

Improving Student Knowledge through Experiential Learning – A Hands-On Statics Lab at Virginia Tech

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Project Report submitted to the faculty of The Virginia Polytechnic Institute and State University for partial fulfillment of the requirements of the degree of:

Master of Science in Architecture, Construction Management Option

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May 28, 2003

Keywords: Statics, Experiential Learning, Experience, Hands-On, Lab, Bloom, Integration, SUCCEED, Structure, Equilibrium, Frame, Taxonomy, Kolb, Bending, Shear, Physical, Active, Exercises, Moment

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Abstract

It has been well documented that humans learn better through a combination of hearing, seeing, and hands-on experience than through hearing and seeing alone. Despite these findings, the majority of college instruction is through lecture. This research seeks to improve the quality of structural education for students in Building Construction, Architecture, and Engineering by allowing them to test theoretical structural concepts in a hands-on, lab environment that parallels their statics lecture class. The paper provides a background on the experiential learning approach, presents examples of others engaged in similar research, discusses the details of developing the experience-based lab class, describes the labs and their structure, and summarizes the outcome of this model class. Lessons learned, including which type of student might benefit most from the experiential learning format and shortcomings of applying the experiential learning model are discussed along with recommendations for future work. An appendix at the end of the paper displays the workbook developed to teach the class as well as pictures of the labs in action and costs of lab equipment. This project is a part of a multi-college initiative at Virginia Tech to develop a three-lab sequence to parallel Statics, Mechanics of Deformable Bodies, and Mechanical Behavior.

Dedication

For my wife, Amy: there are so many things that I could not do without your love, encouragement, and support. This is only one of them.

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1 Introduction

1.1 Background

This project is part of a joint initiative of the Engineering Science and Mechanics, Architecture, and Building Construction Departments at Virginia Tech to improve the structures curriculum. The National Science Foundation has provided additional funding through SUCCEED. SUCCEED is a coalition of schools and colleges working to enhance engineering education for the twenty-first century. The proposed enhancement is being accomplished through the use of experiential learning; integration between courses, departments, schools, colleges, and institutions (Engineering Education For the Twenty-First Century 1992); stressing cooperative-learning, teamwork, and communications skills; and vertical student integration. The specific purpose of this research project is to write, teach, evaluate, and document a hands-on lab that parallels the present statics class. Later projects will develop courses that parallel Mechanics of Deformable Bodies (Deforms), and Mechanical Behavior.

1.2 Problem Statement

A major problem facing students and professors at the statics level of learning about structures is that students simply are not learning, or are not retaining, the necessary knowledge to excel in later structural courses. This forces instructors in later classes to do extensive review before new material can be covered and significantly reduces opportunities for students to learn. Multiple professors I talked to stated that students came out of statics class without basic skills such as the ability to draw free-body-diagrams or find internal forces in a frame or machine, skills necessary for learning Deforms.

There are many studies and literature showing that students learn better when they are physically engaged in the learning process. Research shows that there is a direct relationship between the number of senses engaged in learning and the amount and quality of retention achieved over time (Stice 1987). Despite these facts, studies also show that the average instructor spends about eighty percent of his time lecturing to students (Terenzi 1994). Combine these studies with the fact that universities are being asked to do more with less (Auchey 1997) and you get a great opportunity to

begin to change the way students are taught at the university level. Instructors must learn “how to increase the productivity of their teaching” (Cross 1991) to allow students to learn and retain more. The result will be students who not only have a higher level of retention of structural concepts, but who are also able to move on to complex structural and building concepts more quickly than in traditional educational environments. Industry ultimately benefits by receiving employees who have been exposed to more structural concepts and who are more confident with the concepts they have learned.

1.3 Scope Statement

The purpose of this research is to write, teach, evaluate, and document a model hands-on-statics class in order to demonstrate that it is feasible, affordable, and interesting to students.

1.4 Project Objectives

- Research cooperative learning, multimedia teaching, the scientific method, and previous similar lab classes in order to write a new lab class
- Write a lab manual to run the class
- Order or build necessary equipment to teach the lab
- Teach a hands-on statics lab
- Summarize and clarify the process via a final paper

1.5 Limitations

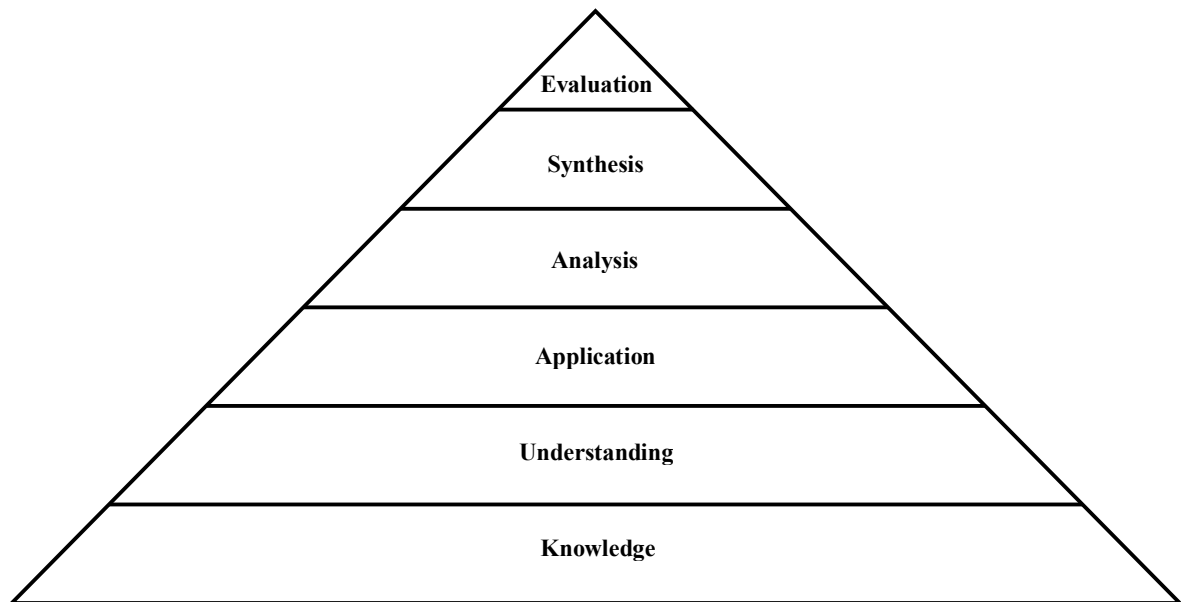
This research will not prove results in a statistical manor, as the number of students who enrolled in the class was only eight, a number too small for statistical significance. In addition, the lab is not meant to be a final draft, but rather a first draft to be revised as more knowledge is gained about the way statics is learned in a hands-on environment. Finally, this research will not establish how the lab will be expanded to a department-wide class and will instead provide information necessary to make decisions about how to go about this process should it be necessary.

Literature Search

1.6 Experiential Learning Theory

The theories used to write and teach the Hands-On-Statics Lab are well founded in the history of education. Bloom's Taxonomy, Kolb's theory of experiential learning, and more contemporary practical guides to teaching at the college level by authors such as Morrison, Ross, and Kemp all, support the need for college students to learn in a hands-on environment. Furthermore, testing shows that students in the construction, architecture, and engineering fields are even more prone to have learning styles that favor hands-on learning than typical college students (Kolb, 1984).

From 1948 through 1956 a group of educators (Bloom, Englehart, Furst, Hill, and Krathwohl) developed what is commonly referred to as "Bloom's Taxonomy of the Cognitive Domain" (Bloom 1954). Bloom's Taxonomy presented a classification of levels of intellectual behavior important to learning. This study found that over 95% of test questions college students encounter require them to think only at the lowest possible level...the recall of information. What follows is a graphic representation of Bloom's Taxonomy as well as definitions and action words for each level of cognition.



Knowledge: Student recalls or recognizes information, ideas, and principles in the approximate form in which they were learned (Write, List, Label, Name, State, Define).

Comprehension: Student translates, comprehends, or interprets information based on prior learning (Explain, Summarize, Paraphrase, Describe, Illustrate)

Application: Student selects, transfers, and uses data and principles to complete a problem or task with a minimum of direction. (Use, Compute, Solve, Demonstrate, Apply, Construct).

Analysis: Student distinguishes, classifies, and relates the assumptions, hypothesis, evidence, or structure of a statement or question (Analyze, Categorize, Compare, Contrast, Separate).

Synthesis: Student originates, integrates, and combines ideas into a product, plan, or proposal that is new to him or her (Create, Design, Hypothesize, Invent, Develop).

Evaluation: Student appraises, assesses, or critiques on a basis of specific standards and criteria (Use, Judge, Recommend, Critique, Justify).

Figure 1: Bloom's Taxonomy

Referring to Bloom, Morrison, Ross, and Kemp state that "Too often, major attention is given in a course to memorizing or recalling information – the lowest cognitive level. One of the challenges in an instructional design plan is to devise instructional objectives and then design related activities that can direct students to

accomplishments on the five higher intellectual levels” (Morrison, Ross, and Kemp 2001). The hands-on statics lab at Virginia Tech uses a physical learning environment, parallel to a lecture course, to force students to process knowledge gained in the classroom and apply it to physical situations. The process of applying classroom knowledge to physical situations places student learning in the synthesis and evaluation levels of Bloom’s Taxonomy. Students are also asked to become teachers to each other and the class throughout each lab. Teaching their peers forces the student to use Bloom’s levels of application, analysis, synthesis, and evaluation as “student-teachers” field unexpected questions and seek to present material in a format that others can also understand.

In his book “Experiential Learning”, David Kolb defines learning as “the process whereby knowledge is created through the transformation of experience” (Kolb 1984). Kolb believes that the student must physically interact with the material being studied in order to understand it completely. Physical interaction gives rise to learning in a continuous cycle in which the student forms abstract concepts and generalizations, tests the implications of these concepts in new situations via concrete experience and then reflects on what was observed. The next time the student comes upon the same situation she will already have the base of knowledge gained during the first cycle and will be able to move on to more complex experiences with the same, or similar material. Kolb goes on in “Experiential Learning” to quote William James from his book “Pragmatism: A New Name for Some Old Ways of Thinking” (James 1907) as James explains the difference between what he calls “knowledge of acquaintance” and “knowledge-about”:

Most languages express the distinction; thus, noscere, scire; kennen, wissen; connaitre, savoir. I am acquainted with many people and things, which I know very little about, except their presence in the places where I have met them. I know the color blue when I see it, and the flavor of a pear when I taste it; I know an inch when I move my finger through it; a second of time, when I feel it pass; an effort of attention when I make it; a difference between two things when I notice it; but about the inner nature of these facts or what makes them what they

are, I can say nothing at all. I cannot impart acquaintance with them to anyone who has not already made it himself. I cannot describe them, make a blind man guess what blue is like, define to a child a syllogism, or tell a philosopher in just what respect distance is just what it is, and differs from other forms of relation.

As students work through the exercises in the hands-on statics lab at Virginia Tech they are able to feel forces at work rather than simply being told what those forces would do as diagrams are drawn on a chalkboard. Students can walk up to the apparatus and manipulate it so that it functions differently, formulate a hypothesis, and test that hypothesis on the spot. It is this experience that leads the students to feel acquainted with the material rather than simply having knowledge about it.

In his book “Teaching Tips for College and University Instructors, A Practical Guide” (Royse 2001), David Royse references Chickering and Gamson who present 50 years of research “on the way teachers teach and learners learn”. The following is a summary of what they believe good teaching practice involves:

1. Frequent student-faculty contact
2. The encouragement of cooperation among students
3. Active learning techniques
4. Prompt feedback
5. Emphasis of time on task
6. Communicating high expectations
7. Respecting diverse talents and ways of learning

These practices played heavily in the development of the hands-on statics lab. Small class size of the lab allows students a high level of faculty contact. Pairing students to teach each other and then teach the class encourages cooperation among students. All lab exercises are constructed in order to allow active learning as students touch and feel forces at work. Students receive prompt feedback in class as well as in the following week as their lab write-ups are reviewed as a class. The lab manual allows students and faculty to focus on learning. Finally, the integration of the lab class with

the ESM 1004 statics lecture class allows students with diverse ways of learning to investigate the material to be learned in a way that best suits them.

As you can see, many examples of teaching and learning theory point to the merits of hands-on instruction. What follows will show that there are also many examples that demonstrate that hands-on instruction is effective and feasible at the college level.

1.7 Experiential Learning Examples

There have been numerous studies on how humans learn best. Such thinkers as Jean Piaget devoted their lives to these types of studies. In addition, many subjects, such as chemistry, are taught in a lab environment. However, for all of the rhetoric compiled about the merits of hands-on learning, I have found very few examples of its use in teaching statics and structures courses. Many colleges and universities are, however, using experiential teaching methods in other disciplines and demonstrating that such methods are feasible, affordable, and provide improved learning outcomes for students.

Lawrence O. Hamer, a professor in Marketing at DePaul University wrote a paper in April 2000 (Hamer 2000) where he compared test grades from students engaged in a lecture-only course to those in a course which combined lecture with various types of active learning techniques. These active learning techniques included pausing every ten minutes for students to reflect on and discuss lecture material and short and long-term group projects. The results of Hamer's study were tested by having both groups of students take a multiple-choice exam with both definition answers and concept application answers. The study showed that students in the class that included active learning performed "significantly better" than those taught under the lecture format (74% correct vs. 69% correct, $p < .005$). This gap was most pronounced in students who performed medium to poorly on the exam. Hamer suggests that the gap in performance is because the active learning format gave poor performing students more chance to elaborate on concepts that they did not understand. This study is in line with Kolb's findings that students learn differently and suggests which types of students should be taking hands-on classes in conjunction with their typical lecture courses: faster learners who are able to grasp the concepts being taught more quickly might be able to forego

the hands-on statics class while slower learners should be encouraged to take the class. This would allow all students to get to a higher final level, as classes will not have to be taught to the lower level of the slower students.

In an article in ASEE Prism in December 1996, titled “Matters of Style” (Felder 1996), Richard M. Felder of the North Carolina State University Department of Chemical Engineering discusses his research of four learning style models: The Myers-Briggs Type Indicator (MBTI), Kolb’s Learning Style Model, Herrmann Brain Dominance Instrument (HBDI), and Felder-Silverman Learning Style Model. Felder discusses how various university professors use these models to tailor teaching to the different student learning styles. He concludes that it does not matter what model is used to assess students; rather, it is important that instructors understand that students do learn differently and that “teaching to the full spectrum of learning styles improves students’ learning, satisfaction with their instruction, and self-confidence”. Felder suggests that instructors use “a variety of teaching methods such as group problem solving, brainstorming activities, design projects, and writing exercises in addition to formal lecturing”. The combination of the hands-on-statics class with Virginia Tech’s present lecture-class gives students an opportunity to sense and visualize structural concepts as well as teach and learn from others in a group setting.

In a paper presented at the 2000 ASEE Southeastern Section Annual Meeting Siegfried Holzer quotes J.C. Bringuir by saying that “Knowledge must be constructed by the learner, it cannot be supplied by the teacher” (Holzer 2000). In this paper he describes experiential learning as a “four-stage cycle involving four fundamental learning modes (styles)”. Holzer reinforces Felder’s research described above by teaching in a way that allows students of all styles of learning an opportunity to grasp concepts in their own way. He also uses Kolb’s learning styles as a guide. In Holzer’s classes, “a concept may be developed or applied in different contexts, at different times, and through different learning modes” (Holzer 2000). He describes that “Sessions generally consist of three parts: (1) a warm-up problem or a puzzler to engage the students; (2) mini-lectures (10-15 minutes long) interspersed with cooperative activities; (3) a minute paper (Cross 1991), where students are asked to reflect and answer

questions about the day's lesson and activities". This method allows students of all learning types an opportunity to master concepts before new ones are introduced.

In a paper titled "Experiential Learning in Mechanics with Multimedia" Siegfried Holzer and Raul Andruet describe a class format very similar to that used for this lab (Holzer and Andruet 2000). The main difference is that Holzer and Andruet are using a multi-media computer environment instead of hands-on experience to develop statics concepts. The multi-media class uses cooperative learning, think-pair-share, and exploration of concepts before definition of concepts to facilitate deeper understanding of concepts by students. In their paper, Holzer and Andruet describe experimenting with various sizes of student groups before concluding that groups of two seem to work best. Holzer uses a mix of Lyman's Think-Pair-Share (Lyman 1987) and Lochhead's Think-Aloud-Pair-Problem-Solve (Lochhead 1987) that he simply calls Think-Pair-Share.

The University of North Carolina at Charlotte has an introductory class for freshmen engineers called "STEP", Studio for Engineering Practice. In this class freshmen Civil, Electrical, and Mechanical Engineers are introduced to Engineering through a number of hands-on projects. The typical format for these classes is "a brief lecture, accompanied by demonstrations and practice at a workstation, followed by an assignment" (Coleman 1995). Projects include a four-bar linkage design project with kinematic verification by a computer program for Mechanical Engineering Students, a balsa bridge design with static-loading-to-failure test by Civil Engineering Students, design and evaluation of a LED battery tester by Electrical Engineering Students, and an interdisciplinary project to design and test a radio-controlled dirigible. Coleman notes, "The course, as an alternative to the traditional lecture format course, was well received by students and the involved faculty" (Coleman 1995). Although Coleman states that the course is expected to be "labor intensive when they are scaled up to full implementation", he notes that after the first two years of class implementation they have "departmental faculty, who have some experience in dealing with entering students in an alternative manner to [their] traditional lecture format" and a "collection of materials, both imported and developed on site, from which to draw projects for next year's classes. This should make it easier for new faculty who are involved with the

expanded and modified introductory courses” (Coleman 1995). The engineering department at The University of North Carolina is also a member of the SUCCEED Coalition.

Diane Beaudoin and David Ollis of North Carolina State University, another SUCCEED member, wrote a paper in 1995 describing “A Product and Process Engineering Laboratory for Freshmen” (Beaudoin and Ollis 1995). The Product and Process Laboratory involves freshmen students playing the role of “user, assembler, and engineer analyst” as they take apart and examine six devices. Devices include a bar code reader, CD-player, photocopier, and video camera. As the authors describe it “The significance of this work will be to demonstrate an immediate ‘hands-on’ introduction to freshmen students in a manner which includes teamwork, oral communication and presentation skills”. This class was offered on a large scale (216 students per year) which shows that “the manpower intensive teaching demand for such a course can be met through a combination of one professor, and properly prepared graduate teaching assistants and senior undergraduate engineers who will serve both as instructors and role models”. Similar to the Hands-On Statics Lab at Virginia Tech, Beaudoin and Ollis prepared an instructor’s manual to be used in association with the lab. According to the authors:

- The lab may be implemented at modest equipment costs and 700 to 1000 square feet of space for six devices.
- The original 5 device laboratory was assembled at a total cost of about \$5,000.
- Once the devices have been obtained, the experiments are easy to generate”.

Students were seen to really enjoy the lab format and working in teams: “The three recurring comments from the students were: 1) ‘we liked working collaboratively rather than competitively’, 2) ‘we liked having time and freedom to tinker through assembly and disassembly of the devices’, and 3) ‘we liked teaching each other through the oral presentations and team activities’” (Beaudoin and Ollis 1995). The Product and Process Engineering Laboratory for freshmen at North Carolina State University demonstrates that it is feasible to teach large groups of students in a hands-on environment at moderate cost and space constraints. While initial implementations of

the class may be demanding, once equipment is built and lab manuals written, the class becomes much easier to manage.

The above examples show that hands-on learning can occur at the university level with moderate initial investments in time and money and a commitment to experiential learning. Additionally, the authors involved in the above projects suggest some strategies for managing students in a hands-on environment such as think-pair-share and the use of properly trained research assistants to aid professors in overseeing classes. Many of the tactics learned will be used to write and teach the hands-on statics lab at Virginia Tech. When combined with traditional lecture courses, hands-on teaching environments result in a learning environment where students of all learning styles have a chance to gain in depth understanding of concept.

2 Description of Work

2.1 Development of the Lab Class

This project began by brainstorming and creating a matrix to determine all of the statics concepts to be addressed by the course (Appendix A). The concepts were then grouped into related clusters that could be taught as labs. The next step was to research the specific concepts to be included in each lab. Each week the concepts for a lab were compiled into a rough draft and a graduate research assistant would meet with the professor teaching the lab in order to discuss them, make necessary changes, and plan what type of equipment was to be built or purchased. Commercially available, table-sized demonstration kits already owned by Virginia Tech addressed some of the concepts. Other concepts would require building equipment on-site, either because kits were not commercially available, or because concepts needed to be demonstrated on a larger scale. Approximately once per month, the graduate research assistant and professor teaching the lab met with a larger team, which included a SUCCEED representative, to discuss the progress of the course. In order to develop the pre and post-class evaluation a graduate research assistant consulted with individuals in the education department who were skilled in statistical analysis; however, the number of students enrolled (eight students) made statistical analysis unfeasible. The lab was taught in the spring of 1998. The graduate research assistant also sat in on one of the sections of the lecture course that paralleled the lab, ESM 1004 - Statics. This allowed subjects taught in the lab to be as parallel and relevant as possible with the student's lecture class.

2.2 Lab Structure

Each lab begins by outlining the concepts to be explored in the lab. Following the outline is a procedure to be followed to set up the first statics experiment. Students are then asked to break off into groups of two to answer a series of questions that force them to hypothesize about what is happening in the demonstration. They are instructed to take turns being the questioner and the explainer as they discuss the questions with each other. During this time, students are allowed to test their hypothesis on the demonstration by measuring forces and manipulating the demonstration to see how

different scenarios behave. After working in groups of two to answer the questions, the students are asked to share their answers with the entire class. Sharing encourages them to formulate their answers in a format that is understandable to all of the students and allows other students to ask questions to be answered by the students themselves, with the instructor on hand to guide as necessary.

Interspersed throughout the lab are questions called “Stop and Think”. The stop and think questions take what was just demonstrated and tie the concept back to text-book concepts such as Newton’s 3rd Law. For example, after working through a demonstration on equilibrium, students are asked to “Stop and Think”: What relationship exists between a pair of forces acting on either side of an imaginary cut in each cable? The answer is that the forces are equal, opposite, and collinear (Newton’s 3rd Law). These stop and think questions bring the learning process full-circle, from lab to lecture and back, so that students are able to make new connections in their minds about how statics works.

Lab write-ups usually consist of two parts: 1) List the main concepts learned in the lab in the student’s own words and 2) Find a place in industry or in your surrounding environment where you see the concepts learned at work. Students are asked to explain their example and the concept it demonstrates using sketches and formulas where necessary. Examples are discussed at the beginning of the following lab period as a class discussion topic. The complete lab workbook developed for this class is included as Appendix B of this document.

2.3 Frame Structure

A frame structure was built for the class out of lumber purchased at a local lumberyard. Measuring approximately eight feet tall and eight feet wide, it allowed experiments to be conducted at a scale such that students could sense weights and forces at work. The structure was drilled with holes at regular intervals along its length so that future lab equipment could be suspended. The cost of this structure was approximately \$75.00 and it took one research assistant approximately 3 days to build. A full listing of materials and cost required to build this structure is contained in Appendix D.

2.4 Lab 1: Hanging Weights

The first lab illustrates the concepts of forces and their components, equilibrium, free-body-diagrams, resultants, and Newton's laws. For this lab, a number of heavy-duty hanging scales were purchased from a farm-supply store. The scales were hung from the main frame structure with weights hanging from them on ropes in various configurations. For the first experiment a stack of weights is hung straight down from one of the scales on a rope. Students are asked to pair with another student and answer the following questions:

- Define weight and the notation used to draw it in statics.
- What are the forces on the rope?
- Isolate the weight and show all of the forces on it (Free-Body-Diagram).
- What is the net force in the system?
- What is the relationship between a pair of forces acting on either side of an imaginary cut in the cable? (Newton's 3rd Law: The forces are equal, opposite, and collinear)

As they formulate their answers to the questions, the students are able to interact with the weights hanging from the. An experienced statics faculty member is present to guide and answer questions.

Next the weight is hung from four scales with a rope between them forming a "V" with the weight hung at the bottom (see figure 2). The scales are placed at ninety-degree angles at the top of each side of the "V" measuring x and y component forces at each side. Students are given an electronic angle meter to determine the angle of the ropes. The reading on the scales is covered so that students could not read the component forces. Again students are asked to answer a group of questions as follows:

- How would you go about determining the tensions in the scales?
- Isolate the weights and the forces acting on them (Free-Body-Diagram).
- What is the net force in the system?
- If you were asked to replace the pair of component forces with a single force, in what direction would you expect the force to act? How would you calculate the magnitude of this resultant force?

Finally, the two scales on one side of the “V” were replaced with a single scale at an angle to test the student’s hypothesis.



Figure 2: Lab 1, Exercise 1.2: The frame structure is built out of 2x6 lumber fastened by lag bolts. The rest of the equipment was purchased at a standard hardware or farm store.

The write-up for this lab asks students to list the main concepts learned and to find a place in industry or their surroundings that demonstrates the concepts learned. Write-ups are reviewed at the beginning of the next class.

The cost of this lab was \$262 and took only the time required to purchase the weights, scales, rope, and angle meter to set up. A full listing of materials and cost required to build this structure is contained in Appendix D. The lab manual can be found in Appendix B.

2.5 Lab 2: Seesaw

The seesaw lab was designed to illustrate moments, equilibrium within moment systems, how component forces influence moment systems, and force-couple systems. A small seesaw was constructed out of a 4x4 piece of lumber with a bolt at its fulcrum. In the first experiment, two different weights are placed on opposite ends of the seesaw equidistant from the center. The following questions are asked:

- Is the seesaw balanced?
- In which direction did it rotate and why?

Next the students are asked to place different combinations of weights on one side of the seesaw, using only a tape measure, and predict where they will need to place weight on the other side to balance the seesaw. Students are then asked to pair off and write down a basic formula and description for how to balance a seesaw before their answers are discussed as a class. Their calculated formula is then used to balance the seesaw and students are asked the following questions:

- Draw a Free-Body Diagram showing all of the forces in the system.
- Compute the force exerted on the fulcrum by the seesaw.
- What is the net force in the system? How do you know this?
- What are the equilibrium conditions of a body in a plane? ($\sum F_x=0$, $\sum F_y=0$, $\sum M_p=0$)

Related experiments can be performed using a rope attached to different places on the bottom of one side of the seesaw to counteract weights on the other. The rope can also be placed perpendicular to the seesaw or at an angle to test different problems. For the lab write-up students are asked to describe what notations are used to describe moments and to verbally describe what factors contribute to the magnitude of a moment. They were also asked to find a place in industry or their surroundings where they see these concepts at work and to list the concepts learned.



Figure 3: Lab 2, Exercise 2.2: The seesaw is made from a 4x4 piece of lumber. A small scale at the lower right side of the picture measures the reaction at an angle.

The cost of this lab was \$273. It took two days for a research assistant to set up. A full listing of materials and cost required to build this structure is contained in Appendix D. The lab manual can be found in Appendix B.

2.6 Lab 3: Equilibrium

The equilibrium lab was designed to illustrate the concepts of equilibrium, free-body diagrams, fixed and pinned connections, and two-force members. For this lab, a structure was constructed using 1x4 lumber, metal brackets, bolts, and rope suspended from the main structure in a configuration that displayed the concepts to be investigated (see figure 4). A weight is suspended from a point on the structure and students are asked to answer the following questions after meeting in pairs:

- Where are all of the forces acting upon the beam? Isolate the beam and diagram these forces (FBD).
- What are the forces acting on the pin connection? On the rope? Diagram these.
- What is the net force in each configuration? How do you know this?
- Use the three equations of equilibrium to calculate the magnitudes of the forces diagrammed previously.

Students are then able to test their answers by reading the calibrated springs that the weights are suspended from. This exercise is repeated with the weight being suspended from a different point on the structure.

The cost of materials for this lab is \$22. It took 4 days for a research assistant to build and set up the equipment. A full listing of materials and cost required to build this structure is contained in Appendix D. The lab manual can be found in Appendix B.

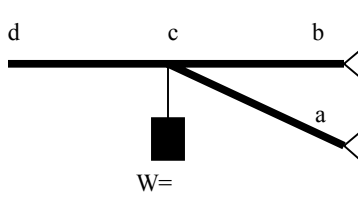


Figure 4: Lab 3, Pinned and Roller Connections

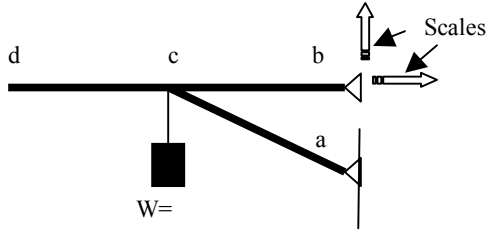
2.7 Lab 4: Frames

The frames lab was designed to teach students to recognize the difference between plane trusses and two-dimensional frames, the difference between collapsible and non-collapsible frames, and to free-body-diagram frame structures. Similar to Lab 3, the frame structures were constructed out of 1x4 lumber, bolts, and rope and were suspended from the main structure to perform the labs. Students are asked to break off into pairs and perform the following exercises while having access to the equipment to test hypotheses:

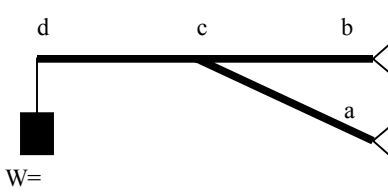
A. Inspect the structure in the back of the room. Is this a Plane Truss? If so, why?



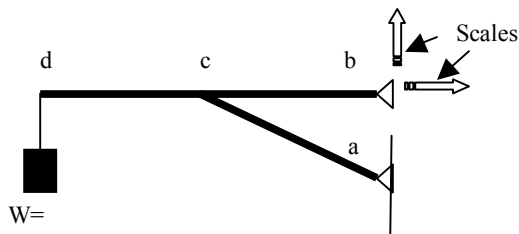
1. Compute the reactions in each member:
2. Check your results using a spring scale. What is the vertical force in the horizontal member?



B. Move the weight to point “d”. Is this a Plane Truss? If not why?



1. Compute the reactions in each member:
2. Check your results using a spring scale. What is the vertical force in the horizontal member?



There was no additional materials cost for this lab as materials from Lab 3 were re-used. It took two days for a graduate assistant to set up. A full listing of materials and cost required to build this structure is contained in Appendix D. The lab manual can be found in Appendix B.

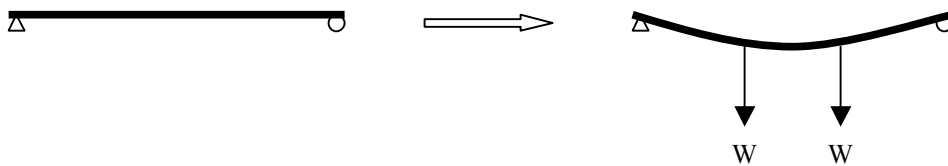
2.8 Lab 5: Shear, Moment, and Bending

The Shear, Moment, and Bending Lab is designed to teach students to identify shear force and calculate maximum shear, identify and calculate maximum moment, identify tension and compression in loaded beams, and to represent shear and moment graphically. For this lab PVC pipes are used as beams. One beam is pinned at one end and on a roller at the other with weights hung from it to impart a moment. Students

are first asked to compute the moment for the beam and draw the shear and moment diagram (See Figure 4, Step 1).

Next a second PVC “beam”, exactly half the length of the first beam and pinned at one end, is placed in front of the first PVC beam (see figure 4, Step 2). This second beam has a “T-bar” at its center. Students are asked to attach scales to the arms of the T-bar and apply force until the shape of the second beam matches that of the first beam (the beam loaded with weights). After reading the scales they are asked to calculate the moment in the beam to learn that it is the same as the moment being applied by the weights.

Step 1:



Step 2:

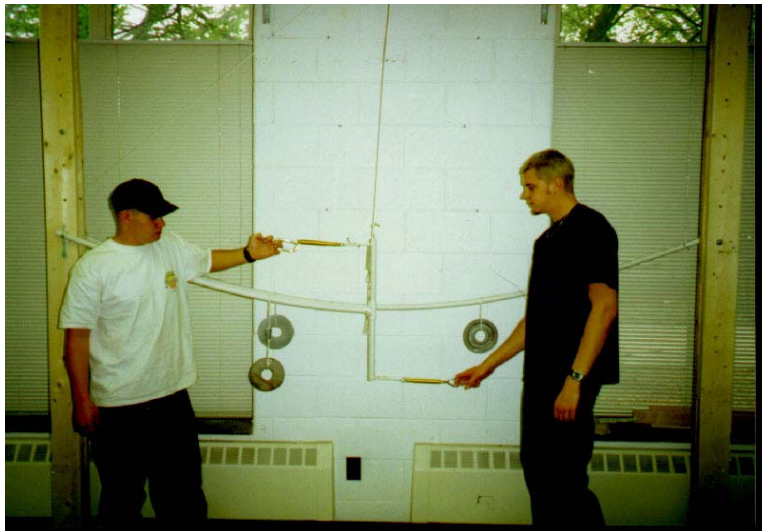
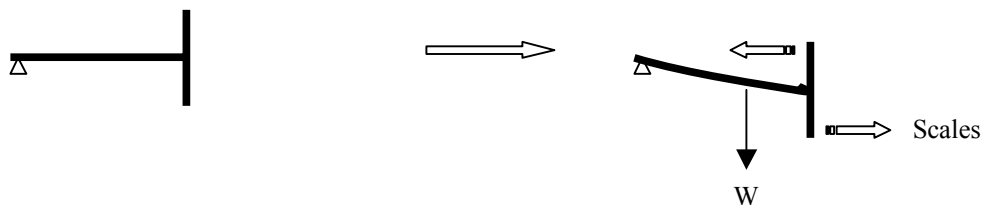


Figure 5: Two students demonstrate moment in Lab 5. The “beam” is made out of PVC pipe. There are actually two PVC beams: one behind, to which a moment is being imparted by two hanging weights, and one in front, which is cut in half so that students can measure the amount of force required to duplicate the curve of the pipe behind it.

The cost of the moment lab is \$5. It took four hours for a research assistant to set up. A full listing of materials and cost required to build this structure is contained in Appendix D. The lab manual can be found in Appendix B.

3 Conclusion

3.1 Lessons Learned

This project and report was undertaken based on sound learning theories, including the work of Bloom, Kolb, and other more contemporary experts on college instruction such as Morrison, Ross, and Kemp. Furthermore, it is supported by hands-on classes being taught at universities such as North Carolina State and The University of North Carolina as well as Virginia Tech. This project and report demonstrates that statics can be taught in a hands-on environment with low materials costs and minimal staff requirements. The class, for example, had one graduate teaching assistant and one associate professor teaching eight students. The same two people could teach a class of ten to twelve students in the same size classroom with the same equipment. In addition, once the frame structure is built, several classes a day could be taught using the same structure, thereby minimizing cost and the need for a full teacher's assistant per class. The frame structure and demonstrations were built for a materials cost of under \$650, plus the labor of a single graduate teaching assistant, who also had the time to write the labs and assist in teaching them. Beaudoin and Olis, referenced earlier in this paper, demonstrated that an incoming freshman class of 216 could be taught using hands-on methods after an initial investment of time is made to implement the equipment and train faculty.

Finally, the students involved rated this class as a 3.65 out of 4.00 as to overall teaching effectiveness. That is the equivalent of 91%, or an "A" grade, on its first run as a new class. With continued support and refinement, the hands-on-statics class has all of the attributes necessary to help students, especially struggling students, to reach a higher level of proficiency in statics so that future Architecture, Engineering, and Building Construction classes can move forward at a faster rate.

3.2 Application

Studies on learning show that different students learn in many different ways. References by Kolb and Hamer in the literature search attest to this fact. It is the suggestion of this author that this class be considered as an elective for students struggling in first semester statics or interested in an interactive educational experience.

Students who are able to grasp this material via a lecture environment will not have to spend time reviewing concepts they are already proficient in. Instead, students who would benefit from being able to touch and sense statics concepts will also become proficient in the basics of statics, therefore not falling behind or, even worse, quitting the engineering program out of frustration. Future classes can be taught at a higher level because all of the students are proficient in the basics of statics. Further study might be beneficial to decide if students should be encouraged to take this class based on a learning styles assessment, grades, or a teacher's assessment of how they learn.

In relation to industry, this project is highly applicable to making better architects, engineers, and constructors by allowing them a more intuitive knowledge of statics, the basis of all structures. The results will also be highly applicable to employee training and continuing education as the same principles of learning apply to these groups as well. The project moderately applies to team and labor management in the workplace because instructors as well as students in the class will indirectly learn about group dynamics, teamwork, and working alongside others who offer different levels of knowledge and aptitude.

3.3 Recommendations for Future Work

This segment of the research began in August 1997, and will continue until December 1998. In August 1998, a similar project will begin to write a lab to parallel Deforms. That project will end in December 1999 and will be performed by someone other than myself. Finally, a service project lab will be developed beginning in August 1999. This "capstone" lab will be taught in the Spring of 2000 and will wrap-up in December 2000. Once all three labs are in place, the instructors can begin with vertical integration as well as continuous class improvement.

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Appendix A: Syllabus and Outline of Concepts to Be Learned

January 7, 1998

Preliminary Syllabus for SUCCEED Lab:

Week 1- No Class

Week 2 - Concepts:

Forces, Components, Equilibrium, Free-Body-Diagrams, Resultants, Newton's Laws

Exercises:

Hanging Weights From Ropes and Scales

Week 3 - Concepts:

Same as Week 2

Exercises:

Tug-Of-War

Equilibrium experiments using mass and spring kits

Week 4 - Concepts:

Moments, Equilibrium, Free-Body-Diagrams

Exercises:

Seesaw experiments

Week 5 - Concepts:

Same as week 4

Exercises:

Wrench and Lug-Wrench demonstrations

Equilibrium Experiment with seesaw

Week 6 - Concepts:

Pin, Roller and Fixed connections

Force/ Couple Systems, Equilibrium

Exercises:

Pin, Roller, Fixed Demonstration

Beam Supported at wall on one side and by tension member at three different points

Week 7 - Concepts:

Same as week 6

Exercises:

Regular Wrench vs. Lug Wrench

Equilibrium with a person on one side of seesaw and pulley on other

Week 8 - Concepts:

Plane Trusses

Exercises:

Students as parts of trusses

Week 9 - Concepts:

Same as week 8

Exercises:

TBD

Week 10 -SPRING BREAK

Week 11 -Concepts:
Zero Force Members, Machines
Exercises:
TBD

Week 12 -Concepts:
Friction
Exercises:
TBD

Week 13 -Concepts:
Distributed Forces
Exercises:
TBD

Week 14 -Concepts:
Shear and Bending Moment Diagrams
Exercises:
Moment Apparatus Demonstration

Week 15 -Concepts:
Centroid
Exercises:
Graphical development of CG

Week 16 -Concepts:
Newton's Law
Exercises:
TBD

Appendix B: Lab Workbook

Lab 1: Hanging Weights

Objective:

This lab is designed to illustrate the concepts of forces and their components, equilibrium, free-body-diagrams, resultants, and Newton's laws. As you perform the following exercises, try to think about how these concepts might be helpful to an engineer, architect, or construction professional.

By the end of this lab you should be able to:

- A. Recognize where forces are acting on a body in two dimensions
- B. Understand Newton's three laws of equilibrium
 1. A body remains at rest, or in motion at a constant velocity if the net force acting on it is zero
 2. $F=ma$ (This is a "special case" of the first law (i.e.: in the first law $a = 0$))
 3. If one object exerts a force on a second, the second object exerts an equal, opposite, and collinear force on the first
- C. Draw a Free-Body-Diagram (FBD) using the following three step process:
 1. Isolate the body
 2. Apply all external forces
 3. Select coordinates
- D. Understand that a single force (a resultant) can take the place of multiple forces (component forces) in a system. To find the resultant force, we use the following concepts:
 1. Pythagorean Theorem: $a^2 = b^2 + c^2$
 2. $F_x = F\cos\theta$, $F_y = F\sin\theta$

Procedure:

Exercise 1.1: Scales Parallel to Each Other

A. Experiment

1. Hang a stack of weights from two spring scales so that the scales are parallel to each other and perpendicular to the floor.

2. Get into groups of two and answer the following questions:
 - a. What is "weight" and what notation do we use to draw it in statics?

 - b. What are the forces in the two cables?

3. Discuss your conclusions as a class.
4. Test your answer by reading the calibrated springs. Were your conclusions correct?

B. Equilibrium

1. Get into groups of two again. Isolate the weights from the rest of the system and show all of the forces acting on them. Show your work.

2. What is the net force in the system? (Net force = the sum of all forces acting upon the system) How do you know this?

C. Stop and Think:

Question: What relationship exists between a pair of forces acting on either side of an imaginary cut in each cable?

Answer: The forces are Equal, Opposite, and Collinear (Newton's 3rd Law)

Exercise 1.2: Inclined Scales

A. Experiment

1. Hang weights with the hanging ropes straight up and down just like in exercise 1.1.
2. Pull on the horizontal cables until the ropes reach an angle of 70 degrees from the horizontal axis.

B. Get into groups of two and answer the following questions:
What are the tensions in the vertical scales?

- a. How would you go about finding the tensions in the horizontal scales? Be creative and don't think too much about the "right way". Devise a method and show your work.

2. Discuss your conclusions as a class.
3. Test your answer by reading the calibrated springs. Were your conclusions correct?

C. Equilibrium

1. In your groups of two, isolate the weights and show all forces acting on them (This is known as a Free-body Diagram). Show your work.

2. What is the net force in the system?

D. Resultants

1. Get into groups of two and answer the following questions:
 - a. If you were to replace the pair of “component forces” with a single force, in what direction would you expect the force to act? Draw this “resultant” force.

- b. How would you calculate the magnitude of the above resultant force? Once again, be creative.

2. Answer the previous questions as a class.
3. Now suspend the weights from a single spring on each rope at the previous angle and read the “resultant” force from the scale. What do you notice about the place where the cable must be attached to maintain the 70-degree angle?

E. Stop and Think:

Question: What relationship exists between a pair of forces acting on either side of an imaginary cut in each cable?

Answer: The forces are Equal, Opposite, and Collinear (Newton’s 3rd Law)

Lab Writeup:

- 1) List the main concepts you learned in this lab in your own words. Where formulas are necessary, try to explain why those formulas work or where they came from.

- 2) Find one place where the concepts discussed in Lab 1 are used in industry or where you see them at work in your surroundings. List your example and the concept it demonstrates. Use sketches, formulas, etc. where necessary.

Lab 2: Seesaw

Objective:

This lab is designed to illustrate moments, equilibrium within moment systems, how components of forces influence moment systems, and force-couple systems. By the end of this lab, you should be able to:

1. Understand what a moment is and what factors contribute to the magnitude of moments.
2. Free-Body-Diagram a system containing moments
3. Solve three equations of equilibrium ($\sum F_x=0$, $\sum F_y=0$, $\sum M_o=0$) to determine the magnitudes of forces and moments which keep a system in equilibrium.
4. Define a couple and recognize the significance of couples in statics.

Procedure:

Exercise 2.1: Balancing a Seesaw

Experiment:

Place two different weights on the seesaw equidistant from the fulcrum, or center-support.

Is the seesaw balanced?

In which direction did it rotate and why?

Now practice placing different combinations of weight at different points on either side of the seesaw and predicting where you will have to place weight on the opposite side to balance the system (you may use a measuring tape only, NO EQUATIONS!!). Record your results by drawing them and by showing your calculations.

Get into groups of two and write down a basic formula and description for how to balance a seesaw.

Discuss your conclusions as a class.

Equilibrium:

Use one of the formulas devised in the exercise above to balance the seesaw with combinations of weights on it.
Check your calculation by performing the experiment.

Get into groups of two and draw a free-body-diagram showing all of the forces in the system.

Next compute the force exerted by the fulcrum on the seesaw. This force is called a *reaction* - the fulcrum is “reacting” to the forces applied to it by the seesaw and the weight on it.

What is the net force in the system (the sum of all forces in the system)? How do you know this?

Stop and Think:

Question: What are the equilibrium conditions of a body in a plane?

Answer: $\Sigma F_x = 0$
 $\Sigma F_y = 0$
 $\Sigma M_p = 0$

Exercise 2.2: Related Experiments

A. Equilibrium Experiment

1. Place 50 Lbs. of weights on one side of the seesaw.
2. Using the pulley secured to the floor and the rope with the scale attached to it, pull on the rope and secure it so that it is perpendicular to the seesaw and the weighted side of the seesaw is raised off the ground.

3. With a partner, free-body-diagram the system and calculate the tension in the rope. How is this system different from one where there is weight on both sides of the seesaw? What principle does this demonstrate?

4. Discuss your conclusions as a class.

5. Test your answer by reading the calibrated springs in the cables. Were your conclusions correct?

Lab Write-Up

1. What notation do we use to describe moments?

2. Describe, in words, the factors that contribute to the magnitude of a moment.

3. Find three places where the concepts discussed in Lab 2 are used in industry or where you see them at work in your surroundings. List your example and the concept it demonstrates.

4. List the concepts you learned during this lab. Where formulas are used, try to explain how they work or define them in words.

Lab 3: Equilibrium

Objective:

This lab is designed to illustrate the concepts of equilibrium, free-body-diagrams, and fixed and pin connections. As you perform the following exercises, try to think about how these concepts might be helpful to an engineer, architect, or construction professional.

By the end of this lab you should be able to:

1. Isolate a body and recognize where forces are acting upon it.
2. Draw the Free-Body-Diagram of that body
3. Use three equations of equilibrium to find the magnitude and directions of the forces diagrammed
 - a. $\sum F_x = 0$
 - b. $\sum F_y = 0$
 - c. $\sum M_o = 0$ (where "o" is any point in the plane)
4. Recognize a "two-force-member"
5. Understand the differences between pin and roller connections and some reasons for the use of each

Procedure:

Exercise 3.1: Pinned and Roller Connections

To clarify the concepts of pinned and roller connections, your instructor has prepared a quick exercise to perform as a class. After you have done this, get into groups of two and answer the following questions:

1. Draw a diagram of the exercise that you just did as a class. Use drawings and text to describe what you learned.
2. Why are pinned and roller connections often used in statics problems?
3. Why and how are they used in real-world situations? Can you think of any examples?

Exercise 3.2: Single Beam Carrying a Weight

A. Weight in Position #1

1. Hang a 10 Lb. weight from the beam at point “b”.

2. Get into groups of two and answer the following questions:

a. Where are all of the forces acting upon the beam? Isolate the beam and diagram these forces (FBD)?

b. What are the forces acting on the pin connection? On the rope? Diagram these.

3. Discuss your conclusions as a class.

4. In your groups of two again, use three equations of equilibrium to calculate the magnitudes of the forces you diagrammed before.

5. Discuss your conclusions as a class.

6. Test your answers by reading the calibrated springs. Were your conclusions correct?

B. Weight in Position #'s 2 and 3

1. Now repeat the above process. This time with the weight hanging from point “c” and finally from point “d”.

Remember to break off into your groups of two to solve problems and then to discuss answers as a class. Use a piece of scratch paper to diagram all of your hypotheses and to do calculations.

2. How did your answers differ and why?

3. What is the net force in the in each system? (Net force = the sum of all forces acting upon the system) How do you know this?

Summary Questions:

1. How does the situation with the weight hanging at “b” relate to Lab #1 where the weight was hanging from scales? Discuss your answers as a class.
2. How does the situation with the weight hanging at “d” relate to Lab #2 with the weight on the sesaw? Discuss your answers as a class.

Exercise 3.3: Two-Force-Members

A.Experiment

- 1.Hang a 10 Lb. Weight from point “d” on the beam again. This time with the beam supported from below by a single support at point “c”.

B.Get into groups of two and answer the following questions:

- 1.Isolate the support and draw its Free-Body-Diagram.
- 2.What is reaction in the supporting member (magnitude and direction)?

- 3.Discuss your conclusions as a class.
- 4.Test your answer by reading the calibrated springs. Were your conclusions correct?

C.Resultants

- 1.Get into groups of two and answer the following questions:

- a. Could you replace the component forces in the support with a single force?
- b. How would you calculate the magnitude and direction of the above resultant force?
- c. This support is called a two-force-member. Define in your own words what that means.

2. Share your answers as a class.

D. Stop and Think:

Question: What relationship exists between a pair of forces acting on either side of an imaginary cut in the supporting member?

Answer: The forces are Equal, Opposite, and Collinear (Newton's 3rd Law)

Summary Questions:

1. Describe how the single support in lab 3.3 relates to the weight hanging from scales at an angle in lab 1.
2. Find three places where the concepts discussed in Lab 3 are used in industry or where you see them at work in your surroundings. List your example and the concept it demonstrates.

Review:

List the main concepts you learned in this lab in your own words. Where formulas are necessary, try to explain why those formulas work or where they came from.

Exercise 3.3: Related Experiments

1. Air Table

Lab 4 - Frames

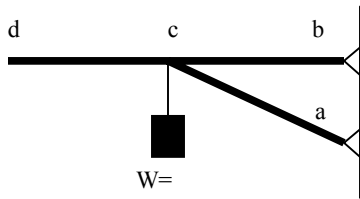
Objective:

By the end of this lab you should be able to:

- E. Recognize the difference between a Plane Truss and a Two-Dimensional Frame
- F. Recognize the difference between a Collapsible and a Non-Collapsible Frame and be able to analyze each
- G. Free-Body-Diagram a frame structure

Procedure:

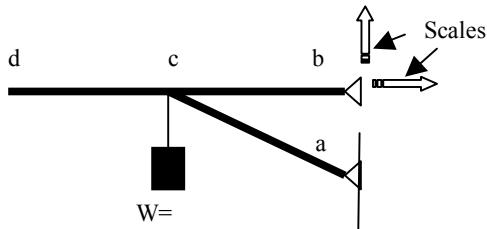
- A. Inspect the structure in the back of the room. Is this a Plane Truss? If so, why?



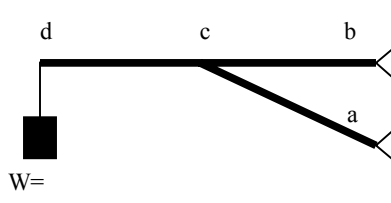
Tasks:

1. Compute the reactions in each member:

2. Check your results using a spring scale. What is the vertical force in the horizontal member?



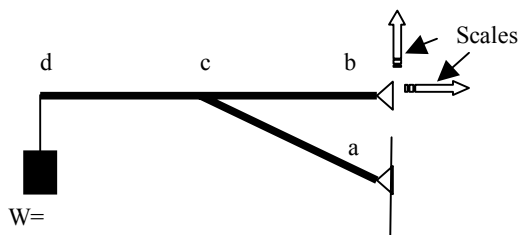
C. Move the weight to point “d”. Is this a Plane Truss? If not why?



Tasks:

1. Compute the reactions in each member:

1. Check your results using a spring scale. What is the vertical force in the horizontal member?



Lab 5 - Shear, Moment and Bending

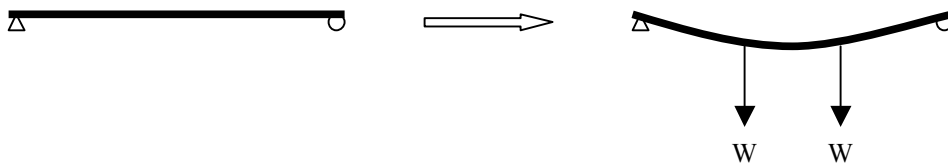
Objective:

By the end of this lab you should be able to:

- H. Identify shear force and calculate maximum shear
- I. Identify moment and calculate maximum moment
- J. Identify Tension and Compression in loaded beams
- K. Represent shear and moment graphically

Procedure:

- A. You are given a beam that is pinned at one end and has a roller at the other. Load the given beam as shown below:

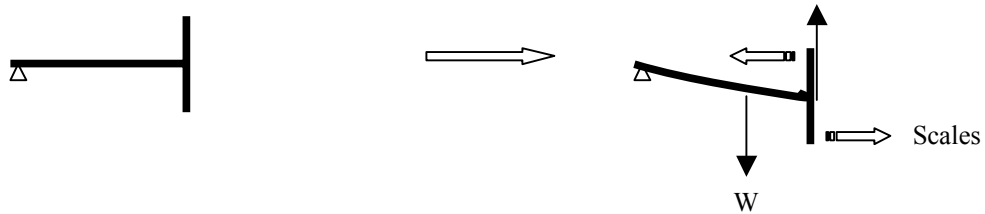


Tasks:

1. Compute the maximum shear and moment for the beam:

2. Draw the shear and moment diagram:

D. Now cut that beam in half and duplicate the shape of half of the previous beam by applying forces as shown below at what was the center-point of the beam:



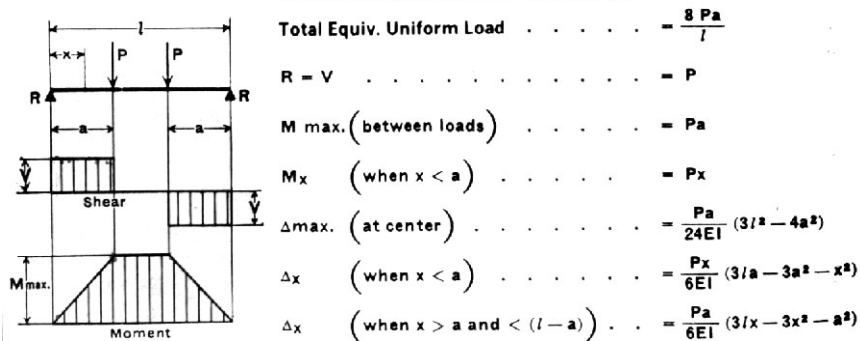
Tasks:

1. Calculate the moment being applied at the center-point.

2. Is the moment being applied equal to the maximum moment calculated for the first beam?

3. What type of force is being applied to duplicate the shape in the first beam? Why is this necessary?

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



Appendix C: Equipment

Lab 1: Hanging Weights



Lab 1: Hanging Weights – Students calculate reactions for Exercise 1.2.



Lab 1, Exercise 1.2: The frame structure is built out of 2x6 lumber fastened by lag bolts. The rest of the equipment was purchased at a standard hardware or farm store.



Lab 1, Exercise 1.2: detail of farm scale used to hang weights.

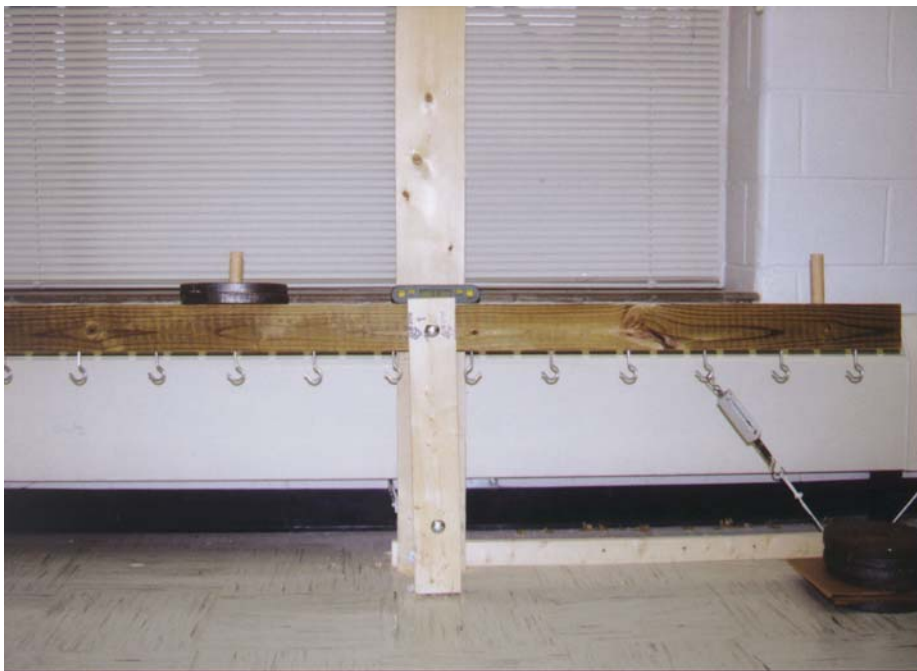


Lab 1, Exercise 1.2: Detail of pulley purchased at a local hardware store.



Lab 1, Exercise 1.2: Detail of how two scales were used to demonstrate reactions in both the x and y coordinates planes.

Lab 2: Seesaw



Lab 3: Equilibrium

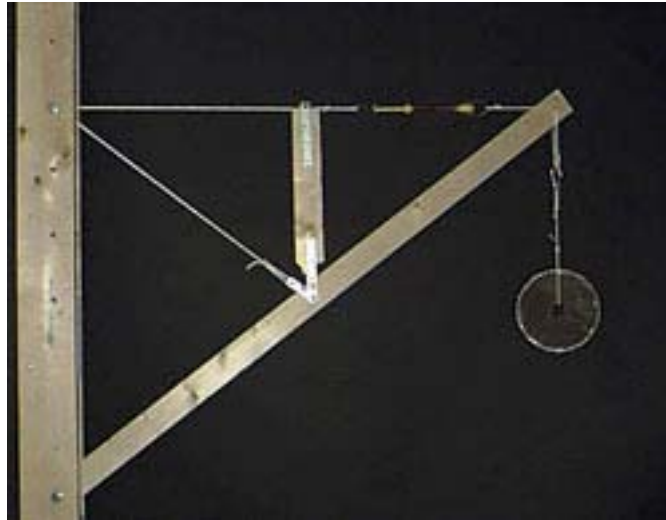
Lab 2, Exercise 2.2: The seesaw is made from a 4x4 piece of lumber. A small scale at the lower right side of the picture measures the reaction at an angle.



Lab 3, Pinned and Roller Connections



Lab 3, Two-Force-Member

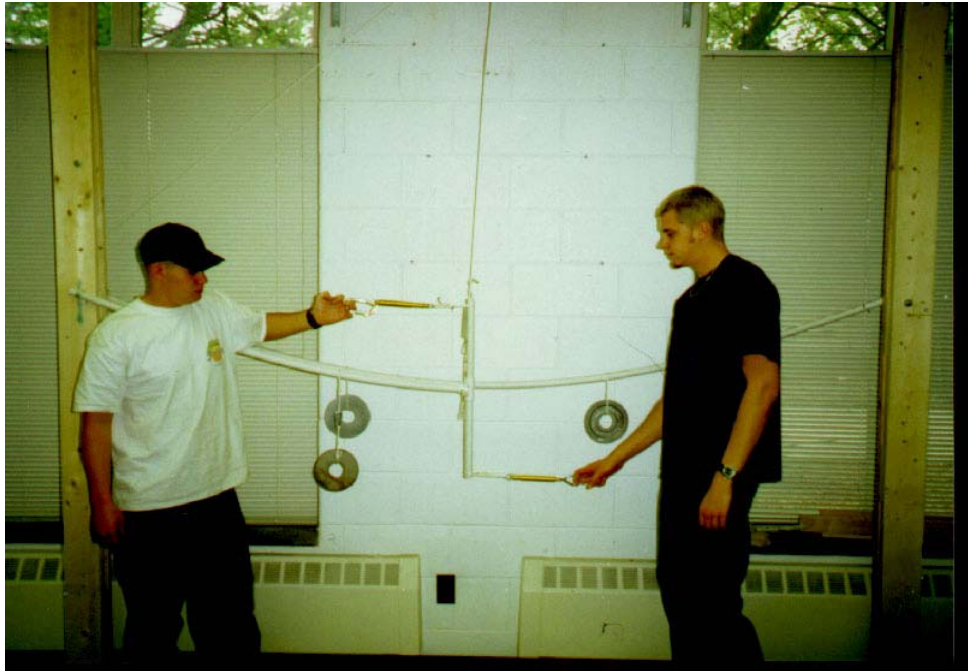


Another picture of Lab 3, Pinned and Roller Connections

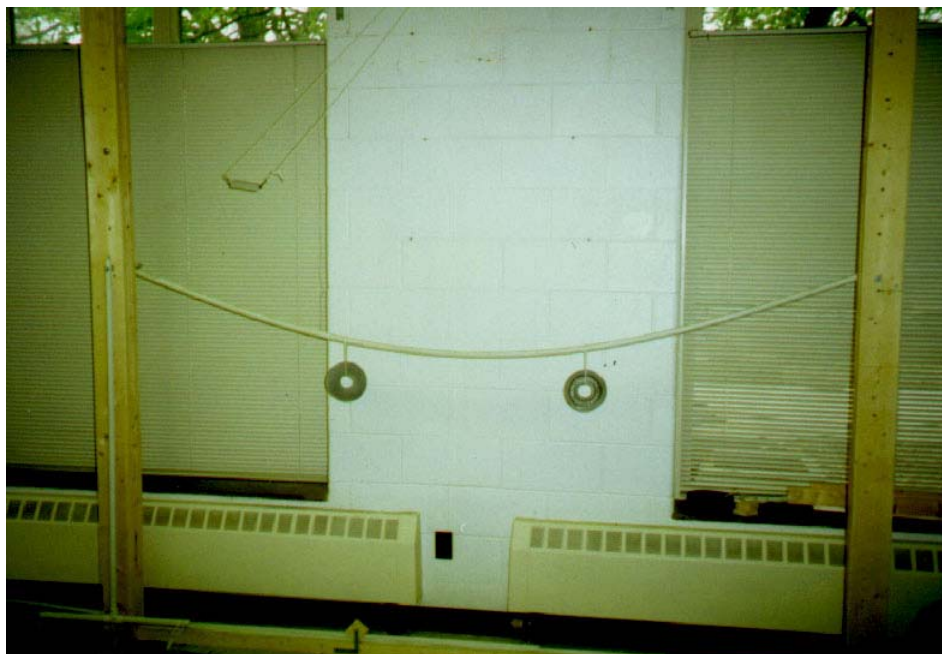


Lab 3: At the top of this member is a roller connection. At the bottom is a pin.

Lab 5 - Shear, Moment and Bending



Two students demonstrate moment in Lab 5. The “beam” is made out of PVC pipe. There are actually two PVC beams: one behind, to which a moment is being imparted by two hanging weights, and one in front, which is cut in half so that students can measure the amount of force required to duplicate the curve of the pipe behind it.



Lab 5: Simple moment demonstration.

Appendix D: Materials Needed and Materials Cost

Main Frame Structure:

| Material | Use | Quantity | Unit | Cost | Total |
|---------------------------------------|--------------------------------|----------|------|------|--------------|
| Frame Structure | | | | | |
| 2x6x8' #2 Douglas Fur | Main Frame Structure | 6 | Each | 5.60 | 33.60 |
| 1"x6" Corner Braces | Anchor to Floor, Ceiling, Wall | 6 | Each | 2.99 | 17.94 |
| 1"x6" Flat Braces | Corner Reinforcement | 4 | Each | 2.97 | 11.88 |
| 3/8"x6" Carriage Bolts, Washers, Nuts | Fasteners | 12 | Each | 0.99 | 11.88 |
| | | | | | 75.30 |

Week 1:

| Material | Use | Quantity | Unit | Cost | Total |
|---|-------------------------|----------|------|-------|---------------|
| Lab 1: Hanging Weights | | | | | |
| 3/4"x12" Long Threaded Metal Pipe | Hold Weights | 1 | Each | 1.88 | 1.88 |
| 3/4" Floor Flange | Hold Weights on Pipe | 1 | Each | 2.47 | 2.47 |
| Weights | | 100 | Lbs | 0.60 | 60.00 |
| 1/4" Nylon Rope | Hang Weights | 100 | Ft | 0.12 | 12.00 |
| 1/4" Rope Pulley | | 1 | Each | 3.97 | 3.97 |
| 200 Lb. Capacity Spring-Scales (From Farm Supply Store) | | 4 | Each | 44.95 | 179.8 |
| 3/8"x6" Carriage Bolts, Washers, Nuts | Hang Weights from Frame | 2 | Each | 0.99 | 1.98 |
| | | | | | 262.10 |

Week 2:

Lab 1.3-5: Related Exercises

- Equilibrium and Resultant Experiments - Small spring scale and mass units kit
- Equilibrium and Resultant Experiments - Possibly a tug-of-war set-up with large springs integral to ropes
- Pythagorean Theorem demonstration kit

Week 3:

| Material | Use | Quantity | Unit | Cost | Total |
|---------------------------------------|-------------------------------------|----------|-----------|--------|---------------|
| Lab 2: Seesaw | | | | | |
| 2x4x8' #2 Douglas Fur | Support Outside of Sesaw | 1 | Each | 2.50 | 2.50 |
| 4x4x8' | Seesaw | 1 | Each | 6.50 | 6.50 |
| 1" Round Wood Pegs | Secure Weights in Place | 3 | LF | 1.33 | 3.99 |
| Weights (Already Purchased for Lab 1) | | 50 | Lbs | 0.00 | 0.00 |
| #6 Screw Hooks | Hook Rope to Measure Force | 1 | Box of 15 | 3.98 | 3.98 |
| Small Spring Scale (Scientific Type) | Measure Force | 2 | Each | 35.00 | 70.00 |
| 3/16" Nylon Rope | Measure Force | 1 | 50' Pack | 4.98 | 4.98 |
| 3/8"x6" Bolt, Washer, Nut | Seesaw Fulcrum | 1 | Each | 0.99 | 0.99 |
| Electronic Level | Measure Seesaw Angle | 1 | Each | 175.00 | 175.00 |
| 25' Measuring Tape | Measure Weight Distance From Center | 1 | Each | 4.96 | 4.96 |
| | | | | | 272.90 |

Week 4:

Lab 2.2-4: Related Exercises

- Moments and Couples – Wrench with extension, Lug Wrench, board with nut secured to it
- Equilibrium experiment – Rope with large integral spring, single pulley secured to the floor

Week 5:

| Material | Use | Quantity | Unit | Cost | Total |
|--|--|----------|----------|------|--------------|
| Lab 3: Equilibrium, Lab 4: Frames | | | | | |
| 1x4x6' #2 Douglas Fir | Frame That Hangs Off of Main Structure | 2 | Each | 2.20 | 4.40 |
| 2 1/2"x3/8" Flat Corner Braces | Act as Hinge, Pin, Roller Member | 4 | Each | 1.97 | 7.88 |
| 3/8" "Spring Link" (Metal Beaner) | Attach Rope to Frame or Scale | 2 | Each | 2.44 | 4.88 |
| 3/16" Nylon Rope (Already purchased for lab 2) | Tension Members | 1 | 50' Pack | 0.00 | 0.00 |
| Small Spring Scale (Scientific Type) (Already Purchased for Lab 2) | Measure Force | 2 | Each | 0.00 | 0.00 |
| Weights (Already purchased for Lab 1) | Anchor Small Frame to Main | 50 | Lbs | 0.00 | 0.00 |
| 3/8"x6" Carriage Bolts, Washers, Nuts | Frame Structure | 2 | Each | 0.99 | 1.98 |
| 1/4"x2" Bolts, Nuts, Washer | Pivot Points of Frame | 4 | Each | 0.49 | 1.96 |
| | | | | | 21.10 |

- Small, table sets (one for each group) of a simple support, three rollers, and three pins secured to the table or to a base.
- Single Fixed set to intro concept of fixed connection in a controlled environment

Lab 3.2: Beam with Weight Hanging from Three Points

- Beam supported at wall by a pin and at it's counterpoint by a rope with a spring scale construction (make it big - like out of whole two-by fours)

Week 6:

| Material | Use | Quantity | Unit | Cost | Total |
|---|-------------------------------------|----------|----------|------|-------------|
| Lab 5: Shear, Moment, and Bending | | | | | |
| 3/4" PVC Pipe | Act as Beam | 12 | LF | 0.22 | 2.64 |
| 3/4" PVC "T" Joint | Act as Moment Arm | 1 | Each | 0.25 | 0.25 |
| 3/16" Nylon Rope (Already Purchased for Lab 2) | Hang Weights | 1 | 50' Pack | 0 | 0 |
| Small spring scales (scientific type) (Already Purchased for Lab 2) | Measure Force | 2 | Each | 0 | 0 |
| 3/8"x6" Carriage Bolts, Washers, Nuts | Anchor PVC "Beam" to Main Structure | 2 | Each | 0.99 | 1.98 |
| | | | | | 4.87 |

| | |
|--------------------------------------|---------------|
| TOTAL MATERIALS COST OF CLASS | 636.27 |
|--------------------------------------|---------------|

VITA

Christopher G. Alcorn

1208 Monroe Street, Denver, CO 80206

Phone: 303-377-0926 Email: cgalcorn@mindspring.com

Overview:

Design-Build Professional with five years national developer experience.

- Commercial office, light industrial, and retail experience (Core/Shell and T.I.).
- Solely responsible for projects up to twelve million dollars in size.
- Undergraduate Degree in Architecture, Masters' Degree in Construction Management.
- Exceptional computer skills.

Education:

Master of Science in Building Construction Management, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Graduate QCA: 3.75/4.0

Bachelor of Architecture, Five Year Professional Degree, May 1997, Virginia Polytechnic Institute and State University

VPI&SU European Studies Center for Architecture, Riva San Vitale Switzerland (Fall 1995)

Undergraduate QCA: 3.57/4.0 overall (Cum Laude)

Major Rank: 14 of 272

Experience:

May 2003 - Present:

Company: Panattoni Construction, *Denver, CO*

Position: Project Manager

Responsibilities: Responsible for management of the entire construction process, from Marketing to clients and conceptual estimating through project completion. Presently involved in conceptual estimates for 500,000 sf retail center as well as various light industrial and commercial office build-to-suits.

August 1998 – May 2003:

Company: Opus Northwest, LLC, *Denver, CO*

Position: Project Manager

Projects and Accomplishments:

- August 2002 – Present:
 - **Project Name:** Compark Lot 3, Building A. Parker, CO.
 - **Project Description:** 68,000 SF, One-Story (Thirty-Two Foot Clear Height) Light Industrial Core /Shell Building.
 - **Construction Type:** Tilt-Wall Enclosure. Joist and Deck Structure.
 - **Notes:** Solely responsible for budget, scope, schedule and quality (in conjunction with project superintendent) from budget estimate through project closeout and warranty. This includes preliminary estimating, bidding, contract writing, subcontractor and design-consultant management, cost management, payment application, and customer service to the client throughout the construction and warranty period.
- April 2001 – August 2002:
 - **Project Name:** McData Headquarters Building. Broomfield, CO.
 - **Project Description:** 168,000 SF, 4-Story, Commercial Office Build-To-Suit Core /Shell.
 - **Construction Type:** Precast Structure and Enclosure. Central Plant HVAC System.

- **Notes:** Solely responsible as above for the core/shell portion of this project. Worked closely with other team-members responsible for site-work and tenant finish. One hundred percent of time spent on site.
- October 2000 – April 2001:
 - **Project Name:** Opus Plaza II at Highlands Ranch. Douglas County, CO.
 - **Project Description:** 83,000 SF, Three-Story, Speculative Commercial Office Shell Building
 - **Construction Type:** Precast Structure and Enclosure. Difficult Storm Sewer Coordination.
 - **Notes:** Solely responsible as above.
- June 2000 – October 2000:
 - **Project Name:** Buildings J, K, and L at Lakewood City Commons. Lakewood, CO.
 - **Project Description:** Three 7,000 SF, One-Story, Speculative Core/Shell Retail buildings.
 - **Construction Type:** Steel Stud Framing. Joist and Deck. EIFS and Block Enclosure.
 - **Notes:** Solely responsible as above.
- April 1999 – June 2000:
 - **Project Name:** Tenant Finish Work at Opus Plaza Two at Highlands Ranch and 361 Centennial Valley. Englewood, CO and Louisville, CO.
 - **Project Description:** Approximately Twenty Tenant Finish interior projects ranging from 5,000 SF to 35,000 SF.
 - **Construction Type:** Interiors.
 - **Notes:** Solely responsible as above.
- August 1998 – April 1999:
 - **Project Name:** Lakewood City Commons Municipal Buildings. Lakewood, CO.
 - **Project Description:** 225,000 SF, Three-Story, Build-To-Suit Municipal Offices and Cultural Center for the City of Lakewood.
 - **Construction Type:** Precast Structure and Enclosure. Deep Excavation at Cultural Center.
 - **Position:** Associate Project Manager /Field Engineer.
 - **Notes:** Involved in scheduling; materials procurement; subcontract qualification; subcontract writing; field quality and safety via field walks; owner/subcontractor meetings and subcontractor coordination under the direction of project manager.
- Highly involved in creation of office processes and procedures – getting better at what we do every day is one of my main drives.
- OSHA ten-hour certified. OSHA Competent person for fall protection, Subpart R, personal protective equipment, respirator safety, crane safety, excavation safety, and scaffold safety.
- Eligible for Class B General Contractors license, Colorado (presently working on acquiring).

August 1997 – August 1998:

Company: Virginia Tech Department of Building Construction, *Blacksburg, VA*

Position: Research Assistant and Teaching Assistant

Project: Write & teach “Hands-On-Statics” class (Extensive research of teaching and learning involved)

May - August 1997:

Company: Opus East, LLC, *Bethesda, MD*

Position: Associate Project Manager

May - August 1996:

Company: Damianos + Anthony Architects, *Pittsburgh, PA*

Position: Intern Architect

**Computer
Expertise:**

PC and Macintosh, Primavera Project Schedule, Microsoft Project, AutoCAD, Timberline, WinEst, Prolog Project Manager, Construction Project Manager, Microsoft Powerpoint, Word Excel, Word Perfect, QuarkXpress, Aldus Pagemaker, Adobe Photoshop.