student understanding of concepts in stress analysis. Dynamic simulations of textbook linkage and gear kinematics problems are challenging modeling exercises for CAD students and can be used to demonstrate the behavior of mechanical systems in an engaging manner. Students in the CAD course strengthened their understanding of basic concepts in engineering mechanics and machine design through using the CAD simulation applications. Instructors for the courses in strength of materials, kinematics and machine design will be using the simulations, animations and graphical displays during the upcoming semester.

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Datum Reference Frame Applications in a Senior-Level, Engineering Technology Capstone Course

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Abstract

Many engineering graphics instructors introduce students to the principles of GD&T using a wide variety of pedagogical methods. Perhaps the logical starting point for teaching GD&T is the selection and use of a datum reference frame (DRF), which is the theoretical frame of reference established by real part features. This paper will describe how instructors of a senior-level capstone course at Illinois State University guide students through the process of selecting and using datum reference frames during the manufacture of products in a student-designed lean production cell. Good and bad examples of student projects having a focus on the consistent application of datum reference frames will be discussed.

Introduction

The key concept in geometric dimensioning and tolerancing (GD&T) is the datum reference frame (DRF) (Neumann & Neumann, 2009). The DRF consists of three mutually perpendicular axes and planes, which intersect to establish the DRF origin. The DRF is the key form of communication between the design, manufacturing, and inspection processes. This paper describes how instructors of a senior-level capstone course at Illinois State University guide students through the process of selecting and using datum reference frames during the manufacture of products in a student-designed lean production cell.

Since all geometric dimensions and specifications are related to the DRF, it is an effective tool to coordinate design, fabrication, inspection, and assembly of products. Within this system, it is key that a designer strategically identify features on a part as datum features to establish relationships specified by the geometric tolerances and to also constrain the part within all degrees of freedom (ASME, 2009; Madsen & Madsen, 2013).

A common mistake that educators make when covering GD&T is only talking about it within the context of a single part. In order for students to fully understand GD&T

concepts, especially the DRF, it is crucial that they work with assemblies of parts (Leduc, 2002). It is also important that students interact with GD&T ideas in multiple ways. Waldorf & Georgeou (2016) discuss the use of Bloom's Taxonomy to integrate GD&T throughout a manufacturing engineering curriculum. They list several ways of covering DRF concepts (pp. 7-8):

- *Application:* Associate product functional requirements with the assignment of datums on drawings.
- Analysis: Relate geometric tolerances to datums and datum reference frames.
- *Synthesis:* Plan and construct a solid CAD model and a part drawing with datums, datum refinements, and location tolerances; Formulate a strategy for location tolerancing to ensure interchangeability of parts; Improve a design to make it easier to fixture, produce, or inspect; Design a production fixture for an operation based on part drawing; and Design an inspection process for a part based on part drawing.
- *Evaluation:* Compare fixturing and inspection alternatives for features or datums that are referenced at MMC.

Course Description

The engineering technology senior capstone course at Illinois State University focuses on the study of industrial production systems including product, manufacturing, and plant engineering through managing a production project in the university's manufacturing lab. In the course, students divide into teams of five with members having a variety of technical roles to develop and implement a lean production process. The 16-week course includes six graded milestone submissions that allow the instructor to evaluate the progress of the teams using formative assessment methods. Table 1 shows the six project milestones and the associated point values for grading purposes. The focus of this paper will be on the GD&T related activities included in milestones 2 (product design) and 3 (fixture design & fabrication) undertaken by a team of students charged with the task of designing and manufacturing the tape dispenser product shown in figures 1 and 2. Of the 12 component parts illustrated in figure 2, four of the parts (items 1, 2, 6 & 8) are shop-made components with the remaining items being standard parts that are purchased.

Table 1. Project Milestones.

Milestone	Grade Weigh t	Description of Milestone Contents
Milestone 1: Team Charter	20 points	 Rules to govern group interaction, Project WBS, Project PERT and Gantt charts
Milestone 2: Product Design	100 points	 CAD models and part drawings, manufacturing process plan, material flow, build a prototype to evaluate, compute prototype cost
Milestone 3: Fixture Design & Fabrication	200 points	 Design & fabrication of fixtures, PERT and cost, Control Plan needed to make product with repeatable accuracy, process plan for LEAN production First Article Inspections (FAI) – make 1 product from fixtures and verify fixtures make quality parts.
Milestone 4: Pilot- run	100 points	Kanban, work instructionsPilot Run: make 2 products using fixtures
Milestone 5: Production Run	100 points	Make products.
Milestone 6: Project Closeout	30 points	Submit PPAP and presentation of project results



Figure 1. Tape Dispenser Project.



Figure 2. Tape Dispenser Exploded View and Parts List.

At the beginning of the course, students were given paper-based concept drawings with nominal dimensions (i.e. no tolerances) of the tape dispenser product that was modeled after "Reggie", the university mascot. As part of Milestone 2, the students were instructed to model the tape dispenser product using "appropriate" modeling tools in the NX CAD system used at the university. In addition to creating CAD models of the project, students also built a prototype tape dispenser using the machine tools in the manufacturing lab. Prior to building the prototype, the students were told it was important that the product be easy to assemble and that the back surface of the Base Spacer Block should be flush with the back faces of the two vertical component parts called "Reggie Left" and "Reggie Right" (see Figures 2 & 3). While building of the prototype product, students were able to identify the component part features that have a direct impact on product assembly and quality. The students determined the hole features identified by dark arrows in Figure 4 were very important and needed to be controlled dimensionally using GD&T. Students correctly determined that in order for the three flat surfaces to be

flush when assembled, these holes must be located relative to the datum surfaces illustrated in Figure 4.



Figure 3. Important Assembly Concern.



Figure 4. Important Hole Locations on Three Components.

Determining Datum Reference Frames

After the students determined that the holes identified in Figure 4 are important part features in the tape dispenser product, their task was to decide the best GD&T tools to use to control the features appropriately. An important part of this task was the identification of the datum features that the hole locations should reference. The phantom lines in Figure 4 illustrate the datum edges that were identified by the students. The next task was to use these datum features to create a datum reference frame on each of the three parts. Figure 5 illustrates the datum reference frame created for each of the three parts.



Figure 5. Datum Reference Frames for Parts.

After the datum reference frame was annotated, the feature control frames for the hole features were created. On this project, the position tolerance was used to locate the holes. Position was used because it is intended to locate center points and axes for features of size. The order of datums referenced in the feature control frame was carefully considered by the students because they determine the machining and inspection setups that must be used during production. Figure 6 shows the parts with the feature control frames added.

The datum features were then labeled on the prototype to help the students see the correlation between datum identifiers and the actual features on the physical product. After the product design and prototype were complete, they were submitted for evaluation at part of Milestone 2.



Figure 6. Feature Control Frames for Holes.

Fixture Creation

The machining fixtures used to hold the workpieces during machining were designed and built next. Considerable attention was paid to the order of precedence of datums in all feature control frames. The order of precedence of the datum features listed in the feature control frame dictates the part locating methodology used in the workholding devices. In the student-designed fixture illustrated in Figure 7, the first (primary) datum feature to be placed on the fixture is Datum A (a large flat face of the part), which is placed flat against the upper surface of the fixture base.

The second datum feature to be used is Datum B, which is placed touching 2 locator pins on the fixture. The final datum feature to be used, Datum C, is placed touching the third locator pin.



Figure 7. Part Location on Fixture.

Common Student Errors

It is not uncommon for students to design fixtures seemingly without regard for the datum reference frame. The use of the primary, secondary, and tertiary datum features in a feature control frame dictate the manner in which a part should be located on a workholding device. Changing the order that datum features are listed in a feature control frame will often require a new fixture be created in order to locate the workpiece using the specified datum reference frame. This can be an eye-opening experience for students when they learn that they must design and build additional fixtures because of

the datum reference frame used in feature control frames. Figure 8 illustrates an example where the feature control frame calls for datum feature A to be placed down on the fixture first, but the fixture incorrectly has datum feature A facing away from the fixture.



Figure 8. Inconsistent use of DRF in Fixture Design.

Another example of a common student error occurs when a feature control frame is added to control the shape and location of the slot on the Reggie-right part. Because the slot and counterbore features are on opposite faces of the part, two machining setups are required.

Students often fail to recognize that multiple machining setups requires the creation of another DRF. Figure 9 shows the Reggie-Right part with datum D and profile of a surface feature control frame added for the slot feature. The fixture shown in Figure 8 could be used to hold the part when machining the slot as dimensioned in Figure 9.



Figure 9. Additional Datum Feature for Second Machining Setup

Conclusions

In order for students to have a deep understanding of GD&T concepts, especially the

DRF, it is important that they work with assemblies of parts. It is also important that students interact with GD&T ideas in multiple ways. The engineering technology capstone course at *institution name* requires students to apply GD&T concepts within the context of a semester-long design & manufacturing project. Students work in teams to analyze the relationships among component part features in a product. After physically building the product, students identify those features that are most important to ensure quality and ease of assembly. Students then use the datum reference frames during the manufacture of the product. This process provides unique learning opportunities for students that they would not experience with a "design-only" project. Fixtures designed and created based on an appropriate datum reference frame typically yield good assembly fits. Poor datum reference frame selection and fixtures created inconsistent with the datum reference frame usually result in parts not assembling properly. The role of the instructor in this process is to give feedback to students at major milestones in the process and also guide them through the problem- solving process when things go wrong.

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Underrepresented and International Student Success and Confidence in a Small, Lab-based CAD Class

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Abstract

In this digest, we explore confidence and success of different demographic groups in a lab- based CAD course. We hypothesize that students with lower spatial visualization ability, who typically struggle in traditional engineering graphics courses, benefit from the relaxed time constraints and frequent instructor interaction of this lab-based class. Our analysis showed that initial spatial visualization test scores were not a good predictor of course grades. Women and international students, both groups with low average spatial visualization ability, had different outcomes: on average, domestic women had higher grades than their domestic male counterparts, while international male students had lower grades than their domestic counterparts. International, domestic minority, and domestic female students reported lower confidence on a survey compared with their counterparts. While the lab-based format appears to help female students' grades, more work is needed to ensure equal benefit for international students and to encourage confidence in all students.

Introduction

The population of students graduating with undergraduate engineering degrees in the US has become more diverse in recent years. From 2010 to 2017, the percentage of bachelor's degrees awarded to female, underrepresented minority (URM), and international students increased from 18% to 21%, 13% to 19%, and 6% to 10%, respectively (Yoder, 2017). Northern Arizona University serves a diverse population, with URM students representing 28% of all undergraduates (Northern Arizona University, 2015). International student enrollment is also increasing (5% of all NAU undergraduates in 2015), with most international students in engineering coming from the Middle East. It is increasingly important to confirm that all students, regardless of demographics, can succeed in engineering classes. Previous studies identified a correlation between grades and spatial visualization ability in 2D engineering graphics classes (Gimmestad, 1989;

Hsi, Linn, & Bell, 1997) and, to a lesser extent, CAD classes (Hamlin, Boersma, & Sorby, 2006; Branoff & Dobelis, 2012; Budinoff & McMains, 2018). This correlation can disadvantage females and students from certain ethnic groups and countries, such as the Middle East, who tend to have lower spatial visualization ability (Segil et al., 2016; Sorby & Veurink, 2012; Sorby, Cubero, Pasha-Zaidi, & Karki, 2015).

This digest focuses on a lab-based class, with one weekly 1.5-hour session where the instructor demos examples in SOLIDWORKS while students duplicate instructor actions on their own PC, and a second weekly 1.5-hour session where students work independently on assignments. Class exams (weighted at 35% of the overall course grade) have lenient time constraints, with most students finishing early. Homework and a project are weighted highly (40% and 15% respectively). Average class size is 22 students.

Most assignments focused on interpreting engineering drawings and modeling 3D objects, which requires spatial visualization ability. Maeda and Yoon (2013) found that the magnitude of the gender difference in scores on a common spatial visualization test, the Purdue Spatial Visualization Test: Rotations (PSVT:R), is lessened by extending the testing time. Similarly, Hsi, Linn, and Bell (1997) identified gender differences for scores on class exams with time restrictions but not for homework and projects, which had more relaxed time restrictions. Because of these findings, we hypothesized that the lenient time restrictions of all class assignments would reduce gender differences in course grades. We were also interested in exploring course outcomes for URM and international students. Groups with low visualization ability could benefit from the small class size, as small classes may be associated with larger gains in spatial visualization skills than large lecture classes (Leopold, Górska, & Sorby, 2001).

In addition to class grades, we sought to explore student confidence. Kelly (2017) found that males have higher engineering graphics self-efficacy than females, and Towle et al. (2005) found a correlation between PSVT:R scores and spatial visualization self-efficacy. There is little research on engineering graphics self-efficacy for URM or international students.

Methods

The 30-question PSVT:R was administered on paper in 20 minutes during the first week of the semester. The Wilcoxon rank-sum test was used to evaluate differences in medians of PSVT:R scores and course grades with a significance level of α =.05. This study includes only male international students to preserve the anonymity of the few female international students.

To gauge student confidence, we administered an optional survey, based on that of

Hamlin, Boersma, and Sorby (2006), with questions related to student perceptions about a SOLIDWORKS homework assignment. An "average perception" was calculated by averaging scores for questions related to confidence (e.g. "how did you feel when you started work on this assignment?"). More details are available in Budinoff and McMains (2018). The survey also asked students for demographic information and how long it took them to complete the assignment. The PSVT:R was re-administered within a week of completion of the assignment.

Results

International and female students had lower PSVT:R scores, as summarized in Table 1, confirming results presented Segil et al. (2016) and Sorby and Veurink (2012). Differences in scores between domestic men versus domestic women, and domestic students versus international students were statistically significant (*ps*<.001).

Group	Score (out of 30)	
Domestic men (<i>n</i> =184)	23.3 (SD=4.48)	
Domestic women (<i>n</i> =43)	19.3 (SD=5.36)	
International men (<i>n</i> =61)	13.5 (SD=6.09)	

Table 1. Gender and demographic differences in average PSVT:R scores.

Average course grades are not presented because about half of the grade data was only available as ordinal data (A, B, C, etc.). The difference in course grades between international men and domestic men was statistically significant (p=.005), but the difference between domestic women and domestic men was not statistically significant (p=.108). This could be due to the larger difference in PSVT:R scores between international and domestic men, or a different factor, such as women benefitting from the relaxed time constraints. A comparison of grade distributions (Figure

I) shows that domestic females who are low visualizers, scoring less than 20 on the PSVT:R, perform similarly to students who scored 20 or higher (difference in grades is not statistically significant, p=.153), whereas domestic and international male low visualizers have significantly lower grades than students scoring 20 or higher (p=.009 and p=.010, respectively).



Figure 1. The percentage of female low visualizers earning an A is approximately double that observed for domestic male and international male low visualizers.

We also analyzed survey results to understand differences in confidence between demographic groups. Because the survey was optional, our sample size is small, which limits us to qualitative comparisons between groups. As summarized in Table 2, while most groups reported similar completion times, URM students reported higher difficulty than white students, and domestic women reported higher difficulty than domestic men (difficulty is measured as a higher average perception). International students reported both substantially higher completion times and difficulty. Domestic women reported higher completion time than domestic men. PSVT:R scores are correlated with average perception (Budinoff & McMains, 2018), so it is not surprising that groups with lower PSVT:R scores reported more difficulty. However, some groups feel more confident, even if they require a similar amount of time to complete the assignment.

Group	PSVT:R score at	Average perception	Average time
	time of survey	(out of 5)	(out of 5)
White (all genders) (<i>n</i> =17)	23.9 (SD=4.82)	2.36 (SD=0.65)	3.53 (SD=0.88)
URM (all genders) (<i>n</i> =7)	21.8 (SD=6.07)	2.70 (SD=1.02)	3.50 (SD=0.46)
International men (n=4)	16.3 (SD=3.70)	3.46 (SD=0.62)	3.75 (SD=0.43)
Domestic women (all ethnicities) (<i>n</i> =9)	23.2 (SD=3.92)	2.58 (SD=0.69)	3.53 (SD=0.84)
Domestic men (all ethnicities) (<i>n</i> =16)	23.9 (SD=6.00)	2.39 (SD=0.76)	3.47 (SD=0.76)

Table 2. Perception of difficul	y and time required to	complete an assignment.
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Discussion and Conclusion

Our analysis indicates that this course especially enables women to succeed but the reason is unclear. The high percentage of female low visualizer who earned an A or B could be a result of the course's relaxed time constraints. Previous studies indicate that measured gender differences in spatial ability scores decrease with relaxed time constraints, but this has not been shown for other demographic factors like nationality. Further study is needed to determine if the differences in spatial visualization between nationality or ethnicity groups is affected by time constraints. Small class size, frequent instructor interaction, and hands-on nature of the class might also have supported better outcomes for females, although it is unclear why females would especially benefit from these factors.

There was a statistically significant difference in the grades of international students and domestic students, likely due in part to lower visualization ability, the effect of which wasn't diminished with the relaxed time constraints. Domestic and international male low visualizers struggled in the class, despite the relaxed time constraints. Further, international, URM, and female students all reported lower confidence than white students and domestic males. It is unclear how social factors affect confidence and selfefficacy. This digest highlights the need to study how student success varies with different class formats and pedagogy strategies, and to better understand the interaction between social factors, visualization ability, and student success.

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Picture Exchange Communication System (PECS) Mediums: Comparative Analysis

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Abstract

This study is a detailed review of the commonly cited software/hardware mediums currently able to host the Picture Exchange Communication System (PECS). PECS is an augmentative and alternative communication (AAC) system that relies on visual cues for communication and instruction. This research examines each supporting technology systems uses, techniques, and current applications. This paper provides a review of the mediums based on instructional, interactive, and behavioral aspects that all users of these systems need to take into account when choosing which will best allow them to communicate. By providing an in depth review, users and families suffering from Autism Spectrum Disorder (ASD) and developmental delay can better understand the uses and options available in order to help them make a decision in which system to use.

Introduction

The Picture Exchange Communication System (PECS) allows people with little or no communication abilities to communicate using pictures/visual cues such as through flashcards that are shown to the intended recipient. A child or adult with autism can use PECS to communicate a request, a thought, or anything that can reasonably be displayed or symbolized on a picture card (Aresti-Bartolome & Garcia-Zapirain, 2014).By doing this the person is able to initiate communication.

Due to the increase in diagnosed cases of ASD, software and hardware dedicated to helping persons with autism have been developed, increasing their vocabulary and communication skills to overcome their weaknesses (DeLeo & Leroy, 2008).

Professors Aresti and Garcia (2014) of the University of Deusto stated that Information and Communication Technologies (ICTs) can compensate and support education of students with special needs, and particularly people with ASD. The aim of this analysis is to provide a detailed comparative review of existing software and hardware mediums currently able to host the Picture Exchange Communication System – PECS. In addition, this research examines various supporting technologies programs designed to be used on computers, tablets or mobile telephones, using PECs in a cost effective manner.

This paper will review the following systems -- including individual uses, techniques and current applications:

- 1. PECS Cards
- 2. IPad and Mobile Devices
- 3. Video Instructions
- 4. Virtual Reality

Literature Review

With the integration and the inclusion of computer and assistive technologies, students with autism, non-verbal learning disorder or disability (NLD or NVLD), or other forms of communication disabilities can now communicate their needs and wants using computer generated PECS, which are more effective and accessible (DeLeo & Leroy, 2008).

Interventions have been developed to focus on alternative communication strategies for children who do not develop speech. These programs involve non-vocal methods of communication (Mustonen, Locke, Reichle, Solbrack, & Lindgren, 1991), and include sign language, picture-point systems, electronic devices, and other picture-communication systems (Carr & Kologinsky, 1983; Mirenda & Schuler, 1988; Reichle & Sigafoos, 1991). Augmented input illustrates the real-world meaning of symbols (e.g., PECS), the many functions they can serve, and demonstrates that the AAC system is both accepted and encouraged as a modality for communication (Romski & Sevcik, 2003; Sevcik & Romski, 2002).

PECS is an example of an augmented input system used to offer children suffering from ASD. ASD causes mental delays, such as language deficits and delays in speech, cognition, and social/personal skills. PECS uses visual cues to let the recipient know the intended meaning by choosing the image located on the card and displaying it to others. It was originally created to offer an alternative form of communication to children suffering from ASD, substituting oral and written forms of communication by having a visual based system using images to convey messages (Bondy & Frost, 1994; Bracken & Rohrer, 2014). Notable studies (Bondy, 2001, Schwartz, Garfinkle, & Bauer, 1998) corroborate the effectiveness of PECS when used by young children with autism. More recent studies have provided evidence that PECS can also be used not only for

communication, but can assist in the development of independent vocalizations; this is speaking words independently from the system (Cagliani, Ayres, Whiteside, & Ringdahl, 2017).

Methodology

The purpose of this study is to provide a review of all the commonly cited mediums based on criteria that all users of these systems need to take into account when choosing which will best allow them to communicate. These criteria were chosen based on motivations new and trained users and their families would consider when choosing a system or switching to a new one. These are:

- 1. Ease of use
- 2. Accessibility
- 3. Cost
- 4. Maintenance
- 5. Future opportunities for scalability

Ease of use refers to difficulty of setting up and performing the necessary functions the medium requires to operate it. Accessibility is the difficulty of obtaining the medium and obtaining additional materials that the medium may require. Cost is the overall price of not just the system but any accessories that may also need to be purchased. Maintenance is the difficulty of maintaining the medium in working order and repair if the need arises. Lastly, future opportunities for growth refers to advances technology/society can contribute to the medium to improve it over time. The four mediums that were chosen for the study are shown in the figure below.

IPad/Mobile



Video



PECS Cards

VR



Figure 1. Mediums used in this study

PECS Cards

This is the original PECS card medium. The system uses basic behavioral principles and techniques such as shaping, differential reinforcement, and transfer of stimulus control via delay to teach children functional communication using pictures (black-and-white or color drawings) as the communicative referent (Yoder & Lieberman, 2010). The child is taught to create a "sentence" by selecting picture cards (e.g., "I want" card plus "juice" card) and delivering the cards to a communicative partner as a request for a desired item (Yoder & Lieberman, 2010).

IPad and Mobile Devices

The introduction of the Apple iPad in 2010 has seen a shift toward technologymediated learning for typically and atypically developing children. Tablets and similar handheld devices offer the promise of flexible, mobile, and individualized learning to support language and literacy development, math, social sciences, etc. (Banister, 2010). However, to date, there is little empirical support that the technology, rather than the content, results in improved educational outcomes, despite media reports to the contrary (Biancarosa and Griffiths, 2012).

Video Instructions

Video modeling typically involves showing a video-recorded display of a target response to teach a child to emit specific behaviors (Bellini & Akullian, 2007). Video modeling has been used to teach a variety of play, communication, social, vocational, and other skills to children with autism (Rayner, Denholm, & Sigafoos, 2009).

Virtual reality

While several programs/uses for helping children with autism and/or developmental delay exist using virtual reality (VR), there are no exact uses for PECS with VR, as PECS is meant to be used as an augmentative way for users to communicate using pictures and symbols, and develop communication between two

users face to face. While VR is generally used in various instructional settings (Chandramouli, Zahraee, & Winer, 2014; Chandramouli, Takahashi, & Bertoline, 2014), from the perspective of this research, current use of VR is intent on teaching emotive understanding and appropriate situational behavior.

Judgement of each medium was based on information from academic journals and peer reviewed sources of the experiences along with findings of the testers and researchers that had performed similar comparisons between mediums or with applications in the same medium. Industry professional Luz Cruz was also interviewed to help with feedback and planning for this analysis.

All the criteria of each medium were categorized and listed. After compiling the data, each medium would then be compared and discussed with Luz Cruz to reach a joint conclusion.

Results

The table below lists the results of all medium criteria discussed in this study.

The IPad/Mobile medium has the most options available for aiding communication, but because of the large amount of tools and applications, it will take longer for people to master. Is widely accessible, but has a high startup cost for buying a device. Devices can last long when proper care and protection (Ex. screen protector) are used, along with having a high growth potential for scalability as new technology and applications are being developed around the world.

The physical medium is the most widespread medium with easy and simple use of the system that gets harder over time as more cards are added. It is also the most widely accessible due to being the medium that hosted the original system. The cards can last long when they are protected by laminating and organizing them. However, this does not have much room for growth as all the major developments have been achieved. And it is easy to lose cards, especially later on when more have been added to the collection the user needs.

The Video medium has a large number of options available, both physical and online, but requires training both user and caretaker to use effectively. It is widely accessible but can have a high startup cost, especially for use of groups where more equipment and a larger setting to house the equipment is needed. Maintenance may require a technician to take proper care and repair of equipment. The video medium has a high growth potential in collaborations and communities, internationally thanks to online collaboration.

	Ease of Use	Accessibility	Cost	Maintenance	Scalability
IPad	Requires training to use all available tools	Incredibly common and widespread	High initial cost, ca be as high as \$500 for a new device plus the application	Most devices come with all required tools. Extra can be puchased easily.	Large scalability and rapid evolution
PECS	Most understood and widespread	Starts simple but becomes difficult over time as more cards are needed	Relatively low cost. If complete set and all other items are needed it will be at most \$340.	With proper lamination, cards can last long, and can be replaced easily.	Not much scalability, only a few possible new developments
Video	Set up can be difficult for groups; easier for single users-caretaker needed to record videos for individual cases.	Large selection of online resources. Can be shown to a group with a video projector.	Case by case. Personal devices work for single users, and monitors/project ors for groups. Groups will cost more than individual.	Case by case. Easier to maintain for individual than group. If creating own videos, a storage device will be required.	Able to grow through online collaboration and communities
VR	Still uncertain. New systems allow more freedom of movement but require large indoor space, may cause nausea.	Easy to obtain. Smaller systems like Google cardboard are portable, but, systems like Oculus/Vive are limited to indoor use	Most expensive. Vive can cost \$500 for the system alone. Google Cardboard will be around \$15.	Requires caretaker support to set up full set systems. Users can be trained to use Google cardboard by themselves.	Most potential for user interaction and development through unique experiences.

Table 1: Comparative Analysis of Various Media & the Major Attributes

The VR medium has the least available options due to being the newest medium. However, this is the best medium to maintain user attention for instruction due to user interaction and immersion. It is widely accessible, but has the highest startup cost for buying a full set device such as the Vive. VR will require caretaker/guardian help to maintain and set up the system as the setup is complicated for people not familiar with the technology. The VR medium has a high growth potential for scalability and best potential to maintain the attention of people with ASD.

Discussion

After reviewing each of the mediums and their specific aspects, it was found that each medium has different strengths which set them apart from each other. Because of each mediums unique purposes and traits there is no medium that has all the best attributes people would need.

This study does have limitations. Only the most commonly cited systems were used as these were the systems that were the best documented and most widely used. Less used mediums that have less data/development were not considered. VR (Particularly with Oculus and Vive) with the PECS system has no current applications to provide data, because it is still a new system and more research into this medium is needed.

Conclusion

Each medium has different inherent characteristics that allow them to serve a unique purpose. There is no one medium that is able to handle all possible needs, therefore each user needs to select on a case by case basis which medium has the best attributes to help them communicate. This should be discussed with a licensed professional who will be able to give the best recommendation after careful analysis of the person.

However, further research is needed to examine the potential of new emerging technologies, particularly of virtual reality's instruction potential. Further research must also be done to determine the effectiveness of these mediums and how they compare to the commonly used mediums using the criteria listed or similar criteria.

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The Necessity and Results of Autonomous Integrity Evaluation of CAD Files

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Abstract

This paper describes the history, necessity, methods, and results in performing largescale collection and comparisons of CAD files for originality over the past 12 years (24 semesters). Higher-educational STEM-focused institutions are finding it necessary to evaluate modeling skills with CAD software in a quicker and more consistent manner. However, increasing mobile computing power and higher data bandwidth foster an alarming ease that students may transgress the institutional, course, and/or ethical standards by duplicating assignments and submitting work that was wholly or partially created/submitted by another student. During a first-year 14-week CAD course, hundreds of students create and submit thousands of CAD files for evaluation. Prior to autonomous technology, manual evaluation of student assignments for plagiarism yielded an average indictment rate of 0.9% per semester, over 5 semesters. Automatic checking has increased this to 7.4%. A program has been written that interfaces with a CAD software to parse through tens of thousands of CAD file assignments in matter of minutes. The program extracts relevant file properties to a spreadsheet, compares the set of files against each other for originality, and flags any file and student names that have identical properties. Over 15 semesters, this method has yielded a 100% conviction rate in 261 cases from a total pool of 3,861 students. A procedure to present the indicted parties evidence, render judgment and sentencing in a condensed period will also be discussed. As engineering instructors, it is a necessary duty to ensure that students adhere to rigorous academic standards, and if not, to call attention to their folly. This method and program strives to that end.
Introduction

The CAD instructional market is finding it necessary to evaluate introductory twodimensional and three-dimensional parametric modeling skills with its software in a quicker and more consistent manner. Within this Institute's first year CAD course, hundreds of students are enrolled, submitting thousands of files, for which there is only one course coordinator to evaluate their originality. Assignment submissions can seem identical when only viewed from NX's GUI, thereby making it difficult to visually detect if a file has been duplicated.

Further, mobile computing platforms are dominating within U.S. higher learning, with price- points decreasing and CAD-sufficient hardware becoming ubiquitous across the top vendors. This lends to the ability for each student to own and use their CAD-ready hardware anywhere and at any time. Unfortunately, this mobility creates environments where students can engage in illegal file transfers or have their work stolen from an unattended laptop. In addition, the rise of cloud-based platforms (e.g. Course Hero[™]) that host student's collegiate work provides easy access for unauthorized duplication.

Background

Of the dozens of CAD software packages on the market today, some have employed add-ins or third-party applications in accomplishing automatic grading, quality, and/or integrity checks (PTC, 2018). Garland Industries combs through user IDs and timestamps for similarities of SolidWorks parts in their API program (Garland, n.d.). Some instructors have created an API to run similar checks for SolidWorks (Johnson, 2018), (Guerci, 2003) and NX (Kirstukas, 2018) for introductory CAD courses. While Guerci's methods were never published, Kirstukas have claimed an evaluation speed of 3 seconds/file, and he and Johnson concluded their method has less than perfect detection rates. This work describes a quicker and more robust method to interrogate NX files that cannot be easily tampered by users.

Current Course Format

Introductory Graphics and CAD is a one-credit introductory course that meets once per week, 14 weeks, for 110 minutes per meeting. All students are required to have personally owned laptops with working CAD software (Siemens NX). The typical semester enrollment totals between 280 and 350 students that must be divided into 8 or 9 sections due to seating constraints of laptop-ready classrooms.

Most assignments are presented as standard drawings similar to Figure 1, with the shape, parameters, and orientation given to the student, and the student is asked to create and submit an NX file in a *portfolio* folder.



Figure 1: Example Model and Drafting Assignment

A student *portfolio* is defined as "the digital collection of every student-created file submitted for grade AND files obtained through the course learning management system necessary to complete all graded assignments". A complete portfolio is worth 10% of the course grade, and is submitted on the last day of the course.

Complete portfolios will contain between 49 – 56 files, varying slightly each semester, totaling between 18 – 20 MB in disk space. The Spring 2018 semester contained 13,832 files within 252 portfolios submitted, totaling a disk space of 4.75 GB.

The syllabus contains a strict "zero-duplication" policy for any CAD model created in the course. Students are made aware that no work should ever leave their possession. Failing to adhere to the this will result in a failing course grade for all guilty parties involved and further disciplinary action if needed.

Integrity Evaluation Properties

User ID

The User ID listing in the file's Part History can list out the User logged into Windows at the time of save. Although using this parameter has yielded success by Kirstukas (2018), when student's use their own hardware, they will frequently have usernames (see the column **User** in below figure) that are not specific or meaningful for comparisons to other students, as denoted by an example student in Figure 2.

Part Save History Report-	22 Dec 2017 10:41							
Dart File: Fild, SabaallCODE	TENCE 4300 CADIA BartfalianIEL 47 D	entfelige)05)kenne2)Fin	I Designt lase					
Part File. E.11_School:CORELENGR-1200_CADIT_Portionos/FL17_Portionos/solis/congcz/Filial Project Kongcz/FilianDEE_EDGED.ptt								
Version	Save Time	Machine	User	Program				
Loaded		NT ×64	Jeff	NX 11.0.2.7 MP4, 05Nov17				
14	11 Dec 2017 22:17	NT ×64	垂正	NX 11.0.2.7				
13	09 Dec 2017 17:14	NT ×64	垂正	NX 11.0.2.7				
12	09 Dec 2017 17:14	NT ×64	垂正	NX 11.0.2.7				
11	09 Dec 2017 17:10	NT ×64	垂正	NX 11.0.2.7				
10	09 Dec 2017 16:34	NT ×64	垂正	NX 11.0.2.7				
9	07 Dec 2017 23:02	NT ×64	垂正	NX 11.0.2.7				
8	06 Dec 2017 13:58	NT ×64	垂正	NX 11.0.2.7				
7	06 Dec 2017 12:04	NT ×64	垂正	NX 11.0.2.7				
6	06 Dec 2017 12:04	NT ×64	垂正	NX 11.0.2.7				
5	06 Dec 2017 12:04	NT ×64	垂正	NX 11.0.2.7				
4	27 May 2015 14:49	NT ×64	Jeff	NX 10.0.1.4 MP2, 06Apr15				
3	27 May 2015 14:19	NT ×64	Jeff	NX 10.0.1.4 MP2, 06Apr15				
2	30 Sep 2014 01:43	NT x64						
1	30 Sep 2014 00:58	NT x64						

Figure 2: NX Part History Information

Unique Part Identifier (UID)

From the Siemens NX Documentation: *starting with V10, each part is assigned a UID when it is created. The UID resides in the part file and is preserved for the life of the part – no matter how many times it is resaved or renamed in the operating system.*

The UID is a unique alphanumeric string that is generated for every part file created with the File > New (or Create > New in assemblies) command, even if custom template files are provided. It is this sole property that is checked for duplication across student submissions. No two student's submissions should ever contain the same UID. If so, it is plagiarism and must be flagged.

It is possible that a single student's portfolio contains several different CAD files with the same UID. This means the student duplicated a file and deleted and/or changed (i.e. 'rolled back') the features enough to build a different assignment. Both files are still the student's own original work and **not** indicative of plagiarism. While this method of creating 'new' files is strongly discouraged, it is never falsely flagged by this application. This application only checks for matching UIDs across different student IDs.

Timestamp

While timestamps are useful to extract self-plagiarism cases, this author currently allows users who have taken the course previously to re-submit older original files if they are the same assignment. The course has an extensive library of assignments that rotate every seven to eight semesters so the probability of old submissions is very low. However, a slight modification to the program could easily check for credible timestamps.

Integrity Evaluation Procedure

The author has written and tested an external .NET application that performs two separate routines to compare the originality of a set of CAD files.

Build Database

Figure 3 below shows an example partial output from a single student, indicating the file properties collected as column headings: semester taken, section number, student folder (the RCSID is a string unique to every student), filename, last timestamp the file was saved (LSDT), and UID. Each row is a separate file.

1	A	С	D	E	F	G	Н	1		1	К	L	М
1	No.	SEM	SEC	RCSID	FILENAME	LSDT	UID	M_FI	LE	M_SEM	M_SEC	M_RC SID	ROW#
2	2	1200-localSP18_Portfolios	1	ackerk2	baseplate	29 Apr 2018 19:12	kayakeet.GenuineInt.1522703059.0.9416.0						
З	3	1200-localSP18_Portfolios	1	ackerk2	boardtruck_assy	30 Apr 2018 10:05	kayakeet.GenuineInt.1525023269.0.9412.0						
4	4	1200-localSP18_Portfolios	1	ackerk2	boardtruck_assy_dwg1	30 Apr 2018 10:50	kayakeet.GenuineInt.1525023269.0.9412.1						
5	5	1200-localSP18_Portfolios	1	ackerk2	bolt	29 Apr 2018 19:12	kayakeet.GenuineInt.1522696831.0.18256.1						
6	6	5 1200-localSP18_Portfolios	1	ackerk2	bushing	29 Apr 2018 19:13	kayakeet.GenuineInt.1522696831.0.18256.2						
7	7	1200-localSP18_Portfolios	1	ackerk2	curved washer	29 Apr 2018 19:13	kayakeet.GenuineInt.1522696831.0.18256.4						
8	8	1200-localSP18_Portfolios	1	ackerk2	hanger	29 Apr 2018 19:12	kayakeet.GenuineInt.1522703059.0.9416.1						

Figure 3: Build Integrity List Output

Check Database

Figure 4 below displays an excerpt of the output after running a Check Database routine. If any UIDs are matched in the database, Columns I through M are now populated and filenames (column

F) are highlighted red. Four of the five shown files have been flagged as duplicated and shared. The "pleat" file is unique to both students, and is not flagged (not highlighted, and columns I – M remain blank since no match was found). The AutoFilter feature in Excel[™] (denoted with small square in Figure 4) is used to sort and filter various properties.

- 21	A	DE	F	G	н	1	J	К L	M
1	No SF	EC - RCSID	FILENAME	- LSDT -	UID	M_FILE .	M_SEM *	M_SEC - M_RCSID	- ROW# -
655	655	1 griffm4	bearing_post	02 Apr 2018 15:38	desktop-9s.GenuineInt.1521401956.0.8044.4	bearing_post	1200-localSP18_Portfolios	1 ruizcm	1088
656	656	1 griffm4	bearing_post_dwg1	02 Apr 2018 15:38	desktop-9s.GenuineInt.1522695480.0.43564.0	bearing_post_dwg	1200-localSP18_Portfolios	1 ruizcm	1089
660	660	1 griffm4	crossflow	09 Apr 2018 00:02	desktop-9s.GenuineInt.1521401956.0.8044.5	crossflow	1200-localSP18_Portfolios	1 ruizcm	1090
661	661	1 griffm4	crossflow_dwg1	02 Apr 2018 13:59	desktop-9s.GenuineInt.1521401956.0.8044.6	crossflow_dwg	1200-localSP18_Portfolios	1 ruizcm	1091
676	676	1 griffm4	pleat	05 Feb 2018 14:52	desktop-9s.GenuineInt.1517761743.0.16512.0				
1088	1088	1 ruizcm	bearing_post	09 Apr 2018 13:51	desktop-9s.GenuineInt.1521401956.0.8044.4	bearing_post	1200-localSP18_Portfolios	1 griffm4	655
1089	1089	1 ruizcm	bearing_post_dwg	09 Apr 2018 14:27	desktop-9s.GenuineInt.1522695480.0.43564.0	bearing_post_dwg1	1200-localSP18_Portfolios	1 griffm4	656
1090	1090	1 ruizcm	crossflow	09 Apr 2018 12:27	desktop-9s.GenuineInt.1521401956.0.8044.5	crossflow	1200-localSP18_Portfolios	1 griffm4	660
1091	1091	1 ruizcm	crossflow_dwg	09 Apr 2018 14:27	desktop-9s.GenuineInt.1521401956.0.8044.6	crossflow_dwg1	1200-localSP18_Portfolios	1 griffm4	661
1100	1100	1 ruizcm	pleat	05 Feb 2018 15:06	desktop-9s.GenuineInt.1517814456.0.5052.0				

Figure 4: Check Integrity Output

Speed

To manually check thousands of files each semester for plagiarism would be impossible. The build list evaluation performance is listed below in Table 1. The number of "Files Written" is different from "Files Processed" due to some internal filtering in the code; files that are given to the students from course staff (e.g. given parts for an assembly assignment) are filtered (using their UIDs) from being written to the database. These files are not created by the students and hence are not required to be checked with this tool.

				Files	Time	Files	Avg.	
Туре	Semester	Sect.	Students	Processed	(h:mm:ss)	Written	s/Student	File/s
Build Database	SP18	9	252	13,832	1:32:33	10,402	22.04	2.5
Build Database	SP17	9	248	12,754	0:55:52	9,499	13.52	3.8
Build Database	FL17	9	315	16,617	0:35:20	12,672	6.73	7.8
Check Database	SP18	9	252	10,402	0:01:43	10,402	0.41	21.6
Check Database	SP17	9	248	9,499	0:01:32	9,499	0.37	24.2
Check Database	FL17	9	315	12,672	0:02:33	12,672	0.49	62.1

Table 1: Program Speed Performance Summary

The Spring 2018 semester included a total of 13,832 files submitted by 252 students. Of these, 10,402 files were student created. The entire check was completed in 94 minutes. Since *Build Database* routine runs approximately **10x slower** than the *Check Database* routine (due to opening and closing each file within NX for property extraction), the application separates them into two independent routines. The instructor can quickly accommodate a late portfolio submission, shown in Figure 5, without having to re-build the entire database. The instructor can simply run the Build Database routine for the late submission (~ 50 files) and append (copy/paste) the results into the previously built "master" spreadsheet that may contain tens of thousands of rows. The quicker *Check Database* routine is then performed again on the "master" spreadsheet.



Figure 5: Current Integrity - Evaluation Procedure

Verification

Manual spot checking of plagiarism occurred until Spring 2009, when a Perl-based script was first used to extract compare User IDs. As mentioned earlier, using this method was less accurate, leading to missed false negatives or time-consuming manual investigation to filter out false positives. Table 2 summarizes the number of files flagged by the current .NET program versus the old Perl-based script.

Semester	Prog. Version	Sect.	Students	Files Written	Students Flagged	Files Flagged	False Negative	False Positive
SP18	NX 11.0.2.7	9	252	10,402	17	148	0	0
FL17	Perl	9	318	16,617	42	160	7	0
FL17	NX 12.0.2.3	9	318	12,672	42	167	0	0
SP17	Perl	9	248	12,754	14	144	0	64
SP17	NX 12.0.2.3	9	248	12,754	14	80	0	0

Table 2: Program Comparison Over Three Semesters

Validation

A conviction occurs when the indicted party enters a guilty plea or even in the cases of a not- guilty plea, fails to provide enough evidence that he/she is innocent. The vertical line indicates the implementation of automatic plagiarism detection between Fall 2008 and Spring 2009.



Figure 6: Plagiarism Detection History in ENGR-1200

A distinct decrease in the rate of indictment in the Spring semesters can be attributed to those students receiving warnings from peers enrolled in the Fall. Offenders usually enroll in the following semester and may share their warnings with others. Unfortunately, but unsurprisingly, the scenario seems to reset with each new crop of first-year students. From Figure 7, conviction rates have increased due to the following course changes: organized due process communicated on the syllabus, new assignments each semester, and an extermination of online download sites. In recent semesters, failed convictions are always due to an instance of theft (the victim's charges are dropped), however the conviction rate among students who are "guilty" (by either of admission or lack of evidence to prove otherwise) has been 100%.



Figure 7: Conviction Rate History in ENGR-1200

Conclusions

One of the more difficult tasks in software education is ensuring the student creating and submitting the digital work are the same student. In cases of alleged theft, the coordinator must corroborate the testimony of both parties with the file "Part History" (to access which party originated the file). However, **there are currently NO applications**, **scripts**, **or programs that will guarantee that a student solely created the digital file they submit.** If a file never leaves a single machine, from creation until submission, there is no practical way to tell *who* in using the machine. However, this application demonstrates a 100% success rate of flagging instances of an NX file being duplicated, opened and saved on other machines, and submitted by two or more students. For those cases, automation is necessary for larger size classes submitting multiple files.

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A Systematic Analysis of Graphics-Based Hardware and Software for Virtual Reality Instructional Framework

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Abstract

This study explains in detail a review of the graphics-based Virtual Reality (VR) hardware and software that were evaluated systematically for use in the NSF-funded study (Project MANEUVER). Project MANEUVER (Manufacturing Education Using Virtual Environment Resources), is developing an affordable VR framework to address the imminent demand for well- trained digital manufacturing (DM) technicians. This paper explains the various important factors including instructional, graphics-based, immersive, and interactive aspects that need to be carefully considered in the decision making process for the NSF Maneuver project, and this can serve as a reference for other similar projects. 3D Virtual worlds can be visualized by means of an extensive array of interfaces such as CAVE (Computer Assisted Virtual Environments), desktop VR, HMD (Head Mounted Displays), etc. The other factors that are important especially from a graphics-perspective include: Hardware (CPU) and graphics requirements, cost, standalone possibility, software compatibility/support.

Introduction

DM refers to the use of computer systems to model, simulate, and analyze models/scenes in order to help design and test in an easier and more cost effective manner than in real life (Holmstrom, Liotta, & Chaudhuri, 2017). Typically, DM employs manufacturing technologies driven by a computer (digital) framework. DM facilitates prototyping, manufacturing, and assembling and is closely connected to computer-

integrated manufacturing (CIM), flexible manufacturing, lean manufacturing, and design for manufacturability (DFM).

NSF Funded study project MANEUVER, was created to train DM technicians by using VR to provide the necessary training in a cost-effective and convenient manner. The study uses a VRenvironment to show users three different 3D printing machines using Fused Deposition Modeling (FDM). Users are able to view accurate representations of commercially used 3D printers and view an interactive tutorial. This is done by allowing users to navigate (walk, pan, and fly) around the printers, viewing them from all angles, observing an animated tutorial on how each printer creates 3D prints, and having interactive head and arm controls to choose settings on the tutorial, which include the ability to select a specific model of printer and a specific process. These are delivered to the user through VR-based simulations alongside tutorials corresponding to instructional modules. For the purposes of this study, simulation refers to the representation of the 3D printing system through the use of 3D VR models and environment (Figure 1), to facilitate instruction and virtual interaction to understand digital manufacturing processes. Users can understand the needed information using this method, as VR provides effective training to accurate 3D models, interactive controls, and the participants' active involvement (Toth, Ludvico, & Morrow, 2014). While the simulation is important, the system that the users interact with the simulation is also important. It is just as necessary to have a thorough understanding of the VR hardware and software that are available. Several systems intended for VR exist; however, they have different instructional,





Figure.1: VR Simulation of Manufacturing Processes

Literature Review

The reason that VR has been effective means of training is due to the benefits it provides in reduced time and cost as well as minimizing risk. VR allows companies to train employees on hazardous situations/objects without exposing them to the danger in the real world.

VR training is used to teach by creating a virtual world that the user can interact with using a headset and motion controls to simulate arm and hand movement. Often entire environments along with the machinery are created in the virtual world. The VR helicopter training program developed by Virtalis for the British Armed Forces to assist in training pilots (Ergürel, 2016) is a good example of such VR worlds. Another real world example is the Juguar land Rover using VR to test the designs of their vehicles and better visualize user interaction (Steed, 2017). VR has been applied in various other engineering and technology (ET) disciplines including introductory programming in automotive industry (Attridge, Williams, & Tennant, 2005) engineering courses (Chandramouli, Zahraee, & Winer, 2014), 3D Design Process for manufacturing (Elbadawi, 2014), construction (Leinonen & Kähkönen, 2000), ET education (Chandramouli, Takahashi, & Bertoline, 2014)

VR training simulations have also been used in a variety of fields for training outside of engineering (Gallagher et al., 2005). Wiet et al., 2002, used a virtual bone dissection simulator to help students obtain a similar experience to performing the activity in a laboratory, providing a quicker and easier method of performing the experiment than the real life counterpart. This type of training can also be performed for complex operations such as Neurosurgery (Delorme, Laroche, DiRaddo, & Maestro, 2012), and laparoscopic surgery (Grantcharov et al., 2004), and has been proven to be an effective teaching method. This shows that VR is a useful training tool for a variety of fields.

Methodology

At the beginning of the study, the Oculus/High Tech Computer Corporation (HTC) Vive was the initial hardware chosen, however, due to multiple factors during the study the hardware had to be changed. When first beginning the study, the Oculus/HTC needed a high-end laptop or desktop with Windows 10 Operating System, Intel i5 Quad Core Processor, NVIDIA® GeForce® GTX 1050 with 4GB GDDR5 with HDMI output, 8GB DDR3 Memory, and Bluetooth v4. However, technical issues were often experienced when attempting to run the system on the laptop.

One important requirement for the VR headset is that it supports high-quality positional tracking. Positional tracking involves capturing the player's real world position

in 3D space and translates this to the virtual world, allowing them to walk around within the given confines of the defined play area. The HTC Vive utilizes two infra-red trackers placed at opposite ends of the play space, allowing for much more accurate tracking when facing away from the computer. However, this has the drawback of being fairly non-portable and potentially causing issues with multiple headsets running in close proximity. The Windows Mixed Reality technology headsets use "inside- out" tracking which captures images from the real environment using cameras on the front of the headset, thus alleviated the need for external sensors. The software then uses data from when the play area is first set up and boundaries are defined to calculate the player's position in space (Aaron, Zeller, & Wojciakowski, 2017). The ability to have accurate tracking is essential to almost all VR experiences as it allows the player to not only look around by rotating their head, but also to be able to have movements in the real physical space translate to the digital. The usage of positional tracking increases the user's sense of presence and immersion in the virtual world.

The HTC Vive head set needed a large amount of room for the boundary, the space needed for the player to move freely. Spaces such as a living room in someone's house would not create much trouble, but in a classroom with several students using the system at once, it becomes chaotic due to the limited space. Because of these issues, it was decided that a new system should be used.

The options that were considered for the replacement VR system were the Samsung Odyssey, Google Card Board Headset (GCBH), and Dell Visor (Figure.1). In order to determine the best system for the study, a comparative analysis was created using the Oculus/HTC as the basis to compare the other systems.



Figure 2. VR Systems Assessed for Project MANEUVER

However, selecting the correct VR system is a multifaceted problem. The system must be able to meet the instructional, graphics-based, immersive, and interactive

aspects needed for users to receive necessary instruction while being immersed in the simulation.

These aspects are the ability to move and look around the virtual scene, the ability to move arms and hands to pick up objects and select options, play sound, and have accurate field of vision for the user to tell depth in the scene.

Moving around and interacting with objects both aid with user immersion and help create a sense of presence in the scene. Additionally, it is hoped that such levels of interaction help facilitate "hands-on" learning and aid with user retention. 3D objects and audio compose the scene and the instruction which the user is expected to learn from. In the case of Project Maneuver, this virtual environment involves several elements of the digital manufacturing process.

This is due to the need to balance educational necessity with the goal of motivating learners with interaction and graphics (Chandramouli, Takahashi, & Bertoline, 2014).

Factors to be considered include:

- Hardware (CPU) and graphics requirements: System requirements must be considered in order to determine if currently available computers are compatible with the system or if they will require a better graphics cards, CPU, etc. As the visual learning style is critical, the system requires the necessary tools for learners to properly interact with the simulation (Chandramouli, & Heffron, 2015).
- 2. Cost: Understanding which system is most cost effective while achieving the intended goal is vital, as staying within budget is necessary.
- Standalone: A Standalone system can function independent of additional hardware/devices and server support is not required; standalone is useful for testing new software before being deployed to company servers.
- 4. Software compatibility/Support: Software compatibility/support refers to the support form the company/community that the system is associated with. How often the company releases new versions of the software or if an available library of online support to help trouble shoot a problem determine if there is strong support.

The ideal system will consist of CPU and graphic requirements compatible to render 3D models, cost within the average range for VR systems (\$300-\$500), is standalone to remove additional hardware and cost requirements, and is compatible with widely acceptable software, such as Unity. Unity was used as the development platform due to the support of this platform from companies and online communities, and is recognized as a common development language. Unity works very well with VR due to the Unity VR

and Steam VR packages, which are free to use applications that allow Unity to be compatible with HMD and desktop VR. The issues/system requirements that we experienced with the Oculus/HTC were used as a base on which the criteria were chosen. The way that the systems are able to solve or improve the flaws experienced during the MANEUVER simulation, will help to determine the best option for the project.

Results

The following table displays all the systems characteristics. This was created based on the previously mentioned aspects considered for the systems.

The Oculus and HTC are the resource-intensive (graphically) and costly systems of all the listed systems. This is due to the needed laptop and high cost of the systems. Google Cardboard (GCBH) is a headset that is able to be folded and arranged into a headset visor. Because of this, it is relatively inexpensive to buy, however it does require a smartphone to be placed into the headset to be act as the device running the VR scene.

Samsung Odyssey and GCBH both need a smartphone, because it has to be compatible with the system, and only the last few generations have the capabilities. However they also require that the phone have a plan as well, so it also has a reoccurring cost to maintain plan for at least the next two years due to plan contracts.

Dell Visor can be plugged into any PC and desktop that is able to run windows 10. However, an adapter and dongle are needed to properly have the system run with a desktop. The adaptor has to a Mini display port to HDMI video adaptor converter; we choose this also, because it needs to be able to support 4K. The dongle is a Bluetooth 4.0 LE + EDR to plug into a USB port; this is needed if the computer does not have built in Bluetooth.

	Hardware/Graphics	Cost	Standalone	Software	Suggestion
			Clandalono	continuito	For Use
Oculus	NVIDIA® GeForce® GTX 1050 with 4GB GDDR5 with HDMI output	\$400 /System, \$1,500 laptop separate purchase	Requires additional laptop	High graphic capability and interaction.	Use if need for high end graphics or high level of precision
HTC	NVIDIA® GTX 1060 graphics card, Intel core i5-4590 CPU Oculus- Intel i5 Quad Core processor	\$500 / System, \$1,500 laptop separate purchase	Requires additional laptop	High graphic capability and interaction	Use if need for high end graphics or high level of precision

Table 1: Comparative Analysis of Systems Assessed for Study

Samsun g Odysse y	Intel core i5 6 th generation CPU, NVIDIA® GTX 1050/AMD RX graphics card.	\$400/system Phone\$300- 500, plan varies	Requires smartphon e with a plan	Accurate controls, requires a smart phone to interact	Good all- around system. Smartphone with a plan will incur cost over time
Google Cardboar d	Simple Setup. Requires modern phone with 360 scene view function.	\$15 Cardboard, Phone \$300-500, plan varies	Requires a modern smartphon e with a plan	Limited interacti on, most affordab le system.	Use if you have smartphone, or limited interaction is acceptable when using VR
Dell Visor	Intel i5 quad core processor, NVIDIA® GTX 965M with 4GB GDDR5 with HDMI output Mini display port to HDMI video adaptor converter Bluetooth 4.0 LE + EDR Dongle	\$300 Visor, \$15 dongle, \$10 adaptor Cost of computer varies.	Standalon e thanks to Adaptor and dongle.	Accurate and programmab le controls.	Good all- around system. Can be used in most indoor spaces, responsive interaction controls.

Discussion

Both Oculus Rift and HTC Vive were not chosen due to the high cost resulting from needed laptop/additional hardware requirements. In addition, Oculus VR head set was not chosen because it does not provide positional tracking. HTC Vive was not chosen because of large space required to use the system. Oculus was the first system used and allowed a better understanding of the desired characteristics needed for users to have an enjoyable VR experience with the simulation. It was found that this system requires tremendous set up time and learning curve for inexperienced users to use the VR simulation. Use minimal to no extra hardware/software to both keep the cost of the system as low as possible but to also keep the set up as simple as possible for users. And lastly that the system could still provide an immersive experience with proper control responses while keeping hardware requirements from becoming overly expensive or difficult to attain.

The Samsung Odyssey was also not chosen due to the need to buy an additional smartphone with a plan, as this cost could possibly keep incurring after the project ends and is much easier to lose/damage smartphones than the large headsets. While the GCBH is the least costly of the options, it did not offer the same level of interaction the other systems could due to their advanced controllers and could not provide the motions of picking up objects and movement/teleportation in the virtual scene desired for users.

The system chosen was the Dell Visor: as it offered the best combination of software

support (Unity and SteamVR package), is a standalone system, affordable, and has hardware and software requirements that could be met relatively easily. While both Oculus and HTC require 1 HDMI port and 3 USB ports for head set and controller tracking, Dell Visor only requires 1 HDMI port and 1 USB 3.0 port to connect the VR head set. Dell Visor uses Bluetooth to connect two hand controllers. Dell Visor provides easy set up and increased flexibility of movement, by reducing the number of ports and connecting wires required for the head set. Dell Visor is Unity compatible, aside from the needed adaptor and dongle, it was a standalone system that could work with both laptop and desktop, was considerably cheaper than the Oculus/HTC.

Conclusion

The new system chosen for the project was successful in running the simulation and allowing users to interact with the simulation in the desired manner. When the simulation was shown at the MANEUVER training event, industry users with vary levels of experience with VR were able to successfully use and interact with the simulation as intended.

The need to provide more efficient training for workers is a need that will only continue to increase as time moves forward. The use of VR will continue to evolve as hardware and software become more affordable and widespread as both companies and consumers become more familiar with the technology. While not all available VR hardware and software can solve the instructional needs required for the workplace, different product options assist to help users determine what system will be the most beneficial for them. With time these systems will only become more accessible due to evolving technology and increasing demand of the workforce for faster and more efficient training.

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A Review of File Comparison Utilities for Assessing Student Work

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Abstract

In academia, CAD file utilities and comparison tools have been used in attempts to speed grading and feedback delivery, decrease workload and human error, and increase grade reliability. Most current CAD packages contain some built-in capability to examine and compare solid models. For those who want something beyond the capability of the stock software utilities, custom software can be created. This paper reviews the capabilities of currently available tools for the assessment and grading of student work.

Previous Attempts at Automated Grading of CAD Files

In perhaps the first attempt at the automated grading of CAD files, Baxter and Guerci (2003) described a computer program to automate the grading of SolidWorks files, notify students via e- mail, and update grade databases. The program compared key data from the student file to that of the instructor file. However, grading algorithm details and results were not presented nor published. Hekman and Gordon (2013) described automated grading efforts of 2-D AutoCAD files.

Students submitted files by email and within minutes, without human intervention, a computer program compared the AutoCAD text descriptions of a student sketch to those of the corresponding instructor-created sketch and delivered feedback consisting of text and an image that pointed out deficiencies in the student work.

In a proof-of-concept pilot study to automate the grading of Creo files, Ault and Fraser (2013) created a computer program to evaluate one specific part. The program compared information from the student file to that from the instructor file, such as volume, the presence or absence of critical dimensions, and the existence of specific features. The computer code was created and owned by PTC and was not available to the university collaborator, so the code could not be easily reused for other applications. Because the program was looking for the existence of specific features, it allowed limited freedom in the

creative and strategic planning aspect of part creation.

Currently, there is only one publicly available program to assist with the grading of CAD files, and it works only with SolidWorks files (Graderworks from Garland Industries LLC). An attempt at the automated grading of NX CAD files has been demonstrated at conference presentations (Kirstukas, 2016 and 2018). Finally, in this same conference, co-author Morris (2019) details a method of detecting the integrity (absence of plagiarism) in NX CAD files. That work is part of a bigger project involving a customizable .NET application that also automatically grades Siemens NX files. In the following text, the computer programs that are either already available or currently under development will be compared using a test part that was similarly constructed in both Dassault SolidWorks and in Siemens NX.

Test Part

The test part has been used to demonstrate the capabilities of Graderworks and the drawing is available at their webpage. The part can be created by several perfectly acceptable methods and various points could be used as the origin. The Graderworks-provided solution file for this part (Solution_To_A10.SLDPRT) was constructed using four sketches, three extrudes, a datum plane, and a rib. For comparison, two additional good and bad models of the part were created in both SolidWorks 2018-2019 and in Siemens NX 12. These parts were created using different modelling strategies than that of the Graderworks-supplied part, and involved symmetric extrudes and the hole feature. This modeling approach was used virtually unchanged in both NX and in SolidWorks.

The good and bad parts have the same volume and surface area, but the bad part has incorrect orientation. The bad part contains one unconstrained internal sketch that results in the hole being in the wrong position. The bad part is not changeable per the design intent in the original drawing as it is missing some dimensions, and contains unwanted and repeated dimensions. The bad part also has a sketch that does not contribute anything to the part. A number of built-in tools and add-in programs were used to try to assess these parts.

Siemens NX Built-in Tools

Check-Mate is a built-in tool in NX that can perform a series of tests on a part to verify that the model conforms to various standards. For this investigation, a total of 24 predefined tests were selected, including the tests "Sketch Fully Constrained?" and "Sketch with Auto Dimensions." When the Check-Mate analysis was performed on the good part, all tests passed, as expected. However, when the same set of tests was performed on the bad part, all tests also passed. Check- Mate failed to notice a sketch internal to the hole feature that had two auto dimensions.

Model Compare is a built-in tool in NX that can compare the geometries of two different bodies. Three graphics windows are displayed, showing the two individual parts and a view that is useful in highlighting differences in the parts. By default, parts are displayed relative to the absolute coordinate system (Fig. 1a). After realignment of the good and bad parts, the resulting overlap view (bottom of Fig. 1b) showed that the two parts were identical except for hole position. This tool is useful to visually confirm orientation, and shape similarity. However, Model Compare cannot be automated so it can be a timeconsuming manual process to align and visually compare parts.



Figure 1: the good and bad parts before and after alignment. When aligned, it is clear that the geometry is the same, except for hole placement.

It is possible that Check-Mate used together with Model Compare could identify nonfully- constrained external sketches and verify part orientation, shape, and size. But these tools do not seem capable of evaluating some of the issues that new solid modelers have trouble mastering, such as constraining internal sketches, building models that honor design intent, or eliminating unused sketches. Perhaps most important, it does not appear that these tests can be automated to allow many student files to be examined and graded quickly.

Dassault SolidWorks Built-in Tools

SolidWorks Design Checker verifies design elements such as dimensioning standards and sketches to ensure that SolidWorks files meet pre-defined design criteria, similar to Siemens NX Check-Mate. However, SolidWorks Design Checker is available only in the Professional and Premium editions, not in the Education Edition that most educators use.

The SolidWorks Compare Geometry tool is similar to NX's Model Compare. However, it requires that both parts have the same origin and orientation. When the parts are misaligned as often happens with student files, there is an option to align geometry with respect to individual coordinate systems within each part. However, student-created files will not in general contain a properly situated internal coordinate system to allow alignment.

Even if these two tools were available in the Education Edition and worked as desired, their use would require a rather lengthy manual process that would not greatly aid the instructor in time- efficient assessment of student files.

Custom Tools

Because the built-in tools are unable to aid in the timely assessment of student files, various add-on programs have been developed by interested third parties. These work only with specific CAD packages and require the ability to write a computer program that can interface with a vendor- provided application programmer interface (API) to allow the program to conduct comparisons between the student file and an instructor file, which is assumed to be perfect.

Dassault SolidWorks Custom Tools

Graderworks has been available for several years and is freely available for a 30-day evaluation period. Graderworks version 3.17 for SolidWorks 2018-2019 compares the geometry of a student part to that of an instructor part and assigns a score based on adjustable weight factors. Various parameters are examined, such as volume, material, shape, and the presence of non-fully- constrained sketches.

A test of Graderworks was made by comparing the good and bad test part files to the Graderworks-provided solution file "Solution_To_A10.SLDPRT". In Run 1, although the good part had the same shape, size, volume, surface area, and orientation as the provided solution part, it scored slightly less than perfect, presumably due to different part origin. The bad part scored just a couple of points lower (Table 1). Although the bad part had the correct volume and surface area, it had different orientation, it was not changeable due to missing, unwanted, and repeated dimensions, it had an unused sketch, and it had the hole in the wrong place due to an under-defined internal sketch. On a second grading run (Run 2), the incompletely defined quantity "Shape Check and Shape Composite Score" scored differently for both good and bad parts, with the bad part actually out- scoring the good part by a small margin for unknown reasons.

	F	Run 1	Run 2			
FileName	Shape	File	Shape	File		
(*.SLDPRT)	Score	Grade	Score	Grade		
a10_sjkbad_part	94.10	95.57	97.11	97.84		
a10_sjkgood_part	96.15	97.11	96.33	97.24		

 Table 1: "Shape Check and Shape Composite Score" scores differently on subsequent grading runs, and causes the final grade to be different

The Graderworks software can evaluate many files quite quickly. However, subsequent runs can produce different shape scores and different grades, which should not happen in an automated grading scheme. Additionally, internal sketches are not evaluated, there is no attempt at accessing model changeability, and there is no orientation detection.

Siemens NX Custom Tools

Kirstukas (2016 and 2018) has described work toward the automated grading and plagiarism detection of student files created with Siemens NX. The program is designed to catch common mistakes of beginning modelers and encourages the creation of simple, changeable part models. The program attempts to write feedback in human language, similar to what an instructor may provide after a manual analysis. When the NX version of the bad part was compared to the good part, the bad part was noted for incorrect geometry, incorrect orientation, missing, unwanted, and repeated dimensions, the unconstrained internal sketch, and the unneeded sketch. Program output is a text file designed to be cut and pasted into Moodle, a learning management system (Table 2).

Table 2. Output from the grading program of Kirstukas

deduction values from gui: 4 / 6 / 3 / 3 / 4 / 2 / 4 / 4 / 6 / 30 / 1 / 0 / 100. gold master filename = sjk_good_nx12.prt

> filename = sjk_bad_nx12.prt Your model has incorrect shape and/or size, and has incorrect orientation. Your model is missing 2 dimensions from the original drawing: 4.5, 48. Your model has 2 repeated dimensions: 1, 3. Your model has 2 dimensions not from the original drawing: 1.22014465515, 2.35510792391. Use fewer numbers and more geometric constraints!!! Sketch(6) which is internal to Simple Hole(6) is not 'Fully Constrained' as it contains 2 auto dimensions. Replace auto dimensions with geometric constraints!!! Sketch(7) is not used and should be deleted. Score = 52

Total Time Elapsed: 0 minutes, and 4 seconds.

In this same conference, co-author Morris (2019) details a method of detecting the integrity (absence of plagiarism) in NX CAD files. That work is part of a bigger project involving an application that also automatically grades Siemens NX files. The automated grading aspect is currently functional and is to be published later in 2019. The program uses a similarity algorithm that currently examines five factors: Volume, Surface Area, Number of Edges, Number of Faces, and Moment of Inertia values. Parts are scored on a scale of 0–5. Morris's program does not identify specific missing or incorrect dimensions, nor does it provide guidance for healthier modeling or sketching practices.

After analysis of the good and bad NX versions of the part, program output is viewable in Excel (Table 3). The model similarity (SIM %) scores shape independent of orientation, placement, or build method, and currently do not factor into the grading. The bad part scored 2.75/5 (55%) due to different moment of inertia values, number of sketches not fully constrained (SNC), number of unused sketches (SNUS), and number of auto dimensions (AUTO). These quantities are shaded in pink and red. The good part was selected as the solution file and checked against itself, scoring a perfect 5/5 (100%).

|--|

SOLU	TION >	sjk_good_nx12	IN.	1	30.6451	100.9643	37	16	2.8605	0	1.7289	21.6183	30.9789	22.2778
TOTAL	SIM %	FILENAME	UNITS	NBOD	VOL	SA	EDGE	FACE	COG-X	COG-Y	COG-Z	MOI-X	MOI-Y	MOI-Z
2.75	98.181	sjk_bad_nx12	IN.	1	30.6451	100.9643	37	16	2.8594	1.7275	-0.1072	21.225	21.8962	30.9155
5	100	sjk_good_nx12	IN.	1	30.6451	100.9643	37	16	2.8605	0	1.7289	21.6183	30.9789	22.2778
											_			
SOLU	TION >	sjk_good_nx12	2	0	0	0		0	5	0				
TOTAL	SIM %	FILENAME	STOT	SNC	SEMP	SNUS	SINV	AUTD	ACTD	FIX				
2.75	98.181	sjk_bad_nx12	4	1	0	1		2	7	0]			
5	100	sjk_good_nx12	2	0	0	0		0	5	0]			

Discussion and Conclusion

Due to the inability of the built-in tools to aid in the time-efficient assessment of student CAD files, various add-on programs are necessary. These programs work only with specific CAD packages. In this paper, one such program has been reviewed that works with Dassault SolidWorks, and two with Siemens NX. Some comparison of features is shown in Table 4.

_	FEATURES	NX Kirstukas	NX Morris	SW Graderworks	
etch	Incorrect Dimension Values	Flagged	N/A	N/A	
Š	Fully Constrained	Flagged	Flagged	External only	
	Unused	Flagged	Flagged	N/A	
s	Origin Location	Flexible	Flexible	Rigid	
olid	Orientation	Compared	Compared	N/A	
Ň	Volume and Surface Area	Compared	Compared	Compared	

Table 4. Grading summary of the bad test part using different add-on programs.

Graderworks is the only automated grading program available for general use and works only with SolidWorks files. Some of the other automated grading solutions have been demonstrated at conferences but have not been evaluated by others. For grading purposes, Graderworks uses material density, volume, surface area, center of mass, and constraint status of external sketches to develop a grade score. However, these quantities tell us little about the modelling strategies used and the changeability of the model.

The custom program written by the first author to analyze NX files performed best here. It caught all issues of the bad file. There is certainly some bias here. The bad file was specifically created by the first author to mimic a file that a struggling beginning student may create and contained issues that his program was designed to catch. However, this program is still under development and testing and has not been released for general use.

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Modeling Cognitive Activities in a Virtual Reality- assisted Industrial Robot Programming Environment

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Abstract

Numerous studies have reported using virtual reality (VR) for training. In these immersive environments, learners were allowed to learn through trial-and-error in order to generate their mental map for specific tasks. Consequently the associated training cost was greatly reduced, and learners were found to perform the desired tasks faster, with fewer mistakes than those trained in traditional ways. Nevertheless, the reported improvement of task speed and accuracy was only summative, without revealing details of the actual learning process.

In this paper we presented an ongoing effort for understanding how individuals navigate in the VR-assisted industrial robot programming environment. A GOMS model is developed via the think- aloud protocol to map out the possible cognitive activities of given tasks. Once completed, this GOMS model may be used to determine an individual's mental map, cognitive load, and detect the misconception during the course.

Introduction

To reduce the cost of training, the use of virtual reality for procedural knowledge inquiry has been reported in various fields (Aggarwal, Black, Hance, Darzi, & Cheshire, 2006; Bliss, Tidwell, & Guest, 1997; Ossmy & Mukamel, 2017). The inquiry of procedural knowledge refers to the learner's internal construction of methods to execute a series of operations to achieve specific goals. According to Card (1981), to perform a procedure, an individual will first perceive the task status via his or her visual, auditory, and haptic sensors, retrieve previous knowledge, compare with the current situation, determine the problem solving strategy, and eventually respond to the external world with the movements. The mastery of the learner can be determined by whether he or she

chooses the proper approach and completes the task within the time given without making mission- critical errors.

By immersing the learner in a controlled, computer-simulated environment, the learning outcomes were often better than that in conventional learning settings, as the distractions were reduced or eliminated. Nevertheless, the evaluation of VR-based learning effectiveness was mainly done by measuring individuals' speed and accuracy (Decety & Jeannerod, 1996; Robertson, Czerwinski, & Van Dantzich, 1997). The total number of mistakes made and time needed to complete the task could only depict the difference between the learner's states before and after treatment in a holistic manner. The specific of cognitive activities happened in the VR-based training process was not clear, due to the fact that it was less observable.

Furthermore, in a computer-simulated environment such as VR-assisted training, the learner's cognitive response might vary from the response seen in the physical world (Witmer & Singer, 1998). The human-computer interface (HCI) might provide short cuts to perform specific operations, or the design of the HCI was so awkward that the process becomes very tedious. If a computer- assisted environment is used to evaluate the individual's task performance, his or her familiarity of the HCI has to be considered in order to properly assess the number of error and time used for a task (Bowman, Gabbard, & Hix, 2002).

To address the mentioned concerns, we propose in this paper to model human cognitive activities within the VR setting in order to better understand individuals' task performance. The modeling strategy, GOMS (goals, operators, methods, selection rules) (Kieras, 2004), is used to model an individual's behaviors of performing assigned tasks in a VR-assisted industrial robot programming environment. The main objective is to determine whether individuals' cognitive activities is task-related or HCI-related, thus a more appropriate assessment can be conducted.

Methodology

GOMS, based on Card's human processor model (1981), has been used by researchers in the area of user interface analysis (John & Kieras, 1996). GOMS, the acronym of *Goals*, *Operators*, *Methods*, and *Selection Rules*, is used to describe tasks and corresponding knowledge to perform them. Once created, the GOMS model can be used for developing training tools and help systems. GOMS can also be used to predict human performance. According to John and Kieras, GOMS can be used only if we want to analyze procedural properties of the system. The task needs to be goal- directed and involving user control, and a user can become skilled due to the task's routine nature.

The following is an example of a typical procedural task in the area of industrial robot

programming. Prior to creating the robot's tool path, the location of a coordinate system needs to be specified (Devine, 2009). By selecting three points along the edges of a workpiece, the X-Y-Z system can be defined. The sequence of point selection is critical, as it is used to establish the positive Z axis, and consequently the end effector of the robot could approach the workpiece correctly. The GOMS model for such a task can be denoted as Figure 1.

GOAL: CREATE-COORDINATE

	GOAL: CHOOSE-POINT repeat until all three points selected
	. GOAL: ACQUIRE WORKPIECE if workpiece exists
	. GOAL: MOVE-CURSOR-TO-EDGE choose edge
	. GOAL: CHOOSE-POINT-EDGE choose a point along one edge
	GOAL: VERIFY-Z-DIRECTION verify if the z axis is in the right direction
F	igure 1. Example of GOMS for creating a coordinate system on the workpiece

The above model only shows the procedure to create a coordinate system. It will need to be expanded to include situations such as removing points that are misplaced, or exiting the whole procedure to start all over. It is also beneficial to categorize the cognitive activities based on their commonality. Table 1 illustrates three most common human behaviors when exploring the VR space, namely navigation, inspection, and manipulation.

Cognitive Activity	Goal	Perceptual Subsystem	Cognitive Subsystem	Motor Subsystem
Navigation	To travel in the	Orient oneself in	Identify the	Execute the plan
	virtual space	the virtual space	goal, determine	via physical or
		via visual,	the	virtual movement
		auditory, or haptic	strategy, and plan	in space
		stimuli	the action	
Inspection	To determine the	Evaluate the	Diagnose the	Verify the
	state of target	target system via	phenomenon via	hypothesis by
	systems &	visual, auditory,	compare-and-	altering the
	propose	or haptic stimuli	contrast	states of the
	alternatives		knowledge with	target
			external stimuli	system
Manipulation	To execute	Utilize visual,	Verify the	Do and adjust
	the selected	auditory, or	execution of	movement if
	alternatives	haptic sensors	tasks via visual,	necessary
		to guide the	auditory, or haptic	
		execution	inputs	

Table 1. Three common types of cognitive activities within a VR setting: Navigation,Inspection, & Manipulation

For each category of cognitive activities, a GOMS template will be first created. Next, each task will be represented by a combination of one or more of these cognitive activities. For example, the CREATE-COORDINATE task consists of all three types, navigation (e.g. ACQUIRE- WORKPIECE), inspection (e.g. VERIFY-Z-DIRECTION), and manipulation (e.g. both MOVE- CURSOR-TO-EDGE and CHOOSE-POINT-EDGE).

In addition to the list of tasks, a complete GOMS system measures the time needed for an individual to perform a goal at the lowest level, such as the time needed move the cursor (or pointer in a VR setting) to the edge of workpiece (line 4 in Figure 1). The duration of time in most cases will be a range instead of an exact number, by measuring the expert users' speed. For this purpose, a think-aloud protocol will be utilized for the user to verbally report his or her cognitive states, specifying the goal(s), operator(s), method(s), and selection rule(s).

Current Stage of Research

Figure 2 illustrates the workflow for developing the GOMS model mentioned previously. We are currently developing the GOMS templates for the three cognitive activities mentioned. The critical tasks for the learner to demonstrate mastery will be chosen from the lab material for TEC 234, an introduction course to industrial robot programming. Next these tasks will be modeled with the GOMS templates, and a pilot study with the help of two or three expert users will be conducted to determine the fitness of these GOMS models. After necessary revision, the GOMS task time will be measured by averaging the task time needed by experienced users (those who complete TEC 234 with satisfactory scores), through the utilization of the think-aloud protocol.



Figure 2. The workflow for developing the proposed GOMS model

Once the GOMS model is created, it can be used to assess the learner's task performance. Because the time needed for each task is presented as a range instead of an exact number, the learner can be considered proficient in a specific cognitive activity, if the time spent by the learner to correctly accomplish the task falls within this given range. The sequence of the operations is another indication whether the learner is on the right track to solve the given task.

Conclusion

An on-going research effort to study the feasibility of an assessment method by modeling a learner's cognitive activities was reported. The need of a different assessment method was identified, and the rationale of using the GOMS model was provided. An example of using GOMS to model the task for industrial robot programming was presented, and the research approach was presented in a flow chart.

By developing GOMS models for tasks in the VR environment, we can detect the lower level performance and determine the learner's level of proficiency. This approach is very promising, as it has been used by multiple HCI researchers to model the user behaviors and study the time needed to complete tasks, such as menu searching, text editing, or button clicking (John & Kieras, 1996). A fully tested GOMS model may also lead to the prediction of learner's performance in the VR environment (Gray, John, & Atwood, 1993; John, 1990), providing suggestion or warning signal to prevent the learner from forming misconceptions and making wrong decisions.

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Coloring Inside the Lines: A Learning Strategy Using Coloring to Help Students Understand Orthographic Projections

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Abstract

We present a learning strategy developed for a freshman engineering graphics course, in an attempt to help students with low spatial visualization ability who struggle to mentally visualize 3D geometry from 2D orthographic multiviews. This method teaches students to "think on paper" to help clarify their mental thought process while they work on orthographic projection problems. Students make guesses about relationships between faces in different 2D views and then test their guesses by coloring in corresponding faces using colored pencils, as an adjunct to 3D pictorial sketching. This hypothesize-and-test method gives students a starting point for visual problems that they may otherwise struggle to begin. In this digest, we present the foundations of this method and share examples, illustrating the method's use.

Introduction

While students who are high visualizers tend to perform well in engineering graphics classes regardless of special intervention, low visualizers often need extra training to succeed. At some institutions, an additional class has been developed that is dedicated to improving the spatial visualization ability of low visualizers so that they can succeed in subsequent engineering graphics classes (Sorby, 2007; Hsi, Linn, & Bell, 1997; Metz et al., 2011). At University of California, Berkeley, no such separate class is currently offered, so there is a wide range of student spatial visualization ability in the freshmen-level engineering graphics class, E25: Visualization for Design. Low visualizers have been observed by instructors to need extra attention in office hours and in lab, especially when learning how to interpret orthographic multiview drawings and make pictorial sketches from them.

Because orthographic projections are a fundamental part of engineering graphics, this topic has been the focus of previous work on how to best teach it. Sorby (1999) notes that despite being such a challenging topic, multiview sketching is typically presented early in graphics textbooks, despite pedagogical research suggesting that students might learn such an abstract task more easily if they started with a more concrete task, namely sketching objects actually in front of them. This would allow students to gain skills in pictorial sketching before multiviews are first introduced (Sorby, 1999). In this digest, we describe pedagogical strategy that uses coloring of faces as a way to build students' logical reasoning while sketching.

Background

In our class, following the Lieu and Sorby textbook (2017), we begin with visualization exercises where students sketch isometric pictorials from coded plans, before the introduction of multiviews. We organize the topics so that students first solve simple problems and then work up to solving more complex problems by building on the skills for solving the simple problems. In terms of geometric complexity, our first multiview exercises ask students to sketch multiviews from pictorials of objects with only axisaligned faces. Then we introduce examples with inclined and oblique faces. To prepare students for interpreting multiviews, we explicitly enumerate these three categories of face orientations and describe the characteristics of each that are relevant for identifying matching faces in multiviews. Then students practice with multiview face-matching exercises, where they write down the labels on faces in one view that correspond to faces and edges in an adjacent view, with or without a corresponding isometric pictorial for reference (see Bertoline and Wiebe (Chapter 10, 2009) and Lieu and Sorby (Chapter 11, 2009; supplemental material, 2017)). Finally students move on to pictorial sketching from multiviews.

However, we have observed that students are often at a loss about how to begin when trying to make an isometric pictorial sketch from a challenging multiview drawing that they cannot holistically visualize. For low visualizers this will occur even with relatively simple examples, but many other students encounter the same phenomenon of not knowing how to start (or getting stuck part way through with no idea about what to try next) the first time they encounter a model for which they do not have a full 3D understanding/interpretation of the geometry.

One possibility for why students get stuck is they may believe that their approach to interpreting the simpler multiview interpretation problems *should* form the basis for solving the more challenging multiview problems. For the simplest geometries, our students probably could visualize the entire 3D shape in their mind, and then sketch from their mental visualization. Therefore it seems possible that students moving from simpler multiview interpretation problems (that they can visualize directly in their mind) to more complex problems (that they cannot) may intuitively be trying to build upon the expertise

they have acquired in solving the simpler problems; however the visualization skills that they have previously mastered aren't sufficient in this context. Beyond the issue of getting stuck on how to start or continue a sketch, when students make sketching mistakes, they often don't recognize them when they occur. One common mistake is that they have sketched a face in 3D space that is consistent with one of the given orthographic views, but not with either of the two adjacent views of the face. Another common mistake is that one 3D face of their sketch might be consistent with the assumption that face A in the front view corresponded to face 1 in the right view, but then another face of their sketch was only consistent with face A corresponding to face 2. Such mistakes may indicate that students have difficulty keeping track of how they are resolving faces in different views or which faces in the multiviews they have already resolved in their sketches.

Implementation

During office hours, Prof. McMains' first goal is to determine what in the student's thinking process led them astray, why they got stuck, etc. Asking students about which multiview faces corresponded to which faces they are sketching is very useful in this regard, but if they do not make these intermediate steps visible, it is challenging to help them see their own mistakes. Even though we had just assigned face matching exercises, students would not seem to think to use this strategy as an intermediate step when making an isometric sketch from a multiview. Having them label faces and then list which faces matched up wasn't a convenient reference to be consulting as they sketched. Prof. McMains first turned to having the students use colored pencils to color in the hypothesized matching faces in office hours so that *she* could see what they were thinking, but it was clear almost immediately that coloring also helped make *the students themselves* aware of their own thinking. This was so effective that now we require all students to purchase colored pencils.

The technique is introduced in lecture, using the same color to indicate the matching faces in all three typical views in a 3-view drawing and showing the corresponding colored faces on a pictorial (Figure 1a). This was inspired by Bertoline et al.'s example of using different colors for each face for a more complicated geometry in their textbook (2009). However, in order to better help students track correspondences, in addition to coloring faces that appear in face view, Prof. McMains also colors the corresponding edge when a face appears in edge view so that each color shows up exactly once in each view (Figure 1b).



Figure 1. a) Color match for visible faces. b) Color match including edge view faces.

Next, similar to "mentored sketching" demonstrations during lecture (Mohler & Miller, 2008), but extending the technique to "mentored coloring" as well, the professor demonstrates how to use coloring to keep track of hypothesized face matches when solving a simple Multiview sketching problem, projecting the coloring and sketching process with a document camera while talking through her reasoning. Choosing one view to start, she first colors each visible face a different color. Choosing one of these as the starting face (what Lieu and Sorby call the anchor surface (p.11-34, 2009)), she describes how she makes an initial hypothesis about which face in an adjacent (2nd) view it might match up to, coloring it in to match. Then she describes how she tests the hypothesis for consistency while finding and coloring the corresponding matching face in the 3rd view, assuming there is such a consistent match. If not, the hypothesis coloring in the 2nd view until a consistent match is found. Next the 3D position is sketched in the isometric. The back-and-forth, hypothesize-and-test nature of the problem solving is emphasized, as this process is repeated for other faces with other colors.

In lab, students practice the technique with a coloring worksheet (Figure 2). The instructors walk around to prompt students who are having difficulty starting a problem to just make a hypothesis, color it, and see where it leads, telling them that pencil can easily be erased. Another category of students have difficulty because they just start making random coloring guesses in all views without testing each hypothesis in turn. Both the hypothesize step and the test step need to be emphasized as equally important.


Figure 2. Lab coloring worksheet.

Discussion

Implementing this strategy has been very successful at reducing the number of students who get Ds and Fs in the class. Before, there would be a number of students in a large class who did very poorly on midterm or final exam problems that involved challenging multiview interpretation, drawing very little beyond perhaps a bounding box, or reproducing the given views on the sides of such a box. On the midterm we now require the students to bring their colored pencils and color in the hypothesized matching faces, which seems to help them then with their isometric sketching. For students who can visualize and sketch without first coloring, they can just color matching faces afterwards to check their work. We will examine the effectiveness of the hypothesize-and-test coloring strategy as a teaching method more extensively in future work.

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Instilling an Entrepreneurial Mindset in a New Generation of First-Year Engineering Students Through a Graphics Course Project

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Abstract

Each year, an increasing number of engineering start-up companies emerge in the U.S. and around the world. Innovation and entrepreneurship have never been so pronounced, especially in science, technology, engineering, and mathematics (STEM) fields. How can we train engineering students to be more entrepreneurially-minded so they are well-equipped to become global innovators? Engineering educators can use entrepreneurially-minded learning activities to help students develop an entrepreneurial mindset, which is a set of beliefs, attitudes, and behaviors. We used an open-ended team project and an end-of-semester poster competition within a freshman-level engineering graphics course to encourage an entrepreneurial mindset in students. The goal of the course project was to develop engineering students' critical thinking and innovation skills while preparing them for their future professions. An end- of-semester course-wide poster competition allowed students to practice teamwork as well as innovative thinking and communication skills. An online survey was conducted during the student poster competition to assess students' understanding of entrepreneurial mindset and satisfaction with the student poster competition.

Introduction

Many college professors are still trying to adjust their curriculum to meet the needs of millennials. In recent years, 72% of high school students and 64% of college students have expressed eagerness in starting a business (Schawbel, 2014). In fact, 61% of high school students and 43% of college students would rather be an entrepreneur instead of an employee after they graduate college (Schawbel, 2014). Now, students from Generation Z are attending U.S. institutions and presenting new demands for higher education. Generation Z consists of students who were born after millennials, in the mid to late 1990s (Moore, Jones, & Frazier, 2017). Many students from Generation Z are even more self-reliant and career driven than previous generations. For example, Kozinsky found that 13% of Gen Z-ers already have their own business (Kozinsky, 2017).

According to one Gallup study, nearly 77% in grades 5 through 12 students want to be their own boss, 45% plan to start their own business, and 42% will invent something that can change the world (Calderon, 2011). On average, Generation Z is more independent than millennials and they are prepared to make their own decisions based on information they find on the internet (Malat, 2016). To do research and teach themselves, Gen Z-ers rely on internet tools such as Google's search engine and YouTube.

As college instructors, what can we do to help develop or improve engineering students' entrepreneurial mindset? How can we sharpen students' critical thinking and innovation skills? How can we better prepare students for their future professions? To answer these questions, we used an open-ended team project within a freshman-level engineering graphics course to encourage an entrepreneurial mindset in students. An end-of-semester course-wide poster competition allowed students to practice teamwork as well as innovative thinking and communication skills (Long & Jordan, 2016; Long & Sun, 2018). This paper will describe the results of an online survey from the student poster competition, which assessed students' understanding of entrepreneurial mindset and students' satisfaction with the poster competition.

Course Curriculum and Description

In this study, the chosen freshman-level engineering graphics course was designed to familiarize students with the basic principles of drafting and engineering drawing, to improve three-dimensional (3-D) visualization skills, and to teach the fundamentals of computer-aided design (CAD). Classes met in a computer laboratory twice a week for one hour and forty-five minutes to fulfill the requirements of the three credit-hour semester-long course. Students completed an open-ended design project and worked in self-selected teams of two to four. Students had to design an existing product and then considered how to improve it. Students received approval from their instructors regarding their design idea along with their innovative and creative methods for solving the problem. Many students incorporated sustainability concepts into their design, which involves engineering design feasibility, environmental impact, social and political consideration, and economic and financial feasibility. To address the importance of sustainable design, students were shown example CAD parts or they watched a series of screencasts by Autodesk (Menter, 2011) that contained real-world sustainable design examples.

Throughout the semester, instructors served as facilitators to ensure that student projects were completed on time. However, direct guidance was limited. Specific class time was dedicated to the project so students could collaborate with their teammates and work on the project. Students were encouraged to think outside of the box and systematically design their project. Before the last day of class, students submitted all project deliverables such as team design report, dimensioned drawing sheets, 3-D parts, assembly, and PowerPoint slides. On the last day of the class, students wore business casual or professional attire to present their work as a team. Each presentation lasted 8-10 minutes, and was followed by 2 minutes of question and answer time (Long & Jordan, 2016; Long & Sun, 2018).

Students completed confidential peer evaluation forms in order to evaluate their own performance and that of their teammates. Criteria was considered such as contribution and quantity of work, interaction and collaboration of the team, problem-solving skills and quality of work, time management, and willingness to be a team player. During the oral presentations, students completed a team evaluation for other groups in the class. Criteria were evaluated such as organization, slide content and aesthetics, presentation skills, and team member participation. Students were strongly encouraged to leave comments, as well as recommendations, to support their evaluation. At the end of the presentation, the instructor summarized the student projects and the top two teams were selected to attend the end of semester student poster competition for all sections of the course. Selected student teams made posters and presented their work to students and faculty on campus. During the poster competition, judges included graduate students, past student winners as well as faculty and staff from Computer Numerical Control (CNC) and Welding Lab, Center of Teaching and Learning Excellence (CTLE), Digital Studio, and Office of Undergraduate Research. Student teams

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competed for 3-D printed medals and different awards such as best poster design, most sustainable design, most sophisticated design, best presentation, people's choice award, and the best of the best award. Figure 1 includes images of 3-D printed medals, award certificates, and a student team's poster.



Figure 1. Student poster competition along with certificates and 3-D printed medals

Course Feedback

Data collection. Prior to the EGR 120 End-of-Semester Poster Competition, a survey was developed based on items from the *Engineering Entrepreneurship Survey* (Duval-Couetil, Reed-Rhoads, & Haghighi, 2011). The survey included Likert-scale and open-ended questions. Some questions used a 5-point scale from *poor* to *excellent* to have students rate their skill levels in areas such as communication skills and presentation skills. The survey also included several questions about student demographics. For example, students were asked to provide their major, sex, ethnic/racial background, etc. Lastly, the survey contained additional Likert-scale items as well as some open-ended questions, which allowed students to uniquely describe what they did and did not like about the poster competition.

Sample and population. In total, 52 students presented 19 posters and participated in the Spring 2018 poster competition. A total of 37 students completed the survey. Based on responses to demographic survey items, over 70% of students who completed the survey were aerospace engineering majors, while less than 19% were majoring in mechanical engineering, more than 8% were studying civil engineering and nearly 3% were pursuing a degree in computer science. In addition, approximately 81% of students who completed the survey were male and over 51% were out-of-state students. Lastly, over 75% of students who completed the survey were White, over 16% were Hispanic or Latino, more than 5% were Asian, nearly 3% were multi-racial and nearly 3% did not want to disclose their ethnic/racial background. As of Fall 2017,

undergraduate students from the Southeastern campus are 56% White, 22% female, 13% international students, 7% multi-racial, 5% Black, 5% Asian, 7% Hispanic, and 33% in-state students with an average age of 21.

When completing the survey, students answered several questions concerning their level of agreement about the poster competition. On average, students thought components of the poster competition were between *good* to *very good*. Students' mean level of agreement regarding the overall poster competition was 3.77 (SD=0.61), on a scale of 1 = *poor* to 5 = *excellent*. Students' mean level of agreement regarding the organization of the competition was 3.61 (SD=0.90), while it was 3.29 (SD=0.96) for information provided before the competition and 3.19 (SD=1.03) for length of competition. Student responses to open-ended questions about what they liked and didn't like about the poster competition provided additional insight. Multiple students said they liked the "variety of projects" or "diversity of project ideas." On the other hand, some students thought the competition was "kind of long" or "too long," especially while "standing." Table 1 and Figure 2 below contain additional details regarding students' level of agreement about the poster competition.

	М	SD
Overall Poster Competition	3.77	0.61
Organization of Competition	3.61	0.90
Information Provided before Competition	3.29	0.96
Length of Competition	3.19	1.03

Table 1: Students' level of agreement about the poster competition



Figure 2. Students' level of agreement about the poster competition

When responding to survey items about skill level, over 50% of students believe their communication skills, presentation skills, analytical skills and ability to evaluate business ideas are *average* to *excellent*. At more than 86%, the highest percentage of survey participants believed their analytical skills are *above average* or *excellent*, which resulted in a mean value of 4.05 (SD=0.57) on a scale from 1 = *poor* to 5 = *excellent*. At over 51%, the lowest percentage of survey respondents believe their ability to evaluate business ideas is *above average* or *excellent*, which led to a mean value of 3.62 (SD=0.82). Table 2 and Figure 3 include a visual representation of students' skill levels in the aforementioned areas.

Table 2: Students' perceived skill levels

	М	SD
Communication skills	3.95	0.70
Presentation skills	3.76	0.82
Analytical skills	4.05	0.57
Ability to evaluate business ideas	3.62	0.82



Figure 3. Students' perceived skill levels

As previously mentioned, several survey questions addressed entrepreneurship. On average, students have taken an average of 0.16 (SD=0.44) entrepreneurship courses outside of engineering. Over 86% of survey participants indicated that they have taken zero entrepreneurship courses outside of engineering while less than 11% have taken one and close to 3% have taken two entrepreneurship courses outside of engineering. Table 3 and Figure 4 provide further information about students' past entrepreneurship courses.

Table 3: Students' number of past entrepreneurship courses, outside of

engineering

	М	SD
Number of	0.16	0.44
classes		



Figure 4. Students' number of past entrepreneurship courses, outside of engineering

While taking the survey, students also answered several questions concerning their level of agreement about entrepreneurship and their engineering classes. Over half of all student participants *agree* or *strongly agree* that students are encouraged to consider starting their own companies in their engineering classes, with a mean value of

3.44 (SD=0.92) on a scale from 1 = *strongly disagree* to 5 = *strongly agree*. More than 55% of students *agree* or *strongly agree* that in their engineering courses (a) faculty discuss entrepreneurship, (b) students are taught entrepreneurial skills, (c) students are encouraged to take entrepreneurship courses and (d) students are encouraged or required to participate in entrepreneurship-related activities. Student responses produced mean values of 3.41 (SD=0.95), 3.37 (SD=0.99), 3.33 (SD=1.09), and 3.52 (SD=0.96). An even larger percentage of students, at over 66%, *agree* or *strongly agree* that students are encouraged to develop entrepreneurial skills and there are opportunities to interact with entrepreneurs in their engineering classes, with mean values of 3.63 (SD=1.06) and 3.59 (SD=1.03). Lastly, over 81% of participants *agree* or *strongly agree* that in their engineering courses students should learn more about entrepreneurship, with a mean value of 4.00 (SD=0.82) or a rating of *agree*. Table 4 and Figure 5 include a visual representation of students' level of agreement around these categories.

Table 4: Students' level of agreement about entrepreneurship and their

engineering classes

	М	SD
Faculty discuss entrepreneurship	3.41	0.95
Students are taught entrepreneurial skills	3.37	0.99
Students are encouraged to develop entrepreneurial skills	3.63	1.06
Students are encouraged to take entrepreneurship courses	3.33	1.09
Students are encouraged or required to participate in entrepreneurship-related activities	3.52	0.96
Students are encouraged to consider starting their own companies	3.44	0.92
There are opportunities to interact with entrepreneurs	3.59	1.03
Students should learn more about entrepreneurship	4.00	0.82



Figure 5. Students' level of agreement about entrepreneurship and their engineering classes

Table 5 and Figure 6 show that students answered several questions concerning their level of agreement about entrepreneurship and the poster competition. Nearly 78% of students *agree* or *strongly agree* they have a general interest in the subject of entrepreneurship with a mean value of 3.93 (SD=0.94), while using a scale from 1 = *strongly disagree* to 5 = *strongly agree*. More than 74% of students believe that entrepreneurship education can broaden their career prospects and choices at a mean value of 3.78 (SD=0.99). Over 70% of students *agree* or *strongly agree* they want to learn about entrepreneurship in their engineering courses and they want to know if they have what it takes to become entrepreneurs, leading to mean values of 3.78 (SD=1.02). Lastly, more than 59% of students *agree* or *strongly agree* they want to become entrepreneurs, are interested in taking entrepreneurship classes, and have ideas for a business product or technology, resulting in a mean values of 3.67 (SD=0.94), 3.56 (SD=0.94) and 3.63 (SD=0.94).

Table 5: Students'	level of agreement	about entrepreneurship	after participating in
the poster compet	ition		

	М	SD
I have a general interest in the subject of entrepreneurship	3.93	0.94
I want to become an entrepreneur	3.67	0.94
I have an idea for a business product or technology	3.63	0.82
I would like to know if I have what it takes to be an entrepreneur	3.67	1.02
I am interested in taking entrepreneurship classes	3.56	1.03
Entrepreneurship education can broaden my career prospects and choices	3.78	0.99
I would like to learn about entrepreneurship in my engineering courses	3.78	1.03



Figure 6. Students' level of agreement about entrepreneurship after participating in the poster competition

Besides the Likert-scale survey items, open-ended questions allowed students to reflect on their individual experiences. The following sample quotes from students describe what they liked and disliked about the poster competition. Overall, students liked having an opportunity to learn from their peers and interviewers, especially professors from their major. They valued the opportunity to showcase their work. Students were also excited about their accomplishment and their future career. They mentioned the lengthy competition, restricted poster design, and unfairness of the People's Choice Award since the winning team could have simply invited their friends to get the most votes.

Sample Student Quotes - What They Liked about the Poster Competition: "It's fun to just stop in and look even if you aren't into engineering." "I enjoyed talking to people" "How there was a lot of good projects to choose from" "How excited all the teams were." "The people interviewing"

"The opportunity to talk to professors involved in the field." "Chance to showcase projects"

"Opportunity to see the (skills) of other fellow students and meet them" "Cookies and location" Sample Student Quotes - What They Disliked about the Poster Competition:

"The groups in the corner didn't get as much public exposure as the ones near the entrance" "The lack of allow ability to create our own posters"

"people's choice: people just called friends" "The length of time I had to stand" "Day before finals"

Conclusion and Recommendations

This paper described a generation change among students taking a freshmen-level engineering graphics course. The paper mentioned how to improve Generation Z's entrepreneurial-mindset and business skills by implementing an open-ended team project and end-of-semester poster competition. The open-ended team project offered students an opportunity to learn the type of design engineering that emphasizes environmental, economic, and social responsibility. It also gave students an opportunity to inquire into, collaborate on, design, assemble, and present their work. An engineering entrepreneurship survey was used to assess students' perceptions of the graphics course-wide poster competition and overall project. Results indicate that the poster competition and overall project provided students with a positive and satisfactory experience, which enabled them to develop and practice critical thinking, innovation skills, and improve their interests in entrepreneurship. Students were able to think "outside of the box" and solve real-world problems, which help improve their business skills as engineering students and enable them to ultimately solve challenges within their future companies, country, or even the world (Mekemson, 2010). The findings in this paper both confirm and expand upon findings from previous studies involving engineering graphics and professional skills such as communication or entrepreneurship (Long & Jordan, 2016; Long & Sun, 2018). As instructors who teach engineering graphics today, it is time to understand our new generation's needs and appropriately incorporate their needs into our curriculum design so that students are well-equipped to become global innovators in the future.

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Does the Glass Box Visualization Method Increase Student Learning Outcomes?

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Abstract

This research study compares incoming engineering technology (ET) students' learning outcomes in an introductory engineering graphics course without and with the use of a physical orthographic projection teaching aid (i.e., glass box). On average, there was not a statistically significant difference between the group (n = 23) that was not introduced to (M = 126.04; SD = 10.00) and the group (n = 22) that was introduced to the physical teaching aid (M = 123.32; SD = 10.06); t(43) = 0.911; p = 0.367, d = 0.27. This paper presents the methodology and results of the study along with construction directions and files for the glass box used.

Introduction

Studies have shown that spatial visualization is a vital skill for both engineering and engineering technology (ET) students, and that students' spatial awareness contributes to classroom success (Ahn, Freeman, & Potter, 2011; Alqahtani, Daghestani, & Ibrahim, 2017; Crown, 2001; Tumkor & deVries, 2015). However, incoming students often struggle to grasp introductory projection techniques (i.e., perspective and parallel projection) to translate three- dimensional (3D) objects onto a two-dimensional (2D) plane (e.g., paper or screen) by hand or mouse. Orthographic projections and more specifically multiview projections are of significant importance for students. Instructors traditionally use textbooks (Bertoline, Wiebe, Hartman, & Ross, 2008; Madsen & Madsen, 2011), graphical presentations, and/or some form of physical model (Tumkor & DeVries, 2015) to help students grasp the concept of multiview projection, with each method having varying levels of success.

The Idea. The concept of using a physical glass box, which can be unfolded to show the six principal views (i.e., front, top, right side, bottom, back, and left side) of a 3D object in third angle projection, as a teaching aid is of course not a new idea. The first known patent of the glass box dates back to May 1943 (U.S. Patent No. 2,319,162). However, despite a continued presence in introductory engineering graphics courses, the *impact of the glass box visualization method on student learning outcomes has never been quantitatively measured in a classroom setting*.

At Purdue Polytechnic New Albany, incoming Mechanical Engineering Technology (MET) students are required to take CGT16300, introduction to graphics for manufacturing, which generally averages 15-30 students per section. The course introduces students to the design process, sketching, engineering geometry and construction, visualization and projection methods, computer-aided design (CAD), and rapid prototyping. Starting in the fall of 2017, a physical orthographic projection teaching aid (i.e., glass box) was introduced and readily accessible (i.e., stored in the classroom and unmonitored) to the CGT16300 students for the entire semester. Generally, students passively witnessed the instructor use the glass box during discussions on projections types (e.g., multiview) and line types; however, for one class example students volunteered to draw in front of the class the front, top, and right-side views as shown in Figure 1. Erasable markers of different colors (i.e., different line types) were used as needed.

After the fall 2017 course ended, a comparison study was then performed on students' learning outcomes at two assessment points and across two conditions: without access to the glass box (i.e., control group; entire class from fall 2016) and with access to the glass box (i.e., investigational group; entire class from fall 2017). Curriculum (e.g., lectures, assignment, exams, schedules, etc.) for both course offerings were identical besides the introduction and availability of the glass box during the fall 2017 semester.

Production. In the spring of 2017, a design for the glass box was quickly conceived using AutoCAD®. Great care was taken to ensure the design would be user friendly, such as magnets and finger holes for ease of disassembly and subsequent reassembly. After the design was complete, the AutoCAD files were converted to DXF files and programmed into a laser cutter for the next stage of development. A sheet of 3/16" thick clear acrylic was chosen as the material for this project due to its durability and the ability to use erasable markers to draw orthographic projections. The 10" x 10" sides were quickly cutout and prepared for assembly. Standard hinges, screws, and nuts were used to allow the box to fold yet maintain its rigidity, while magnets were glued to specific corners to

allow quick and easy disassembly. A photo of the glass box can be seen in Figure 1.

In addition to the glass box, a wooden model and stand were also built to accompany it and help assist in classroom instruction. The model, in this case, was a 3D object designed to showcase a range of features (e.g. bosses, cuts, holes, fillets, etc.) and be used as a teaching aid inside the glass box. The model created for this project was taken directly from one of the students' learning modules (see Appendix). With the help of a Carvey[®] 3D carving machine by Inventables[®], the model was carved out layer-by-layer, glued together, and finally stained to produce an attractive looking centerpiece. The model can be seen in Figure 2. As mentioned, a 12" x 12" x 18" stand was also produced for the glass box to sit on. In keeping with an engineering theme, the stand was designed with a truss-like support base and accompanying school logos were placed in the center of each side. The stand was laser cut much like the glass box sides and fastened together with finishing nails.

The authors have shared the files for making the glass box, stand, and 3D object on Dropbox: https://goo.gl/WcWp4Q.



Figure 1: Model



Figure 2: Glass Box & Stand

Results

The sample for the comparison study consisted of 49 participants (5 females). The investigational group (entire class from fall 2017) consisted of 22 students (2 females) and the control group (entire class from fall 2016) consisted of 27 students (3 females). Over the two assessment points, a total of 141 points were possible for the students to earn. The first assessment point (91 points) was a homework assignment which contained multiple visualization exercises and multiple mechanical multiview sketching exercises (see Appendix). The second assessment point (50 points) was an exam which required students to use AutoCAD to draw a multiview drawing (i.e., front, top, right views) from a dimensioned isometric image (see Appendix). Upon analyzing individual grades, several outliers had to be removed from the fall 2016 group, and this was done using the quartile method.

In order to test the impact of the glass box on ET students' learning outcomes an independent *t*-test was conducted, and the test was found to be statistically non-significant, t(43) = 0.911; p = 0.367, d = 0.27 (see Table 1). The effect size for this analysis (d = 0.27) was found to exceed Cohen's (1988) convention for a small effect. These results (see Table 2) indicate that students in the investigational group (M = 123.32; SD = 10.06) did not perform better on the multiview assessments than students in the control group (M = 126.04; SD = 10.00).

	F	Sig.	t	df	Sig. (2- tailed)	Mea n Diff.	Error Diff.	Lower	Upper
Equal Variance s	1.01 1	0.184	0.91 1	43	0.367	2.72 5	2.99 1	-3.036	8.757
Equal Variance s Not Assume			0.92 3	21	0.367	2.63 6	2.85 6	-3.304	8.576

Table 1. t-test for Equality of Means

Note: 95% Confidence of the Difference

Group	n	Points	М	SD	Median	MIN	MAX
Fall ('16)	23	141	126.0 4	10.00	128.00	94.00	139.0 0
Fall ('17)	22	141	123.3 2	10.06	125.50	99.50	139.0 0

Table 2. Descriptive Statistics

Discussion

Student learning outcomes did not improve with the introduction of the glass box visualization method. Instead, the average grade dropped several points between the control group (M = 126.04) and the investigational group (M = 123.32). However, it is possible that the students in the control group entered CGT16300 with higher levels of prior knowledge and experience concerning spatial visualization and/or orthographic projection. To ensure homogeneous sampling the researchers need to better screen incoming students and/or randomize students from a single course offering into two groups during the same semester. Starting in the fall of 2018, the Purdue Spatial Visualization Test: Rotations (PSVT: R), is given on the first and last day of class. "The PSVT: R is exceedingly used in different fields and programs of engineering" (Alqahtani, Daghestani, & Ibrahim, 2017) and has been shown to be a useful assessment tool in determining students' spatial visualization skills (Branoff, 2000; Guay, 1980).

An additional limitation to this study was the use of a student grader in the fall of 2016 for both assessment points but used only for the first assessment in the fall of 2017. The course instructor graded the second assessment; however, the subjective nature of grading drawings introduces the possibility of grading variability. Generalizability of our findings are also limited due to our samples being predominately male and white.

Finally, exploring how new commercially available immersive and interactive technologies, such as virtual reality (VR), could be used to demonstrate the glass box visualization method need to be explored. VR may be a useful tool to improve students' spatial ability and learning outcomes concerned with introductory engineering graphics courses.

Conclusion

For decades, the glass box visualization method has been a cornerstone in introductory engineering graphics courses and more specifically when teaching multiview projection. However, this research study finds that spending the time to create a physical glass box and introducing it to the incoming ET students will not improve learning outcomes. Using digital lecture slides and/or textbook references to the glass box visualization method will most likely save valuable instructor time and will largely have the same impact on the students. Further refinement of this experiment could potentially yield different results, however, just as the engineering graphics classroom has transformed from drafting tables to computer stations the physical glass box needs to be digitized.

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Appendix First Assessment: Multiview Visualization Exercise Examples

Directions

In the table, match the given surface letter from the pictorial drawing with the corresponding surface number from the multiview drawing for each view.







Cross Slide (BP-6B)

1. What material is used for the Cross Slide?

- 2. How many pieces are required?
- 3. What is the overall width (length) of the Cross Slide?
- 4. What is the order number?

5. What is the overall height of the Cross Slide?

6. What are the lines marked B and B called?

7. What do the lines marked $\textcircled{\ensuremath{\mathbb A}}$ represent?

8. What two lines in the top view represent the slot shown in the front view?

- 9. What line in the right-side view represents the slot shown in the front view?
- 10. What line in the front view

represents surface () in the right-side view?

11. What line in the front view

represents surface ^(D) in the top view?

12. What line in the top view represents surface O in the front view?

 $13. \ensuremath{\text{What}}$ line in the side view represents

surface () in the top view?

14. What is the diameter of the holes?

15. What is the center-to-center dimension of the holes?

16. How far is the center of the first hole from the front surface of the side?

17. Are the holes drilled all the way through the slide?

18. What is the width of the slot shown in the front view?

19. What is the height of the slot?

- 20. Determine dimension S .
- 21. What is the width of the projection at the top of the slide?
- 22. How high is the projection?
- 23. What kind of line is \bigcirc ?
- 24. What kind of line is used at O and P?

Second Assessment: Exam Question

Directions

Using AutoCAD, draw a standard 3 view multiview drawing (front, right, and top) of the Widget.

- File name shall be widget3.dwg
- Widget shall be drawn to true scale (1:1)
- Show only visible, hidden, and center lines (i.e. do not include dimensions, annotations, and construction lines) and eliminate double lines (i.e. lines drawn on top of other lines)
- Center line extensions shall be uniform (pick either .125 or .25)
- Lines shall be drawn on their correct layer
- Spacing between front, right, and top views = 1.00
- All holes = through holes
- Create/Print a .pdf of A-Size layout (widget3.pdf)
 - Include boarder/title block (update title block information)
 - Model scale = 1:1
 - Printer/plotter = Adobe PDF (if using lab computers)
 - Paper size = Letter
 - Plot area/What to plot = Layout
 - Plot offset (origin set to printable area) = X=0.00, Y=0.00
 - Plot/Paper scale = 1:1
 - Drawing orientation = Landscape
- Upload widget3.pdf to answer question



A Cornerstone Course for Engineering Education: The Engineering Design Graphics Collaboratory

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Abstract

The ABET accreditation criterion 5 requires a "culminating major engineering design experience" in the curriculum (ABET, 2018). This is commonly referred to as the senior capstone design course. The freshman engineering education experience is loaded with required science and mathematics courses, and there is little room for an engineering experience. Nonetheless, most faculty want to have some engineering course during the freshman year, and many ideas have been tried over the years. Of these many ideas, the concept of a design project with hands-on activities seems to be the most popular and most beneficial (Smith 2003; Ross, 2013). This paper reports on such a proposed freshman cornerstone course, the Engineering Design Graphics Collaboratory (Barr, 2018). This freshman cornerstone course would mimic the senior capstone course in some ways, and would give the students a realistic glimpse of their engineering future. Keywords

Engineering Education, Engineering Design, Engineering Graphics, Collaboratory

Introduction

This paper is the closing chapter in a four-decade career dedicated, in part, to transforming Engineering Design Graphics (EDG) from a mechanical drafting course to an engineering design course, while retaining appropriate graphics visualization skills that are still needed in design. Changes in the EDG curriculum over the last four decades have been driven by changes in technology. The drafting machine has been replaced by a computer, and the pencil and paper have been replaced by 3-D modeling software. Faculty started transitioning to solid modeling as the core topic in the EDG curriculum in the 1990's and beyond (Barr et al., 1994; Ault, 1999; Branoff et al., 2002; Bertozzi et al., 2007; Planchard, 2007). A concurrent engineering paradigm (Figure 1) was developed in 1994 to express the author's ideas at that time, and over time has had an international influence (Borges and Souza, 2015).

Full implementation of the paradigm was not fully realized until 15 years after it was first published. Now, as we enter the third decade of the 21st century, the 3-D

computer model is firmly entrenched as the epicenter of the modern digital design and manufacturing enterprise. It is time that our teaching methodologies and spaces reflect this modern design reality. During the conceptualization of the EDG Collaboratory course, certain imperative goals were established:

- 1. There should be a design project with a recognized process and with hands-on activities.
- 2. There should be significant teamwork and interpersonal communication in class.
- 3. The full array of graphics needed for modern design should be presented, in both computer and freehand sketching modes.
- 4. The course should lend itself to design analysis and digital prototyping.
- 5. The classroom space for the course should be arranged to facilitate collaboration among the instructor and the students.



Figure 1: The Concurrent Engineering Instructional Paradigm.

The Collaboratory Space

The word "collaboratory" (Wulf, 1993) is used to describe a creative space where a group of people work together to generate solutions to complex problems. In this context, by fusing two elements, "collaboration" and "laboratory", the word "collaboratory" suggests the construction of a space where people explore collaborative innovations. The proposed space for Engineering Design Graphics is shown in Figure 2. The ten flat tables, with four chairs surrounding each table, enable students to interact face-to-face while they work on their design projects using self-supplied laptops. The instructor's podium is in the center, so that the instructor becomes a facilitator with access to all tables, rather than a lecturer at the head of the room. Surrounding the studio are projector screens showing instructional content, and equipment for design documentation such as

3-D printers. Thus, the collaboratory layout encourages teamwork, as would happen in a design studio, as opposed to individual work, as would happen in a traditional drafting room.



Figure 2: The Engineering Design Graphics Collaboratory Space.

Design Visualization Skills: Freehand Sketching and Computer Modeling

Graphics is the language of design, and many research studies have shown that good visualization skills are important for success in engineering (Hsi et al., 1997; Leopold et al., 2001; Adanez and Velasco, 2004; Sorby, 2005; Contero et al., 2006; Connolly, 2009). Furthermore, Danos et al. (2014) recently coined a term "graphicacy," calling for a universal improvement in graphics capability for all students, thus extending these principles beyond engineering into everyday society. The instructional triad shown in Figure 3 serves as the basis for the sketching, computer modeling, and design project exercises used in the cornerstone course. The graphics instructional topics have been driven by recent efforts to define a modern graphics concept inventory (Sadowski and Sorby, 2014), by graphics outcomes surveys (Barr, 2012), and by current leading textbooks (Lieu and Sorby, 2009). Delivery of the graphics concepts is primarily through the freehand sketching mode. Freehand sketching has been reported as an important skill for developing "hand and mind" coordination in both early designers (Marklin et al., 2013; Booth, et al., 2016; Bairaktarova, 2017) as well as in advanced mechanical design courses (Yang and Cham, 2007).

The 3-D computer modeling instruction begins with sketching 2-D profiles and then creating 3-D parts through extrusions and revolutions. However, students in the collaboratory see the true power of the concurrent engineering paradigm (Figure 1) when the parts they build are extended to engineering analysis using finite elements (Balamuralikhrishna and Mirman, 2002), animation studies (Lieu, 2004), and 3-D rapid prototyping applications (DeLeon and Winek, 2000).



Figure 3: The Instructional Triad for the Engineering Design Graphics Collaboratory.

The Design Project

Many different design projects have been tried in the EDG curriculum over the decades. One project type that has been popular in recent years is reverse engineering (Sheppard, 1992; Mickelson, et al., 1995; Barr, et al., 2014). Reverse engineering is the dissection of a common mechanical assembly into its individual parts, studying the geometry and design function of each part, and then reconstructing the parts into 3-D solid model data bases. The students are divided into 4-member teams and each team selects a mechanical assembly. Using simple tools, they dissect the mechanical assembly into individual parts, make measurements and sketches, build 3-D solid models and

assemblies, apply the solid models to various analyses, and then digitally print 3-D parts. The whole project is eventually documented in a bound final report with sketches, 3-D model image printouts, various analysis reports, printed 3-D prototypes, and final dimensioned part drawings. The teams also make a brief in-class oral presentation on the last class day. Figure 4 shows an example of some of the graphics sketches, part and assembly models, and drawings created in the team project involving a hand-held drill.



Figure 4: Examples of the Design Project Documentation: (a) Sketches, (b) 3-D Computer Model of Part, (c) Computer Assembly Model, and (d) Dimensioned Part Drawing.

Student Surveys

A student survey of the collaboaratory topics was conducted during two different school years to gain feedback from the students. The survey asked students to rank the topics based on how helpful the activity would be in their future engineering career. The responses were on a seven- point Lickert scale, with 7 (extremely helpful), 4 (somewhat helpful), and 1 (not helpful at all). Results of the survey for the Spring 2017 and Spring 2018 semesters are shown in Tables 1 and 2, respectively.

In general, the results of the surveys support the contention that the students liked the course exercises. Not surprising, the highest ranked topics pertained to 3-D computer modeling using the popular software SolidWorks. Five of the ten computer topics received scores of 6.00 or higher for both 2017 and 2018. Some of the sketching exercises, and in particular isometric sketching, also received good scores. The students also liked the team design project, particularly the 3-D printing aspect of the project.

It is gratifying to note that the relationship of graphics to engineering design was also ranked very high (scores of 6.19 and 6.02). The most important objective of the course was to transition from an historical drafting course, with one-hundred-year roots on campus, to a design-centric course. Thus, showing how graphics can contribute to a design project is extremely important.

On the negative side, the students rated the oblique sketching exercises the lowest in both surveys (scores of 5.51 and 5.32). In retrospect, the concept of oblique sketching is of little value to designers, since in gives a somewhat distorted view of the object's dimensions. This topic will likely be dropped from the collaboratory in the near future. Also, the lowest rated topic in both surveys was the method of assigning teams (scores of 4.79 and 4.17). Experienced faculty might think that using a personality-typing method, such as the MBTI, would be very useful in forming teams. However, these results disprove that thinking. As faculty, we must realize that college freshmen nowadays have other ways of intermixing, socializing, introducing themselves, and finding teams in the collaboratory will need to be devised.

One final comment was offered by one of the students in the survey. It pertains to the perception that sketching and graphics fundamentals are less important now during this age of 3-D computer modeling. This student quoted: "The results of the survey will probably show that the class thinks the sketching assignments are less helpful for their careers. However, I believe that the sketching exercises helped me understand 3-D objects and made learning SolidWorks easier." Visualization is the key to good design work and team interaction, and the various forms of graphics projected in the course help to develop this visualization skill.

Conclusion

The EDG collaboratory as described in this paper has not been fully realized. In particular, the space layout for the collaboratory does not yet exist, but Figure 2 is still the goal. In addition, the sketching exercises currently used in the collaboratory date back to the 1990's, and new exercises need to be created or redone so that they can be executed with only freehand sketching and no manual tools. The main strategy is to have grid lines (isometric or orthographic) in the sketching solution space to facilitate the freehand mode while retaining some technical quality. Also, some more design checks (intermediate submissions) should be added to the team project. A simple FEA analysis for one of the parts would be a nice addition to the project, as would also asking the team

to redesign one part to make it better, and then re-model it in SolidWorks. Moving forward, faculty will continue to seek student feedback and make small improvements to the EDG collaboratory, as it progressively becomes a premier cornerstone course for engineering education.

Design Graphics Sketching	Ratin
	g C OF
Design Sketching: Visualization Techniques	6.05
	6.02
Design Sketching: Section Views	5.89
Design Sketching: Dimensions	5.87
Design Sketching: Orthographic Multi-Views	5.83
Design Sketching: Sketching Lines	5.77
Design Sketching: Design Features and Modifications	5.60
Design Sketching: Oblique Views	5.51
Ave.	5.82
3-D Computer Modeling	Ratin
SolidWorks: Croating 3 D Parts and Eastures	g
SolidWorks: Creating Barte Using Extrusions and Povolutions	6.52
SolidWorks. Creating Parts Using Extrusions and Revolutions	0.52
SolidWorks. Assembly Modeling and Maurig	0.40
	0.15
	6.10
SolidWorks: Creating Section Views	5.96
SolidWorks: Dimensioning Layout Drawings	5.95
SolidWorks: Finite Element Analysis and Re-Design	5.93
SolidWorks: Mass Properties Analysis and Design Tables	5.77
Ave.	6.15
Team Design	Ratin
Project	g 6 10
Relationship of Graphics to Englineering Design	0.19
Team Project: Printing Rapid Prototypes	0.15
	6.01
Introduction to Engineering and Teamwork	5.96
Team Project: Dimensioned Layout Drawings of Parts	5.94
Team Project: Computer Modeling and Mass Properties	5.88
Team Project: Final Written Report	5.85
Team Project: Project Re-Design	5.81
Team Project: Sketching Project Parts and Assemblies	5.63
Team Project: Written Proposal	5.61
Team Project: Planning Charts and Diagrams	5.55

Table 1: Student Survey Results for Spring 2017 (N = 84).

Team Project: Materials and Manufacturing	5.49
The MBTI and Assigning Teams	4.79
Ave.	5.76

Table 2: Student Survey Results for Spring 2018 (N = 47).

Design Graphics Sketching	Rating		
Design Sketching: Isometric Views	5.83		
Design Sketching: Visualization Techniques	5.74		
Design Sketching: Section Views	5.68		
Design Sketching: Orthographic Multi-Views	5.62		
Design Sketching: Design Features and Modifications	5.62		
Design Sketching: Dimensions	5.60		
Design Sketching: Sketching Lines	5.40		
Design Sketching: Oblique Views	5.32		
Ave.	5.60		
3-D Computer Modeling	Rating		
SolidWorks: Creating 3-D Parts and Features	6.45		
SolidWorks: Assembly Modeling and Mating	6.32		
SolidWorks: Creating Parts Using Extrusions and Revolutions	6.19		
SolidWorks: Finite Element Analysis and Re-Design	6.11		
SolidWorks: Creating Section Views	6.02		
Loading and Using SolidWorks on Your Laptop	5.89		
SolidWorks: Mass Properties Analysis and Design Tables			
SolidWorks: Dimensioning Layout Drawings	5.79		
SolidWorks: Kinematic Animation	5.77		
Ave.	6.04		
Team Design	Rating		
Project	0.00		
Team Project: Printing Rapid Prototypes	6.26		
Team Project: Final Written Report	6.17		
Team Project: Computer Modeling and Mass Properties	6.13		
Relationship of Graphics to Engineering Design	6.02		
Team Project: Dimensioned Layout Drawings of Parts	5.83		
Team Project: Oral Presentation	5.70		
Team Project: Materials and Manufacturing	5.68		
Team Project: Project Re-Design	5.68		
Team Project: Sketching Project Parts and Assemblies	5.64		
Team Project: Written Proposal	5.62		
Team Project: Planning Charts and Diagrams	5.62		
Introduction to Engineering and Teamwork	5.60		
The MBTI and Assigning Teams	4.17		

Ave.	5.70

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Curricular Maintenance: Responding to Partners and Higher Authorities

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Abstract

A 4-year accredited design technology program that places a special emphasis on engineering design graphics is currently in the process of wrapping up numerous curricular changes: the most it has experienced during any similar period in the history of the program. The changes were in response to edicts sourced from a variety of internal and external partners and authorities. Because the program has always been accredited by a Council for Higher Education Accreditation recognized accrediting body and the program has been in the process of completing an accreditation reaffirmation self-study and self-study report, it is anticipated the program's accreditation will be reaffirmed in 2019, which should also uphold its responses to the various edicts. It appears the edicts will have minimal impact on the delivery of instruction and graduation requirements. It also appears the program's special emphasis on engineering design graphics will not be affected. The accreditation reaffirmation process it is anticipated will bear this out.

Introduction

In addition to the evolving technologies and the way business and commerce are conducted, professional programs like almost all other instructional programs in higher education are influenced by academic partners and higher authorities. That is, in addition to being sourced from business and commerce, edicts that affect programs, and to which they must respond, can be sourced from associated programs within an institution, which may impact selected programs; institutional requirements that impact most if not all academic programs within an institution; from state authorities, which affect virtually all programs under the jurisdiction of the state; and from what some might suggest, accrediting bodies—programmatic, specialized, regional, etc.

Recently an accredited undergraduate design technology program, which places a special emphasis on engineering design graphics, completed several initiatives and is in the process of completing several others in response to requirements and guidance provided by its academic partners and higher authorities. At the same time, the program

was conducting an accreditation self- study and preparing their self-study report for accreditation reaffirmation.

The problem of this study was to reflect on what prompted the various initiatives. The purpose was to continue refining the skills needed to respond to programmatic partners and curricular authorities, to assess program effectiveness, and to not just carry on doing things as they have always been done—business as usual. The intent was to also develop an appreciation for the sources of edicts.

The University of North Carolina Undergraduate Degree Completion Improvement

Plan. In a revision to the North Carolina Guaranteed Admission Program, (Current Operations and Capital Improvements Appropriations Act of 2015), the legislation challenged the President of the University of North Carolina, in consultation with the Board of Governors, to adopt a 2017-2018 academic year plan to improve student completion of baccalaureate degrees. Included were specific completion rate targets for each constituent institution and allowances for a variety of strategies designed to best meet the individual constituent institutions' needs (The University of North Carolina General Administration, 2016, December).

Generally, the edicts were in response to decrees that conveyed the needs of the system's general administration to ensure stakeholder sustainability with a focus on timely degree completion, student debt, rising costs for students and families, and the public perception about value. To many, the aforementioned legislation should have been and was a portent for more to come.

On Jan 26, 2018, as an example, the University of North Carolina Board of Governors approved a regulation mandating a maximum of 120 semester hours (SH) for undergraduate degrees (Y. Zhou, personal communication, March 2, 2018).

General Education. According to the institution's Foundations Curriculum and Instructional Effectiveness Committee chair, the College of Arts and Science and the professional programs have always shared a difference of opinion regarding the number of general education hours required of students fulfilling their undergraduate degree requirements (G. Bailey, personal communication, July 23, 2018). The institution, prior to the recent change, required 42 SH of general education courses. Southern Association of Colleges and Schools, their accrediting body, suggests 30 SH.

Degree in Three. Introduced during the 2008-09 academic year, "Degree in Three" provides high caliber, highly motivated students with the opportunity to finish an undergraduate degree in three years. While students can fulfill their the graduation

requirements over the course of six semesters and two to three summers without being over-taxed, Degree in Three is particularly suitable for students with AP (Advanced Placement) and dual-enrollment credits.

Design Minors. In addition, and in the spirit of UNC-GA's pursuit of their goal to reduce time to degree and costs, a decision was made in May of 2017 (R.A. Chin, personal communication, May 24, 2017) to reduce the number of SH needed to fulfill the architectural design technology and mechanical design technology minors from 30 SH to 24. Later and upon closer scrutiny of other professional program minor requirements, the 24 was further reduced to 18.

Trigonometry. Recently, the institution's Department of Mathematics elected to "bank" or in effect cease offering their trigonometry course (D. Bucci, personal communication, June 20, 2018), a prerequisite for two course required of BS in Design majors and those pursuing a design minor.

Association of Technology, Management, and Applied Engineering (ATMAE). As a Council for Higher Education Accreditation recognized accrediting body, ATMAE, with respect to its role as an accrediting body, exists to ensure that the higher education instruction provided by technology, management, and applied engineering programs meet acceptable levels of quality. As part of that oversight, ATMAE ensures that programs meet minimum foundation semester hour requirements. (ATMAE, 2018, p. 9)

Method

The design technology program responded to the edicts with two major initiatives. First, it reduced its foundation curriculum requirements from 42 to 40 SH—a 5% reduction. Then it pared its graduation requirements by 5% from 126 SH to 120. Currently it is in the process of (a) reducing their design minor requirements and (b) expediting the BS in Design as Degree in Three program.

General Education. In a directive from the College's associate dean for instruction (L.R. Pagliari in T. Mohammed, personal communication, May 25, 2016), program coordinators were instructed to begin paring down their foundation credits in accordance with the guidance provided (see Table 1). Within six months, the BS in Design's updated general education requirements were approved (East Carolina University: Undergraduate Curriculum Committee, 2016. P. 2).
	Current	Proposed
Area	FC Semester Hours	FC Semester Hours
S		
General Education (SACS):		
Humanities/Fine Arts	10 (at least one HU/one FA)	9 (at least one HU/one FA)
Social Science	12 (three different areas)	9 (two different areas)
Natural Science	8 (at least one lab)	7 (at least one lab)
Mathematics	3	3
Any of the above	-	3
Sub-Total	33	31
Additional ECU FC:		
English Composition	6	6
Wellness Literacy	3 (Health/Kinesiology)	3
Total ECU FC	42	40

 Table 1. Comparison of Current and Proposed Foundations Curriculum

 Requirements.

Note. Adapted from East Carolina University: Foundations Curriculum and Instructional Effectiveness Committee. (2015, October 19). COMMITTEE: Foundations Curriculum and Instructional Effectiveness. Retrieved from http://www.ecu.edu/cs-acad/fsonline/customcf/committee/as/minutes/2015/fcm1015.pdf

Reduction in Graduation Requirements. In the spirit of UNC-GA's pursuit of their goal to reduce time to degree and to minimize costs, a decision was made in Nov of 2015 to reduce the graduation requirements for the BS in Design from 126 SH to 120, even though a directive from UNC-GA was not forthcoming and probably would not be (L.R. Pagliari, personal communication, February 1, 2016).

Sixteen months later, the BS in Design's request to reduce their graduation requirements from 126 SH to 120 was approved (East Carolina University: Undergraduate Curriculum Committee, 2017. p. 2). In the case of the mechanical technology concentration, this was accomplished by eliminating one of three science courses. For the architectural technology concentration, a core science course was retained and the students were given a choice of one among two science courses. The number of general elective hours was also reduced.

Degree in Three. In the spirit of reducing time to degree and cost, the "Degree in Three" BS in Design, which is nothing more than a plan for fulfilling the BS in Design graduation requirements in six consecutive semesters with two summer sessions sandwiched between, or some combination thereof, is being resuscitated. Key will be jettisoning but not eliminating selected prerequisites. The prerequisite courses were originally incorporated to help facilitate instruction and to keep students from waiting until later to take their science and math courses as examples.

Minors. The jettisoning of selected prerequisites should also helped facilitate the pace with which the requirements for the two design minors can be fulfilled by students. Minor prerequisite courses are identified as part of the minor and must ethically be cited as part of the minor requirements.

Trigonometry. The recent Mathematics Department announcement to no longer offer trigonometry will need to be addressed because the course is an integral part of the BS in Design.

Accreditation Reaffirmation. During the period in which the edicts began coming down, the program began its process of completing an accreditation reaffirmation self-study and self-study report, so the program needed to ensure it remained in compliance with their accrediting body's standards. In addition, it had to negotiate the changes between the accreditation standards under which the program's accreditation was last reaffirmed by ATMAE (2011) and the standards under which accreditation would be reaffirmed in 2019 (The Association of Technology, Management, and Applied Engineering, 2018).

Results

General Education. The BS in Design's was able to pare its general education requirements with very little difficulty—see Table 1. The one hour reduction in Humanities/Fine Arts makes planning easier for students because most courses offered are 3 SH courses and so very few are 1 SH courses. The three hour reduction in Social Science simply eliminated, for this program, a Social Science elective. And because the BS in Design requires additional science hours beyond what is required to fulfill the institutional general education requirements, the additional science hours could be used to fulfill the "Any of the above" requirement.

Reduction in Graduation Requirements. In addition to reducing the BS in Design graduation requirements from 126 SH to 120, the program had to ensure it remained in compliance with their accrediting body's foundation semester hour requirements. The requirements, which were in place when the program's accreditation was last reaffirmed, were as follows: General Education (must include oral and written communications), 18-36; Mathematics, 6-18; Physical Sciences, 6-18; Management, 12-24; Technical, 24-36; and Electives; 0-18, and appear in Table 2.

ATMAE Requirements	Program Semester Hours
General Education (Humanities, English, History, Sociology, Psychology, Speech, etc.) 18-36 Semester Hours	31
Mathematics 6-18 Semester Hours	11
Physical Sciences* 6-18 Semester Hours *Life Sciences may be appropriate for selected programs of study	13
Management 12-24 Semester Hours	24
Technical 24-36 Semester Hours	39
General Electives 0–18 Semester Hours	8
ATMAE Minimum Total 120 Semester Hours	126

Note. Adapted from The Association of Technology, Management, and Applied Engineering. (2011). 2011 Accreditation Handbook. Ann Arbor, Michigan: The Association of Technology, Management, and Applied Engineering.

For the 2019 accreditation self-study report, the foundation semester hour requirements are as follows: General Education (must include oral and written communications), 18-36; Mathematics, 6-18; Physical Sciences, 6-18; Management and/or Technical 42-60; and Electives; 0-18, and appear in Table 3. What may appear to be disconnects is a result of how courses are categorized. While the number of general education hours in Table 3 does not coincide with the general education hours in Table 1, it must remembered that some of the mathematics and physical sciences hours broken out by ATMAE are in fact general education hours. Also, the 3 hour difference between the Management and Technical hours in Table 2 and the Management and/or Technical hours in Table 3 was the result of a technical course being added following the last accreditation visit.

Degree in Three. While the plan has not been finalized, it appears to be workable. Fortunately it does not require an institutional hearing outside the department that administers the program.

Minors. While the original proposal for reducing the number of hours needed to fulfill the requirements for each of the design minors has made its way through most of the approval process and is awaiting its hearing, it will be withdrawn so editorials can be made and resubmitted for consideration.

Table 5. DS III Design Gladuation Requirements, 2010-2019 Catalogue	Table	3. BS	in D	esign	Graduation	Requirements,	2018-2019	Catalogue.
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ATMAE Requirements	Program Semester Hours
General Education (Humanities, English, History, Sociology, Psychology, Speech, etc.) 18-36 Semester Hours	30
Mathematics 6-18 Semester Hours	11
Physical Sciences* 6-18 Semester Hours *Life Sciences may be appropriate for selected programs of study	8
Management and/or Technical 42-60 Semester Hours	66
General Electives 0–18 Semester Hours	5
ATMAE Minimum Total 120 Semester Hours	120

Note. Adapted from The Association of Technology, Management, and Applied Engineering (2018), 2019 Accreditation Handbook. Retrieved from

https://cdn.ymaws.com/www.atmae.org/resource/resmgr/accred_2018/ 2019_Accreditation_Handbook.pdf

Discussion

The North Carolina General Assembly drafts and legislates its state laws. The State's first Constitution contains the legal authority and mandate for the University of North Carolina, a multi- campus public university system. Comprised of all North Carolina's public universities, it is administered by a president and a board of governors.

As a caretaker of the state's resources, the BS in Design continues to abide by edicts sourced from associated programs within its institution; institutional requirements; state authorities, including the Board of Governors; and accrediting bodies. In response, it has and continues to pursue initiatives associated with but not limited to timely degree completion, student debt, rising costs for students and families, and public perception about value.

Now that the two major initiatives have been finalized and the guidance deployed, its effect and impact will need to be assessed. Once the two revised design minor semester hour requirements and the BS in Design Degree in Three are deployed, their effect and impact too will need to be assessed.

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Distribution of the Engineering Graphics Concept Inventory

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Abstract

The Engineering Graphics Concept Inventory (EGCI) has recently been completed and has reached the end of scheduled development. Thus far, the instrument has largely been administered and interpreted by the research team. With goals of making the instrument widely available to be utilized by the engineering graphics community, the EGCI would need a place where it can both exist beyond the duration of its authors, and be properly accessed by researchers. The EGCI is currently undergoing conversion to be put on a website dedicated to housing similar STEM education assessment tools. Plans to evaluate the successful utilization of the instrument in this medium will take place in the fall of 2018. Additionally, having the instrument housed in a sustainable location will allow improvements and refinements to be made as additional settings and populations are reached.

Introduction

This document and presentation will serve as the orientation and best practices for the online version of the EGCI. The EGCI has been refined to its planned level of rigor and is at the point of making it widely available to researchers. Over the fall semester of 2018, the instrument has been moved to a website that will help facilitate the long term goals of the project.

Assessment Instruments in Engineering Education

There are numerous standardized instruments that look to measure various areas in engineering education. Some of these tests are specifically related to graphics and focus on assessing visualization abilities such as the Purdue Spatial Visualization Test: Visualization of Rotations (Guay, 1976), and the Vandenberg Mental Rotations Test (Vandenberg and Kuse, 1978). Others measure specific engineering topics such as the Force Concept Inventory (Hestenes et.al, 1992) and the Statics Concept Inventory (Steif, 2004). Each instrument attempts to identify and measure a particular construct important to a specific area of engineering. Whilst most of the engineering graphics related instruments focused primarily on visualization abilities, the EGCI was intended to address the field of engineering graphics on a more holistic level, attempting to include topics that were deemed fundamental to the field (Nozaki, 2017). The instrument has been completed to its recommended level of quality and is ready for wide spread distribution. Having it available online for use by the intended audience will help satisfy the dissemination goals of the project.

Considerations of the Online Version

Development of the instrument spanned several years and utilized different platforms to acquire the needed artifacts. Paper versions of items were used in the early stages, then evolved to electronic platforms to efficiently reach a wider population. Until now, electronic versions of the instrument were hosted by institutions of the researchers. To avoid potential problems in the future caused by changes in licensing, software availability, funding, and movement of researchers, an independent site was deemed most appropriate to permanently house the EGCI.

There are many ostensible benefits to housing instruments in a like field together. The primary benefit is the increased traffic and exposure to the instrument, as those with an interest in an area would foreseeably be likely to use other similar instruments. Inclusion in other studies where the instrument was not a primary instrument would test the robustness across multiple settings. Maintaining a site that is larger may take more resources, though with enough use, hopefully such efforts would become a reasonable pursuit. Thus, an ideal site would include other similar educational instruments.

Continuous improvement of the instrument must be an option for the host site. As technology and conventions change, so too would related assessment activities. The site should allow for the instrument's authors to make relevant changes should the need arise. These changes include the ability to retain data for future testing and analysis.

With the intent of making the instrument available to a multitude of researchers at different levels of education and institutions, data management and privacy are paramount. The architecture of the online instrument should consider ways to

appropriately conduct research and minimize the risk of breeches in data security. The site needs to be accessible enough where interested researchers can independently administer the instrument, access the data, and interpret the results. The site also needs to be secure enough to protect the integrity of the data and maintain adequate privacy. Data shall be maintained in a manner where future research is possible and mining is not a hindrance.

Use of the Instrument

Based on input from graphics professionals in academia and industry regarding the fundamental concepts of engineering graphics, the EGCI was designed to be used for both outcomes assessment in engineering graphics courses, and to help plan curricula when creating new or revising existing engineering graphics courses.

Instructors and researchers wishing to use the EGCI for assessment will have to make a request, and be approved by the PIs, to obtain a researcher's login and password. Having a researcher account will allow them to administer the exam to their own students or other test subjects, and retrieve those results. To protect individual subjects' privacy, unique IDs will be automatically generated for all subjects taking the test. Demographic data will be gathered from participants, but protect privacy this data will not be associated with the automatically generated IDs.

Currently, the PIs on the project will have access to the entirety of the instrument. This includes site administration, data management, access permission, and instrument maintenance. Primary anticipated use of the instruments' data include longitudinal studies, and continuous improvement to the instrument. Stored data will be easily accessible to researchers, making studies across settings as well as time feasible. Feedback from a variety of sources can help in the improvement of the instruments presentation.

Future Work

The instrument will be constructed on the new platform over the course of the 2018 fall semester, with plans to introduce it for widespread use in the spring of 2019. It is the goal of the project that having the instrument housed in a more robust, sustainable platform will help spread the use to an increased number of settings and populations. Future papers will report on the utilization of web platform to collect results in a new educational assessment instrument. The findings of this work will also provide the authors with experience to advise on website creation and the implementation of similar assessment instruments.

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Investigating Performance Assessment Practices in Post- Secondary Fundamental Technical Graphics Courses

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Abstract

Performance assessment is a common method of determining proficiency and what students can do with that knowledge. Students in engineering design graphics courses engage in performance tasks, such as creating technical sketches or solid computer models of parts, and instructors must determine how well students can execute tasks aligned with the course objectives. The extant literature contains documented changes in the objectives taught in the classes, skills required for industry, and methods of assessing students' proficiencies in the desired skills. This study examined the current performance assessment practices utilized in post-secondary introduction to engineering design graphics (EDG) courses.

A web-based survey was developed, distributed, and employed to investigate course performance objectives, the importance of performance assessment, type of work assessed, and performance practices in introductory EDG courses. Responses from current introductory EDG instructors provided insights into the current performance assessment methods in introductory EDG courses.

Introduction

Fundamental technical graphics (FTG) courses in post-secondary institutions in the United States have seen significant changes in the content and practice (Clark & Scales, 2006; Barr, 2012) due to the significant changes in technology and policy. The inclusion of constraint based computer aided design (CAD) into the curriculum means that, "Examining print-outs of solid models or drawings is no longer sufficient to determine the correctness of geometry," (Wiebe, Branoff, & Hartman, 2003, pp. 7). Large class sizes in these fundamental courses has led to a variety of approaches to assess student artifacts. These assessments were used to make judgements about student's proficiency that were a part of the student's grade as well as provide data utilized for instructional improvement. Significant portions of student's grades were determined by performance

assessment and decisions were made with this data (Baldizan & McMullin, 2005; Elrod & Stewart, 2005).

Discussion of different assessment practices in the literature provide the advantages and disadvantages for each approach but do not explain the extent to which they are being used. The grassroots development of these assessment methods also limit the ability to determine the extent that these methods were utilized. This research helped clarify the type of student artifacts generated and assessment methods utilized in FTG courses.

Methodology

Trochim, Donnelly, and Arora (2015) suggest that surveys are a systematic way to gain information about people's opinions or behaviors through interviews or questionnaires. Performance assessment trends gathered from the EDGD literature were compiled into a questionnaire intended to answer the following research question: What is the status of performance assessment in FTG courses at postsecondary institutions?

The questions for the survey were developed based upon trends discussed in technical graphics performance assessment and rubric literature including Barr's (2012) list of learning objectives that most align with their course's learning objectives, types of student work assessed, assessment methods for this work rubric usage questions. Development of the questionnaire followed Diem's (2002) process for survey development along with Trochim et. Al's (2015) considerations for population, sampling, question, content, bias and administration issues.

Population

The researchers used the 2016 EDGD directory of active members to compile a list of 200 email addresses from which to solicit participants. Fifty members responded, providing a response rate of 25%. Of the 50 responses, 47 taught undergraduate technical graphics courses and 39 of those 47 were currently teaching one of these courses at their university. These 39 respondents met the selection criteria of being current instructors of a FTG course at a post-secondary institution.

Experience was reported as the number of years teaching introductory graphics. The mean experience for this study was 14.59 years (SD = 11.23) and ranged from 1 to 41 years of experience teaching technical graphics. These instructors currently taught between one and six courses per semester (M=1.81, SD=1.06). The academic rank of the participants ranged from graduate teaching assistants to full professor. Academic rank data were self-reported and ranged from lecturer to full professor as seen in *Table 1*.

Table 1. Academic rank of survey population.

Academic Rank	Percentage	Count
Instructor/Lecturer	23.08%	9
Teaching Assistant Professor	5.13%	2
Teaching Associate Professor	5.13%	2
Assistant Professor	12.82%	5
Associate Professor	20.51%	8
Professor	23.08%	9
Other	10.26%	4
Total		39

Results

FTG Course Enrollment. The survey asked the respondents about the number of sections and students per section. The number of sections varied by the university, ranging from 1 to 30 (M=7.76, SD=6.59, n=38), and the average number of students per section reported ranged from 15 to 380 (M=51.31, SD=61.2, n=39).

FTG Student Learning Objectives. Participants selected the objectives that most aligned with their FTG course from the performance objectives, as defined by Barr (2012). The objectives were placed in descending order by the percentage of participants that indicated that it aligned with their course. This ranking can be seen in *Table 2*.

Objectives	Percentage
Ability to create dimensions	94.87%
Ability to create section views	84.62%
Ability to sketch engineering objects in freehand mode	79.49%
Ability to visualize 3-D solid computer models	76.92%
Ability to create 2-D computer geometry	76.92%
Ability to create 3-D solid computer models	71.79%
Ability to generate engineering drawings from computer models	69.23%
Ability to perform design projects	56.41%
Ability to create presentation graphics	43.59%

	Table 2.	Course ob	iectives c	overed in	introductor	y engineering	graphics	courses.
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Ability to analyze 3-D computer models		
Ability to solve traditional descriptive geometry problems	35.90%	
Ability to create geometric construction with hand tools	25.64%	
Knowledge of manufacturing and rapid prototyping methods	17.95%	
Other	17.95%	

The "other" category allowed participants to write in their own objectives and yielded responses including, field sketching, creating moving assemblies, teamwork, tolerancing, and the ability to read and understand engineering drawings. From the list of objectives, the first twelve use the term ability, which indicates that the students should be able to demonstrate some sort of performance to meet this objective.

FTG Performance Assessment. Instructors indicated that a strong majority (94.87 percent, n=39) of courses require students to use an engineering graphics software as part of their course. When asked: "What percentage of the student's course grade is determined by assignments requiring students to demonstrate technical ability?" the instructors indicated that over half of the student's course grade is determined by their ability to perform technical tasks (M=65.18, SD=22.12, n=39). The type of technical tasks that the students create in the class were reported in *Figure 1*.

Responses indicate that the majority of fundamental courses require students to turn in technical sketches (92.31%), computer generated assemblies (89.74%), computer generated engineering drawings (69.23%), and computer generated 3D models (69.23%). Far fewer courses require students to turn in physical models created by hand (5.13%) and digitally fabricated models (15.38%). Respondents who selected the other option (12.82%) were given an open-ended text box and their responses included: field sketches, open-ended design project deliverables, written reports, presentations, and working drawing packages.

A range of assessment methods discussed in the literature sparked interest in the way that each type of work is assessed. *Figure 1,* below, shows the responses and reveals performance assessment method trends. A majority of the performance assessment relies on the instructors and teaching assistants. Ault and Fraser (2013), Baxter and Guerci (2003), Goh, Shukri, and Manao (2013), Hekman and Gordon (2013), Kirstukas (2016), and Kwon and McMains (2015) provide multiple discussions about automated systems and their advantages. However, the survey results suggest that these automated grading systems are not yet widespread despite their stated advantages.



Figure 1. Grading method utilized for different types of work assessed in postsecondary technical graphics courses.

Manual grading methods commonly relied on rubrics in order to define criteria and specify performance that qualifies for each level or grade. A majority of the participants (n=39, 79.49%) indicated that they utilize rubrics for assessing student work in their course.

Conclusions

Across universities, the data suggests that these courses have common objectives. A majority of the participants suggest that their FTG course covers dimensioning, section views, 2-D computer geometry, and 3-D solid computer models, how to sketch engineering objects in freehand mode, visualize 3-D solid computer models, generate engineering drawings from computer models, and perform design projects. These results support that most FTG courses are still currently utilizing the top rated outcomes reported by Barr (2012). This study expanded upon Barr's (2012) work by also including types of work and methods employed in these courses to measure these learning outcomes. This study found that the types of work assessed at a few universities, but the four primary types of student work assessed in FTG courses are technical sketches, computer generated engineering drawings, 3D models, and assemblies. Similarities can be seen across course objectives and types of student work assessed in FTG courses.

Multiple approaches to performance assessment have emerged in technical graphics courses, including computer-automated methods, example Ault and Fraser (2013) and Baxter and Guerci (2003); manual grading with rubrics or checklists, example Barr et al, (2014); verbal protocol analysis, example Menary, Robinson, & Belfast (2011); peer; self; observation; and adaptive comparative judgement. Each of these approaches is thoroughly described in the literature with their advantages and limitations, but it is difficult to tell the extent of their usage. Even though there are many positives, including the speed and accuracy of automated computer grading, the data suggest that these are not widely utilized in FTG courses at this time. However, the survey results from this study support that the majority of the performance assessment is completed by instructors and teaching assistants, with peer assessment in a distant third place. A few universities utilize self- assessment and computer automated assessment systems, but a majority of the performance assessment systems, but a majority of the performance assessment support the need for validated rubrics in fundamental EDG courses as they are the primary measure of student achievement.

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Learning Modules: Iterating the Flipped Classroom

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Abstract:

A perennial goal in education is how to encourage students to develop life-long learning skills and how to best prepare students for a world that is constantly changing. Pursuing this goal, we are developing learning modules, an iteration of flipped classrooms; these learning modules are integrated into engineering design I course to help students demonstrate competency of skills, mastery of concepts, and extended learning via self-directed problem solving. Various topics can be presented to students in these modules, and students in later years in the program can revisit the material on their own, as needed. We established a structural guide for creating a learning module based on studies of the contemporary learner's engagement. This upcoming academic year, we will implement the modules and evaluate their effectiveness in learning as well as both student perception and motivation.

Introduction

A common question in engineering education is how to best address content, problem solving, and group work in a traditional course that has regular face-to-face meeting times. One answer is a flipped classroom approach, moving lecture content online for students to view, read, and prepare between class meetings, and using meetings for problem work either individually or in groups (Zhu, 2016) (Holdhusen, 2015) (Gross & Dinehart, 2016). Lecture content in these studies was often voiced-over lectures or videos of lectures and examples. Others have tested out a fully online project-based design course, in which meetings are virtual, content is available online for students to work on at their own pace, and projects are completed by teams using virtual meeting spaces and other collaborative tools (James-Byrnes & Holdhusen, 2012). In some cases, discussion boards provide a place for students to collaborate and reflect after viewing videos in their flipped class (Zhu, 2016).

Multiple studies have found that flipping content delivery and problem solving

activities results in similar results to traditional classes, and students are positive or neutral about the change. At best, it is more efficient for students, and at worst, it results in similar grades and evaluation results as traditionally presented courses (Zhu, 2016) (Holdhusen, 2015) (Gross & Dinehart, 2016) (Sun, 2016). In the case where a fully online course was compared to a traditionally presented course, faculty involved reported that students were more engaged and provided better quality project deliverables than students in the traditional course, though variation of students in the small samples may also explain the discrepancy (James-Byrnes & Holdhusen, 2012).

Others have demonstrated that there are some practices that improve student engagement, performance, and even motivation. In one case, a traditional engineering graphics course was converted into a hybrid course with a robust online component that included a mix of voiced over lectures, online quizzes related to textbook readings, and videos demonstrating related skills (Branoff, Wiebe, & Shreve, 2011). In another, online modules with a combination of videos and quizzes, structured using conditional release tools, which improved end-of-semester working drawings for a design project (McInnis, Sobin, Bertozzi,

& Planchard, 2010). Providing assessment with content delivery outside of class has been shown to be effective at encouraging students to complete content preparation outside of class (Branoff T. , 2007). Recently, others are reporting that intentional instructional design can improve student motivation and possibly reduce gender-based gaps in motivation (Stolk, Zastavker, & Gross, 2018). Based in Self Determination Theory (SDT), the group was looking to investigate if motivation varied by course design or by gender. They show that motivation is positively influenced to be more intrinsic and identified, internal modes of motivation, in courses that emphasize project-based and non-traditional formats. They also found less of a gender-based gap in motivation in non-traditional courses (Stolk, Zastavker, & Gross, 2018). Previous work shows support for certain practices, including mixing content delivery, assessing content prior to using it in class, moving content delivery out of face-to-face meetings, and incorporating project work.

We look to take existing experience and research related to flipped classrooms and other non-traditional approaches to course design to create a variation on the more common definition of flipped. We are moving content delivery to outside of class meetings, but the focus of our work is designing and testing a learning module template that will increase student engagement with the content. In future semesters, we hope to develop learning modules for use throughout the curriculum; our initial rollout is for a first-year engineering design course. Goals for our learning modules are to 1) allow students to learn content and skills, solve hands-on problems, and complete self-inquiry outside of the classroom; 2) create modules that can be revisited later in semester or in future semesters as needed; 3) prove out a module development template, driven by engagement principles, that can be used for a variety of content areas; and 4) equip students with the confidence and capacity for self-led learning and information literacy.

Learning Module Template and Pilot

Before developing the learning modules for an introductory engineering design course, we established a structure to encourage engagement and positive motivation in students. We planned four areas for each module: Instruction, Examples, Exploration, and Self-Inquiry. Instruction will contain a mix of videos, readings, or recorded lectures, content-specific.

Examples could range from videos showing software tools or equipment instructions, to worked problems or simple assignments or demonstrations. Exploration requires a deliverable, potentially a quiz or assignment, and is intended to both require that students demonstrate understanding of the content and skill from the first two areas, as well as to provide an opportunity for students to stretch beyond the minimum requirement. This allows students who may be ahead or who are excited about the module to challenge themselves, while also supporting those students who may have started with less experience. The final piece of each module, Self-Inquiry, requires students to both reflect on what they've learned, as well as consider how the module relates to their personal areas of interest.

In implementing these modules, not only will the content vary, but the rigidity can also vary to the preference of the instructor and as appropriate for the material and the learners. Titled "Engineering Wizardry", the first learning module developed introduces microprocessors (Figure 1). At certain points in the module, students are required to demonstrate mastery of fundamental skills by scoring a minimum on quizzes before moving on. To demonstrate understanding of concepts, problem solving, and self- explorations, students are required to submit written responses, discussions, photos and videos of their solutions, inquiries, and findings. Students can move at their own pace through the lessons in the module.



Figure 1: Images from "Engineering Wizardry" instruction video

This module is being completed by first-semester engineering students over multiple weeks, and part of our inquiry is investigating how much structure is needed for our first- semester students. A second module covering basic SolidWorks skills is also being employed with the same students, and modules will also be developed for use in a first- year programming course for computer science students.

Built in to the pilot learning modules is student feedback; while the content of the feedback is not graded, students receive credit for completing this end-of-module survey. Our goal is to consider both the motivation of students at the completion of each module, as well as student opinions on the structure, content, and assessment of each module as we begin this implementation. Student will also self-report how much time they spend on each module.

Future Work

By providing learning modules that are completed outside of weekly class meetings, we have already met our first goal, and our second goal is met by creating a central repository for all engineering students, enabling them to return to learning modules in later semesters when they need to refresh their skills and knowledge in a certain area. Content areas currently being considered for module development are in first-year engineering design and first-year computer science courses. The template presented here will be tested through implementation over several semesters, with student and faculty feedback collected to improve upon the template as needed; our third goal will take several semesters to complete. Once the initial implementation is complete over two semesters, we will be able to add some quantitative analysis of motivation, and over the longer-term may be able to survey students and faculty about perceptions and ability surrounding student- led learning. We hope that developing these modules in sufficient areas will enable project- based classes to have more teambuilding and project work during class meetings, but will also better prepare students by their junior and senior year to learn skills such as programming and software skills on their own by seeking out content, readily available online. This skill will be invaluable to graduates in an ever-changing workplace.

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