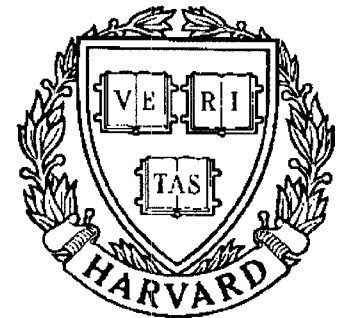


TECHNICAL RESEARCH REPORT



S Y S T E M S
R E S E A R C H
C E N T E R



*Supported by the
National Science Foundation
Engineering Research Center
Program (NSFD CD 8803012),
the University of Maryland,
Harvard University,
and Industry*

Experiences in Offering a Freshman Design Course in Engineering

by J.W. Dally and G. Zhang

EXPERIENCES IN OFFERING A FRESHMAN DESIGN
COURSE IN ENGINEERING

James W. Dally and Guangming Zhang
Mechanical Engineering Department
University of Maryland
College Park, MD 20742

ABSTRACT

This paper describes experiences gained by offering a pilot class in design to Freshman students. The objectives of the course included: design, graphics, analysis methods, teamwork, computer applications and computer programming. Design, the main emphasis of the course, was covered using a project approach. The project involved a swing set that was designed, produced and assembled during the term. The design specifications and constraints were developed during classroom discussion. Assembly drawings and detail drawings were prepared using a CAD program. The piece parts and hardware for the swings were produced and arranged in kits. The swings were then assembled at off campus locations. Graphics was briefly introduced by the conventional lecture process. The students then continued the development of their drawing skills by using Autosketch in the computer laboratory. Analysis methods were introduced on an as needed basis during the discussion of the design of the swing sets. A total of ten basic engineering concepts were introduced in responding to these questions. The aspects of teamwork and cooperative learning in engineering design was emphasized by having groups of five or six students participate together in the design, building and assembly of a single swing set. We showed the importance of teamwork of team performance by grading the teams instead of individual on project accomplishments. The use of computers in engineering was addressed in two different ways. First, application software such as Word Perfect for word processing and Lotus 123 for spreadsheet applications were introduced. We also taught programming in QuickBasic.

INTRODUCTION

The College of Engineering at the University of Maryland is involved in a long term effort to significantly improve the effectiveness of its undergraduate education. The current emphasis is to integrate design into the curriculum, to increase the number of women and minorities enrolled and to increase the retention rate in the College.

The current practice in our College is similar to that found in most of the colleges of engineering in the US. The educational process begins with a concentration of studies in mathematics and in the basic sciences. Most of the first year students sit in huge lecture halls as they are exposed to the basic but fragmented courses in physics, chemistry and in math. The only two "engineering" courses in the first year are "Introduction to Engineering Science" and "Statics". The material covered in the first course is computer programming and an introduction to graphics. The statics course, offered in the second semester is the traditional first course in mechanics taught using vector analysis. The subject of design is not introduced in the first or second years because many instructors and some chairs believe that entering students do not have sufficient understanding of the basic concepts in mathematics, physics and mechanics to design intelligently. Consequently, any attempt to teach design is deferred until as late as the final (senior) year.

The current practice of deferring instruction in design and focusing almost exclusively on developing science, mathematics and engineering science for most of the first three or four years has several negative effects. In the first year the student is essentially excluded from any exposure to engineering. They attend classes that are densely populated and taught in large lecture halls. They find it difficult to ask questions or to participate in any meaningful discussions. They try to follow relatively abstract material that is usually not related to any application that they can imagine or visualize. They soon feel lost, lose motivation and begin to question if selecting a program in engineering was the correct choice. The fact that about one-half of our students (who enter with the best SAT score on campus) quit the colleges of engineering is largely due to this impersonal treatment and the abstract material taught in the first two years of the curriculum.

One approach to reverse this long term trend is to integrate design into the curriculum. The integrated curriculum offers design and theory blended together in the same course and usually in the same class. The engineering applications are crystal clear because they are driven by the design of real products. Consequently, the abstractions so confusing to most students vanish. The design projects are interesting (almost anything is interesting in comparison to organic chemistry) and the students remain motivated in the coverage of both the design and the analysis components of the course. Finally, the industrial environment (although not the culture) can be simulated to give the students a meaningful experience related to the product realization process.

During this past semester we offered a freshman design course to a pilot section of ENES-101 "Introduction to Engineering Science". This is supposedly the first "engineering course" required of all students registered in the College of Engineering at the University of Maryland. The students were randomly selected by moving one of the four regular sections of ENES 101 from the usual lecture-recitation routine into the pilot class on design. A class of 16 students participated in the pilot course. This paper describes some of the experiences gained in this first offering of an entry level design course.

A NEW APPROACH

In this initial offering of design at the Freshman level, we decided to work with a small pilot section. To control the enrollment we capped the registration in this section of ENES 101 at 20 students and 16 students actually enrolled in the course. The students were not informed at registration that they were involved in an

educational experiment, and they were not given an opportunity to transfer out of the section nor did they seek one.

To emphasize design, the course content was centered about a project that involved the design of a specific product. A very serious attempt was made to simulate the design environment that we believe is typical of industry. We selected the product to be designed without involvement of the students. However, the students did contribute through class discussion to the development of product specifications and the design constraints.

It was made clear to the students from the beginning that the project involved a manufacturing phase and an assembly phase, although the exact logistics for handling the implementation of these activities were not described. The design, manufacture and assembly phases of the project are all very important. While we were not able to rigorously introduce to concepts of concurrent design, the three phases did provide the opportunity to directly show the students the effects of both good and poor design on the ease in preparing piece parts and in facilitating the assembly operation.

In addition to the emphasis on design, the course had four other major objectives. We introduced graphics with brief coverages in class of sketching, isometric drawing and orthographic projection. More detailed instruction in drawing occurred automatically as the students practiced in the computer laboratory to become familiar with a CAD program known as Autosketch (1). The second course objective was to cover analysis techniques as required to justify design decisions that occurred as the product was being developed. To respond to questions regarding safety, sizing and stability, ten engineering concepts, that are widely used in engineering, were covered. The order of introduction of these concepts was dictated by the demands of the analysis require to justify the design. We basically followed the just-in-time philosophy in the sequencing of topics.

Establishing the importance of team work was another course objective. Without a doubt it is the most difficult objective to implement. On the first day of class, teams consisting of 5 or 6 students were established. The teams were necessary because of too much work for a single individual to accomplish in the allotted time. Second, design teams are common in industry and we tried to simulate the industrial design environment. Third, it is essential that the students relate a design effort with a team effort where many different people with different disciplines work together in a concerted effort to develop a quality product on a well defined schedule. Finally, a single instructor cannot handle effectively more than four or five teams simultaneously.

The final course objective involved computer applications. We were interested in having the students develop at least entry level skills in three different application programs. These applications includes word processing (Word Perfect (2)), a spreadsheet (Lotus 1-2-3 (3)) and CAD drawing package (Autosketch (1)). We also spend a significant amount of the course time (about 25 %) covering elementary programming (QuickBasic (4)). The programming was a requirement of the Dean's ENES 101 Committee so that our students would not proceed to the Sophomore year deficient in programming skills.

PRODUCT SELECTION

The selection of the product to be designed, manufactured and assembled is extremely important. It must be of sufficient interest to challenge the students, but it can not be so difficult as to be beyond their sphere of understanding. The product must be relatively easy to manufacture and to assemble with the limited equipment available in the academic community and with the limited manual skills of the typical Freshman student. Next, the product should be rich in analysis opportunities that lead to motivated lessons in basic physics or mechanics. Finally, the costs of the product must be low enough so that material required can be purchased without impacting the finances of the college and/or the teams. We believe that about \$50/student, the price of a typical textbook, should be an upper limit on material costs for the product prototype.

We selected a swing set as a suitable product for a course of this type. The initial specification for the swing set defined it as an entertainment center for younger children ages 3 to 10. This opened the design and the student teams were quick to introduce several features in addition to the swings. We believed that the selection of the expanded swing set was easy for the students to understand yet sufficiently complex to design so as to maintain the students interest. The typical design involved a parts list with about 30 unique parts which were sufficiently complex as to tax their drawing skills.

In the design of the swing set, the students were concerned with structures, their strength and the method of analysis for beams, ropes and struts. The questions that they raised provided the opportunity to introduce ten basic engineering concepts of major importance to Aerospace, Civil and Mechanical disciplines. We will discuss these concepts later. The point to be made here is that the product selected should be capable of analysis with material found in the lower division engineering science and physics courses.

We restricted the material used in the basic structure of the swing set structure to pressure treated wood. The reason for the restriction was to simplify the manufacturing and procurement processes. Wood is easy to layout, saw, drill and fasten. Also, the skills involved to work with wood, if you do not seek cabinet maker perfection, are relatively easy to acquire. Metals on the other hand are more difficult to work and the tooling available is much more limited in typical academic work shops.

DESIGN SPECIFICATIONS AND CONSTRAINTS

The primary purpose of the course was to expose the students to the design process. Our approach involved the design of a real product that was common and easy to understand (i. e., a swing set). We also sought to simulate the environment of an industrial design office in so far as possible. Finally, we required that the design and subsequent build and assembly operations be performed by teams of 4 to 6 students.

We began by selecting the product without student involvement in the selection process. However, the students were immediately engaged in a discussion of the major issues related to the design of a swing set intended for children ages 3 to 10. They were quick to identify several issues including safety, area of footprint, material, climate, product life, size for transport, site conditions and social

aspects. After discussing the design issues the students prepared a list of items to be included in the design specification. We collected these lists and produced a master specification which was used by all three teams in their respective designs. This specification is shown in Table 1.

TABLE 1 Design Specifications for the Swing Set

Users	For use by children of both sexes age 3 to 10.
Space	Intended for use by family units on their property rented or owned.
Region	To be distributed by a lumber/hardware chain over several states in the Mid Atlantic region.
Product	Must be safe, durable, easy to maintain, with good spare part availability and low replacement cost.
Assembly	To be assembled hours by male/female parents or a single parent with other amateur helpers.
Product Life	Major structural components to last 15 years.
Total costs	Materials less than \$170 with manufacturing labor to be minimized.
Social Aspects	An entertainment center for groups of up to six children.

After the specifications were established through class-instructor interaction, the teams were encouraged to meet and develop design concepts and to discuss the features to be included in the "extended" swing set. We used major parts of several two hour recitation periods to permit the teams to meet together to discuss concepts and features. We encouraged the student to be open minded and to think creatively about their "product". We showed pictures of a typical set and several students found catalog descriptions of commercially available swing sets. We encouraged the teams to closely examine each one of these designs and to use the better features and to reject what they considered to be the poorer features.

The early creative design activity stimulated many questions regarding the evolving designs. These questions fell into two different categories. The first involved questions related to limits on the design of the produced such as the material that could be used or the maximum area of the footprint. The second category involved questions related to the size of the structural components and swing supports to insure safety and durability. We handled the first category by developing a list of design constraints which placed the same limitations on all three teams. This action may have limited creative developments to some degree; however, it is necessary to manage part procurement in the manufacturing stage of the project. We took the questions on safety and durability as an invitation to introduce design analysis that will be described in the next section.

The design constraints evolved during discussions with individual students and with the teams soon after the specifications were established. These limitations were necessary to provide an additional set of criteria to more narrowly focus the design. The design constraints used are listed in Table 2.

TABLE 2 Design Constraints

(1) SAFETY

Safety considerations dictate that:

- No sharp points.
- No sharp edges.
- Safety factor of at least 6 on strength.
- Height limits of 8 feet.
- Railings on all platforms over 3 feet high.
- Safety factors of 2.5 on stability.
- Smooth splinter free surfaces.
- Instruction for site selection and surface preparation.

(2) ASSEMBLY

Assembly requirements dictate that:

- Assembly must be with only two screw drivers (one flat blade and the other a Philip blade both of medium size), a claw hammer, an 8 inch adjustable wrench and a pair of pliers.
- Assembly of the complete unit must be possible by two unskilled people (any sex combination) in 4 hours or less.
- Disassembly of the complete unit must be possible by two unskilled people (any sex combination) in 4 hours or less.
- All additional tools required in assembly must be provided in the assembly kit.

(3) TRANSPORT

Self delivery by typical auto.

Components part must be packaged so that:

- No single package can exceed 14 feet in length.
- No single package can exceed 40 pounds in weight.

(4) ASSEMBLE SIZE

- The footprint of the completed assembly must fit into an L shaped region with total area of 140 square feet in length.

(5) MATERIAL

- The primary material used in the structure is to be lumber available from the distribution centers.

(6) HARDWARE AND COMPONENT PARTS

- The number of vendors required to supply the hardware and component parts must be minimized.
- The time to procure the components is to be tabulated and recorded.

(7) LABOR

- All labor expending in preparing the piece parts will be tabulated and a record maintained of the tasks and times involved in part production.
- Labor is to be minimized.

With the design specifications and constraints in place all three teams were able to proceed to design unique products but within carefully selected limits.

DESIGN ANALYSIS

When confronted with the need to specify supports for the swings the students were quick to suggest either rope or chains. However, they were at a loss to select the type of rope or to specify its diameter. As we discussed how to size the ropes we were drawn naturally into sketching free body diagrams, and applying the principles of equilibrium to determine the forces in select members of the swing set. The students were receptive to this analysis because it applied to the design and because they were familiar with the concepts introduced from prior exposure in Physics. We moved on from the forces and introduced the concepts of stresses and strain. A comparison of the stress in the swing support with the strength of the rope was made to introduce the concept of a safety factor. A typical blackboard illustration used to describe the relation between applied force, stress and the failure point is shown in Fig. 1.

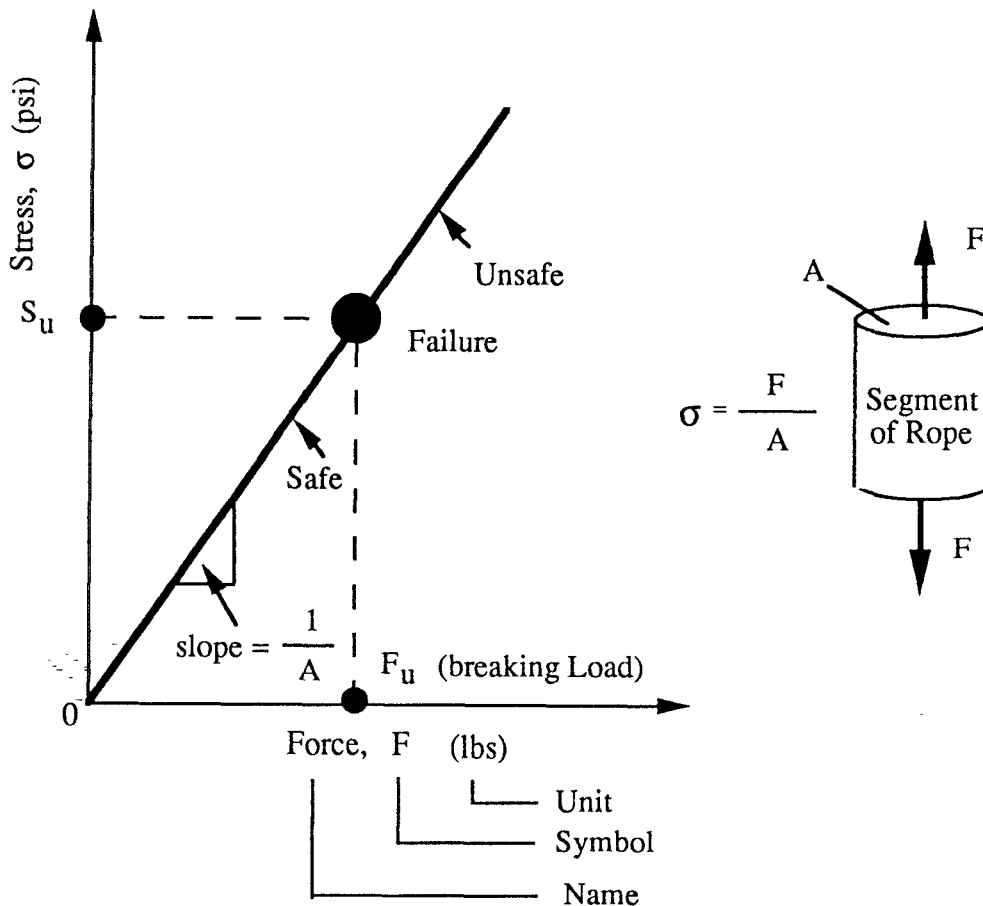


Fig.1 A typical illustration to show failure of a rope and to show the safe and unsafe regions on the F- σ diagram.

We utilized about 10 hours of class room time describing basic concepts that included:

1. Equilibrium / Free Body Diagrams
2. Stress
3. Strength / Failure
4. Safety Factors
5. Energy and Work
6. Centrifugal Forces
7. Strain
8. Stress Strain Relations
9. Scaling Laws / Modeling
10. Superposition

It should be emphasized that these concepts were introduced so as to be able to perform analysis related to the design of the swing set. In all cases the student were able to relate the concept directly to the product being designed. We did not perform involved derivations for the class. We simply stated the equation (i.e. $\sigma = Mc/l$) and showed its usage. We are comfortable with deleting the derivations knowing that the students will have the opportunity to study in more detail the connections between the basic principles and the equations used in subsequent courses.

Space does not permit us to describe the coverage of the ten principles listed above but copies of the lecture notes are available that show the details of the approach followed in treating each major concept.

GRAPHICS

Within two weeks after describing the product to be designed, the students were vigorously discussing their ideas and concepts. Two of the teams were having difficulty communicating while one team seemed in total control. One member in the team, having full control over the project, prepared an excellent sketch showing an isometric rendering of the complete design. He was able to use the sketch to lead the discussion and to illustrate the features incorporated in the design. We shared this sketch with the rest of the class and showed directly the importance of graphics as a method of communication. The fact that one of their peers had the idea initially led the students to elevate the importance of graphics in the design process.

We immediately followed this experience with three hours of instruction in graphics. We did not employ any text but instead described very simple objects and sketched these objects on the black board. We covered in lecture isometric drawing, orthographic projections, dimensioning and the drawing format including the drawing block and the revision block. The coverage was an absolute minimum. At the same time we had four two-hour recitation periods for the students to become familiar with Autosketch. This combination of blackboard discussion and experience at a PC with a CAD program was accepted well by the students and most of them developed adequate entry level skill in drafting. The fact that 50 % of the students had some previous experience in graphics was a significant factor of skills in permitting us to achieve the skills demonstrated by most of the students with a minimum investment of course time.

As the work proceeded the students emphasized the features to be incorporated in the product, the strength and durability of the supporting structures and its stability with regards to tipping. However, the students had not considered methods of fastening the joints. To emphasize the importance of the fasteners, we asked each team to build a scale model of their design. Of course, the models represented another method of graphical communication and afforded us with the opportunity for one member of each team to make an oral presentation to the rest of the class outlining the basic features incorporated in the product. In effect this presentation was analogous to a preliminary design review in an industrial design office. A typical scale model built by the Heart team is presented in Fig. 2.



Fig. 2 Student from the Heart team describing the design features of his product in a design review.

COMPUTER AND DESIGN

The computer was a major element in this course. We instructed the students in computer usage using two different approaches, each with a separate educational objective. At the beginning of the course we emphasized the importance of the computer in engineering and to their own professional development. We informed the class that we would expect them to develop at least entry level skills in three different application programs -- 1. word processing (Word Perfect), 2. a spread sheet (Lotus 1-2-3) and 3. a CAD program (Autosketch). We would have liked to

have included a math program such as MathCad (5), but limitations on time and the complexity of this program did not allow us to be included. The students responded well to assignments that involved these three application software packages. We did not give lecture on the usage of these programs but rather provided manuals and assistance during the laboratory periods. One senior undergraduate student worked in the computer laboratory with the students and provided guidance and answered questions. This approach was successful because the students related better to an undergraduate student advisor (in this case an American female concerned with their welfare) than our typical graduate student advisor (a foreign national with language and cultural differences). We required most of the home work assignments to be prepared using the word processing program and the spreadsheet. In select examples the students generated complete solutions with graphic output, rather than single point solutions, by using spreadsheet calculations. Of course, all of the drawings associated with the release of the design were prepared on Autosketch and drawn with a laser printer. The parts lists and the cost analysis of the parts used in building the product were prepared by using a spreadsheet.

The second phase of computer usage involved instruction in a programming language, QuickBasic. Frankly, we did not want to include programming in this course. However it was included, since all other Freshmen are provided with this instruction, so that our students would not have a deficiency in programming required in higher level courses. We devoted about ten hours of lecture time for programming. The students were much less interested because many of them were familiar with Basic (13 of the 16 students rated their own knowledge of Basic as fair on the first day of class). We attempted to stimulate the students in this segment by using a sports car example involving financing where money was gained or lost by interest receipts or payments.

DESIGN RESULTS

The drawing packages were released about nine weeks after (somewhat later than originally planned). However, after the design reviews associated with the model presentations the students negotiated an extension of the release date so that the changes discussed in the review could be incorporated in a design modification. The typical drawing package consisted of about 20 to 30 pages and included design specifications, design constraints, materials selections and justification, design analysis, parts list, cost analysis, assembly instructions, general assembly drawings, subassembly drawings and detail drawings. A typical general assembly drawing for the Club design is shown in Fig. 3. Note that the product includes two swings, a slide, a climbing rope, a platform, a play house (under the platform), a climbing ladder and a chining bar.

The quality of the drawing packages exceeded our expectations. They were, for the most part, quite complete considering that we had only a very brief preliminary design review and that this was the students first attempt at design and in preparing a complete drawing package. We reviewed the drawings by having the instructor interface with each team on two different occasions. Some errors were found in the drawings and these were corrected. We certainly could have used more time in this final review process because it provides an excellent opportunity to comment on details related to good and bad design and on drawing standards and drawing quality.

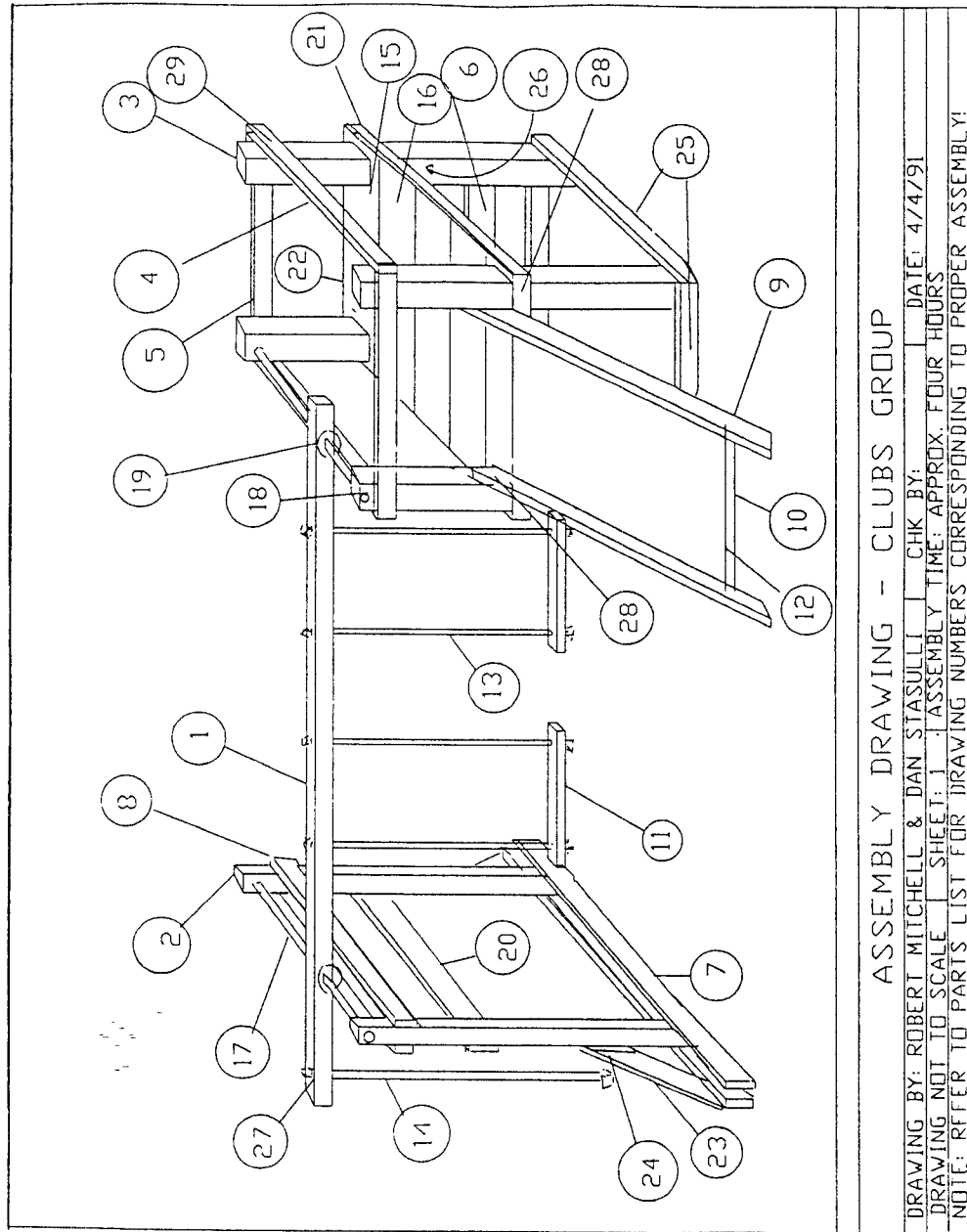


Fig. 3 General assembly drawing illustrating the design features incorporated into the Club product

MANUFACTURING

A design experience is not complete without building the article and testing it to ascertain if it meets the design specifications. To follow this philosophy we organized the same teams into manufacturing units to prepare the piece parts, to procure the hardware and to kit the entire product in a form suitable for transport. We did not permit the teams to work on their own design. Instead, the Heart team manufactured the product designed by the Diamond team, etc. This hand-off of the drawing package to another team simulates the industrial practice of the design division handing the design to the operations division. We would have liked to introduce the concept of concurrent manufacturing but this is a future objective that will require considerable innovation because of the almost total lack of knowledge of manufacturing processes by undergraduate students.

It was not easy to manufacture the assembly kits and in retrospect we should have allowed more time for communication between teams and between the teams and the instructors. We encountered three problems. First, the College has little or no equipment for use in making either wooden models or prototypes. We solved this by using personal equipment. Second, most students both male and female have never used hand tools associated with even the simplest form of carpentry. We solved this by teaching every student how to lay-out a piece part and to use a circular saw, a drill and a hammer. It was interesting to observe that our two women students were as willing and as quick to learn the use of these simple tools as the male students. Third, no space was available in the College to accommodate three large swing sets. We solved this problem by finding three families willing to accept free swing sets (sight unseen) and then assembled the swing sets at these off campus locations. The manufacturing teams consisted of three members. They marked the piece parts and cut them to size. The part number was written on each piece. The piece part production required from 3 to 10 hours depending upon the complexity of the design. We managed the large blocks of time involved by having the teams report on Saturdays (clearly an unpopular development). During the recitation periods the teams prepared envelopes containing the correct size and quantity of fasteners. The three kits were completed with only two weeks of the semester remaining.

While manufacturing the piece parts was a very difficult task, it was extremely important. The students had the opportunity to review another design and to evaluate its strengths and weaknesses. They also learned first hand about the interrelation between design and manufacturing. These students are now ready to discuss concurrent design, particularly those on the team that required 10 hours to complete the piece parts.

ASSEMBLY

The assembly operation was relatively easy and an enjoyable experience for the students participating. Again we formed assembly teams that were different from the design and manufacturing teams. The principle was that the Diamond team would assemble the product designed by the Heart team and manufactured by the Club team, etc.. We facilitated communication by placing one member from the design team on the assembly team. The primary difficulty encountered was transportation. The kits were two large and heavy to be transported by a compact car even with roof racks. We borrowed a pickup truck to solve this. Also, several students had difficulty in arranging transportation to the off campus locations

(around 25 miles from campus). Car pools were organized to accommodate these students. Again, Saturdays (the last two of the semester) were used to provide adequate assembly time.

An example of a swing set at the assembly location is presented in Fig. 4. Note, the happy customers in addition to the assembly team and the instructors.

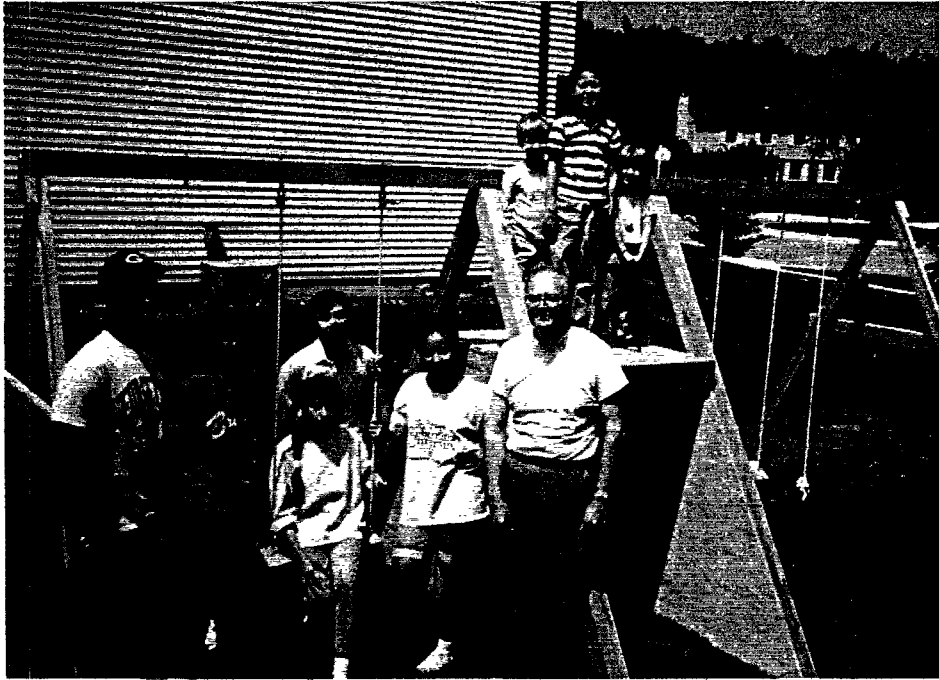


Fig. 4 Assembly team, instructors and customers at the conclusion of the project.

CONCLUSIONS

Our experience with this pilot class was extremely favorable. The designs developed by all three teams exceeded the expectations. We conclude that Freshman students are capable of design provided that the product selected is relatively familiar to them. It is also important that the design analyses required can be performed using theory developed during the lower division courses in physics and engineering science.

The students were motivated by the hands on experience afforded by the design, manufacture and assembly phases of the product development cycle. They appreciated the opportunity to participate in the design office environment even if it was simulated. They learned through experience, the difficulty in producing, defect free drawings and they learned the difficulties encountered in manufacturing when errors occurred in the drawings.

The students adapted to the application software with amazing speed. They quickly became aware of the benefits of using these programs not only in this course but also in other courses.

Working as a team member caused many of the students significant difficulty. As expected all students did not participate with equal skill or even equal effort on a given team. Team leadership was a concern to most student since we did not assign leaders and refused to be drawn into team "problems". The students resolved these problems, but slowly and with considerable reservation.

On the negative side we have some concerns and self criticism. The scheduling of the time was not optimum because we did not have the opportunity to simulate the industrial environment associated with the design change process that is followed after the design is released.

More important is the question of scale. Clearly there are major benefits to be gained by offering a design experience early in the engineering curriculum, however, the number of students involved is high and the instruction must be performed by faculty with considerable experience in design. Next, fall we will enroll about 500 students in the freshman class at the University of Maryland. Is it possible to use methods developed for a class of 16 students taught by two enthusiastic faculty members to a class of 500 that is to be instructed by faculty conditioned to avoid teaching in the lower division.

The scale problem can be solve but it will require class sizes (probably 25 or less) which is much smaller than current sizes. Of course this implies a significant increase in costs to the College at a time when State appropriations are being cut. The solution is also dependent on a change in faculty attitude. Typical faculty members, in response to the reward systems in place in most Colleges of Engineering, tend to minimize the time spent on instruction and maximize the time devoted to research. It is much easier to teach an engineering science course that has not changed significantly in the last 20 years in comparison to an engineering design course where a text book is not even available. If faculty members are to teach design with the required enthusiasm, they must be given time to develop material and must be given assurances that rewards for time spent on instructions are equal to rewards gained by performing research.

ACKNOWLEDGEMENTS

The authors would like to thank Ms Rebecca Lavash, who served as undergraduate student advisor, for her suggestions. Thanks are also due to Kathryn Mohrman, Dean of Undergraduate Studies, for a curriculum improvement grant and to Professor Thomas Regan for his support on the ECSEL project. Finally, we appreciate the help given by Dean Marilyn Berman for cutting through the layers of red tape associated with the Freshman program.

LITERATURE CITED

1. Conner, F., Autosketch, version 3, Addison-Wesley, 1991.
2. Curtin, and Dennis, p., Word Perfect, version 5.0, Prentice-Hall,1990.

3. O'Leary, T. J., and O'Leary, L. I., Lotus 1-2-3, release 2.2, Addison-Wesley, 1990.
4. Weiskamp, and Keith, QuickBasic , Wiley, New York, 1990.
5. Anderson, R.B., Math CAD, Addison-Wesley, 1989.