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Comparison of Spatial Visualization Skills in Two Approaches to Entry-Level Graphic Courses

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Abstract

This paper evaluates possible benefits in offering an entry level engineering graphics course in one of two options: as a course where drafting and solid modeling is included, or as a course where only solid modeling is included. In both approaches, the main objective is to improve students' visualization skills, and both courses are offered with the use of software packages. Traditional projection drafting material is referred to as 2D material, and solid modeling material is referred to as 3D material. The reason for the study is that the trend in the past couple of decades, across engineering and engineering technology programs, has been to move from the typical 2D (drafting) course content to a 3D (solid modeling) course content. Some institutions have completely switched their approach, and some other institutions now have a hybrid offering (i.e., drafting and solid modeling in the same course). Results from this study have relevance in defining course content, particularly with the trend of including 2D and 3D in one single course.

This study looks specifically at a hybrid approach and a solid modeling approach. These two courses are offered a two different institutions that follow semester terms. The objective pursued is to identify any possible benefit, from the point of view of improved spatial visualization skills, from either of these two approaches. The visualization aptitude of the students was measured by administering the standard PSVT:R test before and after 2D and 3D topics were covered in the courses. Test results and demographic information was collected and included in the statistical analysis. The statistical results of the comparison are presented and indicate that, although there are some numerical differences between the two approaches, particularly in the area of standard deviations, they are not statistically significant to make a claim about any improvement in visualization skills due to the use of a hybrid course content, or the use of a solid modeling–only course content, or to the demographic factors studied.

Introduction

The dilemma of having a drafting-based course or a solid modeling-based course is something that became an issue in the past couple of decades, once solid modeler techniques were robust enough to support 3D modeling in industry[7]. The benefits of performing solid modeling techniques have been listed in various publications, most of them citing – among other things - automated design procedures, increased accuracy and quality, visualization of what-if scenarios, faster design and prototyping, better communication and integration, and standardized detailing and drafting practices[4]. The use of these modern 3D techniques for modeling is something that industry has adopted, situation that has propagated to academics, step by step.

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

In this field of graphics and design, which is more linked to STEM education, there are test such as the Purdue Spatial Visualization Test – Rotations[1] (PSVT:R), the Mental Cutting Test[10] (MCT), and Shepard-Metzler Rotation[9] (S-M) Test and its modification[12]. The underlying concept in these tests is the mental rotation of 3D objects. PSVT:R is perhaps one of the most commonly used test, and after its initial development in 1977, there have been reports about improvements and expansion of tests for spatial visualization and spatial orientation. For this PSVT:R in particular, there are reports based on trimetric representation[2], the use of realistic 3D views[14], and the use of pictorials[3].

As well, there are reports on techniques being utilized in order to develop spatial visualization skills (e.g., use of computer software[8], use of 3D printed models[5]), just as there are reports on the applicability and usefulness of various approaches (e.g., new and improved course content[11], training for drafting[6]). These reports are a very small set that indicates the interest in having appropriate materials for improvement of spatial visualization skills, perhaps given the reports that such skills are a significant factor predicting success in technological programs[11].

Methodology

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

The study was completed at two institutions, in institution (A – University of Wisconsin, Waukesha Campus) there is now a hybrid semester course where half of the course uses Autodesk's AutoCAD, and the other half of the semester is done utilizing Autodesk's Inventor. The other participating institution (B – Western Michigan University) offers a semester course which is based on instruction utilizing solid modeling packages, first Siemens' NX and then Dessault Systemes' CATIA. Table 1 summarizes the offerings at each institution. Both institutions have standard composition of students in terms of age, gender, and residence living. Institution (A) is a 2-year feeder to 4-yr campuses in the Wisconsin state system, and institution (B) is a 4-year campus in the Michigan state system. One reason of having two institutions in the study is the independent offerings, implying that there are no students that might have taken other courses. The students at both institutions have already decided on engineering or engineering technology programs, and both institutions are in a semester schedule. The main topics covered in each one of the compared approaches are listed in Table 2. The topics covered at the start of the semester at each institution reflect the fact that they do have different approaches, drafting (2D) or solid modeling (3D).

Table 1. Course offering at each institution.

Institution	A - WI	B - MI
Content	Hybrid (2D-3D)	Single (3D)
	Drafting/Solid Modeling	Solid Modeling
Format	Semester	Semester
Split	7/7 weeks	7/6 weeks
Software	AutoCAD, Inventor	NX, Catia
Students	Engineering	EngTech/Eng

Table 2. Topics covered on each one of the offered courses.

Institution	
A - WI	**B - MI**
Orthographic Projections	S.M. Concepts
Auxiliary Views	Constructive Solid Geometry
Section Views	Constraints
Dimensioning	
	Orthographic Projections
S.M. Concepts	Auxiliary Views
Constructive Solid Geometry	Section Views
Constraints	Drafting
Assemblies	Dimensioning
GDT	Assembly

The instrument selected to evaluate spatial visualization skills of the students was the Purdue test for rotations (PVST:R), given that it is an instrument that requires higher level of spatial visualization skills because of the use of inclined, oblique, and curved surfaces[13]. This set of 30 questions, where the number of mental manipulations increases as the test progresses, was administered three times to both groups of students: at the beginning of the semester, midway through the semester, and at the end of the semester. The decision to include a midway evaluation was due to the fact that it is the moment when 2D instruction switches to 3D instruction at institution (A), and it is the moment when institution (B) switches from the first 3D software (NX) to the second one (CATIA). Additionally, when the test was administered for the first time, demographic information was collected from each participant, mainly gender, race, and program of study.

Results

The surveys were administered to the students during the Fall 2015, and their participation was completely optional. The demographic information for both groups is provided in Table 3. In the first institution (A) there was a total of 19 students participating (from a total of 20 registered), and at institution (B) there was a group of 36 participants (from 40 students registered students). The breakdown based on gender is similar at both institutions (10.5% at A, versus 13.9% at B), with slightly higher percentages of under-represented and no traditional students at institution B (22.2% versus 15.8% for under-represented students, and 33.3% versus 15.8% for non-traditional students). Basically all of the students live off campus, at both institutions.

Table 3. Demographics for each institution participating in the comparison.

Demographic Information				
	Institution A (Graphics)		Institution B (Solid Modeling)	
	#	%	#	%
Number of Students	19		36	
Female Students	2	10.5	5	13.9
Male Students	17	89.5	31	86.1
Under-represented (gender, race)	3	15.8	8	22.2
Non-traditional (>25)	3	15.8	12	33.3

Participation in the survey was without any incentive offered, besides the explanation indicating that this will be used for possible redefinition of course content, and that their help will be greatly appreciated. The test was administered during lecture time, during the last 25 minutes, and there has been a high level of participation (95% at location A, and 90% at location B). Two examples were explained before the first time they did the test and, as clarification, it was indicated that all figures represent solid objects (3D). The distribution of scores for each one of the questions on the test is shown in Figure 1, which illustrates the expected downward trend, as well as the expected trend for the three levels of mental rotational manipulations included in the test.

Descriptive statistics for the compiled test scores at both institutions are provided in the upper part of Table 4. From the table it can be stated that the scores have some minor difference between institutions, these results indicate as well that the average scores, as the semester progresses, show slight increases at both institutions. Similarly, the results show the decreasing trend of the standard deviation as the semester progresses. Regarding the minimum/maximum scores, both institutions show a small increase in the minimum score at the end of the semester.

In order to find out if there is any statistically significant differences between results from each institution, or from pre- to post-, a t-test was performed on the different sets of data. The lower part of Table 4 shows the results when 95% confidence level for the hypothesis is applied. In this case all confidence intervals indicate that there is no statistical significance between the sets analyzed. In order to have statistical significance, as shown in the table for each institution, there needs to be a confidence probability of 35% at institution (A), and 55% at institution (B), which are very low confidence levels.

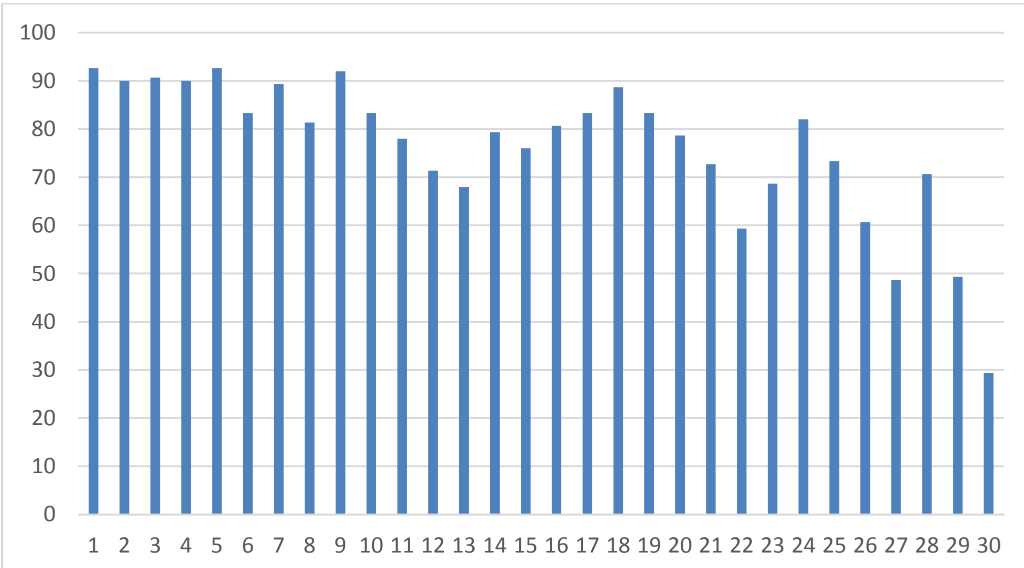

Figure 1. Average scores for each survey question.

Table 4. Summary of Results Comparing 2D and 3D Course Content.

Evaluation Results						
	Institution A			Institution B		
	Pre-	*Mid-*	*Post-*	*Pre-*	*Mid-*	*Post-*
Average	22.84	23.83	24.00	22.43	23.72	24.07
Standard Deviation	4.48	4.86	4.58	4.75	4.00	2.52
Minimum Score	15	15	17	13	12	19
Maximum Score	30	30	30	30	30	29
Median Score	22	24	23	23	24	24
Probability (for t-test)	0.05	0.05	0.05	0.05	0.05	0.05
Lower Limit (LCI)	20.681	21.413	21.464	20.798	22.069	22.674
Upper Limit (UCI)	24.999	26.247	26.536	24.062	25.958	25.371

Looking at the demographic data for a possible factor that predict performance in the administered mental visualization test, a one-way ANOVA was performed for each of the selected factors (i.e., gender – 2 levels, age – grouped in 4 levels from <20 to >30, status in college – in 5 levels from first-year to senior plus other, and nationality – in 2 levels – American and non-American). There was no statistically significant factor on any of the administered surveys, either by institution or combined (since they are considered compatible groups). The closest predictor was gender, with a $p < 0.27$, which is of no statistical significance.

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

Conclusions

The results from this comparison indicate numerical differences between the two course approaches, but there is no statistically significant ($p < 0.05$) difference in the results. Similarly, the results indicate an improvement in the performance at each institutions as the semester term progresses, but without statistical significance. Therefore, even though there is no objective conclusion in terms of the benefit of one instructional approach over the other (2D *vs* 3D), this study has brought attention to other aspects that need to be investigated (*e.g.*, course exercises, teaching approaches, test applicability). Demographic information does not provide a significant predicting factor either.

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

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