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A Freshman Engineering Design Course

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

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J. W. Dally
Department of Mechanical Engineering

G. M. Zhang
Department of Mechanical Engineering and Institute for Systems Research

University of Maryland
College Park, MD 20742

Abstract

At the University of Maryland at College Park, a new freshman engineering design course introduces design through a project approach. This approach has three phases: design, manufacturing and assembly. First, students learn basic engineering concepts by designing a simple product. Next, they manufacture and/or procure the product's components. Finally, they assemble the components and test the finished product. Since drawings for this product are part of the project, students must also learn entry-level computer graphics. Reaction to teaching design so early in the engineering curriculum has been extremely favorable. Students are highly motivated by the design approach and, as a result, learn engineering fundamentals, develop critical thinking skills, learn to cooperate as team members and gain practical hands-on experience.

I. Introduction

The development of technology and increasing competition in the world market challenge our educational system to provide students with superior knowledge, skills, and more realistic design experiences. This challenge has lead to an education reform movement that involves a critical examination of the engineering and science curriculum (1-4).

In engineering education, the curricular goals have been well defined for several decades. It has been a common practice, in most colleges of engineering, to offer a freshman engineering course that covers a general introduction of engineering science. Usually the topics covered in this course include orientation, graphics, a computer programming language, ethics, and often social issues like safety and the environment. This material is usually delivered by a junior faculty member lecturing to relatively large classes.

From our observations, the usual freshman engineering course is unsatisfactory because the students usually do not perform well, often drop engineering as a major and undergo little personal development. Some of the major reasons for the students dissatisfaction are: 1) the materials taught are isolated and abstract without reference to real applications, and occasionally even obsolete; and 2) the usual presentation method by lecturing does not provide a structured opportunity for students to develop their thinking skills. Very often, lecturing fails to encourage the student-teacher and student-student interactions which are so important in the learning process. Much like the courses in mathematics and science, the traditional freshman engineering course turns the students off because it does not present a realistic experience with sufficient linkage between theory and application. Consequently, the course fails to motivate the students and presents a very poor educational experience.

In this paper, we describe a new approach for the first freshman engineering course. Under the assumption that such a course is limited to 2 or 3 credit hours, we narrow the objectives to three major topics, i.e., engineering design, modern graphics, and introductory computer software applications. In teaching design, we use a project-driven approach to simulate three fundamental phases in the product realization process, namely, design, manufacturing, and assembly. The student is motivated to learn graphics by the real need to prepare a drawing package for the design project. We have replaced programming with the development of entry level skills in a computer-aided drawing program and in using a spreadsheet with graphical output. Small classes, with significant student-teacher interaction, ensure success. We encourage student-centered cooperative learning through teamwork. In this paper, we present our experience in offering this experimental course to both freshman students on the College Park campus and female students from Maryland high schools(5-7). The response from both groups has been extremely favorable in spite of the significant demands on their time.

This course is similar in some ways to the freshman offerings at Arizona State University described by Mc Neill, Evans, Bowers, Bellamy and Beakley (8-10). We employ their pedagogical philosophies that the design process is best learned by practice and that to teach design, the process involved must be defined. We differ in stressing a team approach more strongly where hardware (not a model) is designed, manufactured and assembled. The instructor serves much more as a coach than a lecturer with our approach.

II. Freshman Engineering Course

Our objective in developing this freshman course is to integrate introductory topics by blending design and theory. The course involves a project-driven approach that groups students in teams to participate in the design activities associated with the product realization process. They gain a conceptual understanding of the engineering design process through an active learning experience.

A. Project-Driven Approach

A design process in industry, regardless the product under development, is focussed on developing a quality product that is reliable and profitable. The design process involves creative thinking, application of modern technology and economic considerations. A good engineering design not only ensures outstanding performance, but also offers ease in manufacturing piece parts and facilitates the assembly. To follow this philosophy, we interpret total design to be a three-phase process, i.e. design, manufacturing, and assembly. We emphasize the importance of integrating the manufacturing and assembling phases because a design experience would not be completed without actually building the product and testing it to ascertain if it meets the design specifications.

In the typical academic environment, many difficulties may arise when attempting to employ the proposed methods. For example, the cognitive development of our freshman students is characterized by their disposition to view the world in polar terms (right vs. wrong) - with the correct answer as an absolute truth that is known and held secret by the instructor. It is imperative that this binary thought process be changed. We stimulate the students with this project-driven approach and broaden their thinking processes to explore a wide range of solutions. We start the product realization process with detailed guidelines for the design, manufacturing, and assembly phases, which are suggested below.

1) The Design Phase: This is the first stage in the product realization process. The most important responsibilities of the instructor are to initiate the student activities, establish a design environment to simulate that found in industry, and outline the essential design steps. Major tasks in the design phase may include:

1. announcement of the product;
2. formation of design teams;
3. definition of design specifications;
4. development of design constraints;
5. determination of general configuration;
6. analysis of design alternatives;
7. analysis of detail components;
8. completion of a detailed drawing package;
9. team and peer review and design modification;
10. design release.

2) The Manufacturing Phase: This is the intermediate stage. A completed drawing package and parts list describing the product are available at this time. The important responsibilities of the instructor are to assist the students in manufacturing the designed components, identifying the weaknesses in their designs, and improving the product through design modifications. In this stage, the learning process emphasizes hands on experiences, team efforts, and recognition of the inherent relation between design and manufacturing. Major tasks in this phase include:

1. layout of the piece;
2. production of piece parts;
3. quality inspection;

4. procurement of the hardware;

5. kit preparation;

6. design modifications;

7. drawing revisions.

<u>3) The Assembly Phase</u>: This is the final stage. All the parts for the product are available. The product specifications have been defined. The students have become familiar with the product and its parts. Major tasks in this phase are

1. assembly of the parts;

2. testing of product for performance and safety;

3. final improvement by design modification;

4. improvement of the manufacturing processes;

5. summary of the entire design process.

To provide a concrete example of the proposed approach, the major tasks involved in the design, manufacturing, and assembly phases of a playground seesaw are illustrated (figure 1). It is assumed that the seesaw is to be designed and constructed by a team of four to five students. The documentation required in the design phase is given (figure 1). For example, the first description of the product is made after completing the first three tasks, i.e., the local site visit, isometric sketches, and definition of product specifications and constraints. The second report deals with the analytical evaluation of the components used in the design. The third submission is the drawing package, a listing of the parts to be manufactured or purchased, and an estimate of their cost. By combining these three documents, the design team produces a draft of the design package for the team review. A class room presentation of the design release by one or more members of the team permits peer review.

Building the product through this three-phase process illustrates the product realization process in a manner that is crystal clear to the students. Because the project is interesting and real, the students remain motivated in the coverage of both the design and the analysis aspects of the course. The simulated industrial environment provides the students with a meaningful and realistic experience related to the product realization process.

B. Product Selection

The project-driven approach focuses on product realization as the course progresses. Selection of the product is vitally important for successful implementation. Proper selection of a product involves the following considerations.

1) Students' Expectation: In general, students show interest in building a product which they have designed as a team. This is especially true for freshman students because it is a rare hands on experience in a year filled with abstraction. In most cases, it is the first experience in engineering design in the student's career. It represents a significant challenge, especially in the first two weeks of the course. In such a situation the student first asks "How do we start to design the product?". To facilitate the first attempt at design, the product selected should be something very familiar to the students. This selection allows the students to begin by first copying some of the existing design features through observation, and to appreciate the important concept of reverse engineering. The structure of the product should permit analysis with introductory engineering concepts, and should remain relatively simple (15 to 30 part numbers). The product should present a challenging design opportunity that a typical 18 year old freshman student of either gender can successfully complete.

2) Instructor's Expectation: Teaching a freshman engineering course with a project-driven approach also represents a challenge to faculty members. It requires exceptional enthusiasm from the instructor to provide an enlightened and integrated approach which is so essential for a successful conclusion. This is especially difficult under the current reward system, which minimizes the time a faculty member devotes to teaching and maximizes the time spent on obtaining research funding.

There are several technical issues to consider when selecting products: 1) The product size should be reasonably small to ensure that the available working space is sufficient to accommodate the manufacturing and assembling operations; 2) The piece parts must be easy to manufacture because most colleges have little or no equipment to perform complicated machining operations. Also, most students lack skills in using even simple tools such as saws and drills. It is suggested that wood and plastic be used as the major raw material as they are low in cost and easy to machine; 3) Small and simple parts often lead to low costs in maintaining financial feasibility of the product; and 4) Stressing safety is important in avoiding personal injuries during the manufacturing phase.

3) Examples of Product Selections: Two product selections are described to demonstrate the basic considerations outlined above. The first product was a swing set with slides, which was designed and built by freshman students in the first experimental course in the Spring 1991 semester. Three different swings were designed, each by a team of five students. The initial specification defined the swing set as an entertainment center for young children of ages 3 to 10. Since the students were familiar with the swing set, the students were able to modify the existing designs of swing set and incorporate their own concepts. In designing the swing sets, the students were concerned with the support

structures, their strength and the methods of analysis for beams, ropes, and struts. The questions that they raised provided the opportunity to introduce several basic engineering concepts such as equilibrium, stress, strain, safety factors, energy and work, centrifugal forces, and the superposition principle, which are of major importance to aerospace, civil and mechanical engineering. About 30 unique parts were required to build a single swing set. The major raw material was wood which is easy to fabricate. Some multiple parts which fit together in assembly were important in introducing the students to the problems of tolerances. The swing sets are suitable only for a small class because they require large assembly areas. They also created the problem of transporting the piece parts to an off-campus location for assembly. An example of one of the three swing sets constructed in the first experimental course is shown (figures 2a and 2b).

The second product was a seesaw. Female high school students designed four seesaws during a six week course offered in the Summer of 1991. Each of the design groups consisted of five to six high school students. The familiarity of the product to the female students allowed them to define the product specifications and constraints with ease. They initiated their own designs by first imitating, then modifying the existing seesaws, and finally arriving at their own designs. The complexity in the design analysis requires the knowledge of statics (free-body diagram and equilibrium), strength of materials (stress, strain and safety factors), and dynamics (work and energy, and impact effect). The number of unique parts in a seesaw, on the average was about 15. The major raw material used in building the seesaw was wood and the cost was around $100. Tasks involved in the manufacturing and assembling processes are challenging to female high school students, but they are manageable for both the students and instructor. The seesaw is an excellent product selection for a 2 credit-hour course that is especially suitable for high school students or freshmen.

The assembly drawing for the seesaw and a picture of the product after completion is shown (figures 3a and 3b). Both the swing sets and the seesaws have been used on local playgrounds for over a year with good performance. Following the basic principles for product selection, other products such as playground equipment, or a folding chair, or a yankee cart would be suitable selections. An electronic product, or a product based on a chemical process may also serve to demonstrate the product realization process in this freshman course.

C. Teaching Graphics

Engineering graphics is a communication language. An engineer developing a design has to make many sketches and drawings to develop preliminary ideas before he or she can communicate effectively with associates. Graphical methods used in this manner are creative tools. Due to the rapid advancement in computer speed and the significant reduction in the cost of computing, graphical methods used in industry have changed dramatically. Mastering entry level skills in a computer-aided design has become much more important an significant element in engineering education.

We use the design project and the drawing requirements to emphasize the need for graphics. We introduce engineering graphics with a very brief coverage of sketching, isometric drawings and orthographic projections. The classroom lectures cover the most basic concepts in these graphical methods. For example, the coverage of isometric drawings includes simple blocks, blocks with cuts and holes, and simple house like structures. The teaching of orthographic projections focuses on certain fundamentals, such as the need for one, two or three views, the concept of hidden lines for holes and cuts, and the basic principles used in dimensioning.

The main emphasis in teaching engineering graphics is to train the students to use a computer as a drawing tool to design the product. In the computer laboratory, a friendly CAD program, rather than a full-featured and complicated one, should be selected. A typical example of such a software package would be the student edition of Autosketch that we have used in the experimental offerings with great success. The students are asked to read the CAD program manual and to practice through self-instruction. By assigning homework, we check if the students understand elementary usages of the program. It is important to have a knowledgeable student advisor to work in the lab with the students to provide on-site assistance. We have found undergraduate student advisors particularly effective.

To motivate the students studying CAD, engineering drawings of the product that are required must be prepared using the computer. Our experience indicates that the students seem reluctant to initially use the computer to prepare design drawings. However, after gaining entry level skills, the students become adept and do not hesitate to use the computer in producing excellent drawings. The software makes drawing easy, neat in appearance, and clear to the readers. The students appreciate the benefits of CAD more when modifications to the original designs are required. By simply retrieving the existing files, corrections can be made to the file to revise the drawing. In fact, such a training strengthens general computer skills. The experience motivates students to study on their own initiative because they recognize the connection between the laboratory experience and the skills required for their professional development in the future.

III. Strategic Methods in Learning and Teaching

It is understood that goals of engineering education will be more effectively realized if greater attention is given to the process of learning and teaching, instead of focusing exclusively on the course content to be offered. Some strategic methods in learning and teaching are proposed.

A. Cooperative Learning through Team Work

It is extremely important to emphasize cooperative learning through team work. Although traditional educational methods stress independent study and competition, professional assignments for engineers increasingly demand people who are able to work productively as a part of a team (11-12). Introducing the concept of working with others as a team member is imperative. A better balance between individual accomplishments and team work needs to be brought about in engineering education. During our experimental offerings, we asked the students to work in teams because no single individual would be able to accomplish the amount of work involved in the product design in the allotted time. They realize the importance of team work when the development of their product design becomes serious. When they communicate as team members, they bring different interests and views to the product design. They reach solutions that would not have been considered if they were working alone. During the group decision making process, they develop important skills of patience and compromise. This experience brings educational and social aspects into focus. It not only teaches the students how to work with others in developing a quality product, but it also assures that learning is approached from multiple perspectives. In fact, the use of cooperative learning through team work establishes a positive attitude toward learning from peers that is valuable in their subsequent years.

B. Task Partitioning

We would prefer to pursue the method of concurrent design for integrated manufacturing in teaching this freshman engineering course. However, the complexity and knowledge involved in the trade-off studies of concurrent engineering exceeds the capability of the usual freshmen student. In our approach, a sequential method is employed, i.e., the product moves from the design phase to the manufacturing phase, and then finally to the assembly phase. In each phase, specific tasks are clearly defined and assigned to the teams to ensure that all the participating students follow the design process.

As an example, the design progresses through the tasks listed (figure 1). To complete the first task, the students are organized in teams to visit local sites where the product is located. The teams then discuss basic requirements for the product, sketch possible designs by hand, select the one they like the best, and define the product specifications and constraints. The completion of this task aids the students in understanding what they are developing. The students then perform an analytical evaluation of the design. This analysis is based on the engineering concepts and principles introduced in the classroom discussions of the design. The design analysis starts with basic concepts such as free-body diagrams and static equilibrium, and then moves to a higher level concepts such as energy conservation and the principle of superposition. This gradual increase in technical difficulty coupled with an in-depth explanation through classroom discussions enhances the effectiveness in learning theoretical concepts in engineering. Engineering drawings are prepared for each of the components and for the general assembly. A list of parts and their respective costs are prepared for cost analysis, and assembly instructions are included. As noted previously, documentation is prepared at the end of each of these tasks. The design specification provides the design objectives and constraints, and represents a general understanding of the product to be designed. The analytical evaluation provides the justification of components employed and considers the adequacy of the dimensions, material selections, and safety factors. The drawing package provides detailed technical information on each of the components, fasteners, and sub-assemblies. Integration of these documents gives a summary of the many tasks performed in a team effort to produce the design.

The final task in the design phase is the design release. It provides an excellent opportunity for the students to experience the design review process often employed in industry during the product realization process. The instructor interfaces with each team. The students within a team and from other teams examine the completed design packages. This review process highlights the important issue that the product design should be approached from multiple perspectives. Each of the students has contributed his or her individual perspective. For each design team, the completed design package represents a compromise brought about through the discussions and negotiations among the team members during the design phase. Team collaboration provides an opportunity to combine ideas from all members to design a product that is better than the product developed by an individual. The design release also provides an excellent opportunity for students to practice their skills of oral presentation. The open discussion during the design release simulates a design office environment and allows the students to comment on good and bad aspects of the designs, and on the quality of the drawing standards. The design release also symbolizes the end of the design phase and the beginning of the manufacturing phase.

C. Student-Teacher Interaction

The teaching and learning process is a two-way communication between the students and instructor. To ensure effectiveness, the instructor must be enthusiastic in teaching and actively participating in the design activities with the students.

The instructor should function as both a consultant to the students and a coach to each team. The traditional image of a teacher being an ultimate authority and dispenser of factual truths must be abandoned. A close and effective interaction between the instructor and the students, especially in difficult times such as in producing the piece parts, is absolutely essential. The students sense the instructor's commitment and concern for their successful completion of the prototype.

The instructor must carefully plan and prepare materials to be used for the course. An analysis technique should be presented in a progressive manner and in response to the students' need as the design develops (just-in-time). The instructor should not present a method of analysis that is not related to the design activities. As an introductory engineering course, there is no need to cover complex equation derivations. However, the relationship between the analysis techniques and their engineering applications should be made clear to students. When the direct connection between design and theory is clear, the students understand the need for the analysis and are quick to use it to check the merits of their designs.

IV. Observations from Experimental Offerings

During the Spring 1991, we offered this freshman design course to a pilot section of 16 students for the first time. We divided the class into three design teams by drawing from a deck of cards. The product to be designed was a playground swing set, as shown (figure 2b). The second pilot offering was made during the Summer of 1991 to 21 female high school students, who participated in the program for Summer Study in Engineering. We formed four teams using self selection this time. The product was a playground seesaw, as shown (figure 3b). Our experience with these two offerings has been extremely favorable. The participating students were highly motivated. The designs developed by all these teams exceeded our expectations.

A. Motivation

Without doubt, the project generates enthusiasm which, in turn, motivates the students to actively participate in the learning process involved in design. It provides a great opportunity for the student to acquire and understand the basic engineering concepts by actually developing a product. The project-driven approach simulates an industrial environment, encourages the students to develop their analytical skills and to allocate time, money, and available resources to accomplish their goals. Through team work, they better understand the social aspects of working together toward a common self defined set of objectives. This experience strengthens their personal qualities that foster discipline, self-confidence, and the ability to cooperate. At the conclusion of these two pilot courses, the evaluations showed that the students were satisfied. They had received a significant amount of personal attention in their first exposure to engineering education. They took part in a "real" engineering experience, met new people, and enjoyed self-achievement through successful completion of their own product.

B. Student Performance

In this course we do not attempt to introduce a large number of engineering concepts. Our emphasis is placed on narrowing the scope and keeping things simple. The students are required to understand only those engineering concepts needed to perform the analyses related to the product design. However, the students gain a comprehensive understanding of the engineering design process and sense the strong connection between theoretical concepts and engineering applications. Such an experience through active learning stimulates their interest and builds their confidence in taking subsequent courses in engineering science.

Student achievements well beyond our expectations convince us that the students have acquired a rich and meaningful experience. In general, 18 year old freshman students, both men and women, have little or no background on manufacturing processes. They usually lack even the most elementary skills to work with simple tools. The project-driven approach offers them an opportunity not only to learn these skills but to build confidence in their ability to actually work with their hands.

Manufacturing the piece parts they designed is often difficult. However, this difficulty teaches them to realize that product design can markedly affect the manufacturing and assembly processes. For example, the adjustable pivot of one of the seesaws was designed with three half-cylindrical pockets as shown (figure 4a). This configuration was difficult to produce with the tools available to the team. An alternative way to manufacture the adjustable pivot is illustrated (figure 4b), which involves an auxiliary piece which is attached to the pivot. The three holes are drilled to form the pockets, and the auxiliary piece is discarded. Another alternative design of the adjustable pivot is shown (figure 4c). It consists of three V-notches, that can be cut easily from the pivot board with an inclined saw. The V-shape design is much simpler to fabricate than the design with the half-cylindrical pockets. The first article build clearly aids the students in understanding design for manufacture and assembly, and the need to develop prototypes for design verification and improvement.

Excellent student achievements can also be expected regarding their personal development. Preparing students for careers in industry is an important aspect of engineering education. The project-driven course creates an environment to stimulate the students to a more advanced stage of cognitive development. The design experience meets their developmental need for personal autonomy; however, peer-centered learning through team work offers them diverse experiential backgrounds and perspectives. They begin to understand that their thoughts and actions as well as the thoughts and actions of others affect team accomplishments. Such perspectives are central to the academic goals of achieving a better balance between independent thinking and the behavior and cooperative thinking associated with team achievements.

V. Conclusions

A new course in engineering design for freshman was developed and tested through two pilot offerings at the University of Maryland. The course emphasizes the product realization process with a project-driven approach that employed groups of students working in teams. The engineering design is interpreted as a design-manufacturing-assembly process to simulate product development cycle. Computer-aided graphics (CAD) and spreadsheet applications were introduced. Our pilot offerings indicate that the students respond very positively. We believe that they have shown significant progress in academic achievement, personal development, and in developing an appreciation of the engineering involved in creating wealth for society. We believe that this approach is effective in providing our beginning students with a stimulating first experience in engineering. The structure of the course eliminates the narrowness of a single perspective, and introduces the students to solution space that is essential in developing the creative thinking so necessary for competitive design.

We are encouraged that the methods used in these pilot studies have been adopted by others on the faculty at the University of Maryland. Additional pilot sections have involved development of solar desalinization stills and a porch glider. The College of Engineering has revised the curriculum in the freshman year and has adopted ENES 100 Introduction to Engineering Design as a required course for all engineering students. This course, which follows the methods described here, is being offered in the fall of 1992 to 270 students. Nine different faculty members from all of the departments in the College are each teaching a class of 30 students. The product is a wind generator.

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Figure 2b Photograph of a Swing Set

Figure 3a An Assembly Drawing of a Seesaw

Figure 3b Photograph of a Seesaw

Figure 4a Design of an Adjustable Pivot

Figure 4b Design 1 and the Required Manufacturing Processes

Figure 4c Alternative Design and the Required Manufacturing Processes

Bio Sketch

James W. Dally obtained B.S. and M.S. degrees from the Carnegie Institute of Technology, and Ph.D. degree from the Illinois Institute of Technology. He is a professor in the Department of Mechanical Engineering at the University of Maryland at College Park. He is a fellow of the American Society of Mechanical Engineering, Society for Experimental Mechanics, and American Academy of Mechanics.

Guangming Zhang obtained B.S. and M.S. degrees from the Tianjin University, China, and M.S. and Ph.D. degrees from the University of Illinois at Urbana-Champaign. He is an assistant professor in the Department of Mechanical Engineering and the Institute for Systems Research at the University of Maryland at College Park.

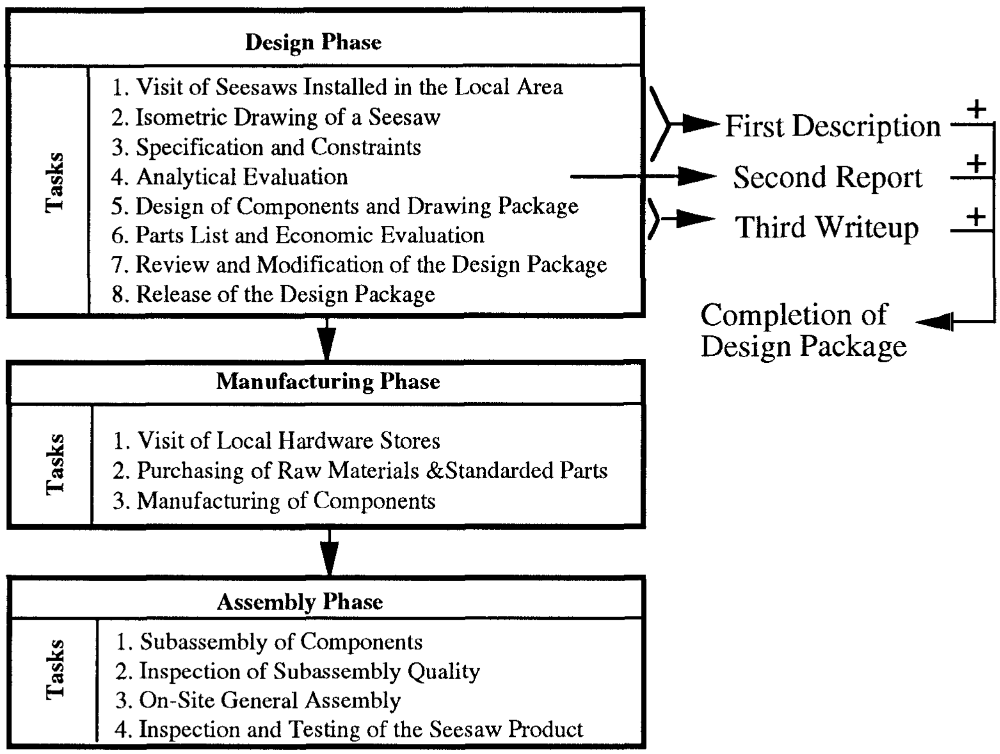


Figure 1 Major Tasks Defined in the Project Development of a Playground Seesaw

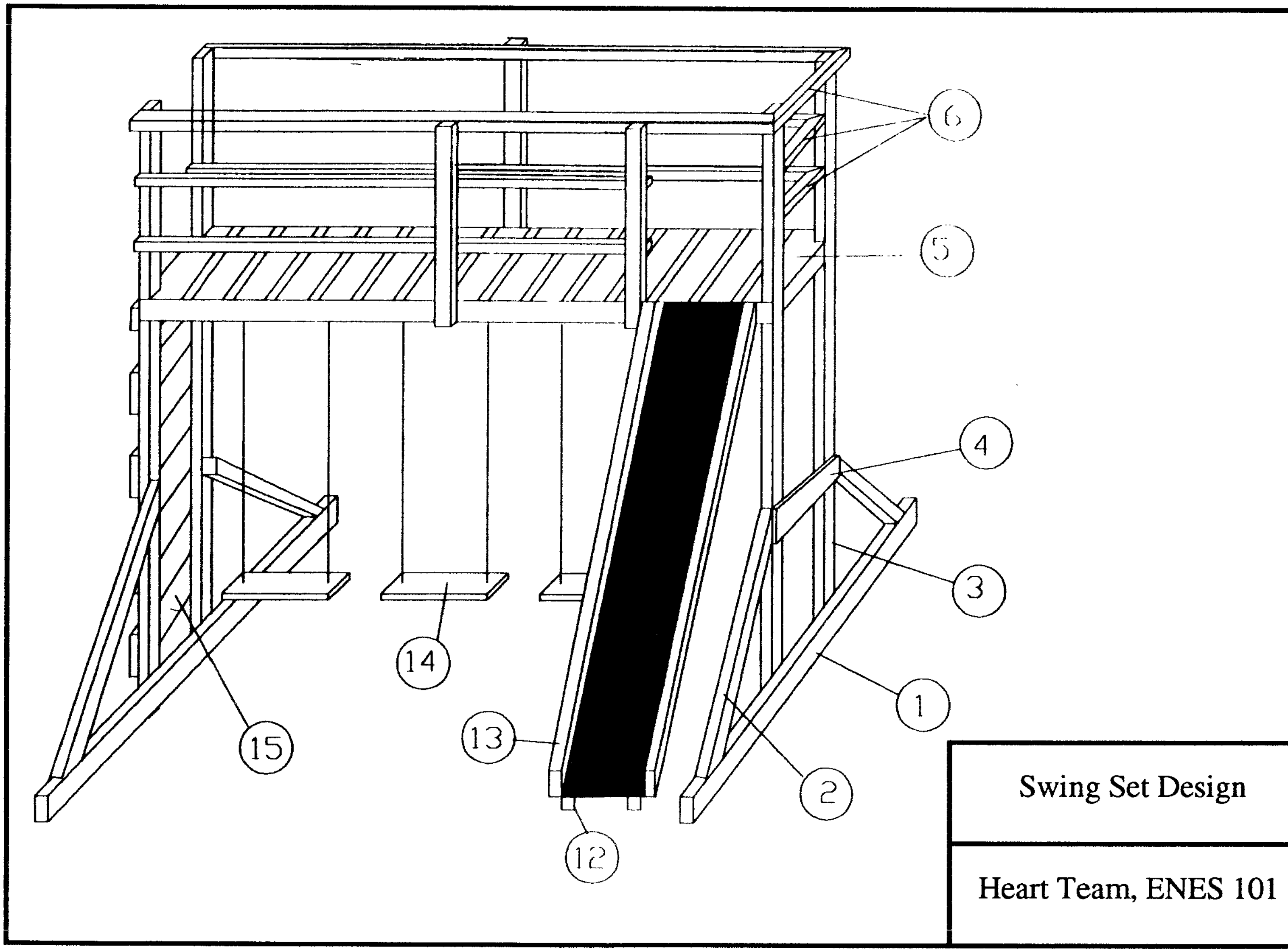
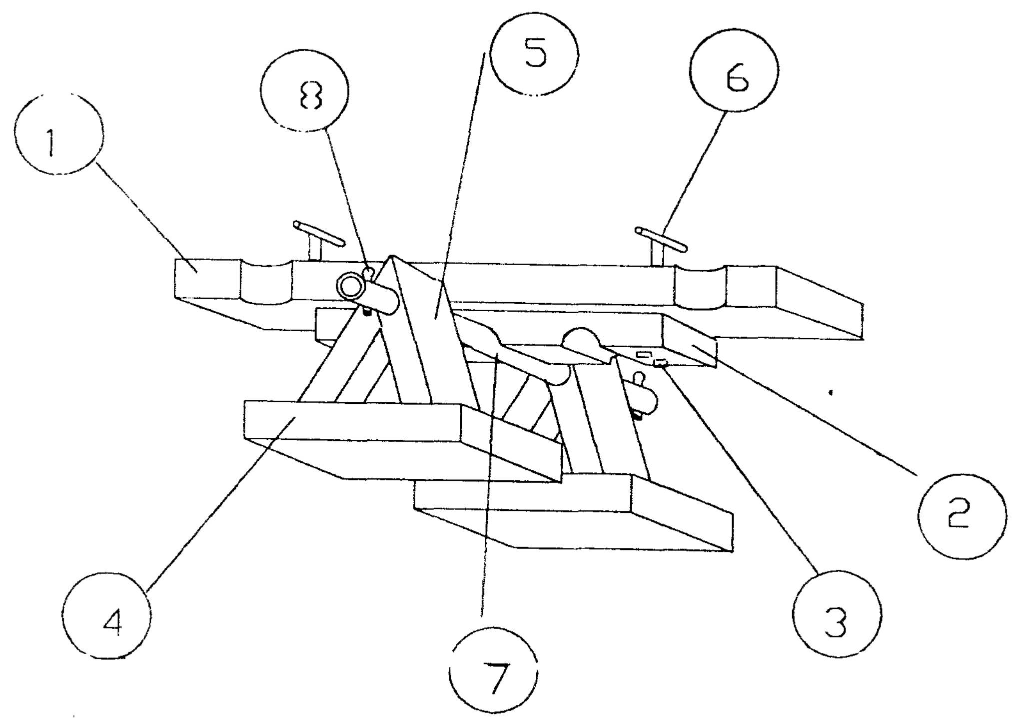


Figure 2a An Assembly Drawing of a Swing Set

Figure 2b Photograph of a Swing Set

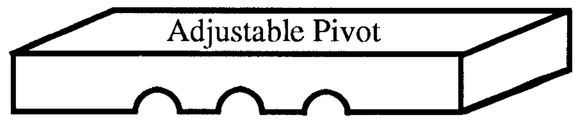


	6. Handle Bar	3. Connection 1	Seesaw Design
8. Connection 2	5. side support	2. Adjustable Pivot	Group 2, ENES 101W
7. Pivot Shaft	4. Bottom Support	1. Main Board	

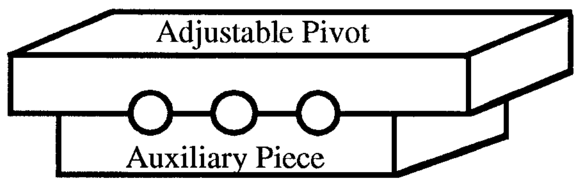
Figure 3a An Assembly Drawing of a Seesaw

Figure 3b Photograph of a Seesaw

Design 1



(a) Design of adjustable pivot

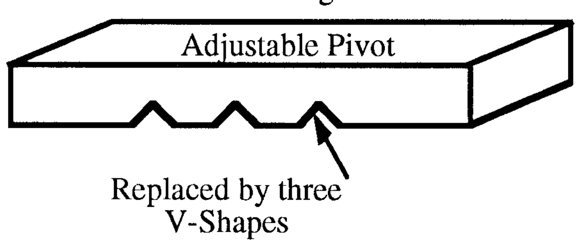


The Required Manufacturing Processes:

1. Attach an Auxiliary Piece
2. Drill the Three Holes
3. Thrown Away the Auxiliary Piece after Drilling

(b) Design 1 and the Required Manufacturing Processes

Design 2



The Required Manufacturing Processes:

1. Cut off the Three V-Shapes from the Pivot Board

(c) Alternative design and the Required Manufacturing Process

Figure 4 Concept of Design for Manufacture