Developing a Nationally Normed Test for Engineering Graphics - First Pilot Tests and Results

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Abstract

This paper describes a work in progress. A variety of engineering and graphics tests that have been used nationally have been collected and studied. From these tests, an engineering graphics pre- and post-test has been developed. As a pre-test, this test will provide engineering graphics teachers with some information about what their students know and don't know and whether they can visualize in three dimensions. As a post-test, it will provide information on the knowledge and skills that have been gained during an academic term or over an academic year. This test is a multiple choice test and is designed to be administered on the Web. When considering Bloom's Taxonomy of Learning, this is a recognition test at Level One or Two – Knowledge or Comprehension. This multiple choice test done on the Web allows the faculty member to get the results quickly. The authors will be validating the answers on the test.

In addition, a practical test – one where the students must demonstrate knowledge and skill by producing sketches and drawings.- has been developed for use as a post-test. This test requires a higher level of learning on Bloom's Taxonomy – Levels Three and Four – Application and Analysis.

Both of these tests are being administered during the 2003 – 2004 academic year and this paper will provide the early results about gains in student knowledge.

Introduction and Background

Until recently, Engineering Graphics has been a required course at most institutions, helping to create a strong foundation for the undergraduate engineering and technology programs. Through the 1970s, a full year of Engineering Graphics instruction was part of undergraduate programs. Engineering Colleges, with the pressure to teach more information and skills in the undergraduate program, either reduced the number of credits and courses or eliminated Engineering Graphics altogether. Engineering Graphics is still a critical area of knowledge for students going to work in industry. As such, programs need to include graphics, but it must be taught efficiently. In the past, with an entire year to cover graphics and descriptive geometry, students had sufficient time to develop visualization skills and learn to create and read engineering drawings. With this much instruction and time to practice graphics skills, the instruction improved visualization skills which are critical for all students. Now programs have to be efficient in delivering graphics instruction and there needs to be a standard way to measure improvement in visualization skills and the learning of ANSI standard engineering graphics. In order to measure efficiency and effectiveness, a nationally normed test is needed so that faculty can work to improve the efficiency and effectiveness and measure the amount of improvement. This means that faculty who teach Engineering Graphics have to agree on the required topics.

Why a Test is Needed

An earlier paper[1] noted a need for a test to determine skill and knowledge before and after taking graphics courses; significant tests have been developed by Guay[2] at Purdue and Sorby[3] at Michigan Technical University. Guay's test evaluates visualization skills with rotation problems; Sorby's test covers a broad range of topics pertinent to Engineering Graphics. The Guay test has been available for over 25 years and has been given to over 400,000 students. These tests have been a valuable resource for us; however, they do not totally cover our 21st century curriculum.

At Ohio State we have two groups of entering freshman engineering students and we want to be sure that both the Honors and non-Honors students are getting the similar instruction in graphics. Historically we have developed mid-term and final examinations each quarter for each graphics course. There was some continuity and some comparability but no assurance that the tests were equal in content or difficulty.

Using the normed test allows comparison of part of the graphics ability for both sets of students. When 75 percent of the Honors students are separated from the majority of the entering freshman class it tends to change the grade profile. Results from this test can help the faculty establish appropriate grades for both groups. In addition, we are continually working on improving instruction and instructional materials. This test will allow us to determine the effectiveness of alternate methods and materials.

Within the engineering graphics community, faculty are working to include as much instruction as possible in limited time. They are trying new approaches and this test can provide them with a method for measuring results. This can be particularly important when there are not enough sections of a class to have both pilot and control groups. As we refine the test it will be made available to faculty teaching similar curricula at other institutions.

Compare with FCI for Physics

Nationally normed tests can have a profound effect on the educational state of a discipline. As an example, consider the case in physics. In the early 90's, the Force Concept Inventory (FCI) was developed and published.[5] Soon physics instructors at a variety of institutions, from two-year colleges to elite universities, were administering the FCI and often modifying their instruction as a result. The FCI not only provided individual instructors with information about the effectiveness of their instruction, it also gave instructors teaching in a variety of settings a way of quantifying and discussing the effectiveness of various instructional methods. Further, Hake's analysis of FCI scores guided the physics community to calculating and reporting the normalized gain in pre-test, post-test situations. His analysis also indicated a link between FCI gains and various instructional methods.[6] Indeed, it is now the case that any time a report of an instructional innovation in mechanics is made, physics educators expect to see mention of the resulting FCI scores and gains.

The success of the FCI led to the development of standardized tests in a variety of other areas of physics, including the Conceptual Survey of Electricity and Magnetism (CSEM), Determining and Interpreting Resistive Electric Circuit Concept Test (DIRECT), Lunar Phases Concept Inventory (LCPI), Astronomy Diagnostic Test (ADT), and Test of Understanding of Graphs – Kinematics (TUG-K).[7-10] As is the case with the FCI, these instruments provide the basis for physics and astronomy educators to evaluate and discuss the effectiveness of their instructional methods. It is the authors' intent that this test should help Engineering Graphics faculty evaluate and discuss the effectiveness of their instructional methods as well.

History

Several tests have been developed over the last two decades to evaluate visualization skills. Among them are the Purdue Spatial Visualization Test: Rotations by Guay (referred to earlier) and the Mental Rotations Test developed by Vandenberg and Kuse.[11] The Sorby test mentioned earlier was designed to test several areas of graphics knowledge. It has been used extensively at Michigan Technical University and by other institutions, including Ohio State. A paper by Crittenden in 1996 reported on an analysis of examinations given to freshman students of engineering design graphics.[12] This analysis indicated considerable variety in the problems given and in the requirements for a final examination or for of a series of quizzes.

Engineering Graphics at Ohio State has always included final examinations. These have involved both questions requiring a choice or a simple answer and graphics practice (formerly mechanical drawing and currently sketching or CADD). These examinations were created for each class each quarter, and while similar, had no evaluation for uniformity or equal difficulty. In recent years we have also used the PSVT: R as a tool to evaluate the students' visualization skills at the beginning of the class; the use was primarily historical and was not used to align the curriculum to the indicated deficiencies in entering students' knowledge. The goal of our new test is to evaluate the incoming students and to modify the curriculum to meet their needs and then determine the amount of improvement. We have also used employer surveys in the past to learn if our graduates are meeting employer needs and expectations and have modified curricula to better meet these needs. We shall continue to do so in the future.

Test Content

The current test is a modification of one developed by Sheryl Sorby at Michigan Technological University. The 50 questions include visualization, scales, orthographic views, pictorial views, dimensioning and tolerances, sections, conventional practice and reading working drawings, both detail and assembly. There are five questions in each topical area except "reading working drawings"; there are ten questions on detail drawings and five on an assembly drawing. Some of these questions, of course, relate back to the seven topics covered in individual questions but require study of the working drawing to determine the correct answer. The development of our test from the Sorby base was done by examining our curriculum and comparing it to the curricula in use at other institutions or recommended in current literature. Table 1 shows a comparison of the topics noted by several authors. Using Crittenden's work[12] as a base we compared to a proposal by Barr in 1999[13], a survey of nine universities' programs by Meyers in 1999[14], a proposed curriculum by Branoff, Hartman and Wiebe[15], a plan developed by Smith[16], and the latest proposal of desired educational outcomes by Barr[17]. Comparing these lists of topics to our curriculum we noted the most common topics and found a great deal of agreement among the various authors. Not every common topic could be included in our examination which is a web-based multiple choice test; questions requiring sketching or use of CADD systems would not fit in our web-based test. We continue to test these skills independently of our normed test.

Application of the Test

As background information, Engineering Graphics and CAD are required for all engineering students at Ohio State. There are two sequences of courses. Engr 181 and 183 are required for all students. Engr H191, H192, and H193 are an option for Honors students and replace 181 and 183. The graphics and CAD content is covered in H191 for the Honors students (and used in H193) and in both 181 and 183 for the rest of the students. In Autumn Quarter 2003, the draft copy of the test was posted on the Web for the students in two of eight sections of Engr H191 as a pretest.

At the end of the quarter, the test was again posted on the Web for these same two sections and was given as a paper test in the other six sections. These 50 questions were 40 percent of the final exam grade for all sections. Three additional problems made up the other 60 percent of the final exam. The students in the six sections recorded their answers on mark-sense sheets and these were analyzed on the university computing facilities. The other three problems are shown in Figures 1, 2, and 3. (Figures to be included in Final Document) The first problem is a dimensioning problem where the students were given orthographic views and asked to completely dimension the views. The second problem is a set of working drawings where students had to read the drawings and answer questions. The third problem required the students to draw a missing view and pictorial when given two views. The last three questions were included as part of the test because we believe that students should be able to do more than recognize whether something is correct. We believe that they should be able to draw orthographic and pictorial views and read working drawings.

The results from the post-test are shown in Table 1 and Table 2. The following section provides more discussion about the results.

At Ohio State, the test will be used as a pre-test to determine the general graphics knowledge level of the incoming first-year class in both the Honors (Engr H191) and regular sections (Engr 181). It will be used as part of the final in Engr H191 and, later, in Engr 183. Note that all of the engineering graphics and CAD is covered in Engr H191 for the Honors students. In the Engr 181 and 183, engineering graphics and CAD are only part of both courses.

TABLE 1: TOPICS CONSIDERED BY SEVERAL AUTHORS

**These topics require CADD or manual graphics and cannot be included in a multiple choice computer-test.

CRITTENDEN	BARR ('99)	MEYERS	BRANOFF et al	SMITH	BARR ('03)	OSU TEST
	Items scoring 3.0					
	or better out of 5.					
Descriptive Geometry		Space Geometry				
Developments						
Dimensioning	Dimensioning	Dimensioning	Dimensioning	Dimensioning	Dimensioning	Dimensioning
Drafting Skills**				Engrg.Drawing	Engrg. Drawing	
Geometric Const'n.						
Geometry			Geometry			
Graphing		Charts & Graphs				
Intersections						
Kinematics					Kinematic Simulation**	
Lettering						
Mathematics						
Orthographic Projection	Orthographic Proj'n.	Orthographic Proj'n.	Multiviews & Aux.	Orthographic Proj'n.		Orthographic Proj'n.
Reading Drawings	Dwg. Stds. & Codes					Reading Drawings
Scales						Scales
Section Views	Sections	Sections	Sections	Section Views	Sectioning	Sections
Sketching**	Manual Sketching**	Freehand Sketching**	Freehand Sketching**		Freehand Sketching**	
Software Use**						
Solid Modeling**	3D Modeling**	3-D Modeling**	CB & Solid Modlg.**	Feature-based Mod.**	3-D Modeling**	
Thds. & Fasteners	Threads	Fastening & Welds		Fasteners		Threads & Fasteners
Tolerances	Tolerances	Fits & Tolerances				Fits & Tolerances
Visualization	3-D Visualization	Visualization	Visualization			Visualization
	2-D CADD**	CADD**			2-D Comp. Sketch**	
	Design Process			Intro. To Design		
	Pictorials	Pictorial Views	Pictorials	Pictorial Views		Pictorial Views
	Reverse Engrg.		Mfg. Processes	Design for Mfg.	Mfg. & Rapid Proto.	
	Surface Modeling**					
	Team Projects	Team Projects		Team Work	Design Project -Team	
		Working Drawings**	Working Drawings**			
		G D & T				
		Hands-on Labs				
		Spreadsheets**				
				Rapid Prototyping		
				Assembly Modeling**	Assembly Modeling**	

Results of First Uses - Item Analysis, Validity, Statistics, Areas for Improvement

An item analysis was performed, looking at three major aspects of each item: the difficulty, discrimination, and attractiveness of distractors.[18] The difficulty is the fraction of students who correctly answered the question. The discrimination indicates how well an item differentiates between students who did well overall on the test and those who did not do well. A summary of these data for the post test administration is shown in Table 1. It is generally considered good test construction to have items vary in difficulty, as this helps to distinguish between levels of student understanding. The item difficulty varied from 0.13 to 0.99, with an average of 0.76 and a standard deviation of 0.24, showing that the difficulty of the items varied. The discrimination analysis revealed only one item with a negative discrimination (meaning that only on this one item did students performing poorly overall outperform the high-scoring students). The average discrimination was 0.22 with a standard deviation of 0.16. Notice that items 22 and 25 are not included; in the administration of the test, it was seen that these two were problematic, and so were omitted from the current analysis. The specific issues with these items will be discussed below.

Further, an analysis of the pretest data was performed to see whether all the distractors (wrong answers) were being selected by at least some small portion of the class; conventional test construction wisdom is that if distractors are not being selected, they should either be removed or replaced with more attractive distractors. For this analysis, both the pretest and posttest data were considered. A chart of distractors not chosen for each item in either administration is shown in Table 2. We see that some questions should be modified to either make the distractors more attractive or to eliminate the unused distractors, but that, for the most part, most of the options are being selected by some fraction of the students in either the posttest or pretest. When distractors are not chosen by any of the students taking the exam, it may mean that they were not good choices. We will interview some of the students about how they interpreted these answers. Results from these interviews will also aid us in creating new distractors that are more appealing to the students taking the test, leading to a better instrument.

In order for an instrument such as this to be useful, it must be both valid and reliable. The overall validity, whether or not the test measures what it is supposed to measure accurately, cannot be determined via one administration of the instrument, and so will not be discussed here. The construct validity, whether or not the test measures what the authors claim it does, can be evaluated via a factor analysis. We will have a factor analysis as part of future work. Given the description above of how the topics for the test were determined and questions selected, the content validity of the instrument is high.

Reliability refers to the consistency of the test's ability in measuring what it intends to measure. A common measure of an exam's reliability is the Cronbach alpha. What the Cronbach alpha essentially does is take the exam and divide it into all possible halves, comparing the variance in student performance on one half of the test with the variance on the other half. Alpha can vary between 0 and 1, and a value of 0.80 or above is considered acceptable. Analysis of the post-test administration of this instrument yielded an alpha of .94, so it can be said to be a reliable measure of a student's understanding of general engineering graphics principles.

Now that we have the results for the test, we are going to make some changes to the figures. Some of the current figures are simply not very clear and not of the quality that we expect from our students. Questions 22 and 25 were questions about reading scales. In 22 we had provided two correct answers and in 25 there were no correct answers provided.

Table 1. Statistical Results for Test Questions

Question	Difficulty	Discrimination	Question	Difficulty	Discrimination
1	0.88	0.12	27	0.84	0.23
2	0.93	0.14	28	0.77	0.39
3	0.91	0.22	29	0.63	0.37
4	0.96	0.01	30	0.65	0.26
5	0.98	0.07	31	0.85	0.14
6	0.86	0.22	32	0.97	0.10
7	0.33	0.52	33	0.87	0.17
8	0.87	0.19	34	0.73	0.13
9	0.52	0.52	35	0.84	0.07
10	0.91	0.11	36	0.86	0.22
11	0.49	0.47	37	0.95	0.14
12	0.46	0.38	38	0.98	0.01
13	0.91	0.19	39	0.93	0.16
14	0.27	0.26	40	0.87	0.31
15	0.86	0.20	41	0.90	0.26
16	0.99	0.01	42	0.79	0.35
17	0.91	0.07	43	0.81	0.41
18	0.81	0.31	44	0.23	0.20
19	0.97	0.05	45	0.83	0.41
20	0.13	0.03	46	0.46	0.33
21	0.98	0.01	47	0.77	0.39
23	0.96	0.01	48	0.82	0.33
24	0.13	-0.07	49	0.71	0.42
26	0.43	0.52	50	0.80	0.32

Table 2. Unused Distractors

Question	Unused Distractors	Question	Unused Distractors
1		27	
2		28	
3	A	29	
4	A	30	
5	A,B	31	D
6	E	32	E
7		33	
8		34	
9		35	A,C
10		36	D
11	B	37	
12		38	D,E
13		39	
14		40	
15	E	41	E
16	C,E	42	E
17	C	43	
18		44	
19		45	
20		46	E
21	B	47	E
23	A,C,E	48	
24	C,D	49	
26		50	

Conclusions and Plans

A normed or standard test is needed within the Engineering Graphics community to help faculty define what to teach and to measure effectiveness of both normal and alternate teaching methods. The use of normed or standard tests in the Physics Education community has proved to be very effective.

Item analysis and the Cronbach alpha test showed good statistics for this test. Item analysis of previous versions have shown that the questions and answers are valid.

Some of the figures on the test are not as clear as they need to be and work will be done to make the figures of uniformly good quality. Some of the answers provided for the multiple choice questions were selected by few of the students or no students. Different answers will need to be created that are better distractors based on student misconceptions.

While this test can be used as a pretest and part of a post test, additional problems and answers need to be developed that test the students ability to do engineering graphics as well as read/recognize whether drawings are correct or not.

The issue of testing whether students can use CAD to create solid models and drawings needs to be addressed. Should the students have partially completed drawings in the appropriate CAD file type and then complete the three or four assignments on the computer? In the past, we have had students make drawings with instruments and sketch. Today, students sketch and use CAD. This is a question that needs to be discussed within the Engineering Graphics community.

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