Practical Application of FEA in Freshman Design using Senior Student Mentors

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Abstract

This paper presents the results of three years of work on an innovative means of addressing several important aspects of the Freshman Design course (EGR 101). In an effort to address the balance of teaching engineering design and decision skills with new technical skills, freshman design teams were paired with senior engineering students taking the Finite Element Analysis course (MEE405). Data were collected using surveys during and following the multi-week project to assess the effectiveness of the interactions and the acquisition of technical skills by the freshmen and the development of applied leadership skills by the seniors.

Key anticipated benefits of the interaction for the freshmen were contact with upperclassmen, exposure to modern engineering software tools and analysis techniques, practical experience in fabricating engineered products from drawings, realistic application of engineering design and decision tools and theories, and enhanced oral and written communication skills. For the seniors, the anticipated benefits were practical practice in leadership and teamwork and application of theory to practical design problems.

Most of these benefits were realized at some level of success, including the identification of some senior students who had not yet developed independent leadership skills Additional unanticipated benefits for the freshmen included a basic understanding of Mohr's circle and stress transformations one year prior to formal introduction to those topics. The seniors were also forced to integrate their knowledge of FEA, failure mechanisms, and the results of mechanical testing.

Introduction

The Introduction to Engineering class (EGR101) at Geneva College is a design and decision-making oriented course which is generally taken during a student's first semester in college. The catalog description provides a clear, if terse, summary of the objectives.

> Introduction to engineering design and decision-making. Christian world-view applied to engineering. Use of logic, experimental design and design criteria. Project oriented.

The class meets for lecture two hours per week and for a weekly three hour laboratory period.

In an audit of departmental objectives[1] using the Levels of Learning (LoL) defined by Bellamy and McNeill[2,3] it was determined that two of the objectives receiving special emphasis in EGR101 were

- Objective 3. To train students in the design process.
- Objective 5. To train students in teamwork and leadership skills.

Three different approaches to design experiences in EGR101 which attempt to help guide students to the level of Application[2,3] for these objectives have been used during the 10 years the course has existed.

1. Use of three separate projects of approximately 4 weeks duration each to expose students to the 3 engineering disciplines taught at Geneva (civil, electrical, and mechanical). Evaluation was primarily based on weekly meetings with the design teams and on measurements of performance for each design.
2. Use of mechanical dissection/reverse engineering to teach basic sketching, problem-solving, and written communication skills, followed by a single design project of approximately 7 weeks in duration. For this project, students were required to proceed through all stages of a formal design process[4] and document this in written and oral reports, as well as to produce and test a final product. Freshman teams were paired with senior students in the Finite Element Analysis (FEA) course, MEE405, for the analytical portion of this project.
3. Use of a single semester-long design project with an integrated text[5].

This report focuses on the project portion of the second approach noted above, carried out during the fall semesters of 1998-2000. The EGR101 classes were composed mainly of freshman and transfer students enrolled in the BSE program, with 1 or 2 non-engineering students per year. Class size ranged from 26 to 36 students. The MEE405 classes ranged in size from 5 to 10 and were all senior students in the mechanical engineering concentration.

Project Objectives

Three of the objectives[1] of the Geneva College engineering program are:

- To train students in the design process, so that they may formulate problems, select appropriate design criteria, generate creative ideas to achieve workable goals, analyze proposed solutions appropriately and accurately, make design decisions with informed judgment and with a view to implementation, and communicate their designs and decision processes effectively, both orally and in writing.
- To train students in teamwork and leadership skills, so that they can conduct themselves in the work place according to Biblical principles, function well in project teams, communicate honestly and effectively, plan, schedule, and accomplish tasks effectively, and with experience assume increasing levels of responsibility.
- To familiarize students with state-of-the-art engineering equipment and methods, so that they are able to design appropriate experiments including data acquisition and analysis, to select and specify appropriate laboratory procedures, to utilize and develop appropriate software tools, and to interpret computer output wisely.

The project described here results from an effort to provide a non-trivial design experience for freshman and to expose them to state-of-the art software tools. It was determined that one way to accomplish this would be to use senior students already familiar with component design and finite element analysis to provide technical support to the freshman teams. This provided the added benefit for the freshmen of developing teamwork skills outside the confines of the EGR101 cohort, and allowed the seniors to utilize and/or further develop their leadership skills. In summary, the anticipated benefits of this inter-class cooperative project were:
For the freshmen

- Exposure to state-of-the-art software and analysis techniques
- Interaction with senior students
  - To further develop teamwork skills
  - To establish mentoring relationships
- Practical experience in fabrication of simple parts
- Realistic application of engineering design and decision tools and theories
- Enhanced oral and written communciation skills

For the seniors

- Practical application of leadership and teamwork skills
- Application of theory of FEA to practical design problems

Student Preparation

The first half of the laboratory component of the EGR101 course (3 hours per week) was spent on exercises intended to build a strong basis for the final project. This included mechanical dissection of a coffee maker, including sketching all components and writing a detailed assembly procedure which was tested using non-engineering-student assemblers. This provided a solid background in sketching, writing, consideration of material properties, and use of hand tools. Other exercises used to help with teambuilding, creative problem solving, and use of the engineering design process included challenge exercises at the college's ropes course, impromptu design exercises, and evaluation of Myers-Briggs Type Indicator (MBTI) and its importance for teams.

The lecture portion of the course followed Voland's model of the engineering design process[5], with assignments from the text and classroom activities emphasizing and applying the 5 phases of needs assessment, problem formulation, abstraction and synthesis, analysis, and implementation.

The MEE405 students had passed prerequisite courses in solid mechanics, mechanics of deformable bodies (including failure theories and fracture mechanics), and mechanical component design, and were past the halfway point of the finite element analysis course when the project began.

Project Implementation

Students were given the following project description, along with detailed oral and written presentation requirements and a project timeline. They were also given a scale drawing of the obstructions which their design must avoid, as shown in Figure 1.

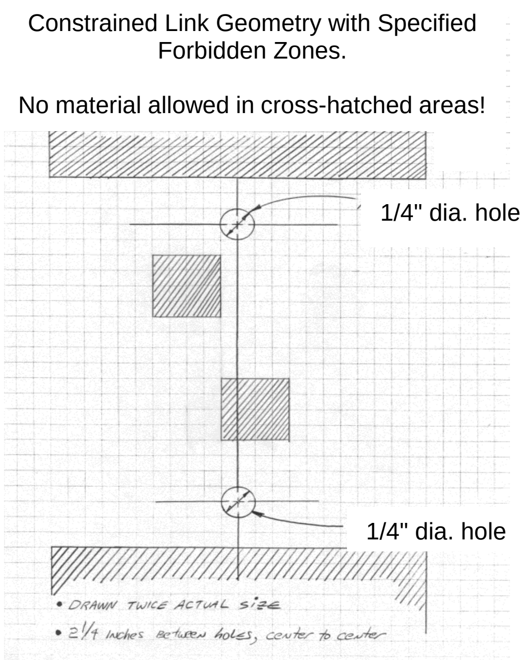

Figure 1. Constraints for Link

Goal: Design and build a structural component to carry load from a suspended walkway to an overhead truss. There are obstructions such as pipes, ducts, and conduits between the two points of attachment as shown on the attached drawing.

Scale: The testing will be done at a reduced scale, using a loading device available in the engineering laboratories.

Material of construction: You will use an easily machined material which will be provided by the instructor (possibilities include oak, acrylic, plywood, and masonite). Hand tools will be provided to do basic drilling and cutting. Access to power tools in the shop will be provided on an appointment basis, with a requirement of a brief safety training class before use.

Criteria for success:

- Optimum use of material
- Accuracy of failure prediction
- Workmanship
- Creativity
- Quality of oral presentation
- Quality of written report

You will give a 5 minute oral report on your design just before testing. The report should include visual aids illustrating your design options, your final design, and results of the FEM analysis. The presentation is your chance to showcase your design, and should be well prepared and done in a professional manner. The last slide of your presentation should indicate where your object will fail and the load at which it will fail. This will be left on the screen during testing of your design.

> The written report will be authored by the EGR 101 team members, with an appendix written by the MEE405 team member(s). This is a formal report which should give details of the complete design *process*, from problem statement to implementation and testing.

Each group was given a piece of material selected by the instructor that was approximately 1/4" thick and approximately 6" square. The materials used included clear acrylic, plywood, pvc, red oak (with the grain at a 45 degree angle), and a particle board. One of the reason these materials were chosen was to give a range of materials from ductile to brittle and to provide a challenge in the use of stress transformation for the 45 degree angle. The seniors would be required to integrate their knowledge of failure theories with FEA.

The groups met and worked on the project during the weekly lab period and at other times during the week. The instructor met weekly with each group to evaluate progress and to remind them to apply the engineering design process (avoiding the temptation to jump to the first solution without appropriate analysis of the options).

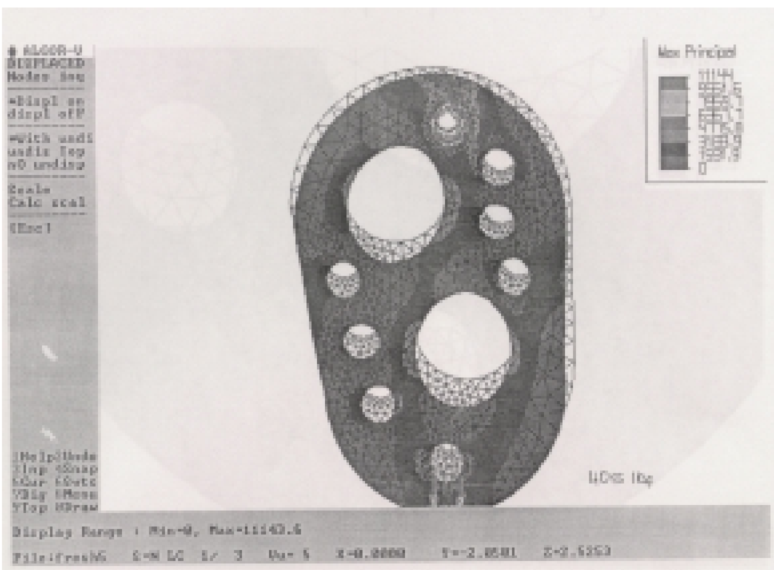

Figure 2. FEA Results

Figure 3. Failed Link

The instructor led the EGR101 students in a brief tutorial on use of Algor for FEA of a simple 2-D shape and then introduced them to the MEE405 students who provided further assistance.

In 1998 and 1999 the student teams were free to organize project responsibilities in any way they saw fit. In 2000 they were instructed to assign one of their members as the Analytical Lead (main contact with senior, and Algor "expert") and one as the Materials Lead (responsible for determining material properties by testing and/or searching databases).

The written report was turned in on the day of component testing, with an addendum turned in the week after testing in which students evaluated the results and compared them with the FEA predictions. The oral presentation was made in the same room as the tensile testing machine, and concluded with a prediction of the load at failure and its location on the part. A typical FEA result is shown in Figure 2 and the part after failure is shown in Figure 3. This particular component failed as predicted. Because of the different materials used, it was important to select an appropriate model for failure and to transform stresses in a way consistent with material properties.

Results I - Student Evaluations

Surveys were used to obtain feedback from both the freshman and the senior students at the conclusion of the project, and a survey was used to obtain further feedback from past freshmen in the fall of 2001.

The initial freshman surveys and peer evaluations showed

- that they enjoyed the hands-on aspects of building the part, but were sometimes frustrated with the real-world aspects of tolerances.
- that some students became very enthused about the FEA software, while others avoided it.
- that the teams generally functioned well, with only a few "slackers".
- that the interactions with seniors were viewed positively, although scheduling issues were often cited as a problem.

The initial senior surveys and evaluations showed

- just over half of the students felt they learned more about FEA by doing this project
- just over half felt they had learned more about working in teams
- a large majority felt the project should be repeated in the future
- a slight increase in interest in management as a major part of career plans
- a high level of enjoyment of the project

Senior comments included concerns with scheduling and timing of meetings because of differing schedules for freshmen and seniors. There were also several comments expressing concern about "ill-defined roles" for the seniors. One insightful comment is worth quoting in full. "Perhaps more clearly defined roles would be better, although I'm sure that is part of the objective of this project, making the leaders define them, or the group as a whole."

The fall 2001 surveys of past freshman students showed (for items scored from 1=strongly agree to 5= strongly disagree)

- The project was a very valuable part of the course (score of 2.1)
- The use of drawings to compare designs and fabricate the final prodect helped better understand the design process (score of 2.0)

- The interaction with seniors was a valuable part of the design experience (2.4)
- The exposure to Algor led to an appreciation for advanced software and modeling tools (2.4)
- The basic ideas of stress and strain illustrated in the project helped in EGR211 (solid mechanics) - score of 2.8, heavily weighted by 4 SD's. Of 34 respondents, 13 indicated SA or A, 6 indicated SD or D.

For items scored on a scale of Often/Sometimes/Never/Seldom

- The students have *sometimes* related lessons from this project to continuing coursework.
- The students have *seldom* (same scale) related lessons from this project to internship or work experiences.

And for items scored on other scales

- The project contributed *somewhat* to identifying and developing personal leadership and teamwork skills.
- The project had *appropriate* levels of emphasis on analytical, machining/fabrication, and presentation skills.

Results II - Instructor Evaluations

The instructor evaluations are based on observation of the students during the process and the quality of the completed projects.

Several freshman students went much further in the use of Algor than was anticipated, to the point of having a better understanding of the concepts and applications of stress transformations than their senior mentors. There was activity in the computing lab most afternoons and weekends.

The teams were highly successful, with very few major problems. They developed a sense of camaraderie which was especially evident in the oral presentations and component testing.

There was some frustration with the complexities of scheduling meetings outside of the normal classroom hours on the part of the freshmen and the seniors. Even though *individual students* would work during evenings and weekends to accomplish project goals, it was difficult to have the *entire team (including senior mentors)* meet outside of the typical "9 to 5" day.

The students learned a great deal while fabricating the parts, and especially when the instructor tested them for conformity/interference with the original drawing of the obstructions. They learned that it is not good enough for the part to look like it is the correct size and shape, but it must be tested for appropriate quality control.

The students did an excellent job of applying engineering design and decision tools. Every group included a well-documented decision matrix showing true engineering analysis of several alternative designs. They made good choices consistent with well-developed design criteria including such issues as cost of machining and minimization of waste material.

The quality of written and oral reports was very good. Written reports improved throughout the course, and the oral report was treated as a serious design briefing. Several groups made significant efforts to interpret the results of the component testing and identify the appropriate failure mechanism by careful physical inspection of the failed component.

The senior FEA students were generally successful in helping the freshman integrate mechanical testing of material properties, basic concepts of stress and strain, and interpretation of FEA results. Even those who made wrong assumptions about failure theories learned that having a pretty computer output does not mean you have a correct physical solution.

It was also possible to identify several senior students who had not yet developed independent leadership skills and to work further with them in the academic and professional advising process during the following semester.

Conclusions

Based on feedback from students and faculty, this project succeeded in meeting several goals directly related to the objectives of the Geneva College engineering program. For the freshmen, this included applying an engineering design process which involved selecting design criteria, generating creative ideas, analyzing the proposed solutions, making design decisions, and implementing the selected design. In the process, they were also able to become familiar with state-of -the art finite element software and apply it in a laboratory setting.   Teamwork skills were also developed, both within the existing freshman groups and in working with senior mentors in FEA.

The opportunity to provide technical and organizational leadership in the context of a design project was one of the key benefits for the seniors. Another important benefit was the integration of material on failure theories/material behavior, FEA, and materials testing in a single project. Students gained a real-world appreciation of crack propagation in a brittle material when observing the testing of acrylic components in a tensile test.

An important unanticipated benefit was an improvement in the skills and confidence in the area of solid mechanics for freshman students who went on to take the sophomore-level solid mechanics course. In particular, student groups who were required to use wood with the grain at a 45 degree angle had already thought about and seen practical applications of stress transformations prior to formal classroom exposure.

The low level of connection of lessons from this project to further coursework, and particularly to internships, is a point of concern for the instructors. It seems we need to work harder on integrating the design process into the courses between the freshman design experience and the senior capstone design project.

The identification of seniors who lacked leadership skills was an important outcome of this course. Although the course was not designed to provide additional leadership training to the seniors, the identification of problems did allow further discussion of leadership issues in the following semester during academic advising.

The project logistics were often difficult for several reasons. The number of students enrolled in each class did not always make it possible to match freshman groups to seniors on a one-to-one basis, leading to communication and work load problems. The difficulties of finding a common meeting time for a group of 4 or 5 freshman students was compounded by the addition of a senior with a very different schedule. In spite of these difficulties, both the students and the faculty found the experience to be valuable and worth repeating.

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4. Voland, G. , *Engineering by Design*, Addison-Wesley, 1999.
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