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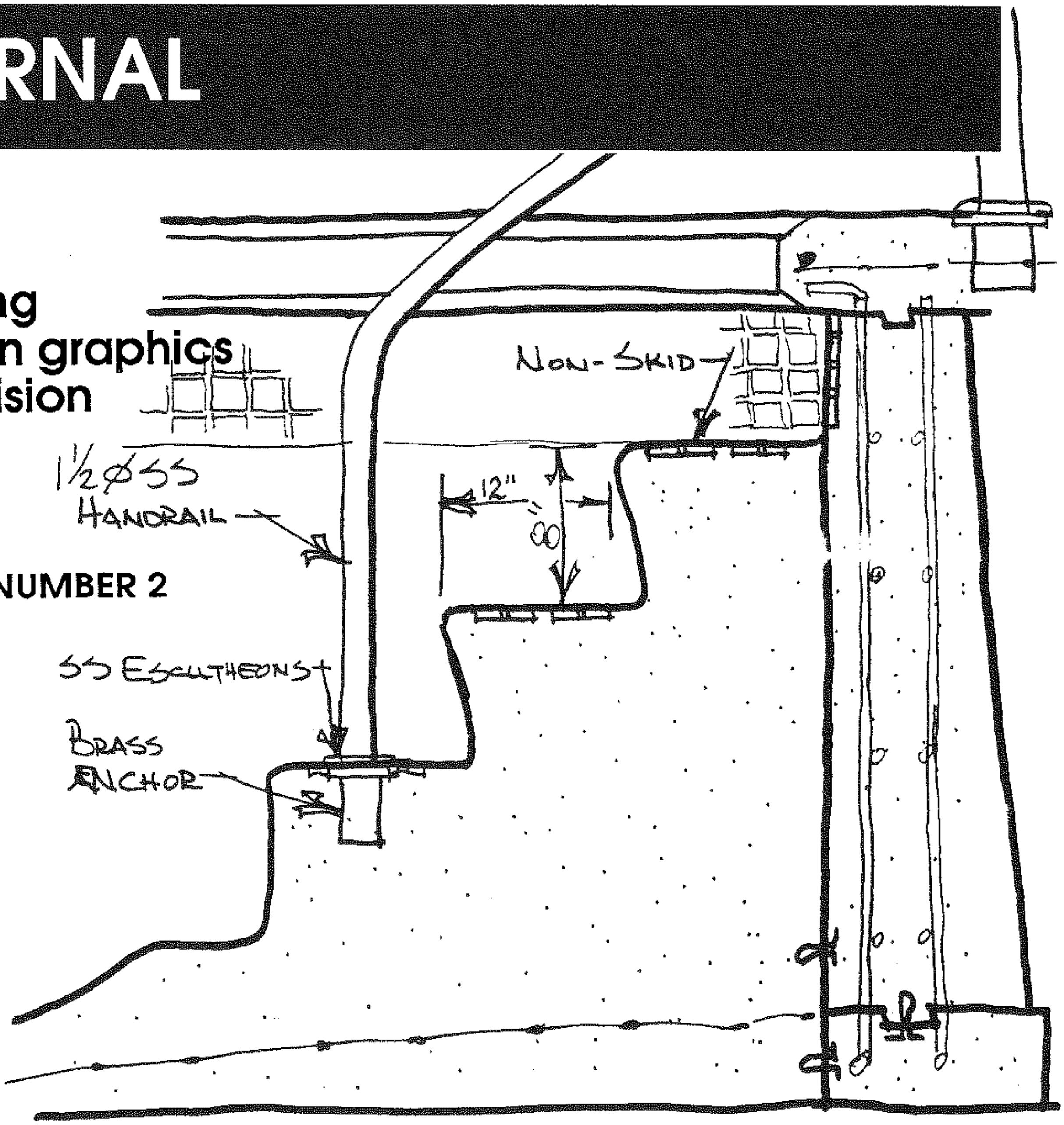

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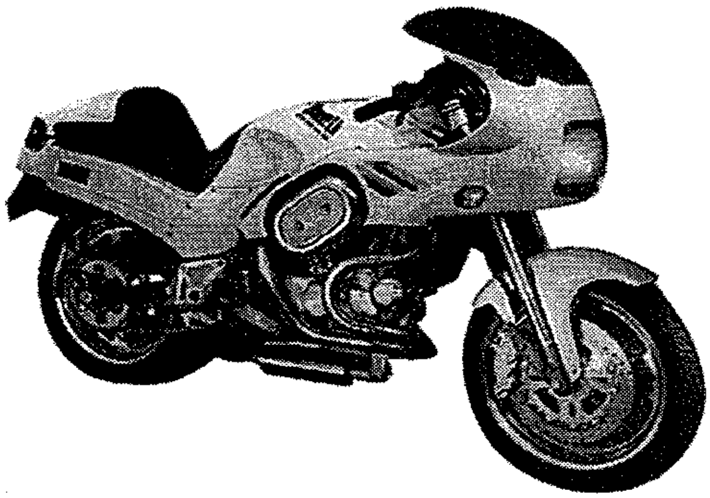

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The *Engineering Design Graphics Journal* is the official publication of the Engineering Design Graphics Division of ASEE. The scope of the Journal is devoted to the advancement of engineering design graphics, computer graphics, and subjects related to engineering design graphics in an effort to (1) encourage research, development, and refinement of theory and applications of engineering design graphics for understanding and practice, (2) encourage teachers of engineering design graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses, and (3) stimulate the preparation of articles and papers on topics of interest to the membership. Acceptance of submitted papers will depend upon the results of a review process and upon the judgement of the editors as to the importance of the papers to the membership. Papers must be written in a style appropriate for archival purposes.

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. . . from the EDGE

Engineering • Design • Graphics • Editor

For those of you who haven't been keeping track, this is the ninth regular issue of the *EDG Journal* to be published under my editorial reign. It doesn't seem possible that I have been publishing the *Journal* for three years. Some of you may not realize that editorship of this publication is a direct result of being elected to the post of Director of Publications for the Engineering Design Graphics Division. When I received a telephone call some four years ago about my willingness to run as an EDG Division officer, my reply was something like, "I'll be happy to run for anything but Editor of the *Journal*." The response was, "Well, we want you to run for Director of Publications." At which I said, "Isn't that Editor of the *Journal*?" To which the nominator explained to me that editor was indeed a major role of the Publications position. Now, you must understand that I had the office next to Jon Duff when he was the editor and I knew what kind of work it entailed, but since a major portion of my teaching involves teaching different aspects of publishing, I decided to bite the bullet and give it a whirl.

By the time I had that first issue in the mail, I felt that I might have to give up my day job and concentrate all my efforts into the publishing of the *Journal*. Needless to say, the first issue was the hardest. Once I had established a cover design, inside layout, and a working relationship with a local printer, things became much easier. The past three years have been filled with trials, tribulations, a lot of work, and the opportunity to meet and work with a lot of great people. At some point this past year I decided that it might be crazy, but I knew that I could handle this responsibility for another three years, which is why my name was up for re-election this past spring. The winners will be announced this month at the Annual Meeting in Edmonton.

I would like to thank my technical editor, Judy Birchman, who has handled the review process of papers for not only the *Journal*, but also the ASEE Annual Proceedings. I think that Judy voted against me, because she knows that if I remain the editor, she will remain the technical editor. Dennis Short has done a great job as advertising manager for four of the past five years. Under his leadership, we have had great advertising which has helped keep us solvent. Craig Miller has recently taken over that position and has already brought in some new advertisers. Rollie Jenison, as division editor, has provided me with information and photographs. Last, but probably most importantly, Clyde Kearns has stabilized the whole operation as the Circulation Manager. I pity the first editor who has to handle this job without Clyde. May he never retire!

I want to thank the membership for giving me this opportunity. Not everyone has the opportunity to produce a product that is sent across the country and around the world.

Mary A. Sadowski

Two added notes.

C. Wayne White, as program chair for the next Mid-Year Meeting wants to let people know that if they haven't sent in their abstract for the meeting, they can still do that at or after the Annual Meeting.

Craig Miller asks that we take the time to mention to vendors at the Annual and Mid-Year meetings that we saw their ad in the *Journal* and appreciate their patronage. We can also ask other vendors why they don't advertise in the *Journal*.

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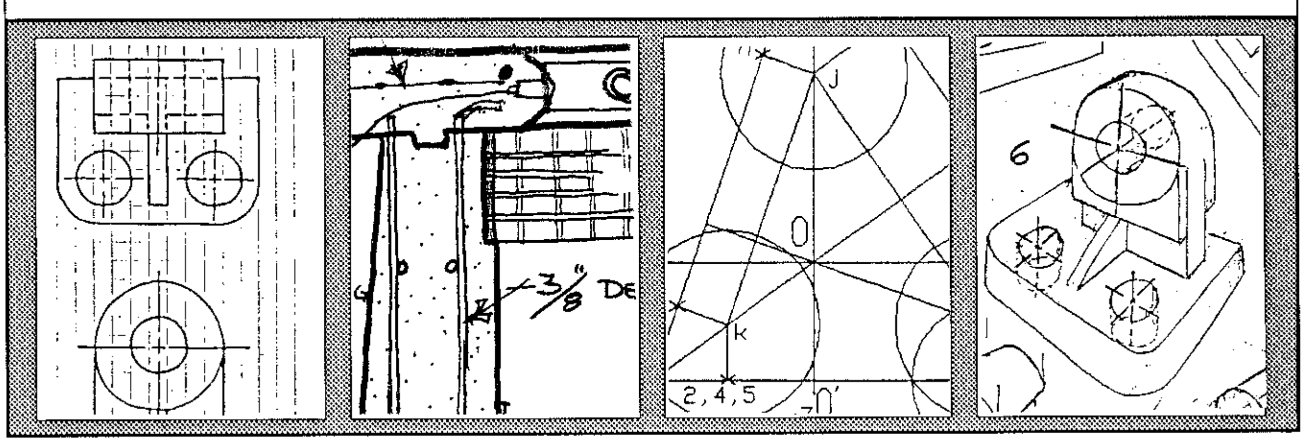

The Effect of Solid Modeling Software on 3-D Visualization Skills

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Abstract

Solid Modeling has been introduced into the first-year engineering course at The Pennsylvania State University. This paper describes an effort to measure the effect of the solid modeling curriculum on the development of 3-D spatial visualization skills in the students. The main instrument used was the Mental Rotation Test (MRT). Although the MRT and our methodology have their limitations, the data generally support the inferences that solid modeling does enhance spatial visualization skills and more than wireframe CAD or graphics taught in a traditional way. New directions underway in the research are also reported.

Literature Review

Spatial visualization skills are an important component of engineering because of their direct relationship to the graphical communication associated with design. Much of what is known about the development of spatial cognition has come from psychological research. An overview of the conceptual issues of that research is given by Liben (1988), and meta-analyses have been carried out by Linn and Petersen (1985) on gender differences in spatial ability and by Baenninger and Newcombe (1989) on the role of experience on spatial test performance. Understandably, the focus of the research from the psychologist's standpoint has been to relate the level of ability (development) to individual characteristics of the subjects. Age and gender are two of the most common attributes identified and studied. The mutability of spatial ability is always of interest because of its theoretical significance. For example, Baenninger and

Newcombe (1989) examined studies of school-age children to determine the gender differences in spatial ability, but they had a particular interest in examining the effect of spatial training. They came to the conclusion that the evidence suggests that "spatial activity participation is minimally related to spatial test performance" (1989:336). They caution that better measures may lead to different findings. And one might contrast the retrospective measures of spatial activity often used in the studies Baenninger and Newcombe reviewed, for example, with potent interventions such as the one described in this paper. For educators, the key issue is identifying the significant characteristics of the training that will have an impact. In fact, whereas the engineering educators, whose work is referenced below, have been interested in the psychological literature, they have not addressed the same questions. Rather, they have been interested in the importance of teaching spatial visualization and how that skill affects the further studies of engineering students. However, Miller and Bertoline are surely right in their review of the psychological literature in stressing the need to use "prior spatial research findings as a basis" both for new studies and for developing a better graphics curriculum (1991:13). We will go further and suggest that, with respect to the apparent ineffectiveness of spatial activity and training, we should have been addressing the same question as the psychologists: what causes spatial visualization skills to develop?

An important component of spatial visualization research has involved the development of measures and what those measures reveal about ability. Linn and Petersen (1985) include a substantial review of many such tests, while Liben reflects on the difficulty of making inferences with respect to what the tests measure (1988). One category of tests involves the rotation and visualization skills that are necessary to determine the relative position of objects and the orientation of objects in three-dimensional space. This type of test has been used to determine the level of visualization skills of engineering students, e.g., Rochford, et al., (1989), Sexton (1992). Sexton's carefully executed study uses two such tests and found that neither the use of 3-D wireframe CAD instruction or a traditional graphics approach were effective at improving visualization. His study also indicated that one type of test was probably sufficient to evaluate the tested skill. He did not control for the test practice effect, but it could not have been significant since he found no significant gains. The issue of mutability, then, was clearly addressed in his study and his findings support Baenninger and Newcombe's conclusion that spatial visualization skills are hard to change. Rochford, et al., added a focus to spatial visualization research that should be of great interest to engineering educators. They examined the role spatial visualization skills play in academic achievement and retention in engineering students. They report that high spatial visualization scores were a predictor both of academic achievement and retention. However, their methodology is a little hard to follow and there appears to have been no control for academic ability, which could have been the cause of high spatial visualization scores and of retention and academic achievement.

" If Spatial visualization is important for engineers – have we been teaching it?"

In recent years, engineering educators have shown increasing interest in the development of spatial visualization skills: Shahan and Jenison (1989), Wiley (1990), Bertoline and Miller (1990), Miller and Bertoline (1991), and Wiebe (1993). There has also been growing attention paid to using solid modeling in engineering education (Barr and Juricic, 1989), Leach and Matthews (1992), and in architecture education (Bolluyt, 1993). In our research these two interests converge in a study of the effect of solid modeling on the visualization skills of first-year engineering students.

The Study

At the University Park campus of The Pennsylvania State University, almost 1,000 students a year take the first year engineering course, EG 50. The course is taught with 15 sections each semester. In 1992-93,

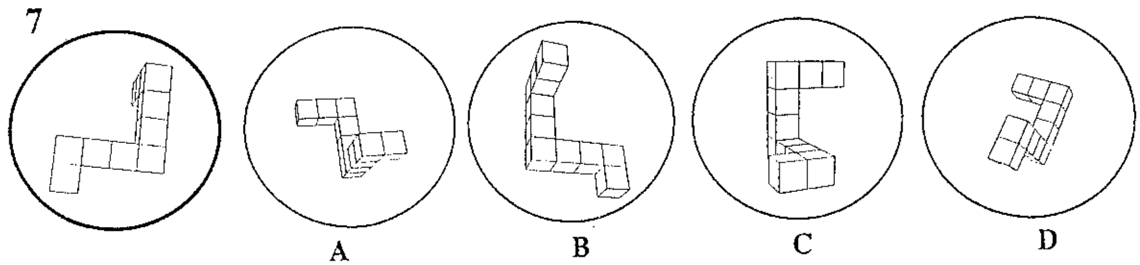

Figure 1. A sample problem from the Mental Rotations Test (MRT)

two sections were experimental in ways not relevant to this study and are excluded. All the other sections devoted 53% of class time to traditional graphics with traditional instruments (multiview, isometric & oblique, sections, dimensioning, spatial analysis) and 22% of their time learning and drawing with wireframe, 3D, CAD software. Solid modeling using Silver Screen was introduced on a trial basis replacing the wireframe CAD in 3 sections in the Fall, 1992, semester and in all 13 sections in the Spring, 1993, semester.

The Mental Rotations Test (MRT) was given once at the end of the Fall semester to the 3 experimental sections and to 4 of the other sections as a control. The test, which is discussed below, was developed by Vandenberg and Kruse (1978) following the research of Shepard and Metzler (1971). Unfortunately, the study began too late to give the test at the beginning of the semester. In the Spring semester, the MRT was given 3 times to 6 sections, at the beginning (Round 1), the middle (Round 2) and the end(Round 3) of the semester. In the Spring semester, one section taught solid modeling intensively in the first half of the semester and one taught it intensively in the second half of the semester. Both these sections were included in the study.

The students are identified with their social security numbers (voluntarily), so individual as well as group statistics may be used. Only group statistics are reported in this paper. In addition, a few other variables such as gender and prior exposure to graphics and CAD were obtained.

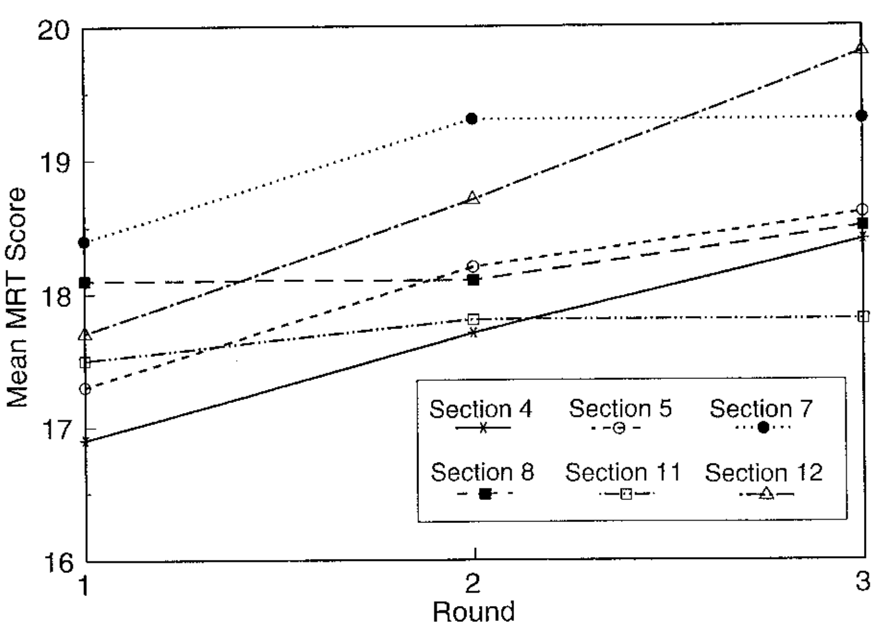

Figure 2. Mean Score versus the Round of Testing for Spring Semester

The Intervention

The change in the curriculum was the switch from a wireframe CAD package to a solid modeling package. The latter not only provides far better representation of 3-dimensional objects than the former, it introduces an entirely new way of approaching the subject. It should also be noted that the superior use of color, the screen display, the interface (e.g., one keystroke to a multiview representation) and ease of use of the solid modeling package represent other influences at work in this study. The "size" of the intervention will be represented by the amount of class time involved.

In the Fall semester, all sections spent 22% of the class time with CAD or solid modeling. Ten of these sections, the "control group," spent 22% of class time with a wireframe CAD package. Two of these sections, the "experimental group," spent 22% of class time with a solid modeling package (Silver Screen 2.15). In one hybrid section, the students split this 22% of their class time between a wireframe CAD package and Silver Screen (11%). In the Spring semester, all sections spent this 22% of class time on Silver Screen.

In comparing the wireframe CAD with solid modeling, we are comparing the effect of curricula built around low-end software upon spatial visualization skills as measured by the Mental Rotation Test. We are not, in general, comparing the wireframe CAD, with its many versions and its auxiliary packages, with Silver Screen which also has several versions. Further, there are many other uses and goals of graphics software and graphics curricula than the development of spatial visualization skills.

The Mental Rotation Test

This test, developed by Vandenberg and Kuse (1978), was chosen because it seemed to measure a very relevant spatial skill, because it had been widely used and this meant we could relate our findings to other studies, and because it had been found to be an effective and reliable instrument. The authors report the reliability measured by the Kuder-Richardson 20 was .88 for a sample of 3,268 adults (ibid, p600). Test-retest correlations were found of .83 for a sample of 336 subjects after one year and .70 for an age corrected sample of 456 after one year or more (ibid, p600). We obtained a copy of the test from Professor Gary Bertoline of The Ohio State University and used their instruction cover sheet. The test consists of ten questions. For each question, the student is shown an original shape and then must identify which two of four other shapes are new views of the original shape (Fig.1). Two versions of the test are available. We used the first test for the first and last rounds and the second test for the second round.

In using the MRT as a measure of spatial visualization skills, we are aware that Linn and Peterson use three spatial ability categories: spatial perception, mental rotation, and spatial visualization (1985:1485). We do not follow their terminology and collapsed their distinctions. We depart in another crucial way, also. As Linn and Peterson note, "Mental rotation items are used to measure the time required for solution rather than the accuracy of solution (which is extremely high)" (1985:1484). We allowed the students such time as they needed to select answers. It is extremely important to know how mutable spatial visualization skills are, and who has what level of skill. To this end we do not want to contaminate our results with cognitive style differences on the impulsivity-reflectivity dimension. This aspect is discussed by Kagan et al. (1964). If such differences are

Section # (N)	Experimental	Control
1 (26)	18.5	
12 (27)	17.7	
15 (25)	18.2	
3 (28)		18.1
4 (28)		17.6
6 (26)		18
11 (23)		17.7
Group Mean	*18.1*	*17.9*

Table 1. Mean MRT Scores by Section, End of Fall Semester, 1992

Section	Round 1 (N = 174)	Round 2 (N = 162)	Round 3 (N = 151)
4	17.3	17.7	18.4
5	17.3	18.2	18.6
*7	18.4	19.3	19.3
*8	18.1	18.1	18.5
11	17.5	17.8	17.8
12	17.7	18.7	19.8
ALL	**17.6**	**18.3**	**18.6**

* *Denotes sections where solid modeling was taught intensively: in Section 7 between Round 1 & Round 2, and Section 8 between Round 2 & Round 3.*

Table 2. Mean MRT Scores by Section and Round, Spring Semester 1993

associated with gender, then gender differences in spatial visualization skills will be affected. We had problems because of the high rate of accuracy, but we preferred this situation to relying on speed.

The Results

All the results are group results where 20 is the maximum possible score (10x2) and zero is the minimum on the Mental Rotations Tests 1 or 2. The results are summarized in Tables 1-4 and Figure 2.

Discussion

Did the solid modeling curriculum enhance the spatial skills of the students?

Comparing Tables 1 and 2, it can be seen that the mean MRT scores at the end of the Spring semester are higher than those for the Fall. This is particularly true if only the control sections for the Fall semester are used. Then, the difference between means, 17.9 (N=105) and 18.6 (N=151) for Fall and Spring semesters respectively, is more marked. However, the methodology does not really allow claims of statistical significance. Since we do not have pretest data for the Fall semester, the difference could be due to differences between students in the two groups.

Two of the three experimental sections in the Fall had higher means than any of the four control sections. The mean of the three experimental sections in the Fall was 18.1, while for the four control sections in the Fall it was 17.9. The difference is not significant.

In the Spring there was an overall shift in the mean MRT score from a pretest value of 17.6 to a post-test value of 18.6. The results for all three rounds of testing are shown in Table 2. The difference is significant at p=.05. However, there was a marked and unexplained variation by section. In both Table 2 and Fig. 2 it can be seen that there were only slight effects in Sections 8 and 11, while in the other four sections the effects are quite marked.

In the Spring, the only shift in means of the two intensive sections occurred during the period when the solid modeling was being taught (see Table 2 and Fig. 2). The change was significant at p=.05 for section 7, but for section 8 the shift in the mean was not statistically significant although it was clearly in the same direction. We were unfortunate because the pretest scores were exceptionally high in these two sections and to get a result at all was impressive. The pattern can be observed in Table 2 for Sections 7 and 8.

Early in the study we wondered if we would find a gender difference and, if so, if the curriculum would alleviate it. In the literature the gender gap in spatial skills is often reported, but the women in our sample are probably more selective than the men are. In fact, we did find a gender difference in both the Fall and the Spring, but it is small and not significant at p=.05 when taking either the Fall or the Spring sample alone. However, in the intensive solid modeling sections, we found very clear gender differences and a very striking effect by the solid modeling curriculum (Table 3). The numbers are small, but the pattern was suggested for both sections with the female students making much larger gains than the male students. To some extent this may be an artifact of the skewed distribution - the higher male pre-test scores allow less room for measured improvement. We thought the result may have been influenced by the slightly higher numbers of females in these two sections than the average section, but this was not unambiguously born out by the data from the other sections. It may well be that

	Intensive Sections (N)	Round 1 Pretest	Round 2 Post-test	Round 3
Section	Female (8)	17.9	19.1	19.3
7	Male (14)	18.5	19.2	19.3
		Round 1	Round 2 Pretest	Round 3 Post-test
Section	Female (5)	16.4	16.2	17.4
8	Male (16)	18.5	17.4	18.9

Table 3. Interaction Between Gender and Intensive Solid Modeling: Mean MRT Scores

the intensive experience is helpful if the spatial skills of the female students have been, and are, suppressed by socialization effects (Baenninger and Newcombe, 1989:330). We will certainly do further work on this topic.

Since the pretest scores were high, the discriminatory power of the MRT was reduced. This made it harder to find statistically significant effects. We decided to break the Spring data into three groups on the basis of the pretest scores: L=0-16, M=17,18, H=19,20. The results for the first and last rounds, R1, and R3, are given in Table 4 and show two clear patterns. First, many students who had either high or low scores on the pretest were likely to score the same way on the post-test. This was particularly true for students who scored in the high bracket on the pretest. The movement that did occur for this group could well be the result of regression towards the mean. Second, students who scored in the middle range on the pretest were very likely to score in the high range on the post-test. Of 38 students who were in the middle range in the pretest, 29, or 76%, scored in the high range on the post-test. However, this is a very skewed distribution and 49% scored in the high range on the pretest and 72% on the post-test. The distribution is probably binomial and we need to verify this before we test for the statistical significance of this finding.

These supportive findings could be due to effects other than solid modeling. They might have occurred because the software is easier to use and has more attractive displays, i. e., there might be a Silver Screen effect rather than a solid modeling effect - or both. Faculty enthusiasm and an atmosphere of excitement and change may have influenced learning and hence the outcome. Also, there is the possibility that the curriculum written for Silver Screen was better than that for the wireframe CAD. The possibility that the shift in means was due to a maturation effect independent of the course is worth investigating in the future, but it would not explain the difference between the wireframe CAD and the Silver Screen sections nor the differential gender effect. A more serious problem is the test practice effect. Like Sexton (1992), we did not control for this and we should in our next study although Sexton's results imply there was none.

Round 1 Pretest	Round 3: Post-test		
	Low	*Medium*	*High*
Low	13	7	12
Medium	1	8	29
High	1	10	54

Cell entries are the number of students who score Low (MRT score=16 or less), Medium (MRT score=17, 18), or High (MRT score=19, 20).

Table 4. Interaction Between Skill and Curriculum

Were there measured influences on the outcome?

We only measured a few other variables. These were gender, the amount of mechanical drawing taken in high school, the amount of CAD in high school, student ownership of a microcomputer and family ownership of a microcomputer. Only two variables emerged as statistically significant in a stepwise regression and both had effects only true at p=.1. Gender had a very slight effect explaining 1.2% of the variance (males scored a little higher than females), and family ownership of a microcomputer explained about 1% of the variance. The most interesting results are that neither the amount of mechanical drawing or CAD taken in high school had any effect on the MRT scores. Apparently, even the selectivity factor of those who chose to take such high school courses is of no consequence here. The results from the intensive sections 7 and 8 in the Spring lend credence to this result. When the intensive solid modeling was not taking place in those sections the MRT scores did not change, even though traditional instrument graphics instruction was taking place. This outcome is consistent with the meta-analysis of Baenninger and Newcombe (1989). And Sexton (1992) also found that having had experience in a spatially oriented course such as "art, blueprint reading, or mechanical drawing" had no effect on spatial skill scores (Sexton, 1992:40). This raises the question, if spatial visualization is important for engineers - have we been teaching it? We know 3-D visualization is very important when we teach students engineering graphics. Did we assume incorrectly that our instruction also improved this ability? Shouldn't our graphics instruction begin with establishing this ability, and, by corollary, shouldn't graphics begin with 3-D and only teach 2-D as a derivative of 3-D?

Current and Future Research

We will do some further analysis of our present data. In particular, we will look at the distribution. We are sure that a simple Gaussian distribution is not the optimal model for the distribution. As we hope to report in our next paper, the data appear to form several clusters. If so, the statistics we have given assuming a normal distribution will need to be changed, although our inferences about the effects of solid modeling will probably be stronger rather than weaker.

We have developed a new and harder version of the MRT and we will also report on it in our next article. It is now composed of six problems from the original test and 6 which use similar but more complex shapes. Each of the four possibilities for each shape is now a true/false question so the student are now scored out of 48 rather than 20. This gives us an instrument with a greater range and greater sensitivity that is particularly useful with relatively high ability subjects. The new test has also solved another problem. Originally, there were always two right answers out of the four possibilities but the students did not know this. In the modification that we were given the students were told that there were two correct answers. When you do this you lose stochastic independence because subsequent answers will be influenced by prior answers. Some subjects, for example, will never look at the fourth image since they assume they know the answer from the results of the first three. If both the first two answers are the same, you may not bother to look at the last two images. However, some will continue as a check. Therefore, the measured behavior is modified during the test in unmeasurable ways. In the new test, the four images can all be right, all wrong or any combination of right and wrong.

An important issue is remedial education. That is, although the development of visualization skills is a worthy goal, perhaps 50-60% of our students already have good visualization skills when they enter the university. We then need to concentrate on those who do not have this aptitude. We can easily use the MRT to identify these students at the beginning of the class and provide enrichment programs early in the course.

We intend to examine the relationship between the MRT scores and the grades received in EG 50, and to do a follow-up study to see the effect upon retention in engineering.

It would also be interesting to try to find measurable influences on the development of spatial skills. We may look at high school grades, hands-on experiences, and test scores.

As an outcome of the first year engineering course we would like students to value graphics, have confidence in their ability to use graphics, and to use graphics frequently. To this end we are developing a scale which we refer to as the Graphics Efficacy Scale. We want to see how this scale relates to the MRT scores, grades, and retention in the first year course and in follow up studies.

Conclusions

We may be doing something right, because we appear to have raised the MRT scores of first year engineering students both when Spring pretest and post-test scores are compared and when post-test scores are compared for the Silver Screen and the wireframe CAD curricula. We think the reasons have to do with the effect of solid modeling and/or Silver Screen. It is worth noting that student attitudinal data not reported here is very supportive of the solid modeling software. In the hybrid class in the Fall where the students studied both the wireframe CAD and Silver Screen, 80% of the students thought that the wireframe CAD was very good compared to 100% for Silver Screen (N=25). And 88% of the students thought that Silver Screen helped them visualize objects in three dimensions whereas 52% said the same of the wireframe CAD. As noted earlier, Sexton (1992) reported a study that found that the same wireframe CAD did not improve spatial visualization and nor did traditional instrument graphics.

The strong interaction with gender in the intensive sections suggests that the solid modeling curriculum is effective for closing the gender gap in spatial visualization skills. In the sections with an intensive curriculum the performance gap between men and women was eradicated or greatly reduced. This preliminary finding was not statistically significant and needs replication.

Approximately 60% of the students in the Spring sample had good visualization skills on the pretest. This reduced the effectiveness of the MRT as a measure for studying this population.

In some of the literature, the mutability of spatial skills is questioned. In this study we found changes in a positive direction. We will try to replicate this finding and study the retention of the gains through follow up studies. We may also seek out non-engineering student populations.

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Visual Perception, Spatial Visualisation and Engineering Drawing

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Abstract

The processes of visual thinking, imagining, visualisation and engineering drawing are examined against the background of some studies in the psychology of visual perception. Questions of object recognition and the 'mechanics' of transforming mental images, and how these relate to the understanding, interpretation and preparation of engineering drawings, are raised. The results of a test in drawing interpretation and freehand sketching are presented and discussed to illustrate the key points of the paper.

Introduction

Drawing is a complex activity that takes time, energy and a large number of mistakes to learn. Drawings and other visual representations provide a framework for visual thinking, a powerful technique in attacking and clarifying a problem. An important aspect of visual thinking is the ability to do spatial manipulations mentally and to use these in solving problems. One who has this ability can think of and deal with many things which another person cannot.

Some people seem to draw very well and very easily. Others find it a struggle to produce even a simple sketch. Whatever the reasons for this, it seems clear that drawing is a complex learned activity that involves not only tool related techniques but, more importantly, also ways to see and interpret the world as it is.

The fundamental problem of drawing is how to represent, on a flat, two-dimensional paper or video display unit, an object which has shape also in a third direction. In flattening three dimensions into two, one of them is lost and the drawing may become hopelessly ambiguous until a way is found to put the missing one back. There are two fundamental answers to this problem. One is to preserve the notion of true shape and to exhibit the many shapes in an object in a series of drawings of the object as seen from various viewpoints. The other is to retain the idea of 'one object, one drawing,' but to transform its real shapes into apparent shapes. Both drawing types must follow a clearly understood code of engineering drawing practice to be useful as a means of graphical communication.

The other side of the coin is the interpretation of engineering drawings, and the nature of imagined spatial operations. A beginner faced with an apparently insane jumble of lines called a mechanical drawing may find their interpretation a formidable problem at first. It is perhaps not too difficult to visualise the separate views from a pictorial drawing of an object. However, until one has attained a degree of fluency in orthographic projection and, without thinking, has come to recognise familiar shapes and components, it is not so easy to picture the solid object from its separate views. Furthermore, once an internal (mental) representation of the three dimensional object has been developed, the capability of performing mental rotations and other spatial transformations of it needs to be developed. For engineers and designers these mental visualisation processes play an indispensable role in fitting together variously shaped parts of complicated mechanical devices, and working out creative solutions to engineering problems.

Overt recognition of the importance of spatial visualisation research in the development of engineering graphics teaching has in the last few years begun to appear in the literature (Wiley, 1989; Miller &Bertoline, 1991; Wiebe, 1993). Sound perceptual and cognitive principles lie at the basis of a proper understanding of how visualisation skills should be taught. In this paper some relevant background information in the psychology of visual perception and spatial visualization are presented. Against this background, the results of an exercise in interpretation, visualisation and drawing are presented and discussed.

Object Recognition

An essential part of the makeup of human beings is their ability to recognise objects. It is through a process of learning that humans come to classify certain configurations as equivalent to, or distinct from, others. How do we represent within us the world outside? And how do we represent outside us 'the world' we create within? Questions such as these form the subject matter of studies in the psychology of visual perception, with the lion's share of the work being done in connection with the first question.

Various theories purport to explain how we organise and interpret the information contained within retinal images. A retinal image of an object is messy, two-dimensional and static, and thus it must be interpreted. The 'lost' dimension needs to be recovered to build a correct perception of a three dimensional world. How is this accomplished?

Firstly, with our binocularly overlapping visual fields there is the stereoscopic effect arising out of the disparate images obtained at the two eyes. The phenomenon of stereoscopic fusion which is active here is very effective in reconstructing 'depth' from 'flatness'. An engineer who draws on flat paper and interprets flat drawings is, however, more akin to a 'one-eyed' human. There must therefore be other pictorial cues that can be used to represent depth in drawings. Perspective cues, in which relative size depends upon distance, is perhaps the best known pictorial cue. Shadow in an image conveys an impression of solidity. The appearance of lesser clearness or brightness of distant objects also gives a powerful impression of depth. Another pictorial cue is that of interposition, or overlay, as illustrated by the apparently overlapping disks in Figure 1.

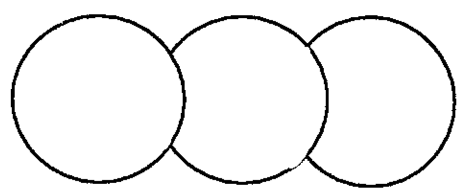

Figure 1. Interposition

The degree of complexity in a drawing can also give cues to depth. By asking people to rate the apparent three-dimensionality in the diagrams in Figure 2, Hochberg and Brooks (1960) found that as the complexity of the diagrams increased so there was a tendency to perceive the diagrams as two-dimensional representations of three-dimensional objects. Figures which were most symmetrical were seen least often as representing three-dimensional objects. The more angles in a diagram, or the more different size angles, the more likely it is perceived as a 2D representation of a 'simpler' 3D object.

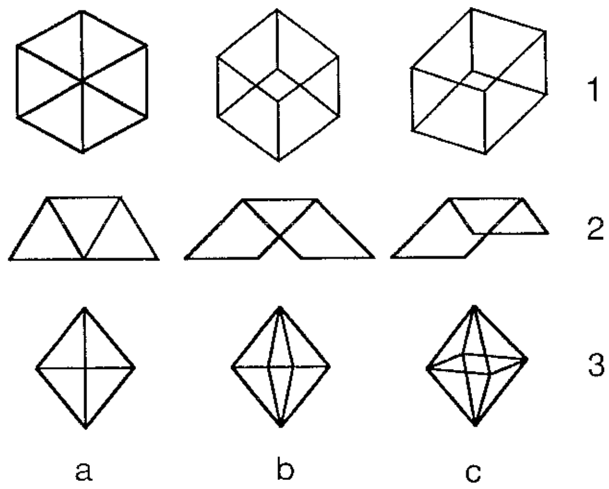

Figure 2. Degree of complexity as a cue to depth

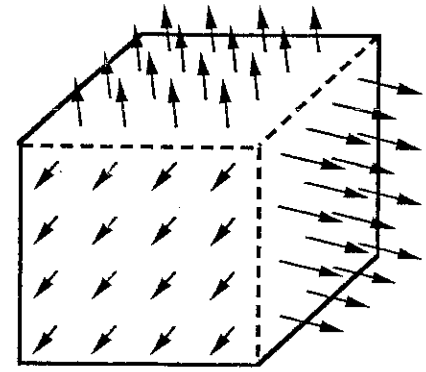

Figure 3. Marr's 2.5 dimensional sketch

There are also dynamic cues which depend on observer or object movement. Here the problem of understanding visual processing of retinal images becomes vastly more complicated. A human observer of a moving object typically samples it with a series of discrete fixations. The problem of integrating successive, slightly different, retinal images is thought to be analogous to the problem of the fusion of two retinally disparate images when stereopsis is achieved. In both cases the brain must discover which aspects of successive retinal images correspond, and match them accordingly.

Important to engineering visualisation are the visual / psychological systems which serve to integrate successive, but discrete, views as the observer fixates different portions or faces of an object, or when he moves around it or within it. It is thought (Hochberg, 1968; Minsky, 1977) that one needs previously acquired knowledge about the properties of objects to integrate discrete glimpses of them. It is suggested that prior knowledge of an object, such as a cube, leads to a coherent interlinked "system of frames," each frame corresponding to a symbolic mental description of one view of the cube. These are then utilised, in some as yet unexplained way, to integrate discrete views of the cube into a three-dimensionally perceived unity. How we perceive what we see is therefore influenced by learning. It is through the process of learning that we classify certain configurations as equivalent to or distinct from others.

Marr (1980) regards visual perception as a problem of information processing which begins with an approximate image of grey-level intensity changes, such as an object might cast upon the retina of the eyes, and ends with a description that depends on that intensity array and on the purpose that the viewer brings to it. In this context engineering designers would be concerned with the derivation of descriptions well suited to the recognition of 3D objects and shapes.

According to Marr's framework, a final description is achieved by constructing a number of distinct representations from the intensity values of the retinal image. The first of these, the primal sketch, makes the more global aspects of an object explicit and provides two-dimensional information about edges, blobs, locations, contours, orientations, etc. In the second stage, Marr's 2 1/2 dimensional sketch, visible surfaces with their orientation and physical properties are represented in a co-ordinate frame that is centered on the viewer. Figure 3 represents Marr's version of a 2 1/2D sketch of a cube in which the visible surfaces are represented in orientation by a set of vector primitives describing the degree and direction of tilt of the surfaces. The final stage of recognition, the 3D model, represents volumetric shape primitives of a variety of sizes, whose positions are defined by using an object centered co-ordinate system.

Take, for example, the two drawings shown in Figure 4. They can be described in either the two dimensional or the three dimensional domain. In the 2D domain these drawings may be described as a collection of points of different brightnesses, as a collection of lines, or as a group of regions. In this sense they represent different stages of elaboration of the primal sketch. Whether points, lines or regions, the representations established for these two drawings would look very different. It is only within the domain of 3D description, couched in terms of surfaces, bodies and solids, that the equivalence of the drawings can be established. The two projections of the same object will have different descriptions in the 2D (picture) domain but will be equivalent in the 3D (object) domain. The thrust of Marr's 21/2D sketch for the representation of surface orientation falls somewhere between the 2D and 3D descriptions.

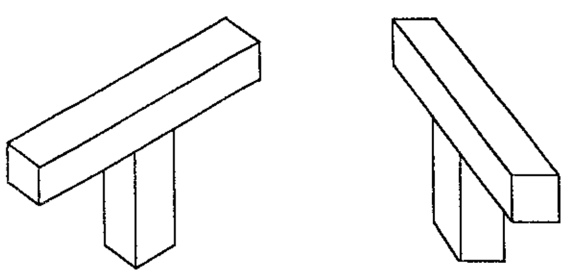

Figure 4. Description is different in the picture domain but equivalent in the object domain

Mental Mechanics

For engineers and designers, the purpose of object recognition from information contained within the retinal images must be to build a mental description in the object centered domain, i.e., described within a reference frame tied to the object itself. A mental description, or mental image, has been described by Holt (1964) as "a faint subjective representation of a sensation or a perception without an adequate sensory input, present in waking consciousness as part of an act of thought." Such mental

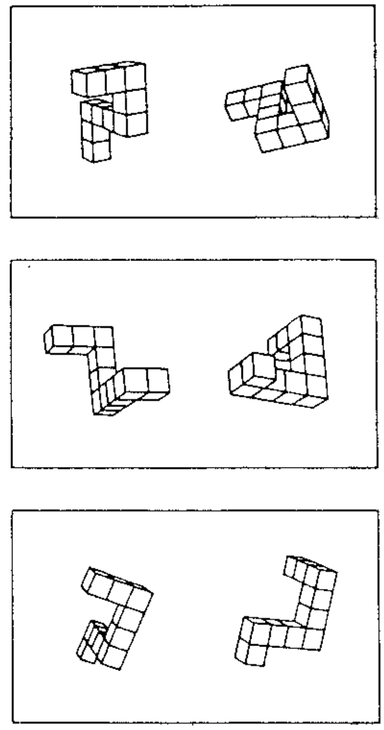

Figure 5. Mental rotation experiment

images can be transformed and manipulated in memory. This is clearly a necessary and highly valuable characteristic that makes it possible for engineering designers to plan actions in advance and to anticipate outcomes.

Shepard, et al. (1971, 1972, 1984) considered mental object rotation and mental 'paper folding' exercises in an extensive experimental study of this human capacity. Subjects were presented with pairs of line drawings depicting a three-dimensional arrangement of cubes (see Figure 5), and were asked to decide whether the two stimuli in a pair could be made to rotate into congruence with one another. Their reaction times were measured to test the hypothesis that the decision time, based on mental image rotation, should be related to the angle of rotation required for congruency. The results showed that the time required to recognise that the two drawings portray objects of the same 3D shape was a linearly increasing function of the angular difference in the portrayed orientations. This conclusion leads to the notion that a mental image of the first shape in a pair is being adjusted incrementally in orientation until it matches the mental image of the second shape, such adjustment requiring more time when greater angles are involved.

The exercise in the 10th week is designed to test the students' abilities of interpreting a three view sketch of a relatively simple object and to represent their mental reconstruction of this object by means of a pictorial sketch on plain paper. It is a test of the seeing / imagining / drawing process described in Figure 7. Students in one class (126 students in total) were presented with the given three-view drawing shown in Figure 9, with the request to draw a perspective sketch of the object from an advantageous viewpoint, keeping the proportions of the object more or less correct. The time allowed was 35 minutes. The results were graded on a scale of 1 (very poor) to 10 (excellent). Such grading can, of course, be a very subjective exercise since all sketches are different. However, by carefully comparing sketches and by taking due account of such aspects as good proportions, correctness of detail shape and location, quality of the perspective, advantage of the viewpoint, precision of the linework and the general strength of the drawing, the subjective elements of grading can be minimized. The grade distribution for the subject class is shown in Figure 10.

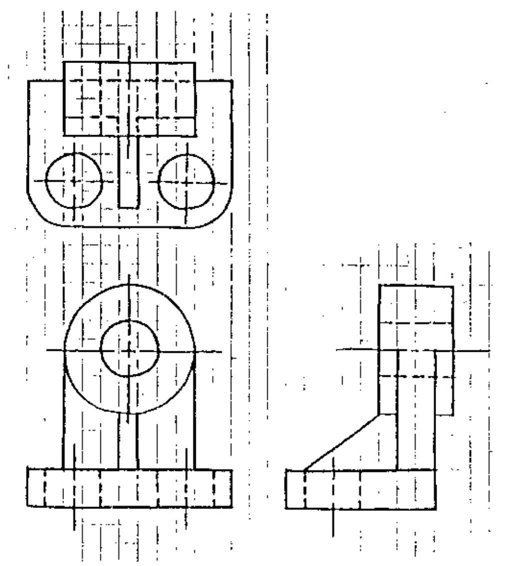

Figure 9. Sketching test — given views

Typical sketches, one selected from each of the graded categories 10 to 1, are shown in that order in Figure 11. The full spectrum of abilities typical in a class of freshman engineering students is represented here. Sketches graded 10 and 9 are generally correct in the detail that is represented. An advantageous viewpoint is taken that shows much of this detail, and the proportions are on the whole acceptable. Sketches graded 8 and 7 begin to show certain inadequacies of proportion or errors in detail, and the perspective can be wrong in some cases. Distortions of form are creeping in and line quality begins to suffer. Grades 6 and 5 contain obvious errors resulting from inattentiveness and misreading of the original three-view drawing. While the principal forms are present, finer detail tends to be overlooked or misread. Gross distortions occur, inconsistent or impossible forms are shown, and lines and edges are missing or appear extraneously. Sketches marked 4 and 3 begin to acquire a touch of the surreal.

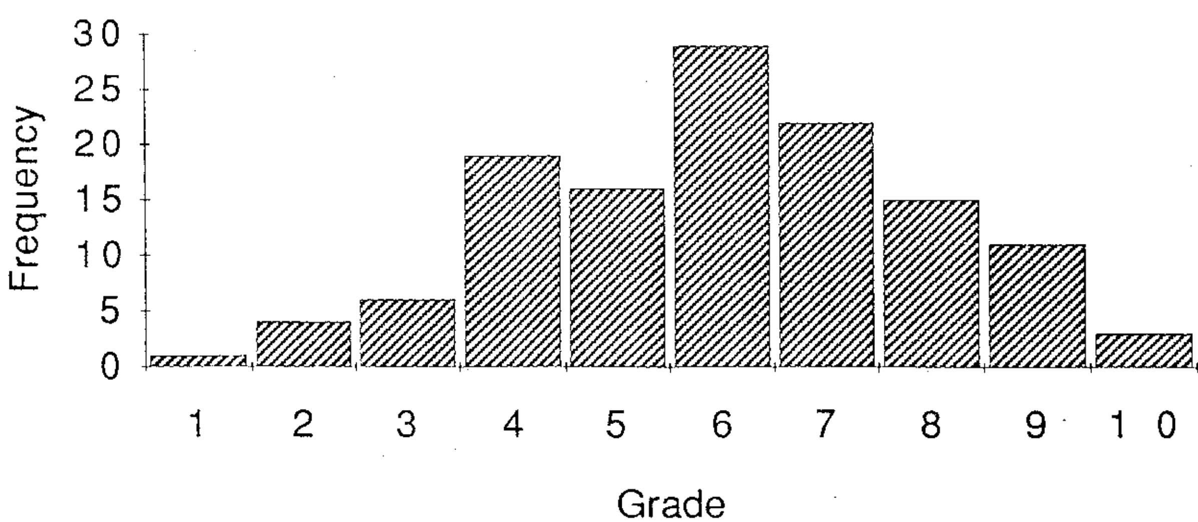

Figure 10. Grade distribution

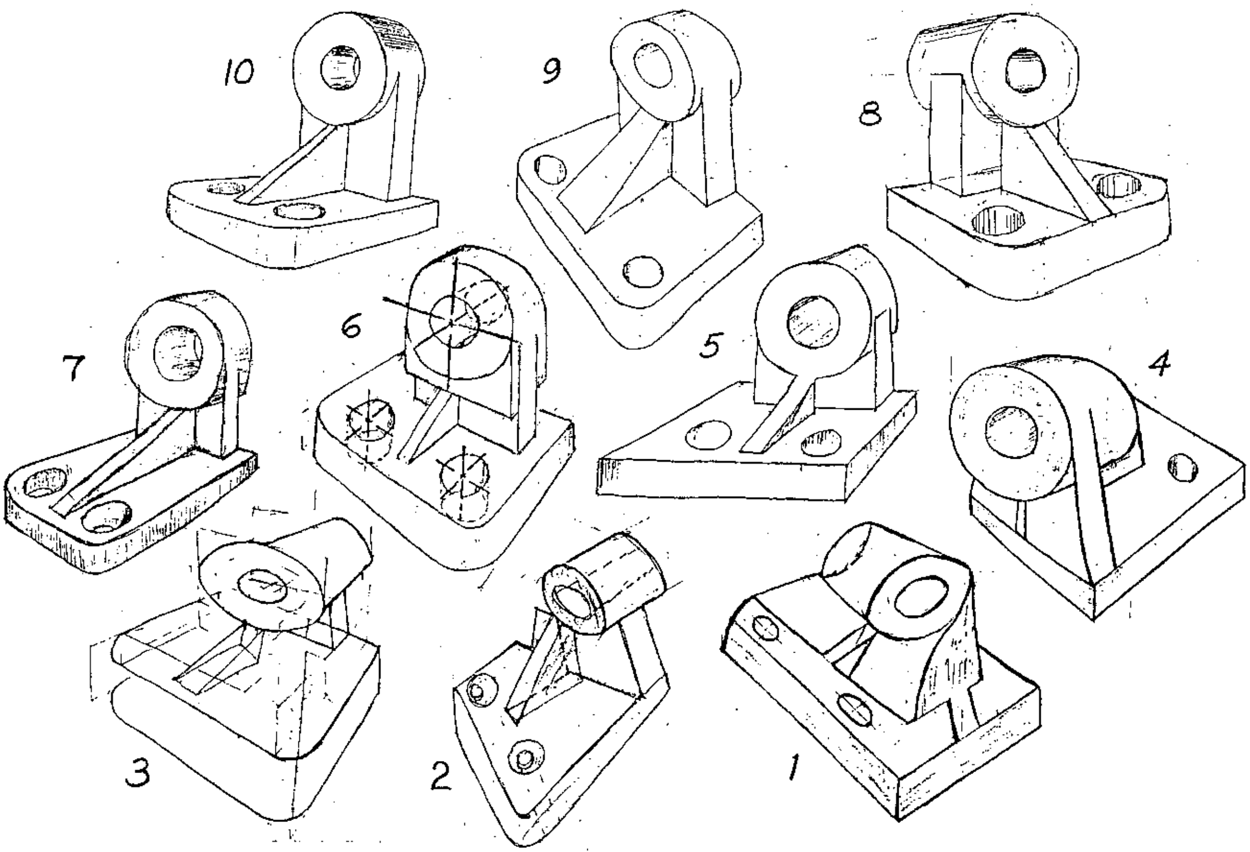

Figure 11. Typical graded sketches

Objects are broken down into their basic elements and then reassembled in a distorted way. Some aspects of the sketch are quite good, but the student ran hopelessly out of time. Drawings in the categories 2 and 1 are reminiscent of the Cubist style of expression. Facets of the object overlap inconsistently, and 'leak' into each other in a structurally baffling way that defies immediate identification. Normal perspective is substituted "with a view of the object taken simultaneously from several viewpoints and fused together into one composition" (Margolius, 1979).

Correlation of the drawing scores achieved by individual students with examination results in other courses taken in the same term yielded the correlation coefficients shown in Table 2. This shows there is practically no systematic relationship between performance in the drawing test and performance in other subject areas. The other courses between themselves are, however, quite strongly correlated. These results indicate that visual perception, visualisation and sketching are somewhat intangible activities with attributes that are different from the quantitative and deductive aspects

Are We Preparing Engineering Students With the Right Skills in Engineering Graphics And Computer Training? A Survey.

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Abstract:

A study was done by the Department of Engineering Graphics at The Ohio State University to determine whether the graduates of the College of Engineering had received adequate preparation in basic engineering skills necessary to function satisfactorily in the workplace. Nine hundred (900) former students and forty (40) employers of Ohio State University graduates were surveyed and the data assembled and evaluated to determine the effectiveness of the core engineering curriculum in two specific areas–graphics and computer skills.

Introduction

The purpose of this study was to investigate the adequacy of graphics and computer training in the core engineering curriculum offered at The Ohio State University. Our approach was to ask graduates of the College of Engineering and some of their supervisors to indicate the importance of several graphics and computer skills in their current jobs and to evaluate the adequacy of their preparation in those areas.

A questionnaire was sent to 900 randomly selected engineering graduates from the years 1987 through 1991 and to 40 employers who consistently hire OSU graduates. (See Appendix I).

The results were tabulated, and for each skill, comparisons were made between the importance of the skill and the level of preparation. These comparisons provide information on skills employers value and on how well our current curriculum prepares students for today's jobs. The inquiry is part of a bigger investigation being done by several universities under the title Gateway Project which is being funded by the National Science Foundation (NSF).

The Questionnaire

The questionnaire, (Appendix 1), listed several basic engineering skills and asked the graduate to indicate the importance of each skill in his or her current job and his or her level of preparation in that skill. Level 1 indicated not important or not well prepared. Level 5 indicated very important or very well prepared.

The main areas of interest were basic engineering skills (math, statistics, mechanics, thermodynamics, etc.); basic graphics skills (sketching, visualization, reading drawings, etc.); computer skills (operations, programming, CADD, etc.); and oral and written communication and problem solving skills. There was also a space for comments to relate any skill needed but not included. Again, this paper focuses on engineering graphics and computer skills.

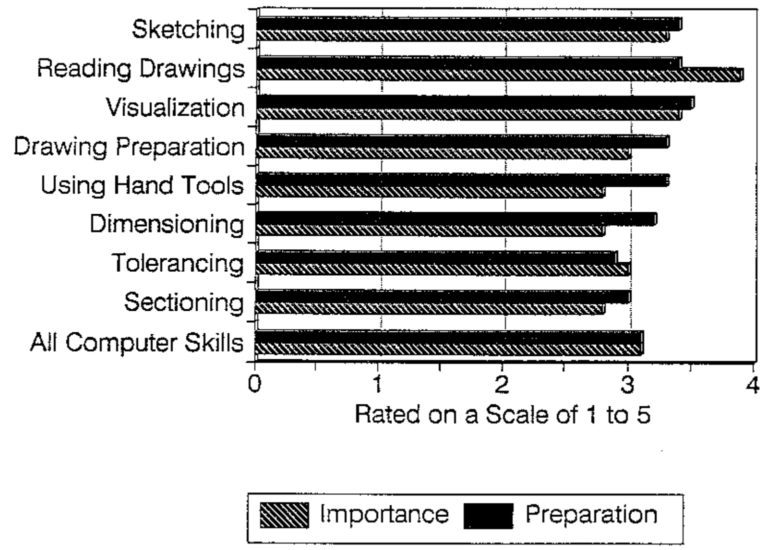

Figure 1. Graphics, by Employers

The Evaluation of Basic Graphics Skills

The evaluation is presented in two sections. First the employers' responses are presented in a graph which shows the relative importance of the various graphics skills. The graph also depicts the employers' opinions of the graduates' preparation in those areas. In the second part of this evaluation the employers' ratings of each skill (importance and preparation) are compared to the responses of graduates having from one to five years of work experience.

Figure 1 summarizes employers' responses to questions about basic graphics skills. Results are shown for eight specific skills and all graphics skills combined. On a scale of one to five (five being most important), the weighted average importance of graphics skills was 3.1. The level of preparation was virtually identical to the importance. The most important graphics skill was reading drawings (3.9) followed by visualization (3.4) and sketching (3.3). All other specific graphics skills had an importance rating of 3.0 or less. For all skills but two, the level of preparation was higher than the importance of the required skill for the job. The two skills for which preparation was judged to be inadequate were reading drawings (importance 3.9 and preparation 3.5) and tolerancing (importance 3.0 and preparation 2.9).

Responses of graduates and employers for each of the eight graphics skills listed on the questionnaire are discussed in the following paragraphs.

Sketching

Graduates with one to five years of experience and employers generally agree that sketching has a relative importance between 3.2 and 3.5 and that preparation is adequate. Only the 1987 graduates showed the importance of sketching to be greater than their preparation. In this case, the term adequate means possessing the ability to communicate and interpret graphic information through sketches.

(See Figure 2).

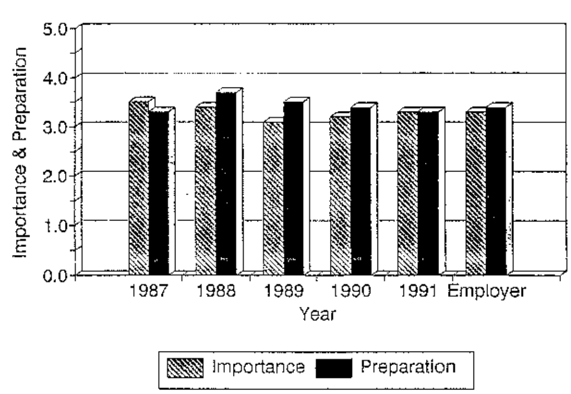

Figure 2. Sketching
Importance and Preparation

Reading Drawings

Reading drawings was identified as the most important graphics skill. Its importance was rated between 3.5 and 4.0 by all groups. Graduates indicated that their level of preparation was approximately 3.0 while employers found it to be higher at 3.5.

(See Figure 3).

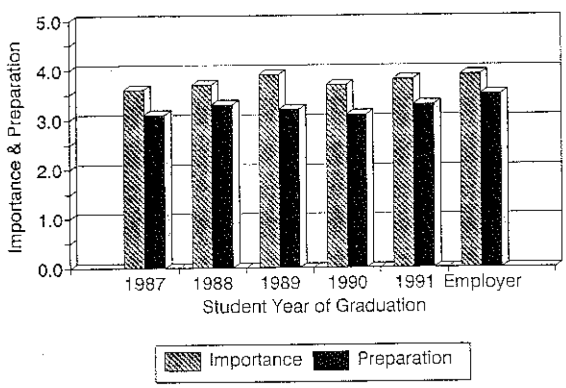

Figure 3. Reading Drawings
Importance and Preparation

The pie charts, Figures 4 and 5, show that nearly 46% of the employers consider this skill important while only 25% think that the graduates preparation was adequate. Again adequate means to look at information on a two-dimensional media and visualize the three-dimensional object or assembly.

(See Figures 4 and 5).

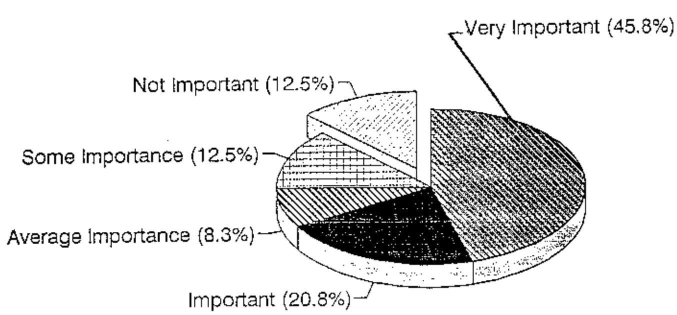

Figure 4. Percent of Managers Who Think Reading Drawings is Important

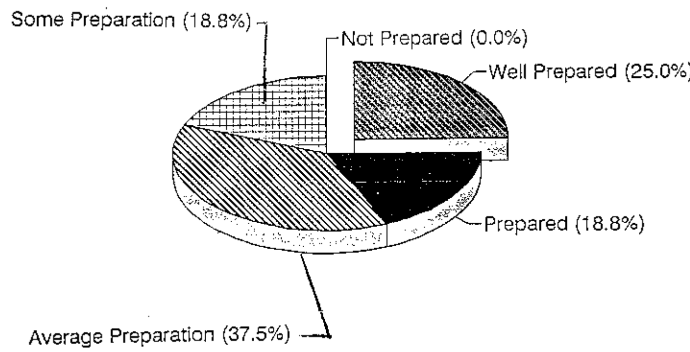

Figure 5. Percent Of Managers Who Think That Those Hired Are Prepared to Read Drawings.

3-D Visualization

Both importance and preparation were rated at approximately 3.4 by all groups. The skill is relatively important, and the graduates generally felt that they had received adequate preparation.

(See Figure 6).

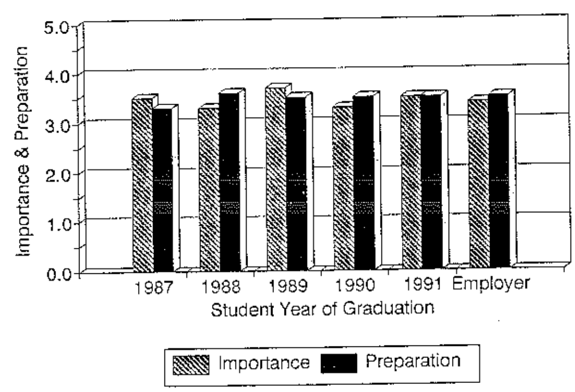

Figure 6. Visualization
Importance and Preparation

Preparing Drawings

Importance is rated below 3.0 by almost all groups, and preparation was deemed more than adequate.

(See Figure 7).

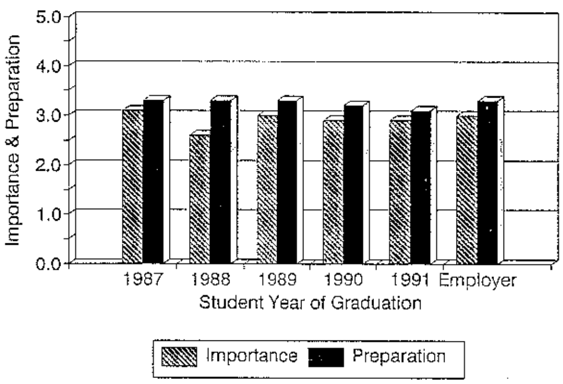

Figure 7. Drawing Preparation
Importance and Preparation

Using Drawing Tools

This skill category shows the greatest discrepancy between importance and preparation with students being far better prepared (3.5) than the job importance (2.5) requires.

(See Figure 8).

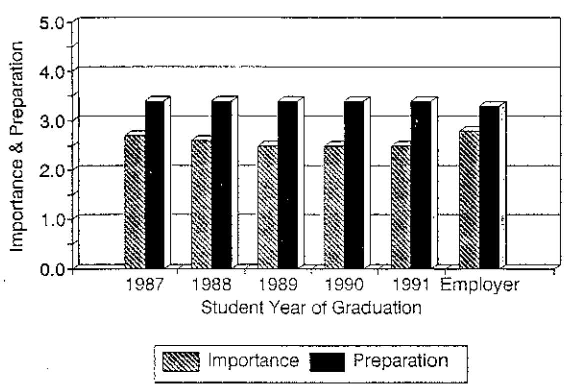

Figure 8. Using Drawing Tools
Importance and Preparation

Dimensioning

Except for the graduates of 1987, all groups agree that preparation in this skill was adequate. Responses from 1987 graduates showed an importance rating slightly greater than the preparation rating.

(See Figure 9).

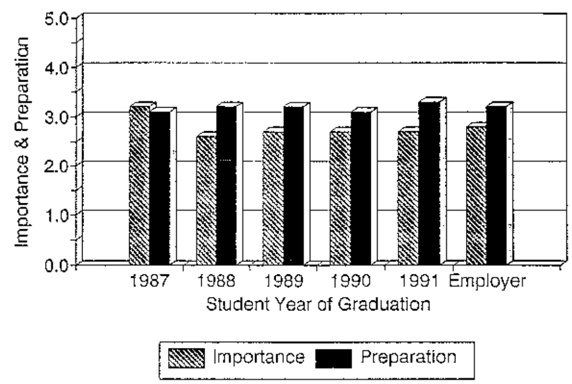

Figure 9. Dimensioning
Importance and Preparation

Tolerancing

Employers and 1987 graduates (the most experience graduates polled) agree that the importance of tolerancing is approximately 3.0 and that preparation is slightly inadequate. Graduates with less experience rate the importance of tolerancing significantly lower and their preparation as being more than adequate.

(See Figure 10).

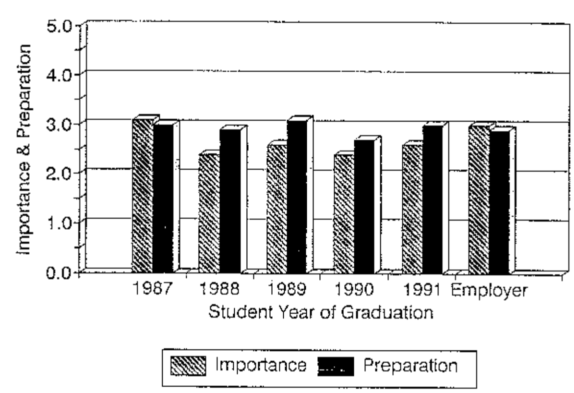

Figure 10. Tolerancing
Importance and Preparation

Sectioning

The importance rating for sectioning varies considerably from group to group with employers rating it higher than any of the graduates. However, all groups found preparation in this area to be adequate.

(See Figure 11).

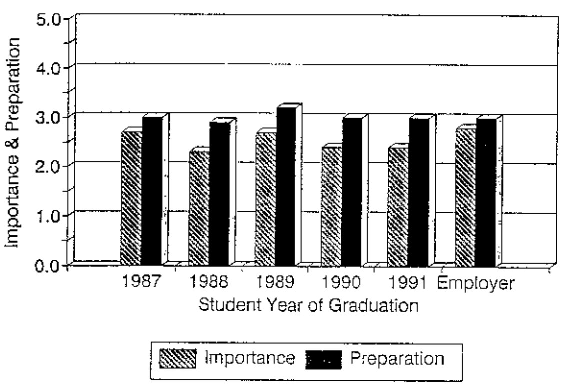

Figure 11. Sectioning
Importance and Preparation

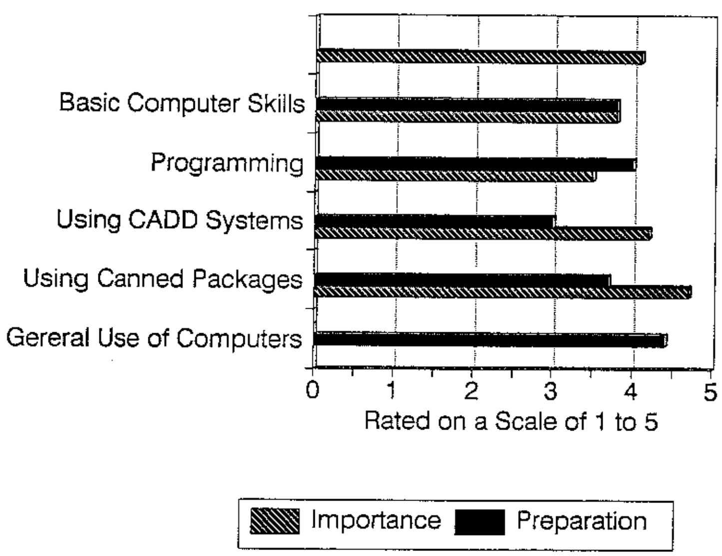

Figure 12. Computer Use, by Employers

The Evaluation of Computer Skills

This evaluation is also presented in two parts with the first showing the employers' responses and the second comparing the responses of all groups. Employers' relative rankings of the four specific computer skills listed on the questionnaire, along with the average of all responses on computer skills, are shown in Figure 12.

Importance of computer skills ranged from 3.5 for "Using CADD Systems" to 4.7 for "General Use of Computers" with the average importance of computer skills being rated at 4.0. In every category except "Programming" preparation was rated lower than importance. The greatest gaps between importance and preparation occurred in the categories of "Using CADD Systems" and "Using Other Software."

Responses of graduates and employers for each of the four computer skills listed on the questionnaire are discussed in the following paragraphs.

Basic Computer Operations

The importance of the knowledge of basic computer operations is higher than any other computer or graphics skill. All groups polled rated its importance between 4 and 5 on a scale of 1 to 5. Preparation in this skill is rated far below importance. However, the level of preparation is higher for more recent graduates. It should be noted that employers rated the level of preparation higher than any class of graduates.

(See Figure 13).

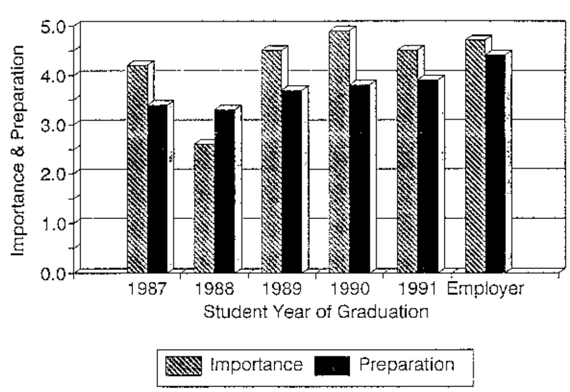

Figure 13. Basic Composition
Importance and Preparation

Computer Programming

Both graduates and employers indicated that preparation in computer programming was adequate. Employers ranked both importance and preparation in this category higher than any class of graduates.

(See Figure 14).

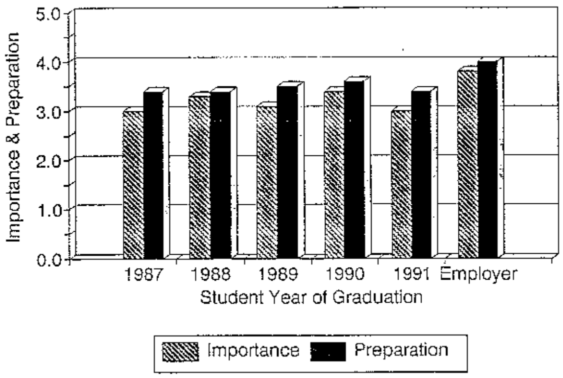

Figure 14. Programming
Importance and Preparation

Using CADD Systems

The greatest discrepancy between importance and preparation in computer skills occurred in this category with preparation found to be quite inadequate. The level of preparation was judged to be virtually identical by all graduates, regardless of year of graduation. Employers rated the preparation significantly higher than the graduates, but they also rated the importance higher than any class of graduates and indicated a significant difference between importance and preparation.

(See Figure 15).

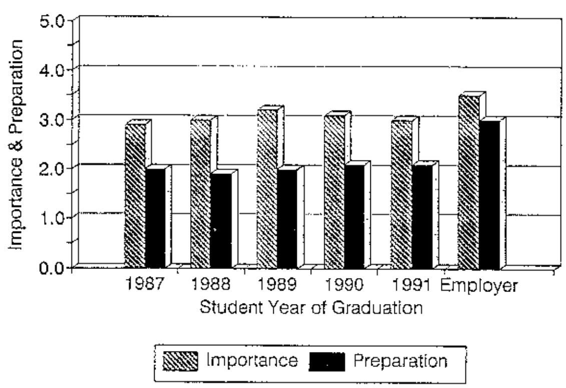

Figure 15. Using CADD
Importance and Preparation

Using Other Canned Programs

Using canned programs other than CADD packages was rated by all groups to be more important than using CADD. Again, the preparation was found to be inadequate. However, 1991 graduates report considerably better preparation than graduates of 1988, 1989, and 1990. Members of the graduating class of 1987 also report preparation as being good.

(See Figure 16).

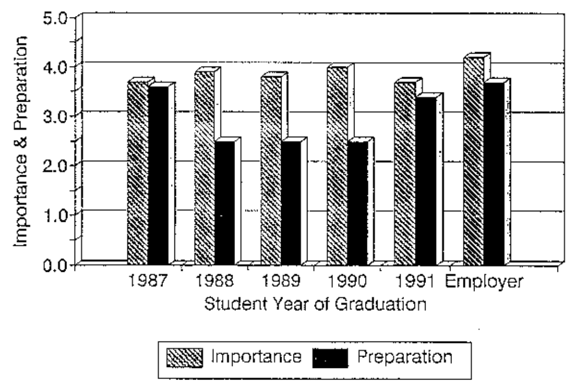

Figure 16. Using Other Canned Programs
Importance and Preparation

Conclusion

There have been other such surveys that have been conducted. "Engineering Education: Preparing The Next Decade," a study by the Engineering Curriculum Task Force of the Arizona State University (1991) was one such study. It found no correlation between academic and on-the-job performance.

The authors of the Arizona State University study concluded that change must occur in the curriculum, and it will take a joint effort of all concerned. This study, however, was geared towards The Ohio State University, its engineering program and those who employ its graduates. Thus, changes are being made to accommodate any lack of preparation reported by the graduates and their employers. The graphics courses have incorporated projects, the use of canned programs, reading drawings and other material to the graphics curriculum.

The authors of this paper feel that the findings are representative since statistically the sample size meets the prescribed testing procedures for the population investigated. All in all, the things being taught in Engineering Graphics at Ohio State University are those needed in the workplace. However, improvement is required in two major areas–reading drawings and CADD, and these have been accommodated as stated above. Several respondents stated in the remarks section or by letter that these areas should be given more attention.

The other areas viewed as lacking were basic computer operations and the use of canned software packages. Several of those responding listed such packages as Mathcad, Pro Engineer, FEM, CFD, Autocad, etc. Graduates of all five graduating classes stated that more time should be devoted to training in computer operations. Many, also, mentioned training in a programming language other than FORTRAN.

Reading drawings and using CADD systems need to be addressed, but just where they are to be inserted in the curriculum remains an administrative problem. Attention will be given to these two special areas at the college level with each department participating to determine when and by whom this information will be taught. Again, as with the Arizona Study, it will take a concentrated effort between academia and industry to move ahead to prepare Ohio State University students to meet the needs of industry.

The letters and recommendations that accompanied the responses to the questionnaire were very positive. In most all areas the graduates felt that they were well prepared for their role in industry. This was confirmed by their employers except in the instances stated above.

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ENGINEERING CORE SKILLS SURVEY

Please circle the numbers that indicate how important each skill is to successful performance in the positions you supervise and how well OSU graduates are prepared in each area. One means not very important or not very well prepared. Five means very important or very well prepared.

	IMPORTANCE ON JOB					PREPARATION				
1. Basic Engineering Skills										
a. math										
calculus	1	2	3	4	5	1	2	3	4	5
diff. eq.	1	2	3	4	5	1	2	3	4	5
b. statistics	1	2	3	4	5	1	2	3	4	5
c. physics										
mechanics	1	2	3	4	5	1	2	3	4	5
fields & electricity	1	2	3	4	5	1	2	3	4	5
d. chemistry	1	2	3	4	5	1	2	3	4	5
e. engineering mechanics										
statics	1	2	3	4	5	1	2	3	4	5
dynamics	1	2	3	4	5	1	2	3	4	5
strength	1	2	3	4	5	1	2	3	4	5
f. thermodynamics	1	2	3	4	5	1	2	3	4	5
g. basic electronics	1	2	3	4	5	1	2	3	4	5
h. engineering economics	1	2	3	4	5	1	2	3	4	5
i. materials	1	2	3	4	5	1	2	3	4	5
j. other ______________	1	2	3	4	5	1	2	3	4	5
2. Basic Graphics Skills										
a. sketching	1	2	3	4	5	1	2	3	4	5
b. reading drawings	1	2	3	4	5	1	2	3	4	5
c. visualizing objects from 2-D media	1	2	3	4	5	1	2	3	4	5
d. preparing drawings	1	2	3	4	5	1	2	3	4	5
e. use of drawing tools	1	2	3	4	5	1	2	3	4	5
f. dimensioning	1	2	3	4	5	1	2	3	4	5
g. tolerancing	1	2	3	4	5	1	2	3	4	5
h. sectioning	1	2	3	4	5	1	2	3	4	5
i. other ______________	1	2	3	4	5	1	2	3	4	5
3. Computer Skills										
a. basic computer operation	1	2	3	4	5	1	2	3	4	5
b. programming	1	2	3	4	5	1	2	3	4	5
c. using CADD systems	1	2	3	4	5	1	2	3	4	5
d. using other canned programs	1	2	3	4	5	1	2	3	4	5
e. other ______________	1	2	3	4	5	1	2	3	4	5
4. Communication and Problem Solving Skills										
a. writing skills	1	2	3	4	5	1	2	3	4	5
b. oral skills	1	2	3	4	5	1	2	3	4	5
c. problem solving	1	2	3	4	5	1	2	3	4	5
d. teamwork	1	2	3	4	5	1	2	3	4	5
e. other ______________	1	2	3	4	5	1	2	3	4	5

5. Comments (especially on any skills you think new OSU graduates lack):

Appendix 1

The First Two Years – Are Engineering Students Learning the Skills They Need?

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Robert R. Britton
Frederick D. Meyers
Department of Engineering Graphics
The Ohio State University
Columbus, Ohio

Abstract

The Department of Engineering Graphics at The Ohio State University has conducted a survey of several hundred recent engineering graduates to determine whether the core engineering curriculum provided them with the skills required for their jobs. Four categories of skills were included in the study. The focus is on two of those categories: 1) Basic Engineering Skills and 2) Communication and Problem Solving. First line managers at companies that routinely hire engineers were asked to complete the same questionnaire. Comparisons were made between responses of graduates and those of employers.

Introduction

In the summer of 1992 faculty members from the Department of Engineering Graphics at The Ohio State University conducted a survey to determine whether the core engineering curriculum was providing engineering students with the skills they needed. A questionnaire was sent to 900 recent graduates of Ohio State's College of Engineering. Equal numbers of engineers were chosen from each of the past five graduating classes (1987-1991). The students were selected randomly with no prescribed mix of engineering disciplines. The questionnaire was also sent to 40 employers who typically hire OSU engineering graduates.

Several basic skills were listed on the questionnaire. For each skill, the graduates and employers were asked to indicate the importance of that skill on the job and the adequacy of the students' preparation. Employers evaluated all of their engineers in general, rather than only the Ohio State graduates. A numerical scale was used to rate the importance and adequacy of preparation.

Four hundred graduates and 26 employers responded to the survey. Responses were sorted into six groups: one for employers and five for graduates – one for each graduating class. In all groups, average ratings for importance and adequacy of preparation were calculated for each basic skill.

Several comparisons were made. In the six groups the importance rating was compared with the preparation rating for each skill. This provided information on whether the engineering core curriculum is emphasizing the skills most important to job performance. Graduates' responses were compared with those from employers to determine whether the perceptions of those two groups were consistent. Finally, ratings from each of the five groups of graduates were compared to identify any changes over time in either importance of a skill or the graduates' level of preparation.

The Questionnaire

A copy of the questionnaire is presented in the appendix. It lists four major categories of skills believed to be important to practicing engineers:

1. Basic Engineering Skills,
2. Basic Graphics Skills,
3. Computer Skills, and
4. Communication and Problem Solving Skills.

Under each major category several more specific skills are listed. Respondents were asked to rate the importance and level of preparation for each specific skill on a scale of 1 to 5, 1 being not important or not well prepared and 5 being very important or very well prepared.

An earlier paper by the same authors presented the responses in the categories of Basic Graphics Skills and Computer Skills. This paper, "Are We Preparing Engineering Students with the Right Skills in Engineering Graphics and Computer Training? A Survey," by Britton, Fentiman, and Meyers can be found on page 22 of this same issue. The focus of this paper will be on responses in the areas of Basic Engineering Skills and Communication and Problem Solving Skills.

Evaluation of Basic Engineering Skills

The specific skills listed under the category of Basic Engineering were: math (calculus, differential equations), statistics, physics (mechanics, fields & electricity), chemistry, engineering mechanics (statics, dynamics, strength), thermodynamics, basic electronics, engineering economics and mater-ials. In nine of these thirteen areas, most groups of respondents rated the level of preparation higher than the importance on the job. The four areas in which preparation was found to be barely adequate or somewhat inadequate were statistics, economics, electronics, and materials. In these four areas, the employers found preparation to be inadequate only in statistics.

When the relative importance of the thirteen areas was studied, differential equations was found to be rated the least important by all groups of respondents with an average rating of 2.1. Chemistry was the next lowest with a rating of 2.4. Thermodynamics, fields and electricity, calculus, and dynamics all had importance rankings between 2.5 and 2.9, inclusive. Strengths, electronics and statics were ranked at 3.0 or 3.1. The most important skills (ratings 3.2 - 3.3) were mechanics, statistics, materials, and economics. Figure 1 shows the average importance and preparation ratings for all thirteen categories.

Discussions of the responses to the questionnaire for each specific skill are presented on the following pages.

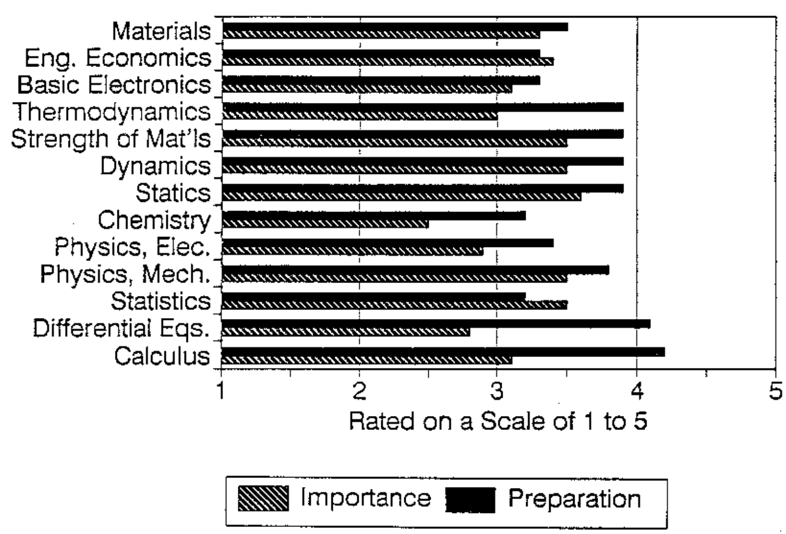

Figure 1. Importance and Preparation by Employer of Basic Engineering Skills

Calculus

While employers rated the importance of calculus higher than any of the five groups of graduates (employer rating - 3.0, graduate rating - 2.5), all groups of respondents agreed that preparation in this area was adequate. The preparation ratings were between 3.8 and 4.1.

(See Figure 2).

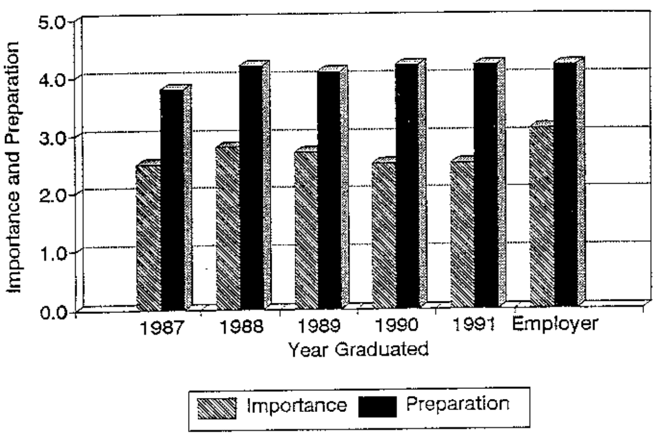

Figure 2. Calculus
Importance and Preparation

Differential Equations

Graduates and employers had significantly different perceptions of the importance of differential equations. The graduates rated their importance at about 2.0, but employers gave them a rating of 2.8. There was also some difference in the preparation rankings. Graduates rated their preparation at 3.6 while employers rated it at 4.1.

(See Figure 3).

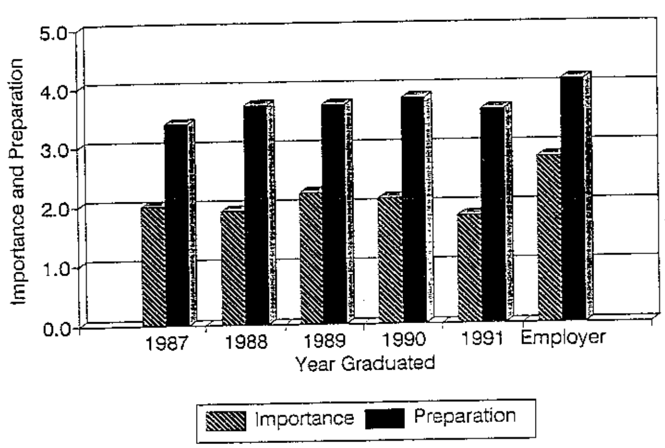

Figure 3. Differential Equations:
Importance and Preparation

Statistics

Graduates and employers agreed that the importance rating of statistics was slightly greater than 3.0, and the preparation rating was slightly less than 3.0, making the preparation somewhat inadequate.

(See Figure 4).

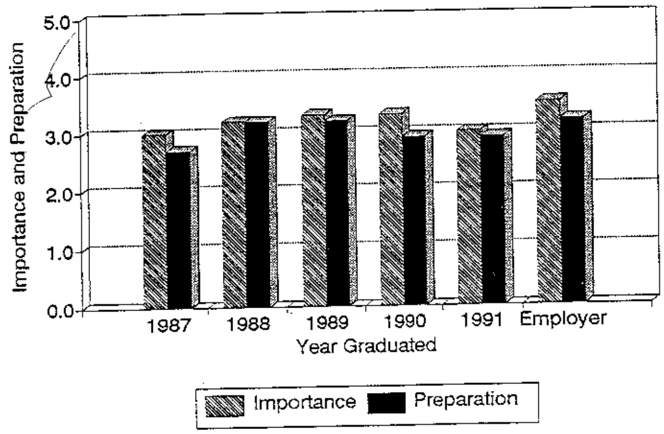

Figure 4. Statistics
Importance and Preparation

Mechanics

Preparation in mechanics was adequate.
(See Figure 5).

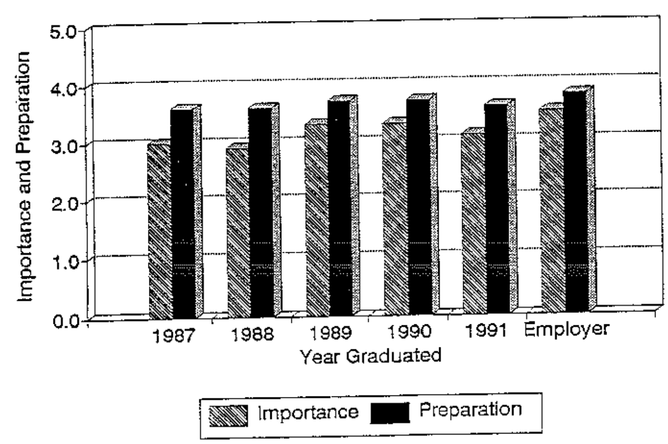

Figure 5. Physics Mechanics:
Importance and Preparation

Fields and Electricity

Preparation in this skill was adequate. (See Figure 6).

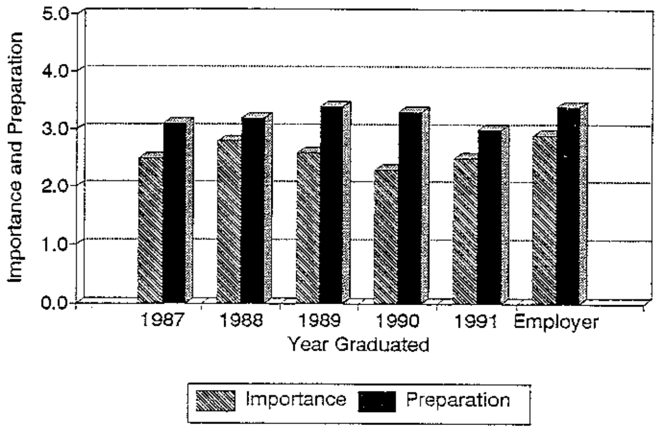

Figure 6. Fields and Electricity
Importance and Preparation

Chemistry

Responses in this area were very uniform. All groups of graduates and employers rated the importance of chemistry at about 2.4 and preparation at 3.1.
(See Figure 7).

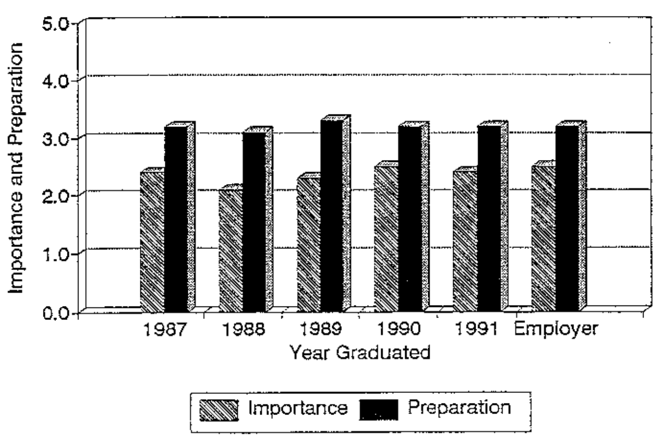

Figure 7. Chemistry
Importance and Preparation

Statics

Employers rated the importance of statics slightly higher than any group of students but, all groups agreed that preparation was adequate.
(See Figure 8).

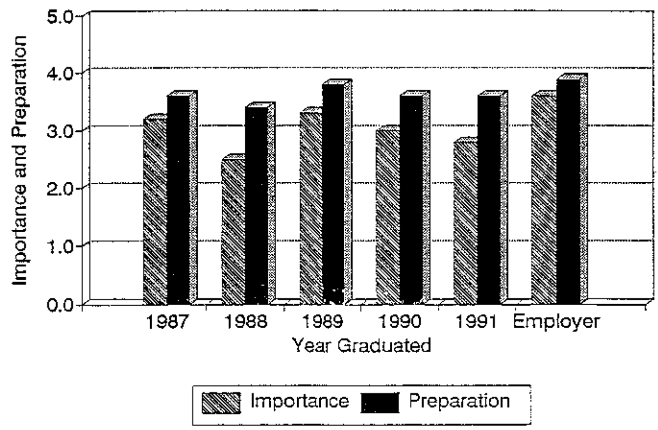

Figure 8. Statics
Importance and Preparation

Dynamics

Graduates with the most work experience and employers rated the importance of dynamics higher than did graduates with less experience. However, all groups indicated that preparation was adequate.
(See Figure 9).

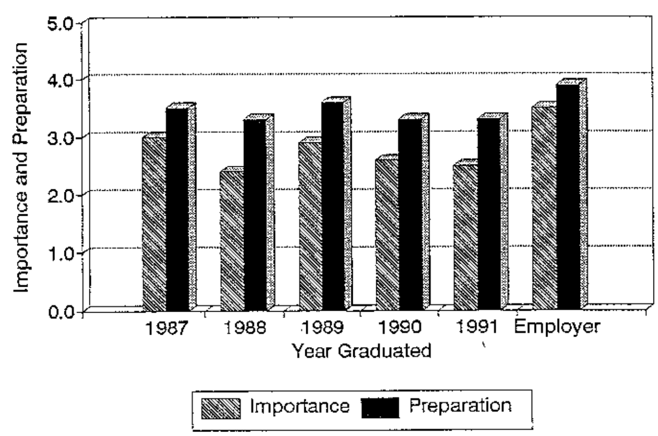

Figure 9. Dynamics
Importance and Preparation

Strengths

Preparation in this area was adequate. (See Figure 10).

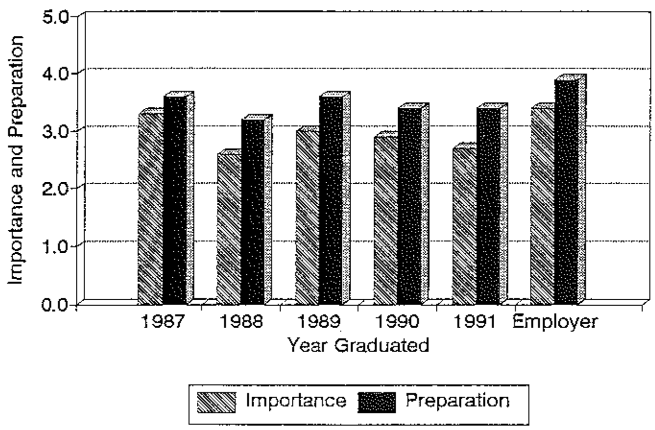

Figure 10. Strengths
Importance and Preparation

Thermodynamics

All groups indicated that preparation in thermodynamics was adequate. Employers' ratings for both importance and preparation were higher than ratings by any group of graduates.

(See Figure 11).

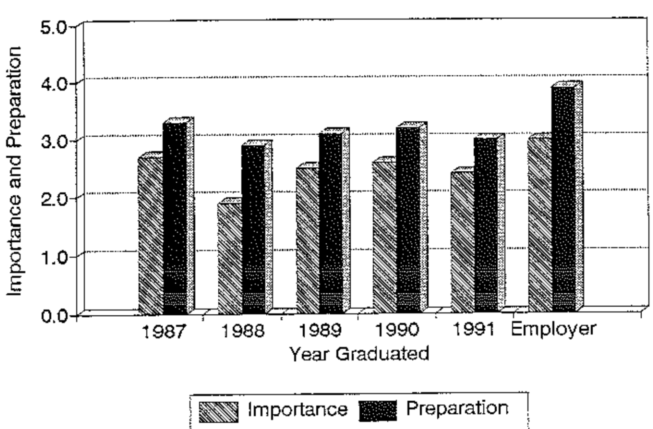

Figure 11. Thermodynamics
Importance and Preparation

Electronics

For all groups of respondents the importance and preparation ratings in electronics were almost identical. Most graduates thought that preparation was slightly inadequate while employers thought that it was barely adequate.

(See Figure 12).

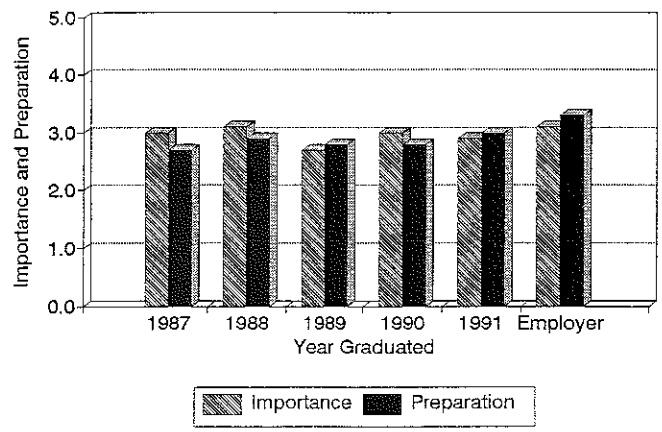

Figure 12. Electronics
Importance and Preparation

Engineering Economics

The preparation rating in engineering economics was lower than the importance rating for most groups. Graduates with four or five years of experience cited the greatest discrepancy between importance and preparation.

(See Figure 13.)

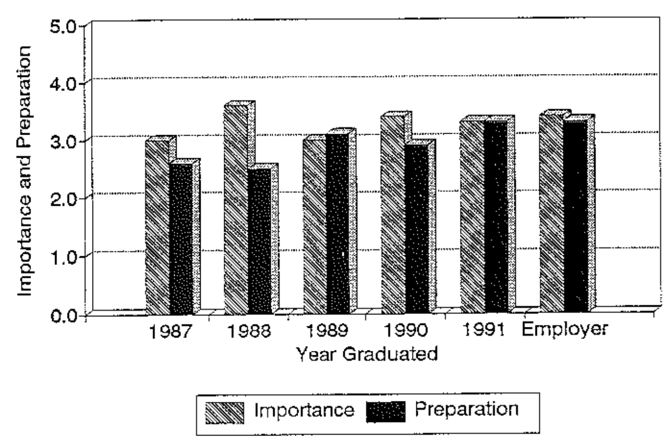

Figure 13. Engineering Economics
Importance and Preparation

Materials

Importance and preparation were given nearly equal values by all groups, with graduates indicating that preparation was slightly inadequate, and employers finding preparation to be adequate by a small margin.

(See Figure 14).

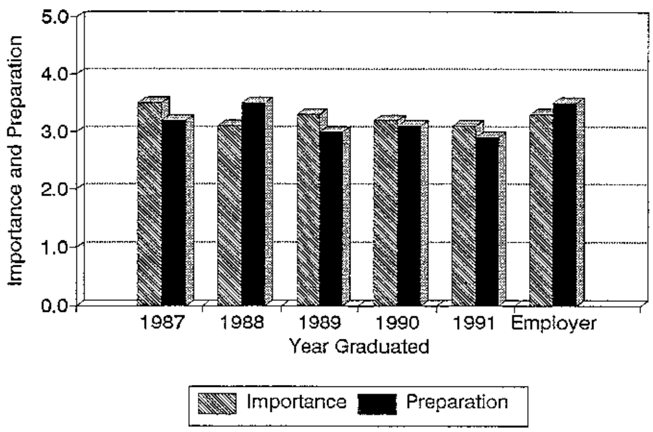

Figure 14. Materials
Importance and Preparation

Evaluation of Communication and Problem Solving Skills

The specific skills listed under Communication and Problem Solving were writing skills, oral skills, problem solving, and teamwork. Graduates and employers, alike, rated these skills to be more important in job performance than any other category of skills included on our questionnaire. Basic Engineering Skills and Graphics Skills were given an importance rating of about 3.0. The importance of Computer Skills was about 4.0. But the importance of Communication and Problem Solving Skills was rated at nearly 4.5 on a scale of 5.0.

Preparation in all four specific areas under Communication and Problem Solving was found to be very inadequate by all groups of respondents. Preparation ratings for oral skills and teamwork were 1.5 to 2 points lower than importance ratings. Preparation ratings in writing and problem solving skills were somewhat better. Furthermore, both the importance and preparation ratings for each specific skill were quite uniform over all groups of respondents. Figures 15-18 show the ratings for the four specific areas under Communication and Problem Solving. Figure 19 presents the average importance and preparation ratings for all four areas.

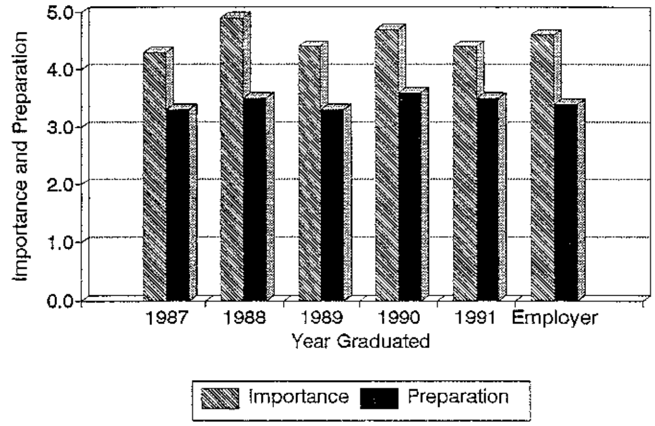

Figure 15. Writing Skills
Importance and Preparation

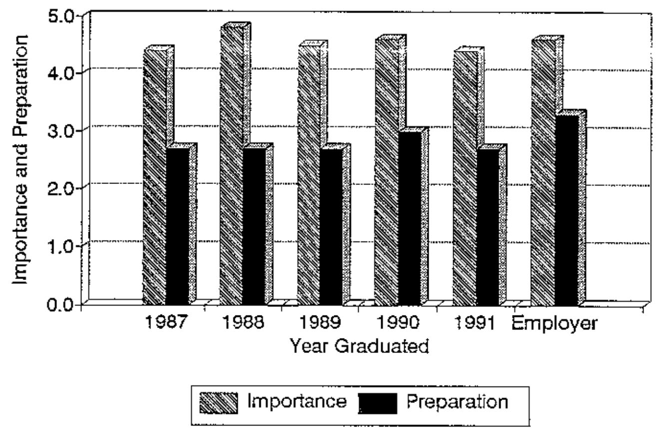

Figure 16. Oral Skills
Importance and Preparation

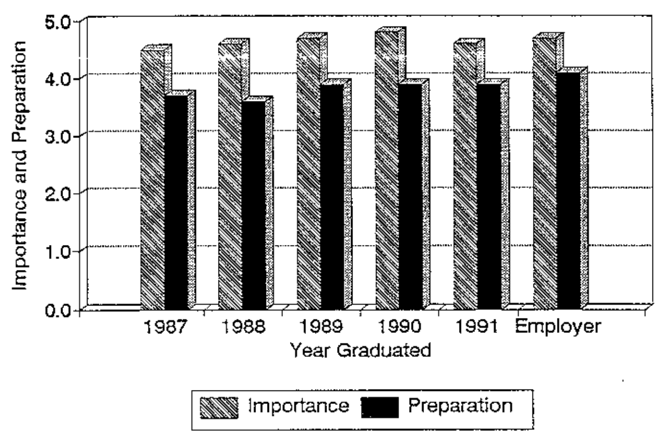

Figure 17. Problem Solving
Importance and Preparation

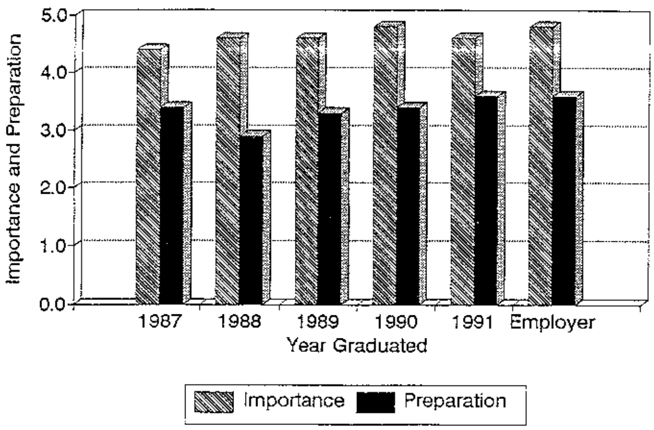

Figure 18. Teamwork
Importance and Preparation

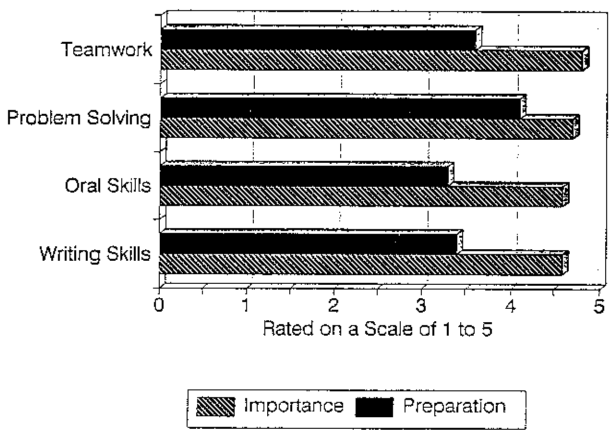

Figure 19. Importance and Preparation by Employer
Communication and Problem Solving Skills

Discussion

Most of the basic engineering skills taught in the core engineering curriculum appear to adequately prepare students for their jobs. Statistics, economics, electronics, and materials are areas where respondents to this survey believe some improvement in preparation is needed.

Some do not consider statistics and economics to be core engineering subjects. However, in a world which is becoming increasingly competitive, the ability to collect valid data and interpret it properly is crucial. A good grasp of statistics is essential in developing that ability. And in this more competitive environment, the ability to make sound costing and pricing decisions is more important than ever. Students need to understand basic engineering economics principles.

Electronics and materials have long been part of the basic engineering curriculum. However, these areas are changing rapidly. Many of the processes which in the past were purely mechanical are now electronically controlled. Today's engineers must understand many more applications of electronics than their predecessors and be able to incorporate them into their daily work. Similarly, the materials from which an engineer may choose has increased tremendously and is growing daily. The slight discrepancy between importance and preparation ratings for electronics and materials may well be an indication that the fields are changing more rapidly than the engineering courses.

Communications and problem solving skills have always been important for practicing engineers. But there used to be more time to complete a project which required these skills – whether that project was designing a piece of equipment or producing a document. Solutions to problems could evolve slowly. Letters, reports, and presentations might be drafted, revised, and then rewritten until they were acceptable. However, because of the rapidly increasing pace at which products must be developed and marketed, new designs and solutions are often required in days instead of months, and communications by fax or electronic mail help make this process nearly instantaneous. An engineer's problem solving and communications skills must be so finely honed that the conceptual design of a piece of equipment or the first draft of a letter must be almost perfect because there will be little or no time for refinement.

Graduates and employers responding to the questionnaire emphasized again and again how important communications skills are. Here are comments from two graduates that are representative of the scores of comments received:

- "Expose the student to more oral and written presentations, one of the most important aspects of my job. If a young professional can't present his ideas in a clear and orderly manner, he loses credibility quickly no matter how brilliant his ideas may be."

• "More emphasis is needed in the communications area for our engineers. It's not enough to be just a good engineer. More and more engineers are expected to be able to deal with customers and upper management. Being successful often depends upon these skills."

Conclusions

Results of our survey indicate that economics, statistics, electronics, materials, and especially communications and problem solving skills must receive heavier emphasis in the engineering curriculum. In the 'Comments' section of the questionnaire, graduates repeatedly called for better preparation in these areas.

One graduate summed up the comments on statistics by saying, "Statistics is absolutely critical, especially [in] design of experiments and analyses of results." Basic principles of statistics and economics can be included in the core curriculum, and those principles can be applied in later design courses.

Early engineering courses need to provide an understanding of basic electronics and an appreciation for their wide-spread use. Electronic controls should be incorporated into the laboratories used for more advanced courses. All engineering students should be introduced not only to the common materials, but also to materials research and data bases or handbooks of materials. Many materials will be developed between the time a student takes the materials course and graduation day. Students must be aware of the sources of information on recent materials development. Only some engineering students now receive this instruction. All should. Communication skills, as well as problem solving, and team-building skills, must be explicitly incorporated into as many core engineering courses as possible. These courses should also provide students with skills they will need on the job. As so many of our graduates have said, "Without these *people skills* many of an engineer's technical skills will go unnoticed."

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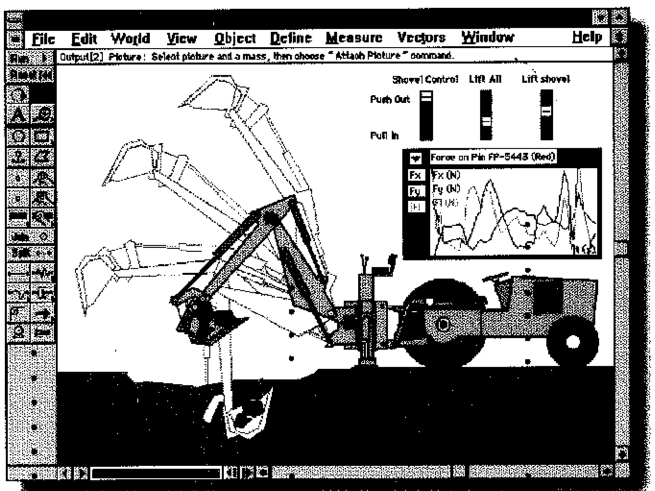
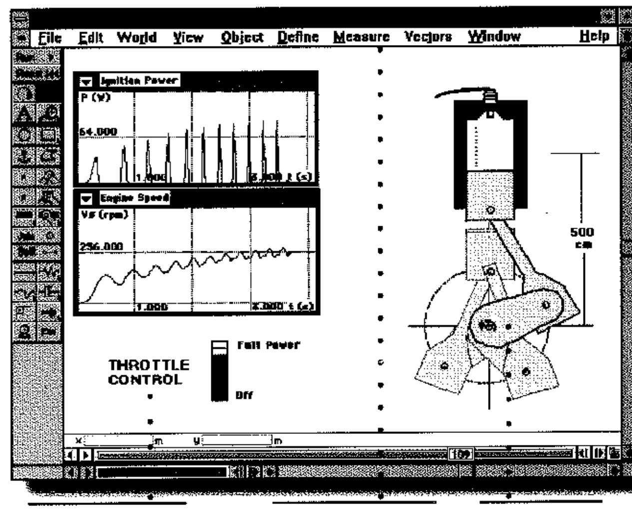
Acknowledgement

The work presented in this paper was supported, in part, by the Gateway Project, a cooperative study of core engineering curriculum funded by the National Science Foundation.

Destroy your only prototype, overload your latest design, and see what 30,000 pounds of force does to a pin joint. And that's <u>before</u> lunch.





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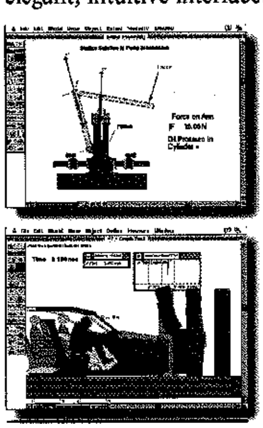

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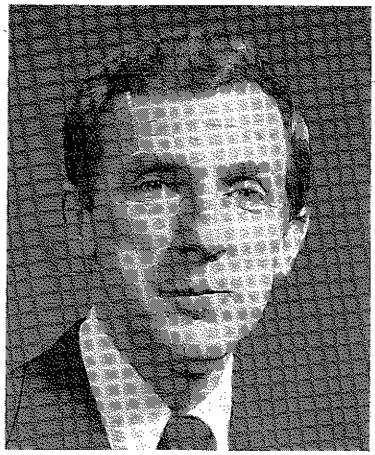

Chair's Message
J. Barry Crittenden

Is it "deja vu" all over again? Will the wholesale elimination of graphics programs which occurred in the 70's occur again to those programs which remain, but this time due to different reasons. In the 70's, most programs were still working in the pencil and paper mode. Our engineering colleagues saw no reason for teaching the principles of engineering graphics, even as associated with engineering design. Programs fell like rain.

Today, budget cuts at universities throughout the country are forcing all divisions within the university to study their organization and set new priorities. Within Colleges of Engineering the chances are quite good that departments and programs associated with engineering design graphics are going to feel the pinch more than their fair share – typically such departments or programs do not offer a degree. Is your program ready for this close scrutiny? Can you justify to your engineering colleagues the continued existence of your graphics program as a separate entity, rather than being absorbed, and therefore de-emphasized, into a typical degree-granting department?

Are we in the engineering design graphics division sufficiently informed and motivated enough to ensure the continued existence of our programs and even the expansion of such programs within all engineering programs? I think not! Would it be practical to debate the pros and cons of engineering design graphics programs? Could this be a reason to convene an EDGD summer school?

We have been accused of preaching to the choir, i.e., speaking to each other at conferences to convince ourselves of the need and importance of the existence of engineering design graphics programs. Maybe it's time to stop describing the technical aspects of engineering design graphics and initiate some soul-searching discussions on why we exist as a profession, how we exist as a profession, and why we should continue to exist. We have done a poor job of conveying the importance of engineering design graphics to our engineering colleagues – thus engineering design graphics programs disappear as independent entities on campuses throughout the country.

At the mid-year conference in Athens, Ohio, in early November, 1993, the topic of a summer school was addressed. No consensus was reached, possibly because some of us envisioned the summer school as simply an extension of the EDGD conferences and possibly because of the costs involved. Might not we gather under the direction of trained specialists in problem solving in order to determine how our divisions and thus its members might best present our concerns to ABET, college deans and department heads, and most importantly, our colleagues. It's time that the Division take steps to stop the elimination of programs needed by our students.

Regular Tetrahedron An Extension of the Equilateral Triangle

By Clarence E. Hall

After having discussed and proven the magnitude of angle MNK to be three times that of angle MCK' as shown in Fig. 1, previous studies revealed the possibility of another approach to displaying graphically the trisection of an arbitrary acute angle with only an unruled straight edge and compass. This is possible, by starting with a given equilateral triangle, its medians, and two arcs of equal radii, that is, equal to BF and AF, with centers at points D and A, as shown in Fig. 2.

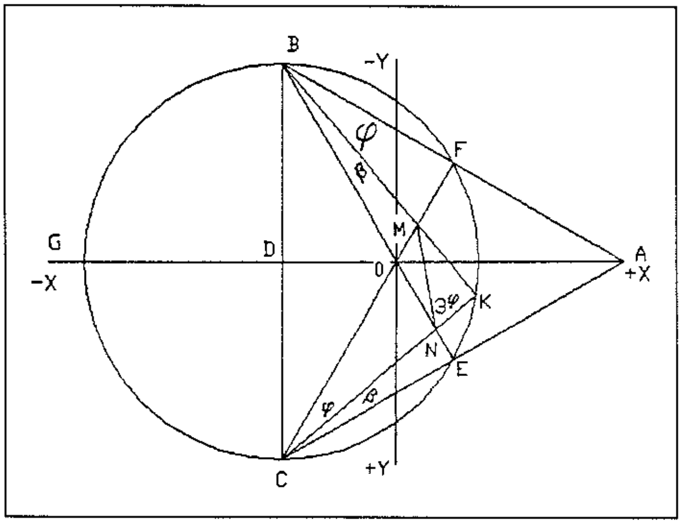

Figure 1.

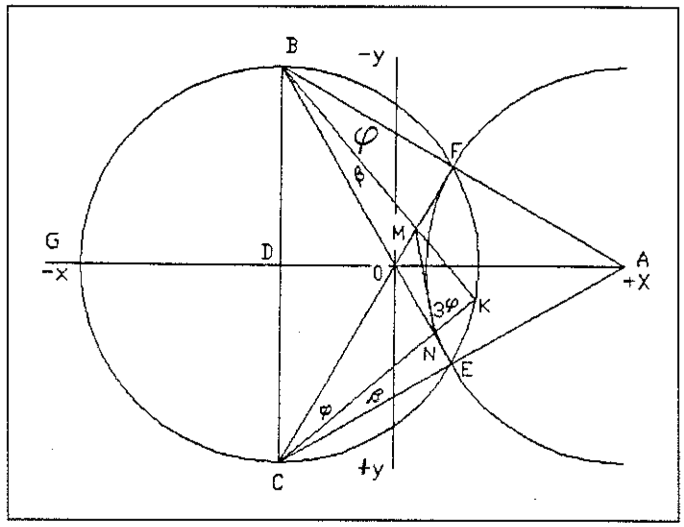

Figure 2.

First, choose some arbitrary point N on median BE between points O and E. From N construct a line tangent to the arc EF whose center is A, and extend the line to intersect median CF at M. Draw line NM.

From C, draw line CN and extend it to intersect the arc BFEC at K. From B construct a line perpendicular to line CK. This line will contain points K and M. Angle K is a right angle since it is subtended by the 180° arc CGB.

This completes the construction shown in Figure 2, and it is, in the main, identical to that of Figure 1. Having previously proved the magnitude of angle MNK to be three times that of angle MCK for Figure 1, this is also true for Figure 2.

Therefore a line drawn through N parallel with MC in Figure 2, will produce an angle between KN and the newly constructed line, parallel with MC, equal to one-third of angle MNK. The remaining angle between the newly constructed line and MN may be bisected, thus dividing angle MNK into three equal parts.

One may also observe that angle CMN is 2θ and the exterior angle for triangle CMN is 3θ.

Someone may remark that this method does not, as yet, enable one to assume any acute angle and trisect it directly. This may be a valid criticism of the procedure just presented, but it does result in trisecting an arbitrary acute angle. It must be observed, from the above discussion, that when line CN is drawn and extended to arc BFEC angle MNK is certainly arbitrary. There remains much study to consider the relationship between the **Circumcenters, incenters, centers of gravity, and the ninepoint circles of the two triangles MNK and MCK.**

(It just may be that this means of graphically relating 3θ and θ. and the procedure used in arriving at this solution, is the first of its kind in the history of geometry.)

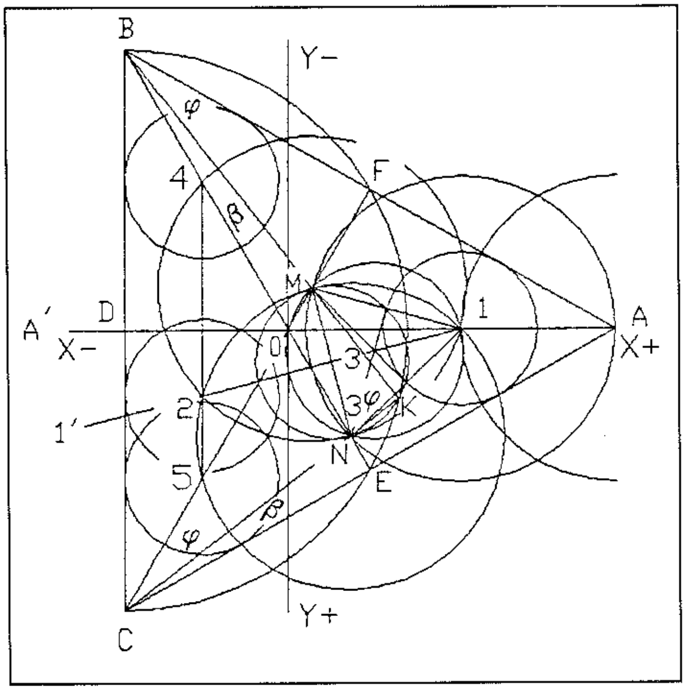

Figure 3

Another procedure may be employed to achieve similar results, and again as in the previous solution, and are formed simultaneously. The following discussion begins with a horizontal line A-A' coinciding with the X-axis, and A positioned at the positive end of the axis. (See Figure 3.) One should be reminded that this construction is possible also with an unruled straight edge and compass.

From A, construct a circle of arbitrary radius, say 1.2 units in length, and label the point where this circle intersects the X-axis between A and A' as 1. *It is suggested that a radius of 1.2 units be used for two reasons. First, one will need increments such as R/2 and R/3 which may be easily obtained if R=1.2. Secondly, this radial dimension will result in a reasonable size drawing when completed.*

Following is a step-by-step procedure for developing the entire design depicting graphically, the relationship between 3θ and θ as shown in Figure 3. Instructions for completing this are shown in the following thirteen step procedure.

Instructions

1. After having located point 1 on line AA', line 11' is drawn making an arbitrary angle with line AA' as shown in Figure 3. It is suggested that the angle chosen be between 10 and 25 degrees. This will result in a more reasonable appearing diagram. Even though angle A'11" is arbitrary, its exact value is (2θ – 30°).
2. From point 1, construct another line 11" making an angle of 30° with line 11'. Line 11" in Figure 3 will coincide with line 1N as construction proceeds.
3. With 1 as center, construct a circle of radius R, [R=1.2] intersecting line 11" at point N. (Once N is located, line 11" may be trimmed to N.)
4. From N, construct a line perpendicular to line 11', and extend it to intersect circle 1 at M. Line MN=1A and is R units in length by construction.
5. Points 1,N,M form an equilateral triangle, whose medians intersect at 3. Construct triangle 1,N,M, its medians and label their intersection as 3.
6. With 3 as center, construct a circle of radius 1-3. Note, this circle contains points 1,N,M and intersects the X-axis at a point between 1 and A'. Label this point O, for it becomes the origin of the overall X-Y coordinate system.
7. With 3 as center, construct circle having a radius O-A. This circle will circumscribe the triangle ABC when completed.
8. From A, construct a line of arbitrary length (say 5 units) making an angle of 150° from A, with line AA', and another line of the same length making an angle of 210° from A, with line AA'. Label the points where these two lines intersect circle O, as B and C as shown in Figure 3. Draw line BC.
9. Construct medians BE and CF. Note: The medians contain points N and M respectively. This is an intrinsic property of this procedural design.
10. With the midpoint of line BC as center, construct a circle of radius DB or DC. This circle contains points E and F. (D is the midpoint of the hypotenuse of both right triangles BEC and BFC.)

11. From C draw line CN and extend it to intersect circle D. Label this line's intersection with circle D as point K.
12. From B draw a line perpendicular to line CK. It intersects line CK and circle D at K. Line CK by construction contains N, while line BK contains M which results as an intrinsic property of this problem.
    The drawing as it now exists is essentially the same as Figure 1 and Figure 2. Consequently, since proof has been given that angle MCK is three times angle MCK, this should be adequate proof that angle MCK is three times the size of angle MCK.
13. From the midpoint of line MN as center, construct a circle of radius R/2, or MN/2. This circle intersects circle D in two points, and one of those points is K.

Note

A circle of radius R/2 with the midpoint of MN as its center will intersect circle D in one or two points. If at only one point it will be the point of tangency of circle MNK and circle D, and their centers will be collinear. Should there be two points of intersection only one will be K.

A significant observation

Having chosen an arbitrary angle 1',1,A' which was designated as (2θ-30°), and completing the construction as indicated, resulted in angles MNK and MCK being generated simultaneously, yet their relationship is three to one or one to three as one may describe such.

On one occasion a circle of radius R/2 was constructed from point 1, and it seemed tangent to lines AB and AC. The analysis of this apparent tangency proved the circle to be tangent to the two lines as indicated. After this, a circle of the same radius was drawn with point 2 as center. This circle proved to be tangent to line BC. Similar circles were constructed with points 4 and 5 as centers. These are tangent to lines BC, AB and AC. (See Figure 3.)

Additional investigation revealed circles 1, 4, and 5 resulted from the intersection of spheres with the tetrahedral planes converging at each vertex of the tetrahedron.

This became evident when four copies of Figure 3 were constructed and arranged to form a regular tetrahedron. Figure 4 in the adjacent column is a two-view drawing of the regular tetrahedron generated from the plan view. The front view is a right section of the tetrahedron. Point O is the origin of the X-Y coordinate system, with O" being the top (apex) of the regular tetrahedron and O' is in the base plane ABC.

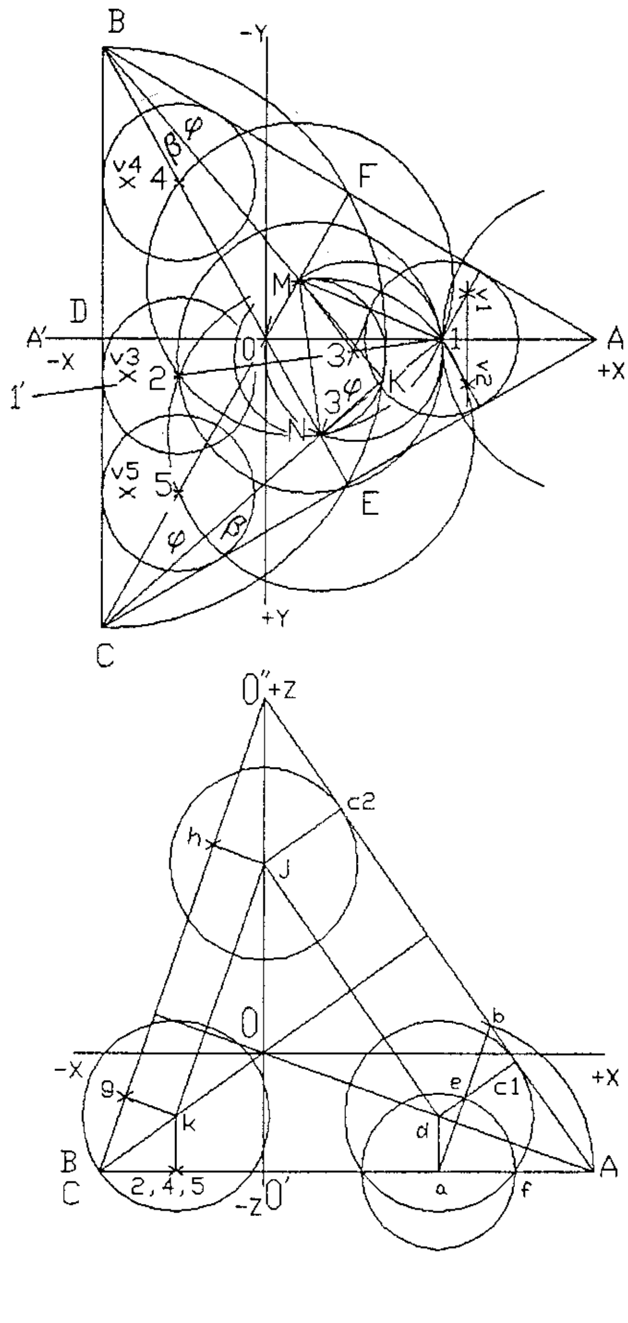

Figure 4.

The center of each sphere is situated on the axis of the regular tetrahedron at a distance of $R*3\sqrt{2/4}$ units from each vertex. Each sphere is tangent to the edges of the tetrahedron converging at each vertex.

All points shown in the plan view are in the base plane ABC except V1, V2, and the x's which are points common to spheres 2,4,5 and plane BC0". Circles 1,4,5 result from the intersection of the spheres whose centers project as points 1, 4, and 5 in the plan view. Circle k in the front view is the projection of spheres 2,4,5 in the plan view. Spheres 1,4, and 5 are identical. Sphere J near the apex of tetrahedron is identical with those at the other vertexes.

Line "ab" is perpendicular to AO and line d-c1 is perpendicular to line A0". These facts enable the construction of a regular tetrahedron when R is given.

The radius of circle 1 is R/2. Points V1 and V2 in the plan view are common with sphere "d" and planes AO"B and AO"C. "e" in the elevation view is the front projection of V1 and V2.

"a" is the front (edge) view of the center of circle 1 of the plan view.

"d" is the front view of the center of sphere whose center is $R*\sqrt{2/4}$ units from plane ABC. This is also the perpendicular distance from the center of each sphere to each of the three tetrahedral planes which it intersects. Line dc1 is the radius of sphere "d" and its length is $R*\sqrt{6/4}$ units.

It is of particular significance that the vertical distance between O and d is:

$$\left(R\sqrt{6/6}\right)*COS(2\Theta-30°).$$

The product of this value and $2\sqrt{2}$ represents the projection of the horizontal distance from 0' to point 1 in the plan view, which is:

$$\left(R*2\sqrt{3/3}\right)*COS(2\Theta-30°).$$

Conclusion

This writer readily admits one has yet to trisect an arbitrary acute angle using only an unruled straight edge and compass, but the foregoing solutions are steps in the right direction. What has been accomplished and presented is only the tip of the iceberg. This problem remains under further investigation for the relationship between the center of gravity, the incenter, the circumcenter, and the nine point circle of each triangle MNK, MCK, and BCK are yet to be considered. There seems to be no reason why circles M and N in Figure 3. should intersect the X-axis at 1, or the circle at point 3, and radius 3-1 of the same figure should intersect the X-axis at the origin of the X-Y coordinate system.

In view of these occurrences, one might expect some unique relationship between one of the above mentioned properties of the triangles to exist, even though such relationship will, no doubt involve some irrational quantity.

References

Hall, C. E. (1993). The equilateral triangle. *The Engineering Design Graphics Journal*, 57, (3), 38-42.

TABLE OF COORDINATES

In Fig. 4, MN = R = unity, and sides ABC = S. For computations, $S=R(\sqrt{3} + 2*COS(2\Theta-30°)$ or $S=R(\sqrt{3} + 2*SIN(60°+2\Theta)$. In the given solutions the angles $(2\Theta-30°)$ and/or $(60°+2\Theta)$ are arbitrary angles.

Points:	X	Y	Z
O	0		
O"	0		$S*\sqrt{6}/4$
O'	0		$-S*\sqrt{6}/12$
A	$R*2\sqrt{3}*COS(2\Theta-30°)/3 + R$	0	" " "
B	$-S*\sqrt{3}/6$	$-S/2$	" " "
C	$-S*\sqrt{3}/6$	$S//2$	" " "
D	$-S*\sqrt{3}/6$	0	" " "
E	$S*\sqrt{3}/12$	$S/4$	" " "
F	$S*\sqrt{3}/12$	$-S/4$	" " "
M	$R*\sqrt{3}*SIN(60°-2\Theta)/3$	$-R*SIN(60°-2\Theta)$	" " "
N	$R*\sqrt{3}*SIN(2\Theta)/3$	$R*SIN(2\Theta)$	" " "
K	$S*COS(2\Theta-30°)/2-S*\sqrt{3}/6$	$S*SIN(2\Theta-30°)/2$	" " "
1	$R*2\sqrt{3}*COS(2\Theta-30°)/3$	0	" " "
2	$-R*\sqrt{3}*COS(2\Theta-30°)/3$	$R*\sqrt{3}*SIN(2\Theta-30°)$	" " "
3	$R*\sqrt{3}*COS(2\Theta-30°)/3$	$R*\sqrt{3}*SIN(2\Theta-30°)/3$	" " "
4	$-R*\sqrt{3}*COS(2\Theta-30°)/3$	$-R*COS(2\Theta-30°)$	" " "
5	$-R*\sqrt{3}*COS(2\Theta-30°)/3$	$R*COS(2\Theta-30°)$	" " "
V1	$R*2\sqrt{3}*COS(2\Theta-30°)/3 + R/6$	$-R*\sqrt{3}/6$	$-(R*\sqrt{6}*COS(2\Theta-30°)/6 - R*\sqrt{2}/12)$
V2	$R*2\sqrt{3}*COS(2\Theta-30°)/3 + R/6$	$R*\sqrt{3}/6$	$-(R*\sqrt{6}*COS(2\Theta-30°)/6 - R*\sqrt{2}/12)$
V3	$-R*\sqrt{3}*COS(2\Theta-30°)/3 + R/3$	$R*\sqrt{3}*SIN(2\Theta-30°)$	V3z = V2z
V4	" " " " "	$-R*COS(2\Theta-30°)$	V4z = V2z
V5	" " " " "	$-R*COS(2\Theta-30°)$	V5z = V2z
a	$R*2\sqrt{3}*COS(2\Theta-30°)/3$	0	$-S*\sqrt{6}/12$
d	$R*2\sqrt{3}*COS(2\Theta-30°)/3$	0	$-(R*\sqrt{6}*COS(2\Theta-30°)/6$

The above discussion will open an entirely new era of technical studies by means of Engineering Design Graphics.

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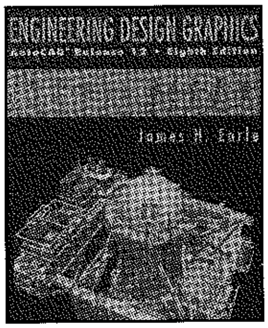

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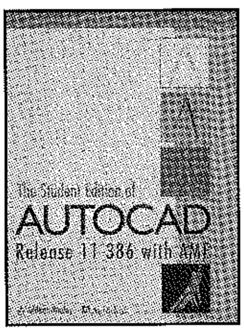

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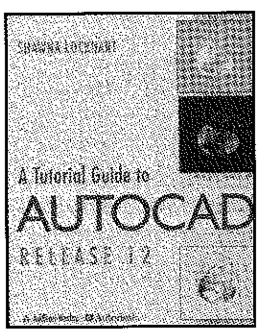

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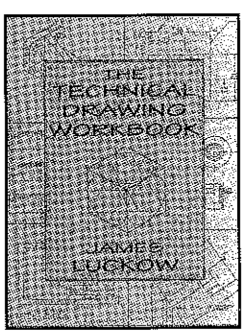

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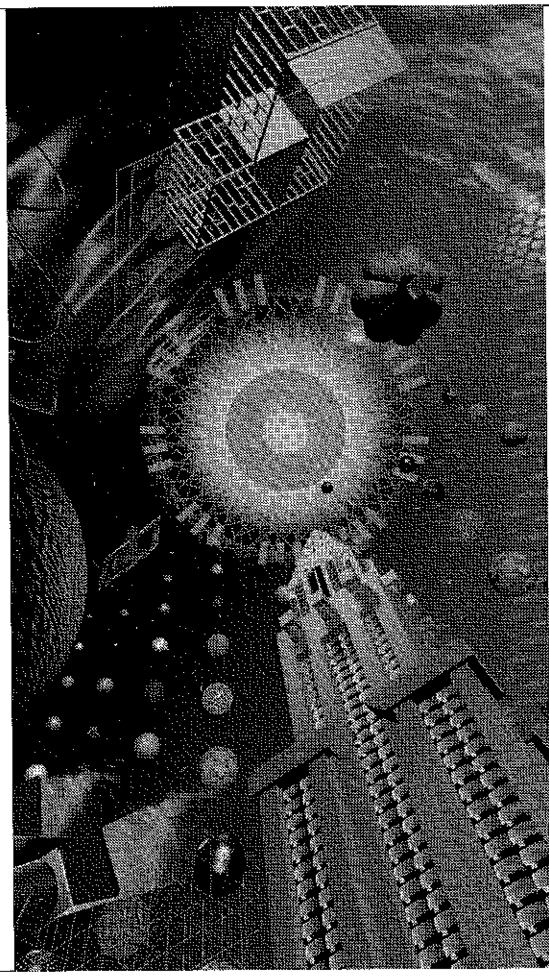

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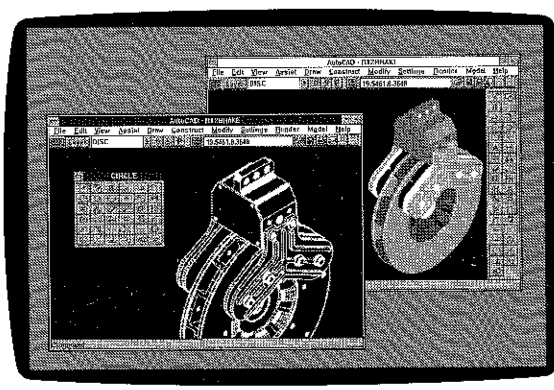

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