Teaching Design to High School Women

by G.M. Zhang and J.W. Dally

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ABSTRACT

This paper describes experiences obtained by teaching high school women design during the Summer Study in Engineering Program for Women High School Students. The program is designed to encourage talented women to pursue engineering careers. An introductory engineering science course was offered to the women participating in this summer program. A project approach was employed in teaching the course to motivate the students and to introduce the concepts involved in teamwork. The students were organized into groups to carry out the design, building, and assembly of a seesaw. Engineering concepts were taught in the classroom on an as needed basis during the design process. While the students were acquiring entry level skills in computer application programs, they used these programs to prepare documents and drawings to describe their seesaw designs. The aspects of teamwork and cooperative learning were stressed as the design project progressed. The women were motivated, actively participated in the project, and appreciated the opportunity to learn engineering design through a project approach.

1. Introduction

The College of Engineering at the University of Maryland established the Summer Study in Engineering Program for High School Women in 1975. Recognizing the strategic need for encouraging talented women to pursue engineering education in college, the University has provided funding for women high school students to study engineering in the summer [1]. The program provides an introduction to engineering science and engineering design. Women students learn to use computers, to prepare engineering drawings, and to engage in engineering design during their participation in the program.

The College of Engineering has also begun to implement a long standing program to increase the effectiveness of undergraduate engineering education. It currently emphasizes the need to revise the curriculum at the College and to increase the enrollment of women and minorities. Supported jointedly by the University of Maryland and the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) project, a pioneering work to teach engineering design for undergraduate students at the freshman year has been carried out [2,3]. A demonstration course was offered during the Spring 1991 semester to sixteen undergraduate students on the College Park campus. A design project to design and then manufacture and assemble a swing set was introduced with considerable success [4].

In this paper, we present new experiences obtained by teaching high school women through the 1991 Summer Study in Engineering Program for Women High School Students. Twenty-one senior women students enrolled in this summer program. Following the project approach developed with typical freshman students, we formulated a new project - the design of a seesaw for the summer program. The class of 21 students was organized into four groups of 5 to 6 students each. The product development process was divided into three stages, i.e., design, manufacturing and assembly. In each stage, specific steps were defined to guide the students in learning a systematic approach to engineering design. The engineering concepts related to the design of the seesaw were taught as needed for each step in the process. The students were motivated because they found themselves in a simulated industrial environment, learning the knowledge and skills relevant to their future needs. While the students were learning software application programs, they used the computer as a tool to prepare documents and drawings. As teams, the students worked diligently and cooperatively under the extreme pressure of deadlines. Although tense and tedious at times, the group work was enjoyable for all the students and the instructors. Our experiences in teaching design to high school women were extremely favorable.

This paper is organized as follows. In section 2, we outline the basic structure of the design course. In section 3, the major contents of the course are described. Section 4 presents the major student activities in learning engineering design. In section 5, we present the responses from the participating students and the observations from the instructor regarding teaching engineering design through a systematic approach. Section 6 summarizes the results obtained in teaching this entry level design course to high school women and discusses its impact on providing our students with a higher quality education.

2. Basic Structure of the Design Course

In preparing this design course for high school women, ENES 101W "Introductory Engineering Science", our intention was to provide them with the opportunity to determine what engineering is and what an engineer may do. We believe that students at the high school level have, at least, intuitive ideas about engineering design as long as the project to be developed, such as a seesaw, is familiar to them. Following concepts developed during the demonstration course offered in the Spring 1991 semester [4], this design course for high school women in the summer program consisted of four parts, namely, lectures, a design project, computer labs, and a guest lecture. Its basic structure is shown in Fig. 1.

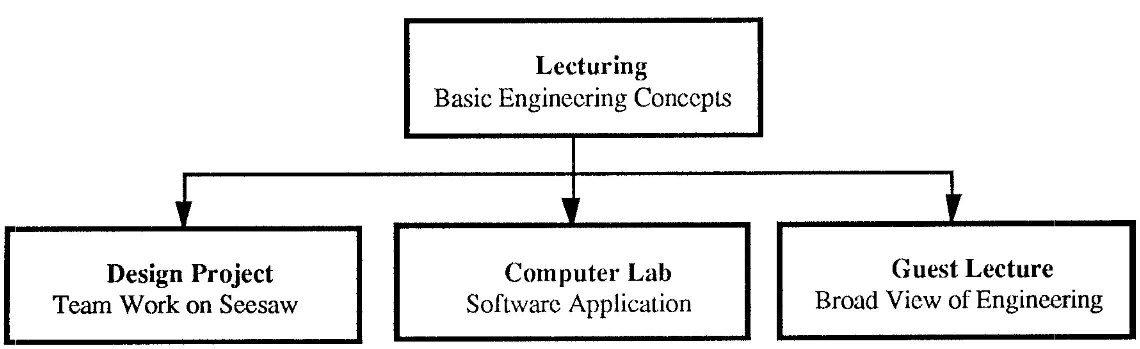


Figure 1 Basic Structure of the Design Course

Under this structure, the students were to learn the basic engineering concepts through lectures, and then apply these concepts in the design of a seesaw. In the computer labs, the students were to acquire entry level skills in three software packages, i.e., WordPerfect (word processing), Lotus 1-2-3 (spreadsheet) and AutoSketch (computer-aided design). They were required to use the computer as a tool in the development of the seesaw. A guest speaker was invited to present the students with a broad view of engineering.

In order to make sure that this basic structure of ENES 101W fit the expectations of the participating high school women, we conducted a survey of their expectations. By assigning homework to practice WordPerfect, the students were requested to write a short essay "What are your expectations of ENES 101W?" It is interesting to note that the students shared three common expectations, i.e., gaining the knowledge of engineering, learning how to use the computer, and learning engineering design. One student wrote the following paragraph in her essay:

> "I expect to learn as much as I can because the knowledge I gain is useful to know in the future. I also expect to have fun in this class. I think the seesaw project is not only a way to learn how to design a product, but it will help my classmates and me to work as a team. ENES 101W will prepare me for school this fall by teaching me something new everyday and reviewing topics I will need to know."

With positive feedback from the participating students about the basic structure, we started teaching the design course using a project approach. The design course was taught for six weeks. In each week, the class met three times. Each class period was divided into 50 minutes of lecture, 50 minutes of computer lab, and 25 minutes of group discussion. To provide hands on assistance in learning software application programs, a graduate student was appointed to work in the computer lab and provide a help session for the students on a daily basis.

3. Major Contents of the Design Course

3.1 Lectures of Eight (8) Basic Engineering Concepts

Since the seesaw was selected as the product to be developed, eight engineering concepts essential to its design were introduced to the students through lectures in classroom. These concepts are listed below. During the process of learning these concepts, the students were guided into the design process step by step.

1. Free-Body Diagram
2. Static Equilibrium.
3. Stress Analysis
4. Strength of Materials
5. Safety Factor.
6. Work and Energy
7. Impact Effect
8. Engineering Drawing

It should be emphasized that these concepts were taught so that the students were able to perform analysis related to the design of the seesaw. Through the analytical evaluation of the seesaw design, the students gained a better understanding of these engineering concepts because they were able to relate them directly to the product being designed. An an example of learning the concept of free-body diagram, the students drew the free-diagram for each of the components of the seesaw product, then analyzed the acting forces and reactions on the component under investigation. Using the concept of free-body diagram, the students examined their design for equilibrium conditions, evaluated the stresses developed within their seesaw components, and justified their design decisions. We tried to avoid performing derivations of equations, such as the flexure equation. Instead, we taught the students through experimentation to visualize the bending stress developed in a beam when subjected to an external force.

In order to overcome the difficulty that a text book was not available, seven sets of lecture notes were distributed to the students. To aid in the learning process, homework assignments were also assigned to reinforce the engineering concepts covered in class. These homework assignments were composed of basic, intermediate, and high levels to ensure that the students from high school were capable of adapting to the college environment. The assignments also promoted their creativeness in problem-solving. A mid-term examination and a final examination were given to evaluate the progress of the students in learning the engineering fundamentals and the effectiveness of teaching the basic engineering concepts.

3.2 Development of the Seesaw

We believe that the best way to motivate students is to impose standards and expectations. In this summer program, the development of the seesaw progressed in three stages. In each stage, we assigned specific tasks to make sure that all the students knew the requirements. Figure 2 lists the major tasks defined in the design, manufacturing, and assembly stages, respectively.

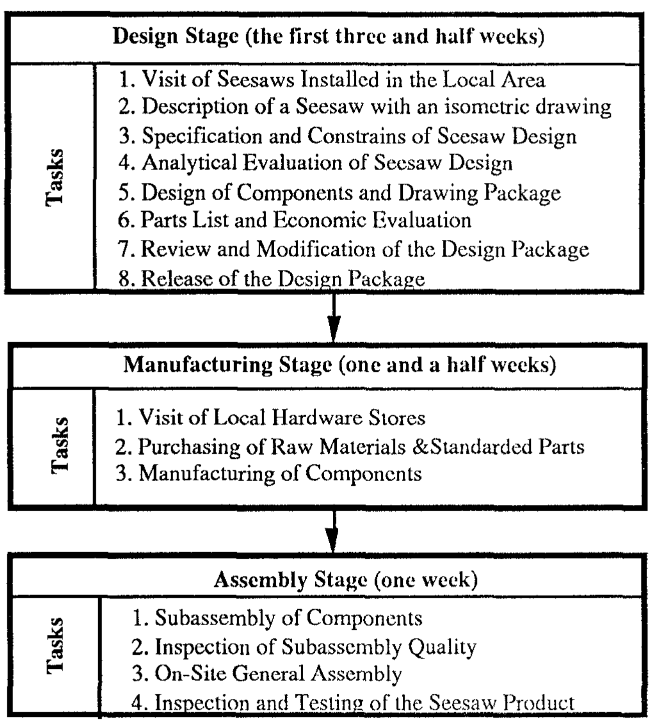


Figure 2 Major Tasks Involved in the Design, Manufacturing, and Assembly Stages

As a demonstration example in this paper, we refer to the tasks listed under the design stage. A natural question which came from the students at the beginning of the design process was "How does one start the project of designing a seesaw?" We responded by asking the students to follow the tasks defined in the design stage. As a result, the students, working as a team, visited public playgrounds where seesaws were located to determine how different seesaws worked and what were their primary components. After the site visit, the four groups discussed basic requirements for a seesaw design, sketched possible seesaw designs by hand, selected the one they liked best, and worked out the specifications of the seesaw to be designed. Table 1 presents the specifications of the seesaw design formulated by one group. It is evident that the completion of the first three tasks enables the students to initiate their design.

Table 1 Design Specifications of the Seesaw

Users	For use by individuals of both sexes age 3 to 10 with a weight limit not to exceed 300 lbs.
Social Aspects	Capable of entertaining social groups of up to four children.
Space	Intended to be used by family units on their own property.
Assurance	Guaranteed to be safe, durable, easy to maintain, with good spare part availability, and low replacement cost.
Product Life	The anticipated life of the product is 10 years.
Assembly	Rudimentary assembly by the consumer.
Total Cost	The total cost not to exceed $125.00

At the end of each stage, we also requested that the students summarize what they had accomplished and to propose the tasks to be addressed in the next stage. We have observed that this project approach has provided the students with a conceptual understanding of the design, manufacture, and assembly stages of the product development cycle. The students have learned a systematic approach to perform an engineering design through a hands on experience.

3.3 Computer Skills

Due to the rapid reduction in the cost of computing, our working environment has been changed significantly. Mastering entry level skills in basic computer application programs has become a necessity in education. Consequently, acquiring entry level skills on the computer was a major objective in this design course. The three application programs selected for this course were:

1. WordPerfect (word processing software).
2. Lotus 1-2-3 (spreadsheet software).
3. AutoSketch (computer-aided design software).

We did not give lectures on the usage of these programs. Instead, we provided the students with two manuals, i.e., the Student Edition of Lotus 1-2-3 [5] and the Student Edition of AutoSketch [6]. We also prepared three sets of lecture notes for the students to study WordPerfect because the application program seemed rather easy to understand.

We requested that the students read these manuals and lecture notes. By assigning homework, we checked if the students understood the elementary usage of these programs. We provided a graduate student to work in the computer lab and to provide on-site assistance. To motivate the students studying the application programs, we required that all the reports and drawings related to the design project be prepared using the computer. We have observed that this arrangement is successful. At the beginning, the students are forced to use the computer as a tool to prepare the design documents. After gaining the skills through practicing, the students find that they are rewarded by being able to use the three application programs, especially AutoSketch, not only for preparing the design documents, but also for their professional development in the future.

4. Student Activities

Although the design of a seesaw seems to be one of the simplest projects, its completion from the design, to manufacturing, to assembly reflected a real challenge to the 16 to 17 years old women students. They lacked design experience and knowledge of manufacturing processes. In fact, most of them had never used hand tools such as a circular saw to cut wood or a drill to make holes. During the process of product development, they faced many difficulties. To our surprise, they resolved these difficulties through hard work and cooperative learning. Within the six-week period, all four groups successfully completed the prototype of a seesaw. The main activities involved in the design project are summarized as follows.

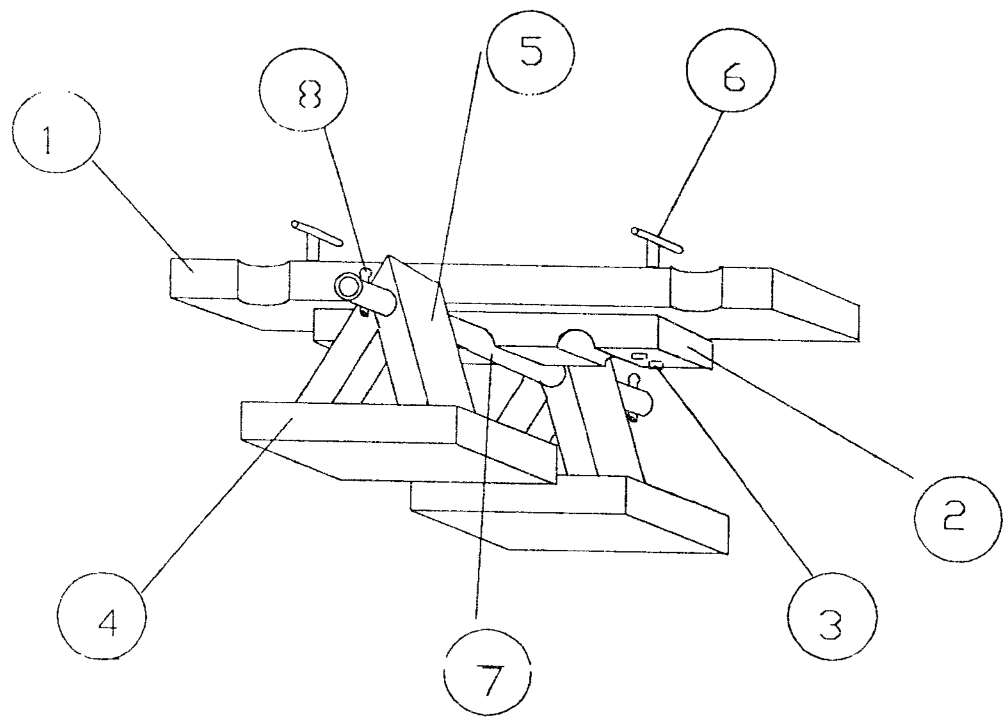
4.1 Team Work

On the first day of the course, we emphasized the importance of team work. We informed the students that design teams are common in industry and the ability to work with others as a team member is imperative. When the students formed their groups, they immediately knew from the start that the development of a new product required great efforts. It would be impossible to satisfactorily complete the project without team work.

We observed that, working as a team member often caused the students some difficulty. "How am I to design a seesaw with people I didn't even know?" This is especially true when they started working as a team. It took some time for the students to adopt the concept of team work, especially, when the project got more serious and interesting. All the group members had to take into consideration everyone's ideas. They exchanged many ideas and reached solutions that might not have been thought of if they were working solo. Additional new ideas always evolved during the group meetings. In preparing the drawing package on AutoSketch, the drawings were divided among the group members. Each person was responsible for three or four drawings. The completed drawing package for a group depended on each member's participation. Under the deadline pressure, each member appreciated the work completed by other members. During the group decision making process, the important skills of patience and compromise had to be exercised. Working in a group brought an educational and social aspect into focus and it taught the students how to work together to accomplish the set goal. As a student remarked "We gained knowledge from each other as well as made friends."

4.2 Design

When the instructor announced that the students would build beautiful seesaws on the first day of class, most of the students responded conservatively. Quite a few students thought "There is no possible way this could be done. It is hard to imagine 21 women students building real-life playground equipment." It is evident that the significant amount



	6. Handle Bar	3. Connection 1	Seesaw Design
8. Connection 2	5. side support	2. Adjustable Pivot	
7. Pivot Shaft	4. Bottom Support	1. Main Board	Group 2, ENES 101W

Figure 3 General Assembly Drawing Illustrating the Seesaw Design Features

Figure 4 Design Release Presentation

4.3 Manufacturing Components

A design experience is not complete without actually building the first article and testing it to ascertain if the new product meets the specifications. More importantly, the designer will not be able to justify his/her work without going through the manufacturing process of the components.

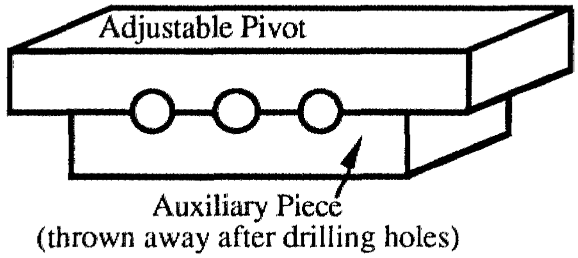
After the design release, each group took the responsibility for fabricating its own seesaw. First, the students went to two local hardware stores to purchase the raw materials needed. When they were at the stores, they realized some of their component designs were unrealistic. For example, the dimensions of woods available at the store did not fit their needs. Before starting the component manufacturing, they had to, once again, modify their component design to meet material availability and costs.

During component manufacturing, the women students had to learn entry level skills associated with conventional hand tools such as saws, hammers, and drills. The students were eager to learn these practical skills even though some of them had previously never hammered a nail. Figure 5 shows the workspace when the women students were busy manufacturing components. They also learned the basic skills required to operate conventional machine tools such as a milling machine, drill press , and grinding machines. While participating in these activities, they learned the first lesson in design for manufacture. For example, manufacturing the three half cylindrical shapes of the adjustable pivot shown in Fig. 3 caused great difficulty because of lack of proper equipment and tools. We discussed three alternate ways to make this component, as shown in Fig. 6. The first alternative was to attach another piece of wood to the adjustable pivot and make three full cylindrical shapes first and then to discard the attached piece. The second alternative was to make the three

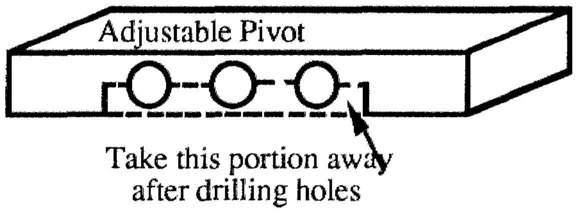
Figure 5 Women Students Working on the Shop Floor

full cylindrical shapes on the adjustable pivot and then cut half of each of the three cylindrical shapes. This second alternative could reduce the strength of the adjustable pivot significantly when the seesaw is under operation. The third alternative was to change the design of the three half cylindrical shapes to the three V-shapes shown in Fig. 6c. A saw could be used to make these V-shapes easily. The design group accepted the third alternative by changing the original design to incorporate V-shape.

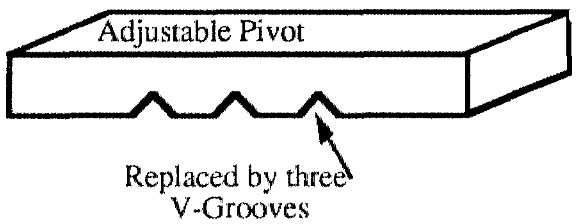
During the assembly and testing stages the students learned more work-related design experience such as the concept of tolerance and the importance of process planning. The students learned that the dimension of a hole should be larger than the diameter of a shaft which rotates inside the hole. When assembling the handle bars shown in Fig. 3, the students learned that the shoulders on the vertical bars should be made before the horizontal handles were attached to them. When the whole seesaw product was assembled, they sensed the importance of making a prototype during the product development cycle. The prototype suggested the changes necessary in the product design (in the next stage to follow). One student said "It's amazing that you can learn so much from the design of an object as simple as a seesaw." Figure 7 presents a pictorial view of the seesaw after assembly. By comparing the isometric view of the seesaw design shown in Fig. 3 with the photograph of the prototype ,the similarities are evident. We enjoyed the opportunity to demonstrate that 21 women high school students could successfully design a prototype of a seesaw.



(a) Alternative No. 1 Using an Auxiliary Piece



(b) Alternative No. 2 Removing Material



(c) Alternative No. 3 Replacing by V-Grooves

Figure 6 Three Alternative Ways to Manufacture the Adjustable Pivot

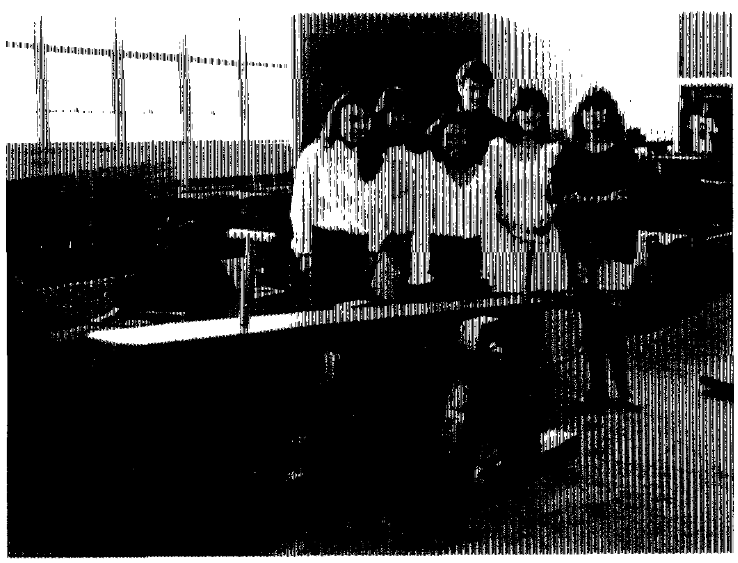


Figure 7 One Design Group with Their Seesaw Product

5. Responses and Observations

Our experience with the 1991 Summer Women Study Program has been extremely favorable. Through a design project approach, we created a suitable environment for the high school women students to learn engineering design. While they were learning basic engineering concepts and/or computer application softwares, they applied concepts learned into the design project. To summarize the developments made in teaching this design course, we provide responses from the students in section 5.1, and observations from the instructors in section 5.2

5.1 Responses from the Participating Students

5.1.1 About the Design Approach

"The engineering course 101W used a systematic approach in teaching the students about the seesaw design project. The seesaw design project was the most time consuming and important project or assignment in this class. However, the systematic approach helped break the project into many steps which made it easier and less nerve-wrecking. First, our group gave an initial description of the seesaw design with its requirements. This description helped us to get a general idea of what we would be building. The equilibrium problems, graphic drawings, free-body diagrams, safety factors and stress analysis we learned in class helped us calculate and present an analytical evaluation for the design. Next, after learning the AutoSketch program, we were able to use the computer to enhance the seesaw design and the components of the seesaw. Then we went to the store and got an estimated cost of the materials that we would be using. After doing all the work, we were able to put together a more complete and professional document describing the seesaw design. Using this document, we built and assembled the seesaw in a playground area."

"The mere thought of designing and building a seesaw seemed to be incredibly overwhelming at first. 'Where do we begin?' was the question that my group pondered over and over again during that first week of class. We wondered if we would ever be able to complete the whole project in six weeks.

Despite our apprehensions, the seesaw project is now in its final stage. But we probably never would have been able to get as far as we did if we hadn't been taught to use a systematic approach to design.

The systematic approach to design consists of several steps: the initial description of the seesaw, the definition of the specifications, the analytical evaluation, the drawing package, the parts/estimated price list, and the manufacturing, assembly and testing of the seesaw design. By using this method of design, we were able to get organized easily. We knew what task we had to accomplish at each group meeting. Once we accomplished each task, we were ready to start working on another one. The systematic approach to design and engineering taught us how to budget our time. By using this method, we were able to get the job done within a six-week period of time."

5.1.2 About Learning Computer Skills

"One of the reasons why the systematic approach to design worked so well was that we were able to use three different software packages: WordPerfect, Lotus 1-2-3, and AutoSketch. At least one software application was used to complete each step in the systematic design process. WordPerfect made documentation much easier and quicker than normal. Lotus 1-2-3 was a helpful application when it came time to make a parts/price list.

Plus, our seesaw component drawings looked neat and professional after we used AutoSketch to create them."

"The computer was an important assistance in the design. It was used for all of the component drawings, the word processing, tables, charts, and graphs. Using the computer not only saved time, but made my team's design package easier to do and neater in appearance. I gained valuable experience in three different computer programs: WordPerfect, Lotus 1-2-3, and AutoSketch. Moreover, I became comfortable with using a computer whereas before taking this class, I had very little computer skills. The use of the computer by each of the members in my team made the design package clearer to the readers because it provided a word processor, supplied visual aids, and produced accurate and precise drawings."

"Another dominant aspect introduced by ENES 101W, is the utilization of computers, not only for word processing, but also for charts, graphs, and drawings. The cost estimation of our seesaw design was compiled using Lotus 1-2-3, a spreadsheet program. Before this engineering class , I believed that anything with the word "spreadsheet" in it was definitely for computer freaks. Yet, as I began to use the application for report and presentation purposes, I found that this was assuredly not the case. Furthermore, not being a terrific artist, I quickly found that drawing by hand, using only a ruler and a pencil, was not only quite tedious, but additionally somewhat inaccurate. By using AutoSketch in class and for the seesaw design, I felt like a real virtuoso on the drawing board. Without AutoSketch, the drawings for the seesaw design, especially the individual component drawings would have been of utmost inconvenience."

5.1.3 About Cooperative Learning

"This engineering design course let us experience a cooperative learning process. Unlike high school where many of us do all of the work in group projects, here I felt like an equal, with everyone in the group doing her own share. One aspect I particularly enjoyed about my group is that if one person couldn't be at a certain meeting, no hard feelings were held for that person. For instance, I arranged a meeting one Saturday and one of my fellow group members couldn't be there due to work conflicts. Yet, a few weeks later, when I couldn't be at a meeting, that group member stayed after class and worked by herself to complete the task that needed to be done for that day. Together, as we worked as a group so much more was accomplished than what one individual could do. With six people working on the project, we accomplished a substantial amount of work. Our group showed a real sense of camaraderie, I feel. We worked together, cheering over our triumphs and agonizing over our obstacles. Additionally, I detected a great sense of support when we presented our project. I had all of my group members cheering me on, smiling and winking at me when I was talking. I feel that this type of cooperative group learning was one of the paramount features of the class and one which I appreciate the most. This was most definitely the greatest aspect of the class, not to mention the most fun!"

"Working in a cooperative learning process to complete the seesaw design, enabled the members of my team to function both individually and as a team member with a minimum of supervision. Team collaboration provided a chance for everyone's ideas to combine in making a seesaw that we all wanted. As a team member, I have learned that working as a team has its advantages and disadvantages. At times it can be very frustrating when fellow members do not do their part, but when everyone works at their goal, the final outcome will be fruitful. Now that my team's design is finished and even though our seesaw design at present is very different from our original plan, I am glad that I got the chance to experience working in a team. I feel the members of my team and I strived for a common goal and succeeded."

5.2 Instructor's Observations

Without doubt, the first and most important observation from the instructor is that the design project generated the driving force which motivated the women students to actively participate in the process of learning engineering design. There is no need to emphasize the importance of selecting a design project which fits the need of the participating students. It is evident that a proper selection of the design project provides a great opportunity for the students to understand the basic engineering concepts that they have learned and/or are learning. It also allows us to simulate an industrial environment in product development. Consequently, it encourages the students to develop their analytical skills and to allocate time, money, and available resources. Working as an individual and a team member, the students understand the social and technological systems, and strengthen their personal qualities that foster discipline, self-confidence, and the ability of working with others.

The second observation is that high school students at their junior or senior level clearly have the capability of learning engineering design. Not only is it possible, but also it is needed. To ensure success, a careful organization of the design course to provide opportunities for the students to learn engineering design. This includes the preparation of necessary lecture notes and homework assignments to overcome the difficulty of the lack of a suitable textbook, the preparation of notes for computer application programs that correspond with the design project, and the decomposition of the entire project into individual tasks which fit the student capabilities.

The third observation is that the instructor(s) must be enthusiastic in teaching the design course and actively participating in the design activities with the students. A close and effective communication between the instructor(s) and the students is absolutely essential because it enables the students to sense the instructor's concern for their progress. The instructor(s) should create opportunities to encourage the participation of all the students in the design process, such as the design release presentation. It is the instructors responsibility to provide the tools, equipment and workspace for manufacturing the components for the students when they need them. It should be pointed out that there is a pressing need to resolve the funding necessary to equip and support the design laboratories and computer facilities for effectively teaching engineering design.

In the 1991 summer program, the instructor received strong support from the leaders and the supporting staff members of the College of Engineering, the ECSEL program, and the Department of Mechanical Engineering. Without their support, it would have not been possible to complete this course with such great success. However, the efforts of the instructor devoted to teaching of this course may not have been recognized fairly. If faculty members are to teach design with enthusiasm, they must be given time to develop material and they must be given assurances that rewards for time spent on instructions are equal to the rewards gained by performing research.

6. Conclusions

In a six week summer course, we offered an introductory engineering science to twenty-one high school women. Using a project approach, we taught engineering design through the product development cycle, i.e., actually making a prototype of a playground seesaw. The women students learned basic engineering concepts and computer skills which are needed by all engineers for a successful career in the modern economy. More importantly, they gained hands on experience through participating in the design, manufacturing, and assembly activities. We believe that this approach for teaching engineering design to undergraduate and high school students represents a new direction in engineering education.that can be scaled-up for much larger class sizes.

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