AC 2011-623: RE-CONFIGURING AN ENGINEERING DRAWING COURSE: MAPPING GOALS AND METHODS TO LEVERAGE CADD FUNCTIONALITY

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Re-configuring an Engineering Drawing Course: Mapping Goals and Methods to Leverage CADD Functionality

Abstract

The availability and rapid evolution of Computer-Aided Design and Drafting (CADD) software plays a central role in shaping drawing classes in several ways. First, industry has migrated almost universally to CADD as a method of design and documentation, and expects engineering graduates to be competent in its use. Second, ever-more powerful CADD tools bring with them the possibility of new teaching methods. Finally, the rate of change in technology requires an Engineering Technology program to continually refresh its curriculum in order to best meet the needs of its students.

This paper illustrates a procedure for re-configuring a first-year Engineering Technology drawing course in a way that connects instructional activities and exercises with clearly-defined goals based on industry practice. The procedure maps those goals from the old to the new lesson plans even as methods are changed to leverage CADD functionality. The context of this illustration is a course that has traditionally been taught with an emphasis on manual (drawing board) over CADD work. The course and the approach to its reconfiguration are built on the foundational pedagogical approach of learning by doing, as they are learning a skill, not just knowledge. The basic cycle of "Hear, See, Do, Receive Correction, Do Again" is implemented both on the board and with CADD.

The reconfiguration of the course was motivated by a desire to increase the students' competency on CADD, as well as to expose them to a broader range of CADD functions used in industry. This drove an increase in the amount of time the students are using CADD. Some goals of the course cannot be mapped into the CADD environment. These include competency with lettering, geometric constructions, use of drawing instruments, and descriptive geometry. Other goals can be met either on the board or on CADD. Examples include proper techniques for making a drawing, practicing orthographic projections, sections, and auxiliary views. In the reconfigured course, these are taught almost exclusively on CADD. A third group of goals can be met only on CADD, including competency in basic modeling commands, and exposure to relatively new software models used in industry, such as Frame Generator.

The effectiveness of the reconfigured course will be assessed in several ways. First, students taking the course before and after reconfiguration will be given the same or similar exams. Any significant drop in scores will indicate that course goals are not being met. Second, students' performance in competencies not previously covered will be assessed by exercises or exams.

Introduction

The University of Pittsburgh at Johnstown Engineering Technology (ET) program, like many others, requires all students to take a course in Engineering Drawing. This requirement is important because engineers frequently need to convey information in graphical form. For drawings to be correctly constructed and interpreted requires a shared understanding of the rules of the "language" of mechanical drawings.

"Mechanical drawing is a language of lines, views, dimensions, signs and abbreviations, notes and explanatory matter, all for the positive conveying of exact information. … A drawing, therefore, … should be absolutely free from ambiguity…" [1]

The University's Engineering Drawing course (ET0011) is designed to teach students this language of Mechanical Drawing, so they can convey and interpret graphical information free from ambiguity, but it also meets other goals. Designing new parts often requires an engineer to construct geometry in a way that meets a specific design intent (for example, centering a circle on a triangle.) An engineer must also be able to extract needed data from a limited expression of positional information (for example, finding the distance between two skew lines which are shown only in two two-dimensional views.) For these reasons, ET0011 includes goals of competence in geometric construction and descriptive geometry, which are distinct from the goals of competence in creating or interpreting mechanical drawings.

When ET0011 was first taught, Computer-Aided Design and Drafting (CADD) did not exist, so the course taught only manual techniques on drawing boards. This was perfectly adequate to meet the goals stated above. At the same time, it was incidentally teaching the only method of drawing creation that was commonly practiced in industry. As CADD became available, and was rapidly deployed in most companies engaged in engineering work, it became apparent that students and their prospective employers would benefit from a course that enabled them to gain competence in some form of CADD. Therefore, ET0011 was reconfigured from two three-hour sessions per week on the drawing board to three two-hour sessions, with one of those sessions on CADD. An additional modification occurred with the advent of 3-dimensional (3-D) parametric solid modeling, when several of the CADD sessions in ET0011 were devoted to teaching the basics of a 3-D program.

Since that time, CADD functionality and deployment has continued to expand. The University of Pittsburgh at Johnstown, like any other that trains engineers, must work to meet the challenge expressed below.

"The challenge for engineering and design engineering technology academic programs is to keep curricula current in the face of the onslaught of technical progress in many areas. Furthermore, the challenge is exacerbated by the fact that the tools of technology are being upgraded constantly in industry. …we can best serve our students in the CAD area by ensuring that key technologies and trends are taught and incorporated into classes. This will provide a foundation for continued growth and competency as industry develops new processes and methods."[2]

Not all of our graduates engage in graphical communication, but those who do are universally using CADD. As a result, the goals of ET0011 are being expanded to include a higher level of competence with both 2-D and 3-D CADD programs, as well as an introduction to some functions that are commonly used in industry, such as assembly modeling and sheet metal design. To meet these new goals, the course is being reconfigured such that 2/3 instead of 1/3 of class time is spent on CADD. This reconfiguration has been implemented on a pilot basis in one of three sections of the course.

In the process of redesigning the course, pre-existing goals must not be thoughtlessly ignored. Therefore, a reconfiguration method was developed that maps the connection between lesson plans and course objectives from the original to the new structure. It is anticipated that this method will be useful in the future, as ET0011 continues to adapt to the continually changing CADD environment. This method could also be applied effectively by other schools that are updating drawing classes, as well as other types of courses.

Reconfiguration Method

A disciplined method for reconfiguring the drawing course is necessary for several reasons. First, the methods employed need to ensure continued support of the established goals of the course. Second, the linkage between goals and methods needs to be documented in order to prevent a gradual drift away from the goals as incremental changes are made to lesson plans. A transparent methodology supports the process of collaboration as colleagues discuss course objectives and redesign lesson plans. Finally, a clear methodology can assist in communicating the effectiveness of the reconfigured course to others, including department heads and ABET evaluators.

The core concept of this reconfiguration method is to link each instructional activity to a course objective, and to plan new instructional activities that provide an appropriate level of support for the same and/or new objectives. This concept is supported by a graphic device that enables the visualization of the linkages between methods and goals in both the existing and the reconfigured course structures. An example of such a graphic device is given in Figure 1. This is not the only way to visualize the linkages, but any other visualization should include all of the course objectives and assignments, as well as the connections between them.

In Figure 1, the goals or objectives of the course are listed in the center column. With them are listed a desired levels of competence to be achieved by the students. The competence levels are ranked from 1 to 5, with 1 being “Familiar with the concept or skill”; 3 is “Competent, with a foundation for further growth,” and 5 is “Firmly mastered.” The desired level of competence may be revised during the reconfiguration process. Finally, new goals may be added for the new configuration.

The other four columns in Figure 1 consist of stacks of segments which represent individual class sessions. Lines are drawn from segments in the lesson plans to goals in the center column. These lines represent the idea that a particular session supports a course goal, or sometimes more than one course goal. For example, the second CADD session in the old lesson plan supports the goals of AutoCAD (ACAD) basics, as well as Geometric Construction.

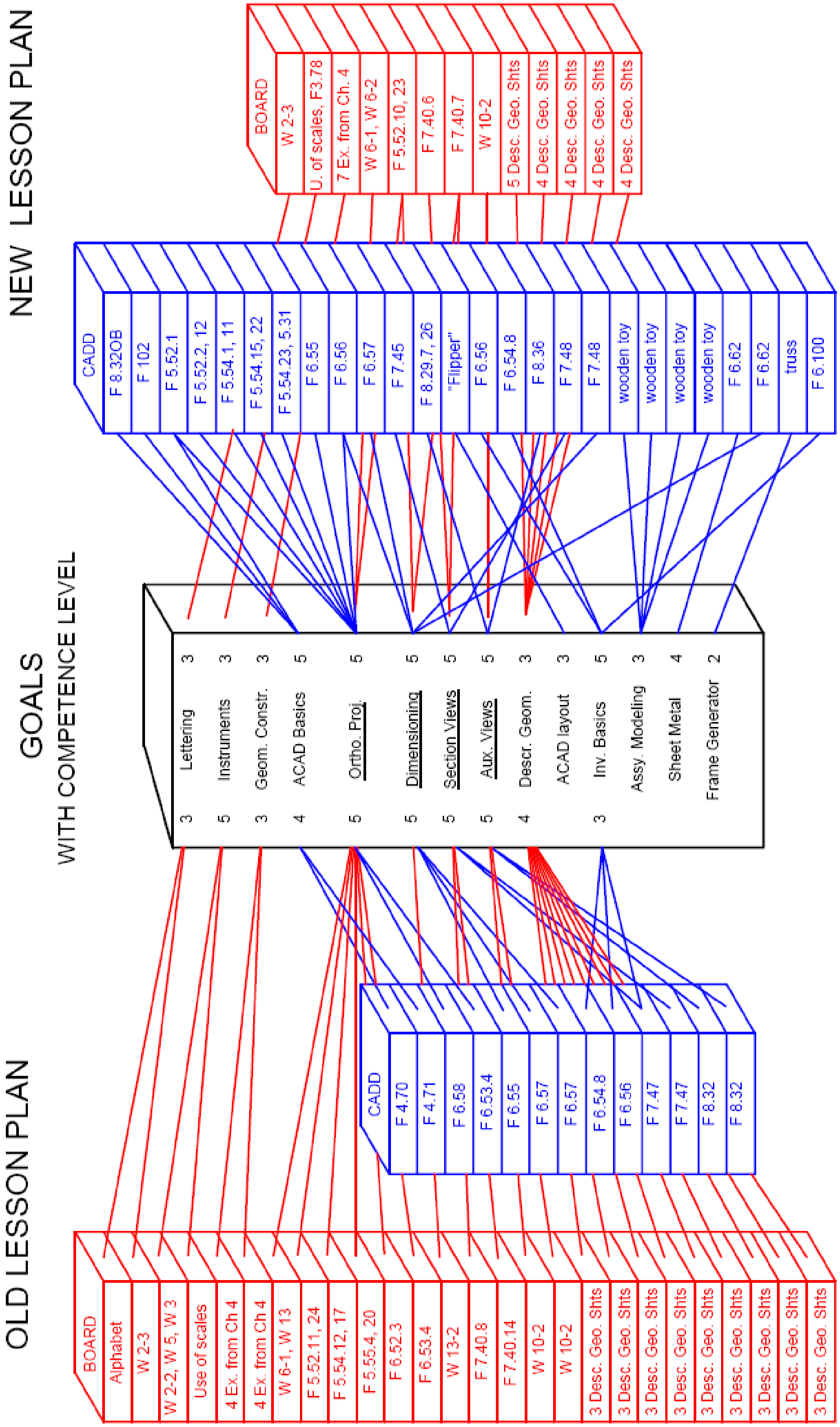


Figure 1: Visual representation of mapping method.

The proposed reconfiguration procedure consists of the following steps:
1) Identify current course goals and/or objectives, including the expected level of competence.
2) Link current activities to the course goals. If there are activities that do not support course goals, they can be eliminated right away.
3) Identify desired changes and/or additions to course goals.
4) Plan new activities that support the new course goals, including those goals that continue from the previous curriculum.
5) Visually map the goals with connections to teaching activities, to make the connections transparent and to establish the basis for dialog and modification.
6) Implement the new teaching activities.
7) Evaluate whether or not the new teaching activities accomplish the course objectives.

Changes made to ET0011

When applying the proposed reconfiguration procedure to ET0011, the original and revised goals were identified, and are illustrated by Figure 1. A core group of goals, indicated by underlining, consist of Orthographic Projection, Dimensioning, Section Views, and Auxiliary Views. These core goals have a desired level of competence of "5", or "Firmly mastered," before and after the reconfiguration. It is understood that the goals listed are short-hand for more fully expressed goals. For example, "Orthographic Projection" means that students should be able to complete unfinished views based on sufficient information given, draw a missing view based on two given views, construct adequate views based on a given isometric view, and develop an accurate mental image of a part based on given views.

The reconfiguration of ET0011 includes a modification of the desired level of competence for some of the goals. Regarding the tools used to make drawings, the emphasis shifts from manual drawing board instruments to CADD, in accordance with the changing needs of engineering graduates. This is shown by the desired level of competence for use of Instruments being reduced from 5 to 3, and increased from 4 to 5 for AutoCAD Basics, and from 3 to 5 for Inventor Basics.

Some goals were also added during the reconfiguration process. In the old lesson plan, AutoCAD was used only for drawing parts, but it is also a very useful tool for laying out geometry for new designs. Therefore, a goal was added that students become competent in the use of AutoCAD for design layouts.

Figure 1 also illustrates the fact that the reconfiguration of ET0011 facilitated the addition of course goals and exercises that expose the students to powerful new CADD functionality. These include Assembly Modeling, Sheet Metal Design, and Frame Generator. While time is not available to permit complete mastery of these subjects, this exposure demonstrates the usefulness of a few modules and can motivate the student to continue exploring independently.

Finally, the desired level of competence for Descriptive Geometry was reduced from 4 to 3. This reflects the reality that there is simply less time available to devote to this goal. It is also supported by the fact that in recent years some more difficult exercises have been assigned for practice, but tests did not include problems of the same level of difficulty. In other words, a de facto reduction in the desired level of competence has already taken place.

As illustrated in Figure 1, the “Old” and “New” lesson plans are linked with lines to course goals that they support. Noticeably, there are four goals that can be met only on the board. These are Lettering, use of Instruments, Geometric Construction, and Descriptive Geometry. Perhaps the biggest challenge of this reconfiguration process is to adequately support these goals with a reduced number of sessions on the board. There is one less exercise devoted to Lettering, but an emphasis on lettering can be continued for all of the board exercises as a way of compensating. A reduction in the amount of time allocated to the use of Instruments is justified by the lower desired level of competence. Geometric construction is condensed to one session with 7 exercises, from two sessions with 8 exercises. Finally, Descriptive Geometry is allocated 5 sessions with a total of 21 exercises, down from 9 sessions with 27 exercises.

Figure 1 shows that all four “core” goals are supported by both board and CADD sessions. These goals are supported by about the same total number of sessions under the old and new lesson plans, as summarized in Table 1. However, there is a significant increase in the number of supporting exercises in the new plan. This is accomplished by two means. First, board exercises are compressed 20%, from an average of 1.2 exercises per session to 1.4 exercises per session. Second, CADD exercises are compressed 80%, from 0.66 exercises per session to 1.2 exercises per session. This greater compression on CADD is made possible by the fact that drawings can be made more efficiently on CADD than on the board, and by the use of templates to focus student activity on the subject matter at hand rather than on simply reproducing geometry. An example of a template used to teach Orthographic Projections is given in Figure 2. In this exercise, the problem geometry is given, and does not need to be re-drawn. The student can spend all of his or her time analyzing the parts and determining where to add lines to complete the views.

In the University of Pittsburgh at Johnstown’s schedule, a semester consists of 14 weeks of instruction. The course includes 4 tests, 3 of which are given during a class session in the semester. The fourth is given during finals week. This leaves a total of 39 class sessions. Under the old lesson plan, 26 of those sessions were on the drawing board (far left, or first column), and 13 on CADD (second column). Under the new lesson plan, those numbers are reversed. Each segment lists the assignment that is given for that session. It is understood that this also represents the instructional activities needed to prepare the students to do the assignment. Examples of assignments are given in Appendix A.

Table 1: Summary of support for core goals.

	Number of ***sessions*** supporting goals			
	Old Plan		New Plan	
Goal	**Board**	**CADD**	**Board**	**CADD**
Orthographic Projection	6	2	2	7
Dimensioning	1	3	2	4
Section Views	2	2	2	2
Aux. Views	2	2	1	2
Total	11	9	7	15
	20		22	
	Number of ***exercises*** supporting goals			
	Old Plan		New Plan	
Goal	**Board**	**CADD**	**Board**	**CADD**
Orthographic Projection	10	2	4	11
Dimensioning	1	2	3	2
Section Views	2	1	2	2
Aux. Views	1	1	1	3
Total	13	6	10	18
	19		28	

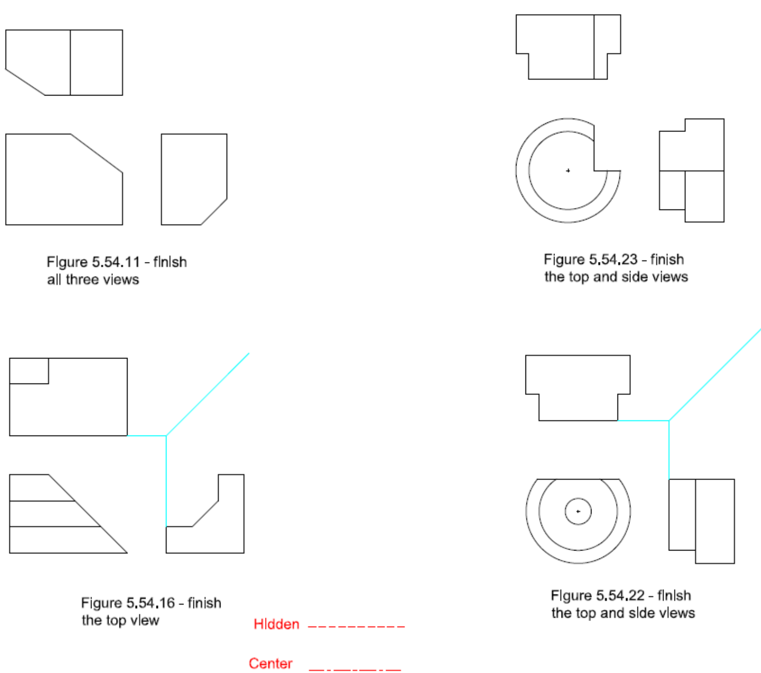


Figure 2: CADD template for multiple exercises in Orthographic Projection (Completing Unfinished Views.)

Assessment of Changes to ET0011

The proposed reconfiguration method includes a performance assessment to evaluate whether or not the course objectives are being met after the reconfiguration occurs. In the case of the changes made to ET0011, the assessment is needed to evaluate whether the loss of board time negatively affects student performance relative to course goals. In this assessment, only board tests were examined. The assumption that student performance on CADD will improve with increased time on CADD was not tested.

Two sets of tests were compared. Each set consists of the two board tests given throughout the semester. One set (Group A) is taken from the section of the class being used as the pilot for the new configuration, which has 2/3 of the class sessions on CADD and 1/3 on the drawing board. The other set (Group B) is from the section that is being taught as it has been taught before the reconfiguration, with 2/3 of the class sessions on the drawing board, and 1/3 on CADD. The sections were taught by two different instructors. The assessment focuses on one core objective and one secondary objective of the course, which are orthographic projection and descriptive geometry, respectively. Three of six problems from the first test, and two of five problems from the second test were compared. It is understood that this limited study is vulnerable to misinterpretation due to variation in student aptitude and teaching methods between the two sections.

In order to eliminate the effect of variations in grading practice, the problems were compared by noting the occurrence of errors rather than comparing assigned grades. For example, Problem 2 of Test 2 required the student to manually construct the angle between two surfaces, and the true shape of one of the surfaces, given two non-orthogonal views. Student solutions were tabulated progressively from 1 to 6 where 1 is perfect, 2 contains one minor error, 3 succeeded in one of the two attempted constructions, 4 succeeded in one construction but did not try the second, 5 attempted two constructions but succeeded in neither, and 6 did not even make an attempt. Tabulated data and histograms from the comparison are given in Appendix B.

This assessment method is similar to the one used by Garmendia et al.[3] and Baldizan and McMullin[4], which evaluated students' performance on individual problems in detail, in view of specific goals. Other forms of assessment such as student testimonials (Lee and Low[5]) and pass/fail ratio (Potter et al.[6]) are inadequate to measure actual performance to individual goals.

The three problems evaluated from Test 1 all address the general area of orthographic projection, but they include two types of exercises. In Problem 5, students were required to manually draw an isometric view, given three orthogonal views. In Problems 6 and 7, students were required to manually draw a third orthogonal view, given two complete orthogonal views.

Table 2, below, summarizes the performance in terms of the percentage of students who completed the problem perfectly or with one minor error. These students can be considered to have firmly mastered the material, which is the desired level of competence for Orthographic Projection.

Table 2. Percentage of students with zero errors or a minor error in test problems.

TEST PROBLEM	GROUP A (CADD-intensive)	GROUP B (Drawing board-intensive)
Test 1, Problem 5	59.2	50.0
Test 1, Problem 6	25.9	62.5
Test 1, Problem 7	25.9	37.5
Test 2, Problem 2	39.1	68.4
Test 2, Problem 6	25.0	54.5

The results show that the performance of students who spent less time on the drawing board was inferior to the performance of those with more board time for 4 of the 5 problems evaluated.

While this is not the desired result, it does highlight the need for assessment and feedback in any course redesign process. In the context of the pilot program at the University of Pittsburgh at Johnstown, adjustments will be made to the CADD curriculum so that course objectives are not compromised. These adjustments are detailed in the next section, below.

During the reconfiguration of ET0011, some level of competence in three additional CADD functionalities was added to the course goals. These functionalities are Assembly Modeling, Sheet Metal Design, and Frame Generator. The exercise in Frame Generator was not graded, but was assigned in order to give the students some basic exposure to the program. The Assembly Model was graded by completion, but students were required to correct errors in their models to the satisfaction of the instructor. The average grade for the Assembly Drawing was 8.4 out of 10. The average grade for the Sheet Metal exercise was 9.5 out of 10. These averages indicate a level of competence commensurate with the course goals. There is no basis for comparison with the old curriculum, since these modules were not previously covered.

Proposed Adjustments to ET011 Lesson Plan

Feedback from the assessment is being used to adjust the new CADD curriculum, in order to bolster performance relative to course goals. First, a comparison of the "Old" and "New" Lesson Plans in Figure 1 reveals a reduction in the number of exercises that involve constructing a third view based on two given views. Figure 5.55 (See Appendix A) in the textbook is a series of this type of problem; the old lesson plan contains two of these problems, and the new lesson plan only one. This is also the type of problem in Test 1, Problems 5 and 6, where "CADD" students performed relatively poorly. Also, the new lesson plan includes an increased number of exercises that involve completing unfinished views, as in Figure 5.54 in the textbook (See

Appendix A.) The new lesson plan will be adjusted to exchange one or more from the 5.54 series for several of the 5.55 series. This will be done with a template similar to Figure 2, so that students' time will be spent on understanding the part and constructing the missing view, rather than copying the given geometry.

Second, the number of Descriptive Geometry worksheets per class session needs to be reduced by at least one in the CADD curriculum. It was observed that students had trouble completing 4 or 5 worksheets per class session, and time pressure may have contributed to a lower level of comprehension. The reduction can be accomplished by allocating one more class session to Descriptive Geometry, and eliminating a few of the more complex exercises. The elimination of the more complex exercises can be justified by the fact that in past years students have not been tested on them, illustrating the fact that firm mastery (level 5 competence) is not expected. More complex Descriptive Geometry exercises include connecting two skew lines with a line of a given grade and constructing a line parallel to a plane at a given bearing. The most complex construction that has been tested recently is finding the angle between a line and a plane, and this will continue to be taught.

Summary

The proposed reconfiguration procedure was conceived for the purpose of maintaining support for course goals during a process which changes the way that content is delivered to students. Constructing a graphic device that includes course goals is an excellent way to encourage the review and evaluation of these goals. The visual linkage of teaching activities to course goals facilitated the construction of a new lesson plan by making the level of support easy to see and compare to the previous lesson plan. Assessing performance relative to the stated goals was instrumental in identifying weaknesses in the new curriculum, and the visual representation of the two lesson plans made it easy to see what adjustments should be made.

Conclusions

Implementation of the proposed reconfiguration method during the redesign of ET0011 at the University of Pittsburgh at Johnstown was successful. The proposed method is flexible and robust enough to be used at other schools and for other types of courses.

References

1. Follows, George H. "Universal Dictionary of Mechanical Drawing." The Engineering News Publishing House New York 1906 p. 9.
2. Connolly, Patrick. "CAD Software Industry Trends and Directions." Engineering Design Graphics Journal. Volume 63, Number 1, Winter 1999. P 32.
3. Garmendia, Mikel, et al. "First Year Engineering Students' Difficulties in Visualization and Drawing Tasks" European Journal of Engineering Education. ISSN 0304-3797. p. 319.
4. Baldizan, Maria Elena and Kurt M. McMullin. "Evaluation of Student Learning for an Engineering Graphics Course." Journal of Professional Issues in Engineering Education and Practice, ASCE, Vol. 131. No. 3. July 1, 2005, p 197.
5. Lee, K.S. and Maria L.H. Low. "Engineering visualization and modeling: teaching and management using the IT approach." International Journal of Mechanical Engineering Education, Manchester University Press, Vol 32. No. 2, undated, p. 177.
6. Potter, Charles, et al. "A longitudinal evaluative study of student difficulties with engineering graphics." European Journal of Engineering Education, Vol. 31, No. 2, May 2006, p. 206.

APPENDIX A

Examples of Assignments

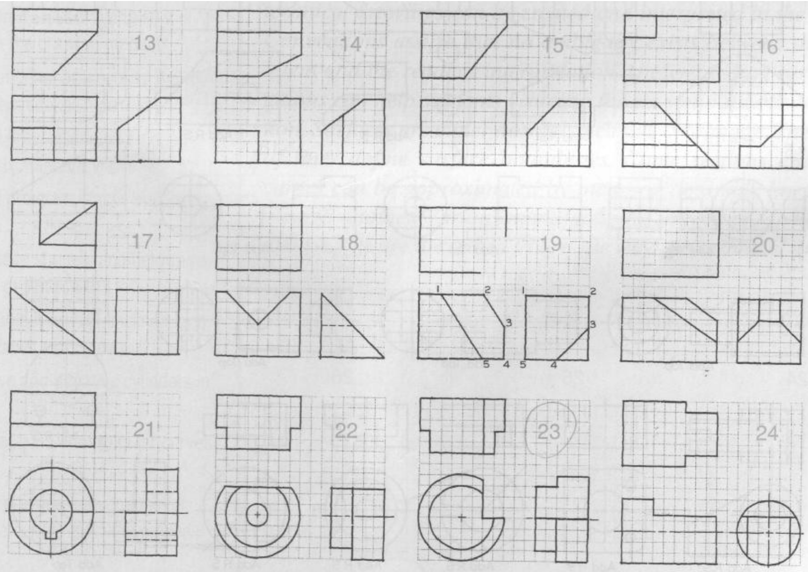


FIGURE 5.54 ■ Missing-Line Sketching Problems. (1) Sketch given views, using Layout A–1 or A4–1 adjusted (freehand), on graph paper or plain paper, two problems per sheet as in Fig. 5.51. Add missing lines. The squares may be either .25″ or 5 mm. See instructions on pages 143 and 144. (2) Sketch in isometric on isometric paper or in oblique on cross-section paper.

Figure 5.54 from text – completing unfinished view.

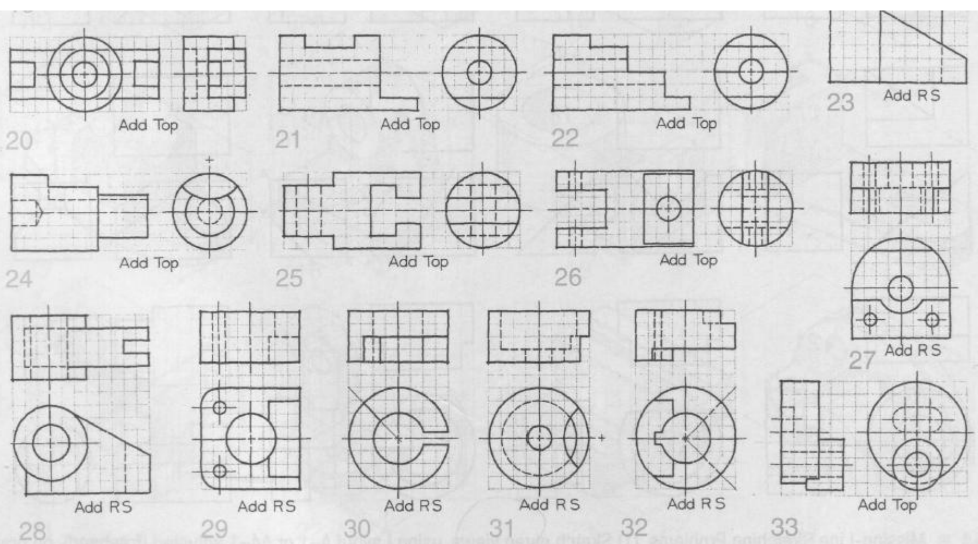
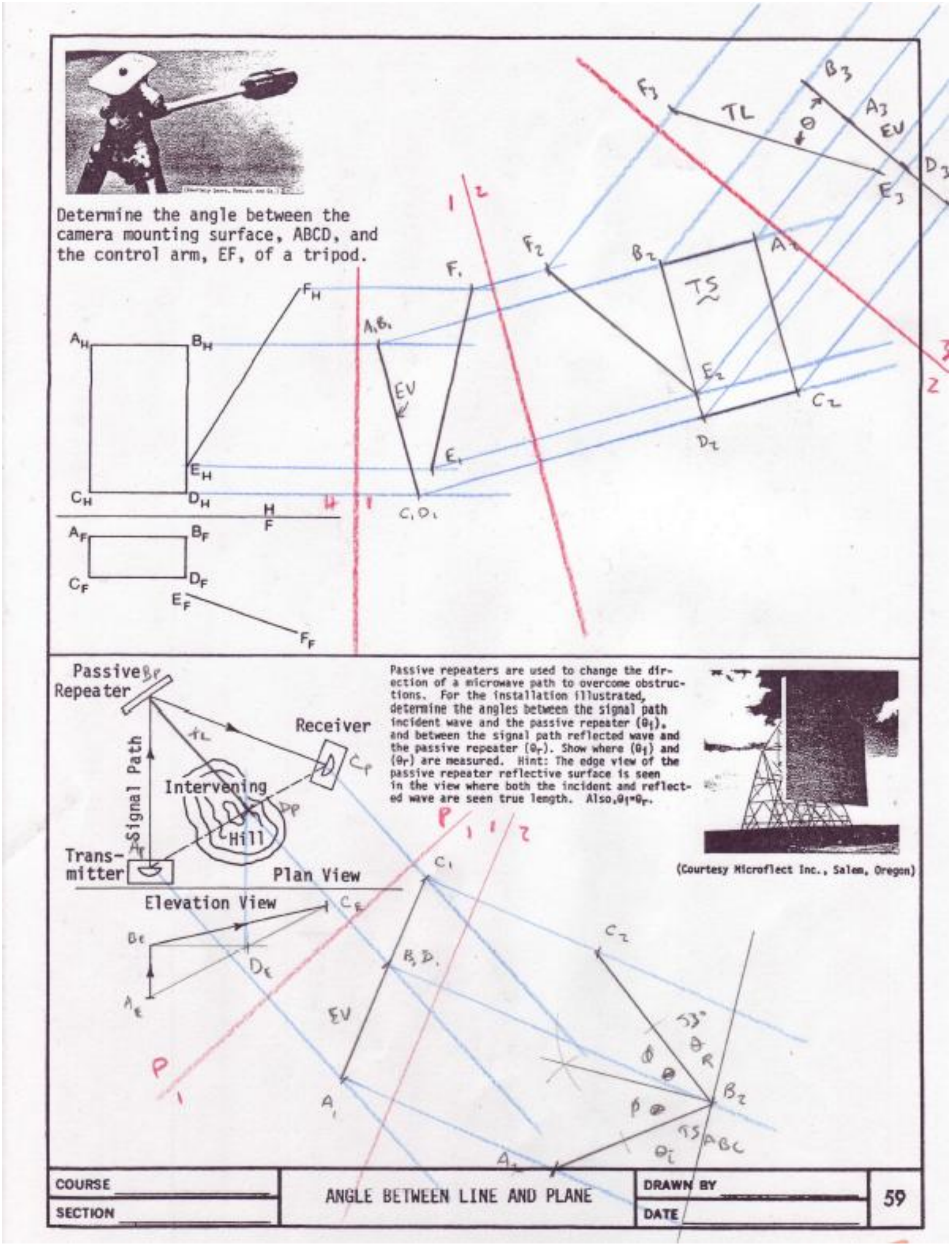
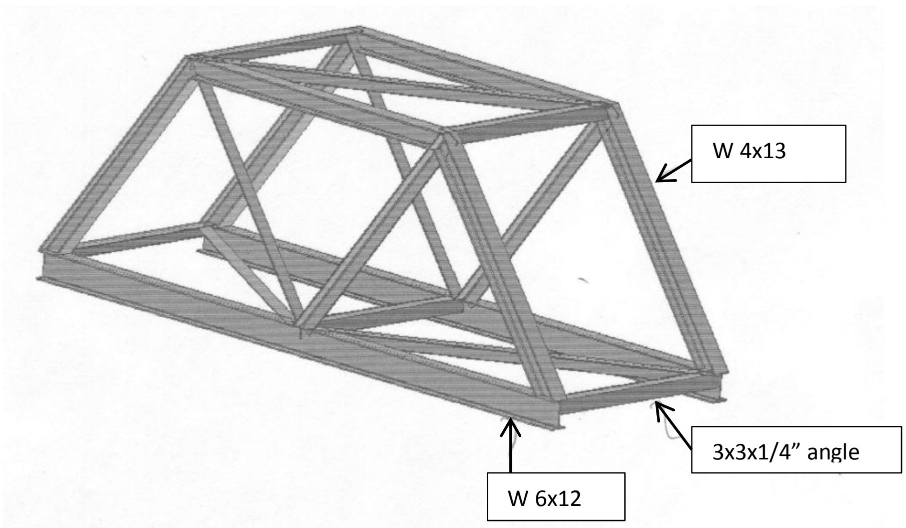


FIGURE 5.55 ■ Third-View Sketching Problems. (1) Using Layout A–1 or A4–1 adjusted (freehand), on graph paper or plain paper, t problems per sheet as in Fig. 5.51, sketch the two given views and add the missing views, as indicated. The squares may be either .25″ See instructions on pages 143 and 144. The given views are either front and right-side views or front and top views. Hidden holes with lines are drilled holes. (2) Sketch in isometric on isometric paper or in oblique on cross-section paper.

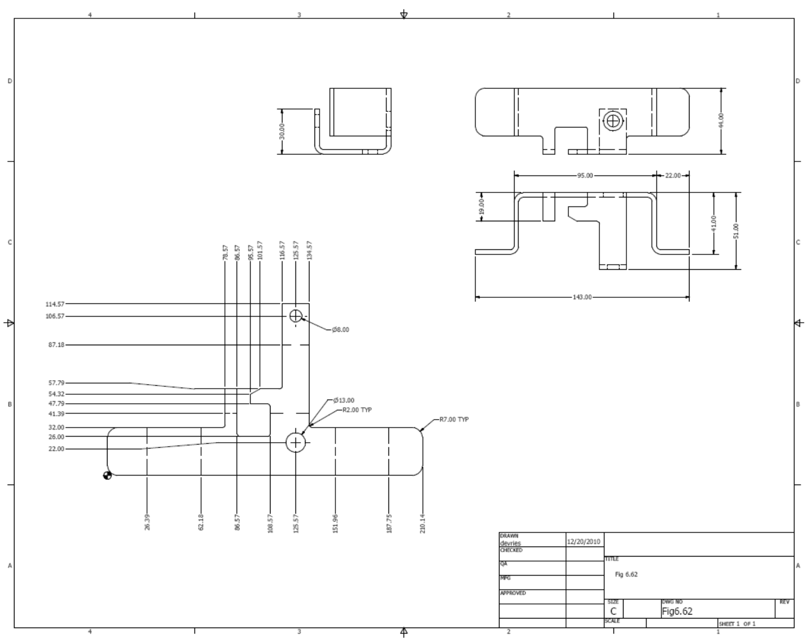
Figure 5.55 from text – drawing missing view.



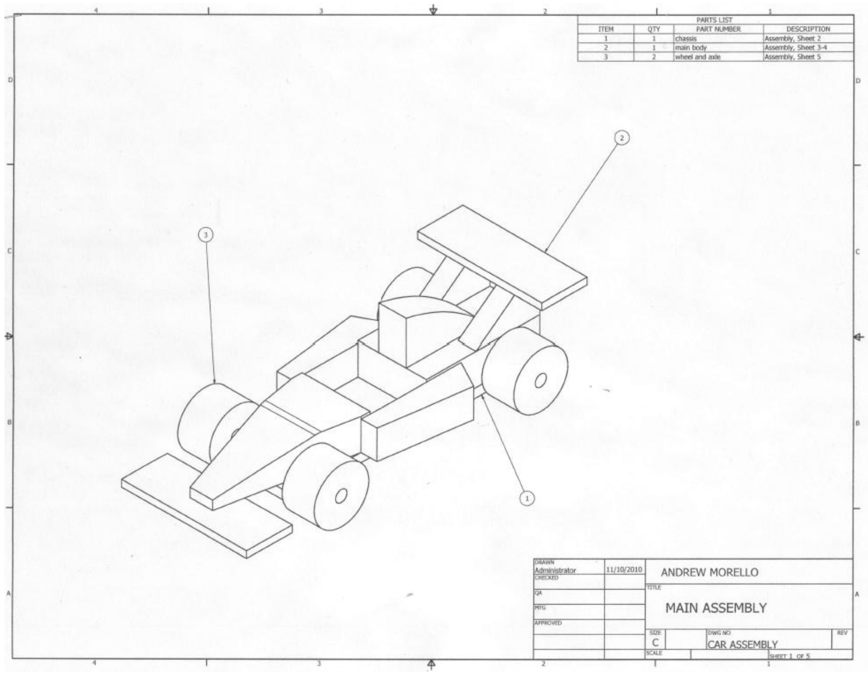
Descriptive Geometry – true shape of plane, and angle between line and plane.



Frame generator exercise.



Sheet metal exercise.



Assembly drawing.

APPENDIX B

Comparison data and histograms for assessment

Table 2. Occurrence of Errors in Test 1, Problem 5

Error	**Group A** (CADD-intensive)		**Group B** (Drawing board-intensive)	
	Number	**Percentage**	**Number**	**Percentage**
None	6	22.2	4	16.7
One minor	10	37.0	8	33.3
Form OK, missed a few lines	2	8.3	8	33.3
Squared round shapes	3	11.1	3	12.5
Copied projections (missed the concept)	6	22.2	1	4.2
Total graded	27		24	

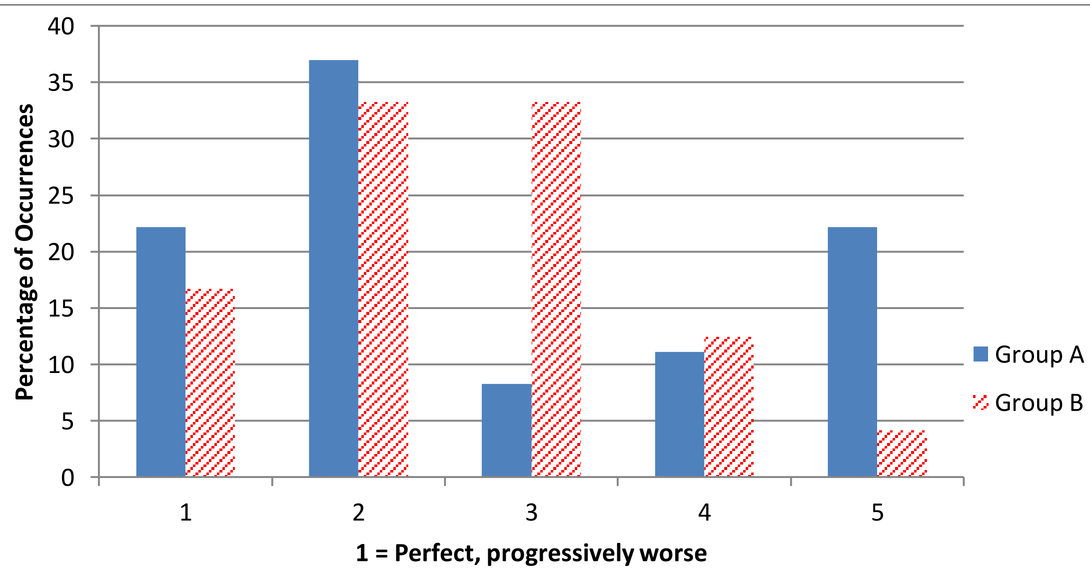


Figure 3. Test 1, Problem 5 (Construct Isometric View)

Table 3. Occurrence of Errors in Test 1, Problem 6

Error	**Group A**		**Group B**	
	Number	**Percentage**	**Number**	**Percentage**
None	2	7.4	8	33.3
One error in form	5	18.5	7	29.2
Two errors in form	16	59.2	9	37.5
Missed a lot	4	14.8	0	0
Total graded	27		24	

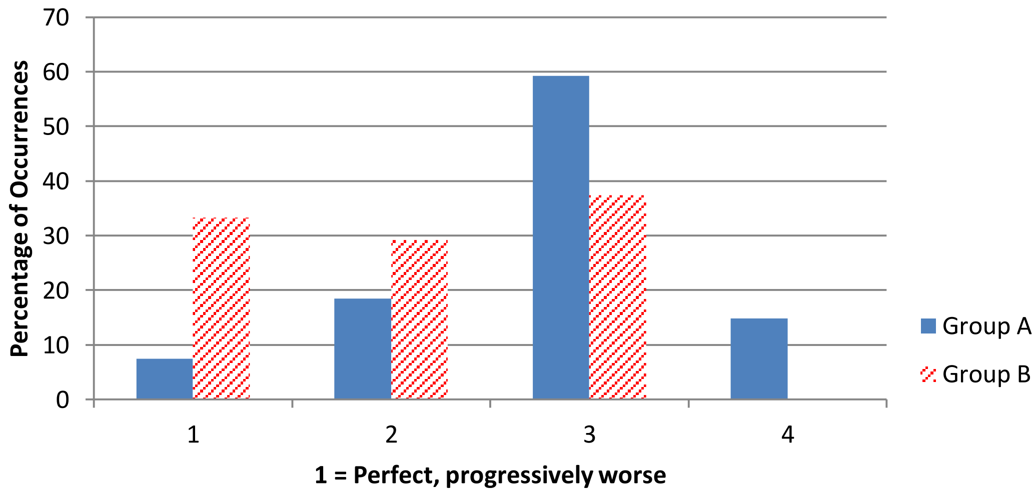


Figure 4. Test 1, Problem 6 (Construct Missing View)

Table 4. Occurrence of Errors in Test 1, Problem 7

Error	**Group A**		**Group B**	
	Number	**Percentage**	**Number**	**Percentage**
None	5	18.5	3	12.5
One error in form	2	7.4	6	25.0
Two errors in form	5	18.5	5	20.8
Three errors in form	7	25.9	9	37.5
Not even close	8	29.6	1	4.2
Total graded	27		24	

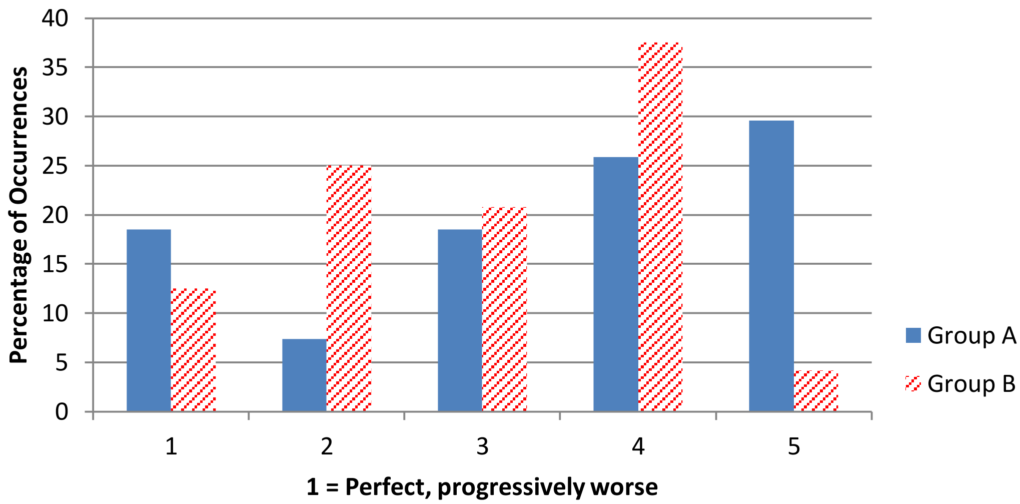


Figure 5. Test 1, Problem 7 (Construct Missing View)

Table 5. Occurrence of Errors in Test 2, Problem 2

Error	Group A		Group B	
	Number	Percentage	Number	Percentage
None	7	30.4	13	68.4
One minor error	2	8.7	0	0.0
One construction OK, not other	6	26.1	2	10.5
One construction OK, other not tried	4	17.4	2	10.5
Attempted two constructions	4	17.4	1	5.3
All wrong	0	0.0	1	5.3
Total graded	23		19	

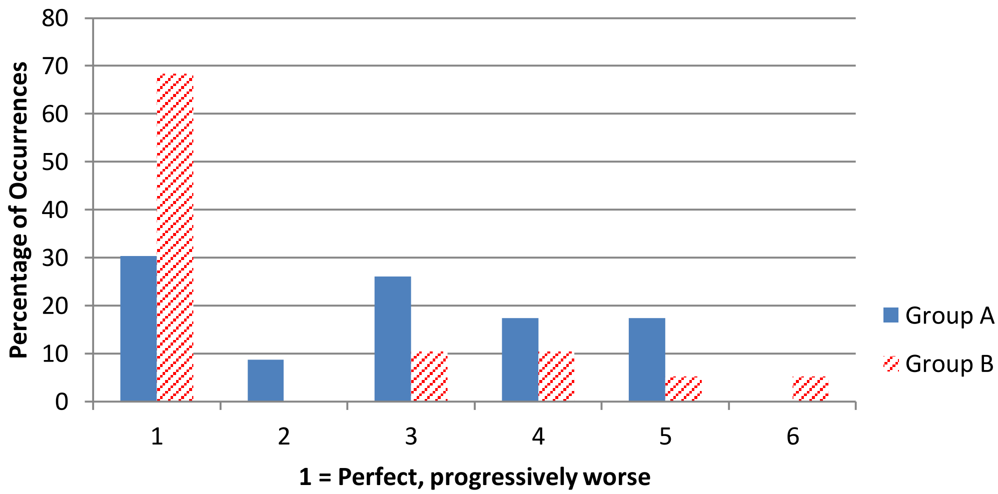


Figure 6. Test 2, Problem 2 (Descriptive Geometry)

Table 6. Occurrence of Errors in Test 2, Problem 6

Error	**Group A**		**Group B**	
	Number	**Percentage**	**Number**	**Percentage**
None	6	25.0	11	50.0
One minor error	0	0.0	1	4.5
Perp. OK in last view, not others	5	20.8	1	4.5
Perp. OK in last view, no reverse	1	4.2	2	9.1
First aux. view OK, wrong perp.	2	8.3	3	13.6
First aux. view OK no more	4	16.7	1	4.5
Nothing right	6	25	3	13.6
Total graded	24		22	

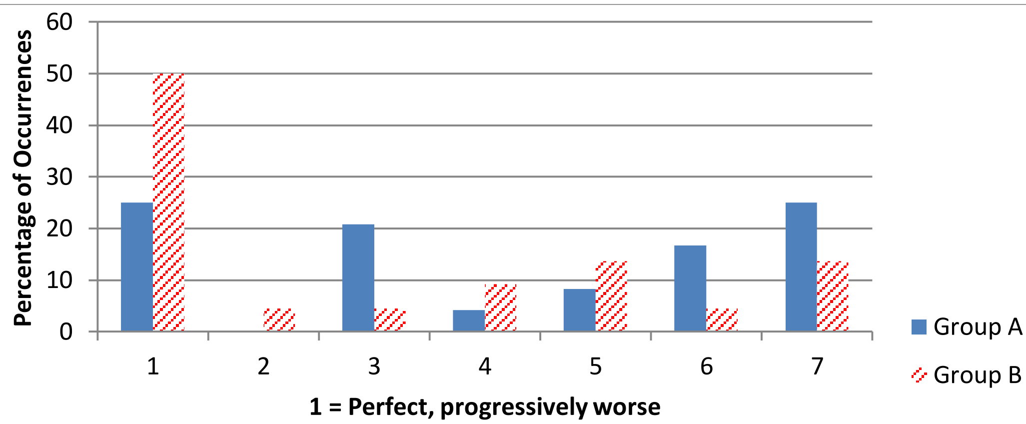


Figure 7. Test 2, Problem 6 (Descriptive Geometry)