# Enhancement of an Introductory Course in Dynamics and Machine Elements

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Abstract

This paper discusses improvements which were made to an introductory dynamics and machine elements course at Penn State Altoona, in Altoona, Pennsylvania, in the Fall of 1998. The improvements included implementing two team design projects, one on kinematics and the other incorporating kinetics and machine elements as well; inclusion of peer assessment of the design projects; balanced incorporation of graphical, analytical and design software-based analysis and synthesis throughout the course; involvement by an engineering technology student intern to foster team collaboration; implementation of an industrial topic thread through the course; and a pre-team-formation assessment of background and skills of students, followed by team selection based on the assessment. The outcome of the course improvements included improved student morale and interest level, and higher student evaluations.

Course Overview

Mechanical Engineering Technology 206, *Dynamics and Machine Elements,* is a sophomore-level course in kinematics and kinetics as applied to mechanism and machine design. It is delivered each Fall semester to Mechanical Engineering Technology (Associate Degree) students at Penn State Altoona. The course develops an understanding of the application of mathematics to the design of mechanisms and machines to perform certain tasks (*synthesis*, or creation of new mechanisms, and *analysis*, of existing mechanisms), and provides an introduction to complex machine elements such as gears and cams. The course has traditionally been taught with side-by-side use of analytical techniques and graphical techniques, with the students also building physical models of mechanisms. Mechanical drawing was complementary to the analytical techniques, and the models gave a connection to physical reality. The course text [Norton] included simulation software (Windows-based), but the software was used only sparingly, and only in parts of the course.

The course as traditionally delivered was judged by the instructor to be inadequate in some ways, including the fact that the broad scope was difficult to cover adequately, the students had some difficulty visualizing the connection between the mathematics and the functions of mechanisms with which they had limited exposure, and had a limited ability to quickly visualize and physically model the mechanisms.

## Project Description

In Fall Semester 1998, a grant was awarded by the Penn State University Schreyer Institute for Innovation in Learning to help reduce these limitations of the course as it is traditionally taught.

Two areas were focused on:

- Developing a tight interlacing, throughout the course, of

1. analytical software, which provides for visualization as well as analysis and synthesis;
2. mathematical (analytical) techniques;
3. hands-on experimentation;
4. model-building; and
5. graphical (mechanical drawing) techniques; and

- Establishment of project-based team collaborations for peer support throughout the course.

Improvements in the first area were directed at providing for a much more extensive use of the simulation software provided with the text. The software allows students to design simple mechanisms and machines and immediately visualize the impact of design changes. An example of a software screen, for link length and position input, is shown in Figure 1. The program is relatively easy to learn and use, and relates clearly to analytical concepts described in the text, so it avoids the so-called "black-box syndrome," where "students will not understand or perhaps even care what it [the software] is doing." [Wankat, p.156]

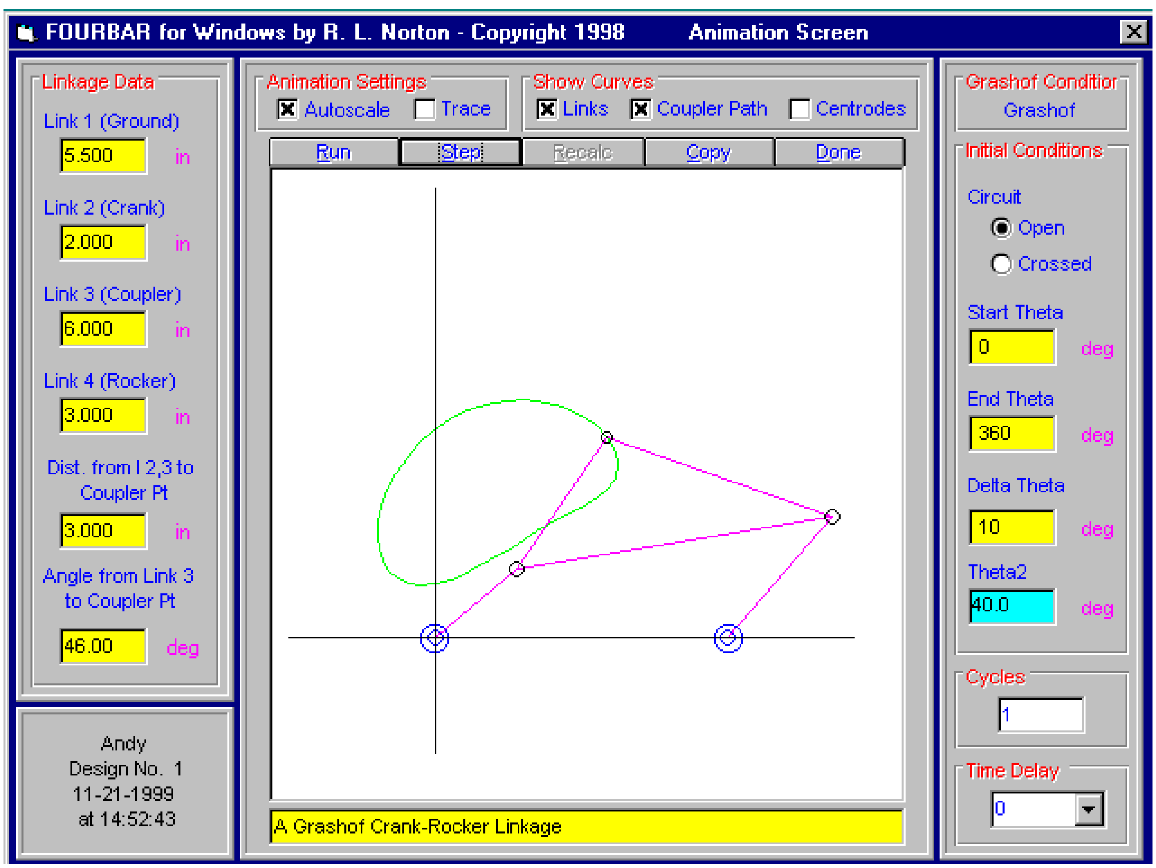



Figure 1: Simulation Software

In addition to the increased emphasis on the software, a sequence of classes in a modular arrangement was developed which would address a concept in a lecture format (50 minutes, two days a week), followed with a laboratory (2 hours per week) in which analytical software and/or graphical techniques are used to develop and visualize the problem solution. For instance, a lecture might cover graphical synthesis for two positions. The laboratory, early the next week, has the students perform graphical analysis in a drafting room. In the next lecture, the laboratory experience is reinforced and a new topic introduced (three-position graphical synthesis, for instance), to be covered more fully in the following lecture, and so on. Homework (assigned weekly) is given in analytical, graphical and software solutions to problems, pointing out the relationship between and limitations of all three.

The second area, establishment of project-based team collaborations, was targeted to help alleviate both the prior broad scope and real-world experience limitations of the course, with two projects assigned in which teams would address mechanism and machine design problems. The first project is limited to kinematics, where the masses of the parts of a mechanism are not considered, and hence forces are not involved. Kinematics involves a geometric solution to a motion problem, and is followed in design by kinetics, which introduces real parts with mass, and real forces and torques. The second project involves adding masses and designing for forces and torques, as well as including complicated machine elements such as gears.

The former course outline was modified to include better integrated laboratory experiences and two class projects, using the same text which was used in earlier deliveries, which included simulation software. The general outline for the course includes the topics, in sequence:

1. Introduction to the Course
2. Fundamentals of Kinematics - Degrees of Freedom, Links and Joints
3. Degrees of Freedom; Mechanisms and Structures; Number Synthesis
4. Transformation; Inversion; The Grashof Condition; Practical Considerations

5. Introduction to Graphical Synthesis; Function, Path and Motion Generation
6. Limiting Conditions; Dimensional Synthesis
7. Quick-Return Mechanisms; Coupler Curves
8. Cognates, Straight-Line Mechanisms; Dwell
9. Introduction to Position Analysis; Complex Number Representation
10. Position Analysis of Linkages
11. Introduction to Synthesis; Two-Position Motion Generation
12. Three-Position Motion Generation
13. Pivot Location Specification; Center-Point and Center-Point Circles
14. Four- and Five-Point Synthesis; Other Synthesis Techniques
15. Introduction to Velocity Analysis; Graphical Velocity Analysis
16. Analytical Velocity Analysis
17. Graphical Acceleration Analysis
18. Analytical Acceleration Analysis
19. Introduction to Dynamics; Newton's Law; Mass Moments
20. Center of Percussion; Models; Energy Methods
21. Dynamic Force Analysis - Newtonian Solution and Analysis
22. Law of Gearing; Nomenclature, Interference and Undercutting
23. Types of Gears; Gear Trains
24. Shaking Forces; Energy Methods; Flywheels
25. Static and Dynamic Balancing
26. Basic Engine Dynamics
27. Cam Dynamics
28. Cam Polynomial Functions; Critical Path Motion
29. Sizing the Cam; Manufacturing; Practical Design Considerations

These topics roughly organize the course into three sections: Kinematics; Kinetics; and Machine Elements.

Grading consists of:

1. Two in-semester exams - 10% each
2. Homework - 15%
3. Quizzes - 15% of the class grade
4. Mid-term project - 20%

5. Final project - 25%
6. Class Participation - 5%

Apart from a better-sequenced lecture/lab format, much of the effort in course enhancement was devoted to fostering a collaborative environment and on student evaluations and assessments. The Schreyer Institute grant included support for a project intern, who was responsible in the first year for supporting team experiences. For instance, early in the first year, the intern (a junior in a four-year electromechanical engineering technology program at Penn State Altoona) met with the student teams and provided them with an overview of team roles and responsibilities.

The first step in developing the class teams involves developing and delivering an instrument early in the semester to assess the skill set of the class. The instrument (attached in Appendix A) includes questions relating to four aptitude areas: graphics (Question 4), analysis (Questions 2 and 3), mechanical aptitude (Questions 1 and 3) and communications (Questions 5, 6 and 7). Each student's responses to these questions is evaluated and four teams selected (two with four members, two with five members) to represent as heterogeneous a group across the four evaluation areas as possible. In other words, each team is formed as much as possible with one member with strong mechanical aptitude, another member with strong drawing skills, and so forth. The students are not informed of their strengths or potential roles on the team, and the teams formed at the semester midpoint are carried through to the final project. Teams are required to work together only on the two projects, although they seem to retain some cohesiveness in laboratory exercises from time to time.

Teams are identified and assigned the first project, a kinematic design problem involving three-position synthesis (attached in Appendix B) at about the fifth week of the semester. The project is due at approximately the mid-point of the semester. The project assignment includes graphical synthesis, software analysis and synthesis and generation of a report and a presentation in-class of the project by each team at the semester mid-point. At this time also a mid-semester evaluation of the course (Appendix C) by the students is delivered. At about the eleventh week of the semester, the final project is announced to the class, and the same teams are assigned to carry out a kinetic design to complete the machine (attached in Appendix D). Similar requirements as in the mid-semester project are imposed: graphics, software analysis, a report and presentation and completion/improvement of the physical model. Both projects include the same peer assessment instruments, counting for 25% of the grade on the projects. The final project is due on the last day of class.

Projects are graded with a weighting of 25 points (out of 100) for technical correctness, 20 points for the report, 20 points for the presentation, 10 points for the model and 25 points for the peer assessment. Each student receives the same score for 75% of the project grade as the rest of the team, and varying peer scores for the remaining 25%. Project peer evaluations, for the first section (statements) are scored by adding all the possible maximum scores in each team, and counting the individual scores for each team member. For instance, the maximum total score (on a scale from 1 to 5) for a four-member team for each statement is 20 points, giving 180 points for all statements in the first part of the evaluation. In the second part (numerical rankings and qualitative assessment), the scores for each student from all the team members are added together and the total subtracted from the sum of the maximum number of points possible and the number of team members. This will ensure that a student who has been ranked first in all categories will receive the total number of possible points. For a four-person team, the maximum number of points is 43, and for a five-member team the maximum number of points is 70. The weighting of the second portion of the peer assessment is thus less than that for the first portion. Students who fail to turn in peer assessments are penalized by losing their own scores in the evaluation.

Results

The course has been delivered under this modified outline for two successive fall semesters (1998 and 1999), to a total of 47 students. The outcome of the course following the improvements has been found to be more positive than earlier deliveries of the course in the traditional manner. From the instructor's perspective, the course seems to flow more smoothly from component to component, and seems to be better integrated overall, content-wise. The software seems to well-connect the analyses with real-world visualization, and greatly assists the students with problem solution. The students seem to better grasp overall the more-integrated material in the course, with final grades in the first year after adoption higher than in earlier deliveries. Morale and enthusiasm seem higher as well: the students often engage in lively discussions in class relating to the projects and to other real-world situations, especially in the second half of the semester. The results of the mid-semester project evaluation from the first year (attached in Appendix E). The ratings from the Student Review of Teaching Effectiveness (SRTE), which are administered in computer-gradable form at Penn State University, for the entire course for the first year seem to support general positive impressions by the instructor of student approval: the two key categories, overall quality of the course and overall quality of the instructor, received 6.28/7.00 and 6.71/7.00 ratings, respectively, from the 14 students responding from a class of 18. This can be compared with the SRTE ratings from the year before the improvements were made, 1997: a course rating of 6.00/7.00 and an instructor rating of 6.28/7.00. Informal discussions with the class during the last few days of the first year of offering (1998) also indicated appreciation for the new class format and satisfaction with the class and the material covered and learned.

In the first year, the second project was completed technically very well by the teams, and a definite improvement in the professionalism of the second project as opposed to the first was noted, even though the second project was much more difficult, and deliberately highlighted limitations of the software and analytical tools available to the teams. The teams were able to come to grip with these limitations well in the final reports, showing good grasp of the subject matter. In addition, all teams made team presentations in the second project, while two of the teams had single spokespersons in the first project. In addition, the second presentations were much more comprehensive and professional. Peer assessments were shared with students on a composite basis, and were uniformly high on both projects. Only a few students (those who were, even to their peers, clearly not contributing substantially to the project) received less than very positive peer reviews; some adjustment to spread out the ratings is probably in order, possibly by making the assessments more of a zero-sum proposition to some extent. The evaluation already includes a ranking by all the members, which, in the future, may be weighted more heavily to give a better indication of team member contributions to the project.

The team collaboration efforts in the first year, supported by an intern with little experience in this area, were in addition to the adjustment to a new sequencing of the course lectures and labs. The additional effort required to modify lesson plans and stay on top of a much more tightly sequenced course produced some time burden on the instructor. The intern also had difficulty meeting with project teams owing to his own classes conflicting with many times in which project teams were available to meet. If there was a less-than-satisfactory aspect of the project, it was in the ability of the intern to be as effective as possible, given his other course commitments and lack of teaching and team building expertise, although the workshops at the Institute and personal attention from the instructor certainly seemed to be of value. The course would have benefited from an intern with perhaps less technical expertise in the subject matter, but more experience and training in team efforts and educational theory, and better able to contribute to course improvements from the very beginning. An intern from the Penn State College of Education, given the emphases planned for the intern's efforts, would perhaps have been more appropriate than the engineering technology student who served as intern.

The classes were held in four separate rooms, owing to the requirements for mechanical drawing equipment, computer terminals and lecture space, which made continuity difficult at times, although the variety of settings may have been stimulating as well. There were also some administrative difficulties with scheduling these many classrooms. In the

Some difficulties were also encountered with the greatly increased use of the software, which required some considerable effort to install and maintain on the computer network at the campus. The version of the software used in the past enabled the programs to be run directly from the diskette included with the text.

<u>Future Plans</u>

Now that a better integration of lecture and lab materials exists alongside a more comprehensive sequencing, and some evaluation and assessment instruments have been developed, the course will be delivered in the future with the little change to the innovations made. The instructor may pursue the use of commercial design software (Pro/ENGINEER, for instance, is available now at the campus), at least for comparison with the course simulation software (which, in the areas of licensing and robustness is adequate as course software but is not commercially viable), to better prepare the students for tools they may use in the workplace. Another area in which some changes might be made is in evaluation by the students. A final evaluation, to augment the SRTEs and track changes in perceptions between the mid-semester and final projects, will likely be developed and delivered in the future. More revealing peer assessments may also be explored, as noted previously.

The course has excellent potential, now that considerable effort has been spent on improved content integration, software support and team collaboration, for continued success in student retention, morale and performance.

Summary

In Fall Semester, 1998 enhancements were made to a course in machine design at Penn State Altoona, Mechanical Engineering Technology 206, *Dynamics and Machine Elements*. The course deals with the design of mechanisms and machines through mathematical modeling. Improvements included tightening integration between simulation software, graphical analysis and mathematical approaches to the design of mechanisms and machines; and development of student team collaborations around two class projects. Extensive use of the software throughout the course, and a focus on team projects (which included peer assessment) produced motivated and engaged classes since adoption of the new course format, who acquired a good grasp of the many concepts in this broad offering. Student satisfaction and morale have been higher, as evidenced by student evaluations and demeanor, and the course runs more smoothly, with higher achievement of mastery and integration of the material by the students, than in previous offerings of the course.

*Appendix A: Team Skills Assessment Instrument*

**ME T 206**

Team Background Survey

In order to select teams with members with varying backgrounds and skills, we'd like to know more about you. Please provide responses to the following questions, to the best of your ability. Please make sure you put your name on all the pages.

1. In an automobile, what function does the transmission serve?

2. If you have a variable z which is a function of BOTH variables x and y, and variables x and y are independent of each other, sketch how you can represent these variables below.

3. If you're sitting outside, where the ground is uneven, will it be better to have a three-legged or four-legged stool? Why?

4. Sketch your wristwatch in the space below.

5. In a few sentences, write why you want to become an engineer.

6. How old are you?

7. If you had to choose between a career in which you would make a lot of money, but your work would be useless and ignored, or a career in which you made very little money, but your work would be very valuable and would live on long after you, which would you choose, and why?

*Appendix B:  Mid-Semester Project*

**ME T 206**

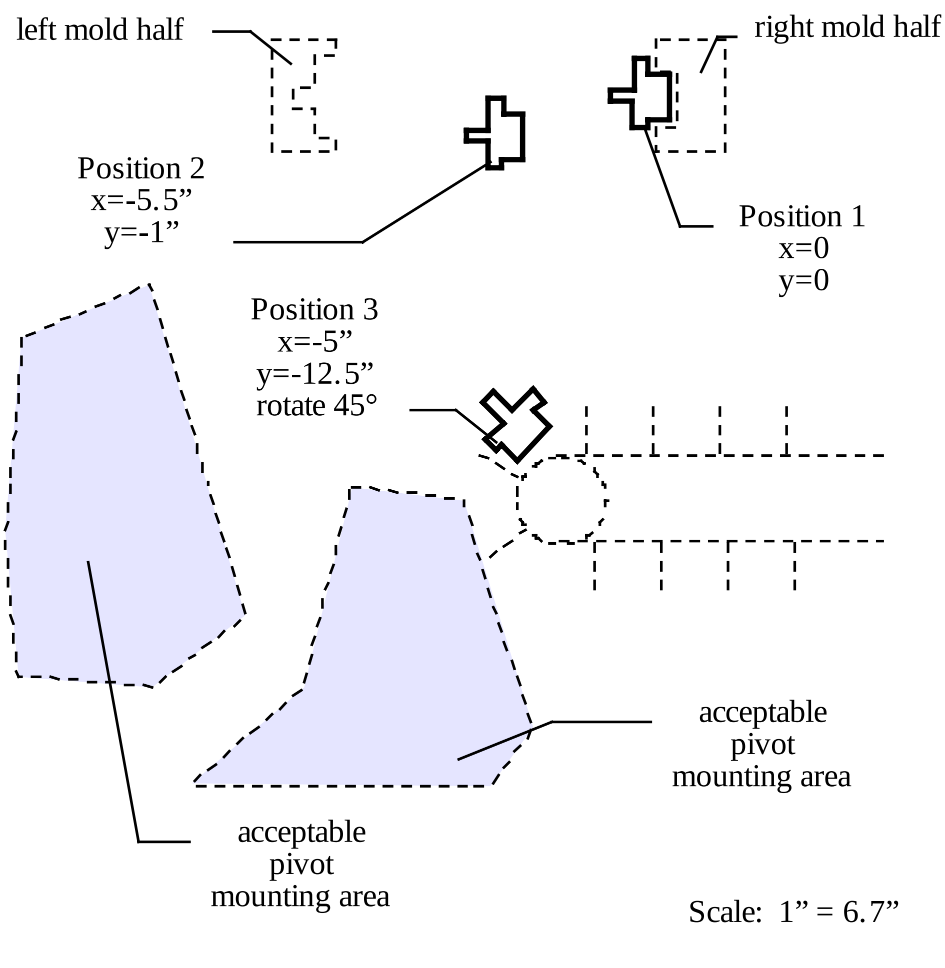
Fall Semester 1999

Mid-Term Project

14 October 1999

*DUE:  Friday, 29 October 1999*

This team effort involves the kinematic design of a mechanism to remove castings from a mold, and place them on a conveyor belt, as seen below.  When the mold separates, the mechanism removes a casting by gripping a protrusion on the part, then swings the casting out and down to an awaiting conveyor bin.  As the next casting is molded, the mechanism returns to the mold to begin the cycle again.



Your mechanism must make the three positions indicated. Design a fourbar with coupler output to achieve the three positions indicated sequentially, with a driver dyad to achieve the range of motion with a timing ratio of 1.4 to quick-forward to the conveyor from the mold. *All fixed pivots can only be placed in the shaded areas.*

Your team's assignment involves:

1. Using FOURBAR to synthesize the mechanism using selected pivots in the allowed zones.

2. Graphically synthesizing a fourbar with your defined pivots.

3. Constructing a working foamcore model of the complete mechanism, including the driver dyad.

4. Writing a report on the design and design process, to be turned in.

5. Making an oral presentation on the project in class.

The products of your team will include:

1) a report containing the design, including

b. a narrative including
   1. the design process followed
   2. description of the dimensions and pivot mounting locations of the mechanism
   3. a calculation of minimum and maximum transmission angles of the driver dyad
   4. an outline of the contributions from each team member

b. an appendix with all relevant sketches and drawings of the mechanism

c. an appendix with computer output demonstrating the correct functioning of the mechanism

2) a ten-minute (maximum) presentation by all team members on your team's design and the design process you followed.

3) an accurate, working model of the mechanism, correctly jointed and grounded, and showing the correct sequential positions of the mechanism in the industrial environment.

Your grade will be a team grade on the products above which will include a peer assessment. The report and presentations will be due on the project due date, Friday, October 29th, 1999, in class. *No* late projects will be accepted. This project counts for 20% of your course grade.

*Appendix C: Peer Evaluation Instrument*

**ME T 206**

Midterm Project Peer Evaluation

**Due: Tuesday, 2 November 1999 in class**

This midterm project peer evaluation constitutes 25% of the grade you will receive on the midterm project.

Please answer the following list of statements about yourself and each of your group members. Assign a rating of 1 to 5 for each statement for each group member, *including yourself*. ***Your individual evaluations will be held strictly confidential.***

Statement:

1. Was dependable in attending group meetings
2. Willingly accepted tasks.
3. Contributed positively to group discussions
4. Completed work on time or made suitable alternative arrangements.
5. Helped others with their work when needed.
6. Did work accurately and completely.
7. Contributed a fair share to the written report.
8. Worked well with other group members.
9. Overall, was a valuable member of the group.

Rating: 5-strongly agree 4-agree 3-neutral 2-disagree 1-strongly disagree

Statement

| Member | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
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Now, using the results above as a guide, rank each group member, *including yourself*, and give a qualitative assessment, using the numbers below. Feel free to list any comments you have about your fellow group members and about yourself on the back of this page.

| Numerical Rank: | 5 Members | 4 members |
|---|---|---|
| | 1 - highest | 1 - highest |
| | 5 - lowest | 4 - lowest |

Qualitative Assessment:

1 - Excellent
2 - Very Good
3 - Good
4 - Adequate
5 - Somewhat Deficient
6 - Poor
7 - No Meaningful Contribution

| Member | Numerical Rank | Qualitative Assessment |
|---|---|---|
| | | |
| | | |
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*Appendix D: Project Student Evaluation Questions*

*Responses included scoring values as follows:*

*1-disagree strongly 2-disagree somewhat 3-neutral 4-agree somewhat 5-agree strongly*

1. I enjoyed the team mid-term project in this course
2. I feel that my participation in the team project will benefit me in the future.
3. The team project in this course was challenging.
4. The learning objectives of the project were clear.
5. I felt that the work I put into the team project helped me learn the material in the course.
6. I believe that working in teams enhances my learning ability.
7. Working on the team project has enhanced my skills as a team member.
8. I feel that working on the team project has enhanced my ability to construct persuasive arguments.
9. As a result of working on the team project in this course, I feel that I am more confident in my ability to analyze and evaluate arguments advanced by others.
10. The collaborative project helped in my reading and understanding the course text.
11. I learned a great deal in this course.
12. Working in the team project has increased my comfort level in interacting with others.
13. The team project has increased my cooperation skills.
14. I feel I am able to handle conflicts better as a result of the project.
15. The professor in this course was very helpful with respect to the team project.
16. The undergraduate intern in this course was very helpful with respect to the team project.
17. The blend of graphics, computer and physical modeling in the project was helpful to my understanding of the course material.

*Appendix E: Summary of Mid-Term Project Student Evaluations (1998)*

*The scoring by seventeen of the eighteen students in the first year class is summarized as follows, by question. The scoring values were:*

*1-disagree strongly   2-disagree somewhat   3-neutral   4-agree somewhat   5-agree strongly*

| Question | Average Score |
|---|---|
| 1. I enjoyed the team mid-term project in this course | 3.70 |
| 2. I feel that my participation in the team project will benefit me in the future. | 4.23 |
| 3. The team project in this course was challenging. | 4.88 |
| 4. The learning objectives of the project were clear. | 4.06 |
| 5. I felt that the work I put into the team project helped me learn the material in the course. | 4.18 |
| 6. I believe that working in teams enhances my learning ability. | 4.24 |
| 7. Working on the team project has enhanced my skills as a team member. | 4.35 |
| 8. I feel that working on the team project has enhanced my ability to construct persuasive arguments. | 3.82 |

| | |
|---|---|
| 9. As a result of working on the team project in this course, I feel that I am more confident in my ability to analyze and evaluate arguments advanced by others. | 3.71 |
| 10. The collaborative project helped in my reading and understanding the course text. | 3.82 |
| 11. I learned a great deal in this course. | 4.29 |
| 12. Working in the team project has increased my comfort level in interacting with others. | 3.94 |
| 13. The team project has increased my cooperation skills. | 3.94** |
| 14. I feel I am able to handle conflicts better as a result of the project. | 3.94 |
| 15. The professor in this course was very helpful with respect to the team project. | 4.47 |
| 16. The undergraduate intern in this course was very helpful with respect to the team project. | 2.35 |
| 17. The blend of graphics, computer and physical modeling in the project was helpful to my understanding of the course material. | 4.24 |

** The number of responses was 16 for this question only.

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