Teaching with Technology: A Strategy for Pedagogy and Practicality using CAE Software

Loren Sumner, Renee Rogge
Mercer University / Rose-Hulman Institute of Technology

Engineering schools across the country face the growing challenge of adapting to rapidly changing technology. Computer aided engineering (CAE) software exemplifies this trend. The Mercer University School of Engineering initiated a three-year project to establish an engineering analysis center utilizing CAE resources in undergraduate education. Learning modules have been designed and implemented to enhance teaching of engineering fundamentals without compromising the depth or breadth of course material. An infrastructure of learning modules complements the general analysis thread in engineering education while imposing controlled exposure to CAE software. Learning modules expose students to state-of-the-art CAE tools without requiring a specialized CAE course. Encouraging the development of CAE skills, the project aims to facilitate and enhance undergraduate scholarship such as capstone senior design projects. This paper discusses the project strategies, concerns, plans for assessment, and some formative assessment results. The project reveals a practical means for faculty to begin developing and implementing active learning techniques.

Introduction

The Mercer University School of Engineering (MUSE) strives to prepare graduates to serve the rapidly changing demands of practicing engineers. The faculty endeavor to bring insight and wisdom from a variety of different perspectives and appreciate the role of technology in the careers of practicing engineers. The curriculum is carefully designed to achieve specific program outcomes, including those listed under Criteria 3 of the ABET Criteria for Accrediting Engineering Programs. Criteria 3 recognizes the value of technology by stating in outcome k) that: "Engineering programs must demonstrate that their students attain an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."

Advancements in technology continue to improve the analysis tools and capabilities of engineers. Time-consuming and tedious tasks, such as calculations with a slide rule, interpolations for fluid property values, and plotting data by hand, have been assumed by graphing calculators, powerful computers, and discipline-specific software packages. The intensive mathematical tasks required in the application of engineering principles are often better executed by a computer.

Engineering education must adapt to changes in technology and the practice of engineering or risk sending unprepared graduates into the workforce [1-3]. One notable example is the increasing prominence of computer aided engineering (CAE) tools used to simulate engineering systems. Mechanical engineering magazine articles by associate editor Thilmany [4, 5] reveal the trend for a more direct role of analysis in design via finite element simulations. Furthermore, CAE tools are being implemented by bachelors-level engineers who may not have received instruction in the basic principles upon which these tools operate [2]. A balance between traditional engineering theory and experience with the intricacies of CAE should be considered.

In an effort to enrich the undergraduate experience at MUSE, a three-year, multidisciplinary project implementing CAE resources was undertaken. The general benefits of CAE in industry are well recognized. Three-dimensional solid models, illustrative graphical results from numerical simulations, and reduced computational time requirements appear to educate, persuade and attract customers. It seems reasonable that CAE should have the potential to impact teaching and learning in engineering education in a similar way. CAE currently plays a role in engineering education, but typically emerges in specialized courses such as drafting and solid modeling, finite element analysis, computational fluid dynamics, etc., although a general implementation of finite element analysis has been investigated in the past [3, 6].

This project serves to investigate the potential for a broad impact of CAE on engineering education. Project goals seek to a) utilize CAE to enhance the pedagogy of select fundamental engineering topics, b) expose students to CAE tools typical of industry, and c) enhance the analysis capabilities of students. The primary focus of the project pertains to the interaction of pedagogy and CAE. Formative assessment efforts address the influence of CAE on student learning in individual courses. The second project goal pertains to exposure to CAE. Careful planning and placement of the learning modules throughout the curriculum ensures that students enrolled in a participating discipline achieve some experience with CAE during their tenure at MUSE. The third project goal aims to enhance the analysis capabilities of students expected to be evident in activities such as senior design. The impact of the project is being assessed summatively through the school's capstone senior design course. Preliminary assessment findings are discussed in the assessment section later in this paper.

The project, funded by the W. M. Keck Foundation, establishes the Keck Engineering Analysis Center at MUSE and supports faculty efforts to design and implement active learning techniques with CAE. The Keck Center refers to the computational laboratory that houses 22 SUN workstations, outfitted with state-of-the-art engineering software (Table 1). The Center also contains 2 personal computers, a projection system, printing facilities, and network capabilities. Eight faculty members from MUSE are affiliated with the project and are responsible for the incorporation of CAE into their respective engineering disciplines. The courses affected by the project and the discipline responsible for course content related to CAE are detailed in Table 2.

Table 1. Software available on the Sun workstations

ANSYS	OPNET
Cadence	ProEngineer
CATIA	Process Engineer
CFX	Quest
Matlab	V5-Inspect

Table 2. Engineering disciplines involved in the project and associated courses.

Discipline	Courses
Biomedical Engineering	Basic Transport Phenomena*
	Biofluids*
	Biomechanics*
Computer Engineering	Computer Networks*
	Digital Design*
Industrial Engineering	Computer Assisted Manufacturing Systems*
Mechanical Engineering	Visualization and Graphics*
	Solid Mechanics*
	Machine Design*
	Fluid Mechanics*
	Engineering Analysis*
	Finite Element Analysis
All MUSE Disciplines	Statics**

*Required class in discipline, ** Required for all engineering degrees

This three-year project was awarded in January 2003, and a six-phase plan of implementation began immediately. The plan includes support for faculty to develop learning modules during summers. The implementation of learning modules and related assessment occur during the academic year. A Frontiers-in-Education conference paper[7] shares details regarding the plan of implementation.

Strategy

Beyond the obvious necessity of access to computational facilities, achieving the project goals depends heavily on the development of sufficient CAE skills by faculty and students. Project implementation intends to introduce students to analysis potential and CAE software as an indirect consequence of the occasional interactive in-class demonstration with CAE resources. Dynamic, 3-D simulations or analyses are designed by the instructors to aid discussion of fundamental engineering topics. The exposure to CAE, 'sprinkled' throughout the student experience, is expected to motivate interested students to consider the benefits of CAE in senior design or independent research projects.

The project strategy utilizes the concept of a learning module. A module is a single active learning lecture, or short series of lectures, conducted in the Keck Center. Participating faculty design and coordinate modules to form analysis threads embedded in engineering curriculum such as the mechanics thread discussed by Jenkins[8]. This exposure to CAE provides additional analysis tools for students to explore in the solution of engineering problems and allows the introduction of problems that may typically be too complex for a traditional lecture technique. The average participating three-credit-hour lecture course may incorporate one or two modules during a semester.

Participating faculty members design and implement modules as deemed appropriate to benefit course learning objectives. The module concept provides faculty members with an incremental means to start exploring active learning techniques. A new instructor may focus on a single module and develop that module in response to gained experience.

Although coordinated to form analysis threads, modules are designed to supplement the teaching of course topics without disturbing the existing engineering curriculum. A similar effort at the University of Kentucky Extended Campus Program designed three finite-element analysis modules to supplement the teaching of fundamental engineering topics and to raise student awareness to the finite element method[3]. The modules of the present project share this motivation, but with a broader range of CAE tools and engineering courses coordinated to support a sustained exposure to CAE analyses throughout students' undergraduate careers. Furthermore, comprehensive assessment efforts address critical issues and the success and impact of the current project.

Learning modules provide an excellent opportunity to impact the experiential component of learning. Experience is a vital component of learning as recognized throughout educational research [9] and in detail by the Kolb educational model [10]. A well-designed module allows a student to explore classically theoretical discussions through intricate visualizations of real stress fields, velocity fields, stress concentrations, etc. These physical portrayals of engineering concepts are expected to help students relate theory with reality. An ability to correctly manipulate theoretical equations does not always imply an understanding of the physical implications. Steif and Gallagher [2] partially motivate their efforts for utilizing finite element analysis in basic engineering courses by citing studies with Physics students finding that students generally demonstrate only a weak connection between equations and reality.

Module Content

Some modules associated with this project have been presented to the engineering education community[8, 11-13]. A module will focus on specific learning objectives and will typically provide students with step-by-step procedures for computer activities and a worksheet to be completed during lecture. The instructor lectures or demonstrates while guiding student efforts. Homework may also be assigned which requires use of the facility.

Jenkins [8] utilizes the CAE facilities in a required sophomore-level Statics and Mechanics of Materials course. The first of two modules used in this course introduces students to 3-D solid modeling via a uniaxially loaded beam. The instructor provides step-by-step instructions to help the students construct the first solid model (Figure 1). Following beam creation, students apply integrated finite element analysis software for a basic static analysis. At opportune times during the activities, the instructor discusses the importance of units, material property selection, and other modeling decisions for static stress analysis including the selection of location, type, and direction for constraints and force application. Students investigate the effect of various loading conditions on the stress field in the beam (Figure 2) and can even explore model accuracy and convergence by creating and running two analyses on the same model.

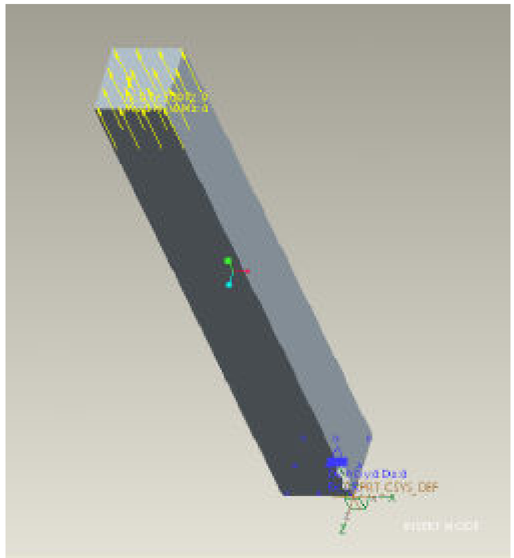
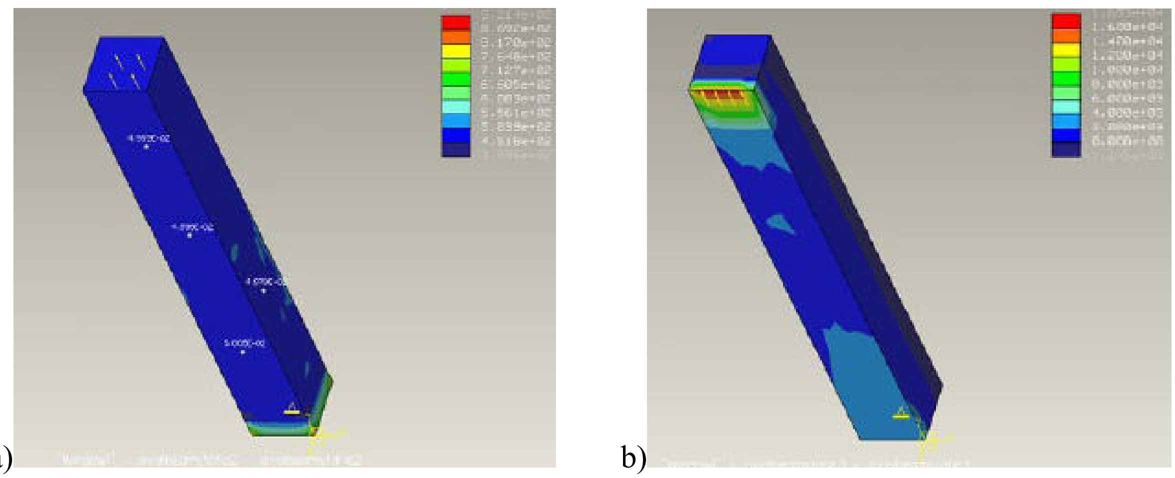


Figure 1. Axial beam model with appropriate loading and constraints.



a) b)

Figure 2. Axial beam model stress field: a) uniform pressure, b) edge loading

A homework assignment reinforces the learning objectives of the in-class tutorial. In this assignment, the students conduct static analyses on a beam with a circular cross-section and a uniform load while varying the material properties of the beam. This exercise reinforces the principle that axial stress will remain constant (i.e. independent of material property), while the axial deformation varies as a function of the material's elastic modulus. Results are compared with hand calculations.

Sumner [13] implements a learning module in an introductory fluid mechanics course for mechanical engineers to provide students with experience envisioning fluid flow. Students are able to visualize laminar flow in a curved pipe using computational fluid dynamics software. Step-by-step procedures lead students through various visualizations of the flow and pressure fields. 3-D visualizations such as those shown in Figures 3 and 4 are manipulated as desired by each student during the in-class investigation. Formidable topics for discussion include the no-slip boundary condition, the parabolic velocity profile of laminar pipe flow, developing flow at the pipe entrance and around the pipe bend, etc.

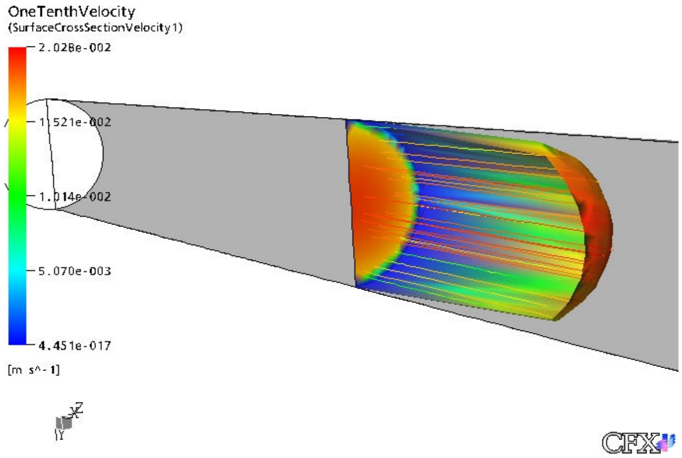


Figure 3. Surface rendering of velocity profile.

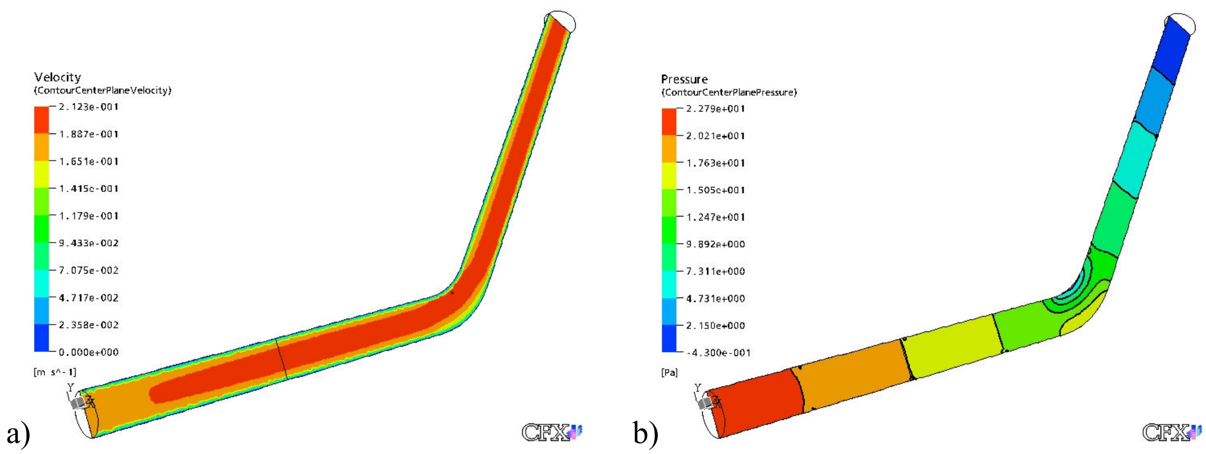


Figure 4. Center plane contour plots: a) speed, b) pressure field

Concerns

Engaging students with CAE software during lecture has been a cause for concern regarding the quality of engineering education. The design of modules and implementation plan of this project recognize and appeal to four major concerns: the possibility for 1) loss of engineering focus, 2) loss of engineering content, 3) loss of lecture credit appropriation, and 4) unrealistic lecture preparation demands on faculty.

Loss of engineering focus relates to the concern that engineering fundamentals will be replaced with engineering software. In a worst-case scenario, lecture discussions may reference software rather than the physical laws governing the situation. CAE software applies engineering fundamentals 'behind the scenes' and a student that lacks fundamental engineering knowledge may conduct an erroneous engineering analysis. Some students may already perceive engineering as the utilization of a collection of equations rather than judicial application of physical laws. Recognizing the responsibility of the engineering profession, such misconceptions concern engineering education and the investigators associated with this project.

Lecture modules are designed and implemented by faculty with sound pedagogical ideas to enhance *specific* lecture topics. Only topics that could benefit from dynamic visualizations and controlled student/computer interaction are considered. The instructor implementing his/her module then also controls the class discussion and thus the engineering focus. The CAE software is used as a supplement to the course, much in the way that a laboratory activity may provide insight into a fundamental engineering topic.

Loss of engineering content, to be distinguished from loss of engineering focus, refers to a loss of time on topic due to lectures devoted to training of software or simply time consuming software procedures to setup and run a simulation in class. In this shortcoming, the computer serves as a 'black box' from the students' perspective. Students learn to input necessary information and retrieve the results. Interfacing with a computer takes some finite time and limited training and thus creates an unavoidable expense in terms of class time. This is a primary concern of the project and addressed repeatedly by formative assessment feedback. Module designing requires considerable effort to minimize software manipulations and to generate procedural handouts such that familiarity with software is not necessary.

Loss of lecture credit appropriation is a general concern regarding active learning strategies during a lecture. Independent of the specific engineering topics supported by a module, the extent to which CAE is stressed may vary tremendously. A module may be designed to provide visualizations only and bypass any discussion of the underlying CAE analysis. This may be extended to include basic analysis concepts such as the mathematical modeling of the analysis and interpretation of results. This may be further extended to include typical procedures of the corresponding CAE tool or even to guide student efforts to generate their own results. One extreme imposes only a minor deviation from a traditional engineering lecture, while the later extreme would more appropriately contribute to laboratory credit hours. Generally, the modules of this project attempt to create an active *lecture* and are not intended to support laboratory credit hours, although the Keck Center is used by some courses with laboratory credit. With this concern in mind, module design begins with presumed expectations of student abilities and then develops accordingly as the instructor gains experience implementing the module.

Unrealistic demands on faculty commitment may hinder the development and implementation of modules. Designing a successful module requires significant attention to details and a familiarity with a particular software package. Interested faculty members may have difficulty finding the opportunity to learn a new CAE package and some faculty members may be more experimentally inclined (rather than numerically). For the current project at MUSE, several faculty members posed ideas for lecture modules long before the implementation of the project. Participating faculty are eager to share their module development with other faculty who may not have had the time to develop their own modules. To further facilitate the development of modules, module design efforts were funded over the summer months. Surveys will be used to quantify the effort required of faculty during the teaching semester.

Assessment

Module level and project level assessment activities are important to the long-term planning of the Keck Center. Formative assessment of the teaching effectiveness of each module provides the feedback necessary for instructors to continuously improve course modules. Summative assessment of the project evaluates the three project goals and facilitates investigations regarding faculty workloads, the development of active learning techniques, and the possible influences of CAE on student motivation. Summative assessment involves three components: 1) general pedagogy perceptions of students and faculty via end-of-semester surveys, 2) an in-depth focus on the impact of CAE on student learning in a sophomore-level required course, and 3) the role of CAE in senior design projects.

Formative and summative assessment efforts regarding pedagogy will vary among the different learning modules and associated learning objectives. These learning objectives are not necessarily similar to those of a traditional lecture in that the modules seek to complement (rather than replace) the traditional lecture style. Module objectives tend to address visualization and physical interpretation abilities rather than the reduction and manipulation of appropriate equations.

Active learning techniques can pose a formidable challenge to instructors requiring significant effort to develop the instructional technique[14]. Recognizing the need for individualized and continued development, *instructors* design and conduct the formative assessment activities for their individual learning modules. The findings of formative assessment activities are presented in various publications[8, 11-13]. In summary, formative assessment results show a largely positive influence on student perceptions of learning and encourage continued module development and implementation. Furthermore, instructors have recognized that preparation and experience dramatically influence module success. Modules also appear to be more effective earlier in the semester, or at least before the end-of-semester crunch. Participating faculty have also noted that in-class worksheets must be designed carefully with reasonable expectations of students' abilities.

Summative assessment of the project's influence on pedagogy seeks conclusive evidence regarding changes in student learning due solely to module activities. To approach this challenging task, a concentrated effort focuses on learning enhancement in a Statics and Mechanics of Materials course which implements the two modules of Jenkins[8]. Multiple sections of the required course allows flexibility in designing an assessment strategy with the potential for a control group. In the past, module implementation has been staggered between two sections of the course so that one section may serve as a control group while both sections eventually experience the modules. Before-and-after quizzes have a strong visualization component such as requiring students to infer the possibility for particular internal stresses in a multidimensional part under specified loading conditions. Results are not yet available from this ongoing component of project assessment. Rutz, *et al.*[15] conducted such an investigation of the influence of certain instructional technologies on student performance in Statics.

End-of-semester student survey results provide more immediate feedback regarding student perceptions of lecture modules and CAE. Combining survey results from two semesters, Figures 5 - 8 present student responses to four different questions. Figure captions convey the exact wording of the survey questionnaire presented to the students.

Student opinions regarding the usefulness of lecture modules were probed with the question in Figure 5. On a scale of 1-5, with 1 implying that lecture modules were not at all helpful and 5 implying that the modules were essential to learning course subjects, the distribution of 229 responses shown yields an average response of 3.3. Although this average indicates a slightly useful perception of the learning modules, the distribution of responses suggest that a large body of students may not be benefiting from the modules.

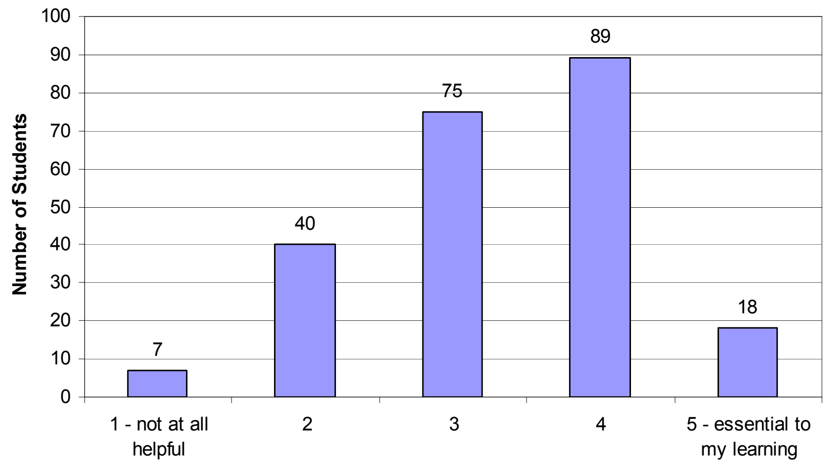


Figure 5
Student responses to “Did the class time spent in the Keck Engineering Analysis Center help you understand course subjects?

Figure 6 reveals students’ perceptions of the importance of CAE in engineering education. With a response of 1 implying it to be not at all valuable and 5 implying it to be essential to engineering education, the distribution of 163 responses with an average of 4.0 suggests that

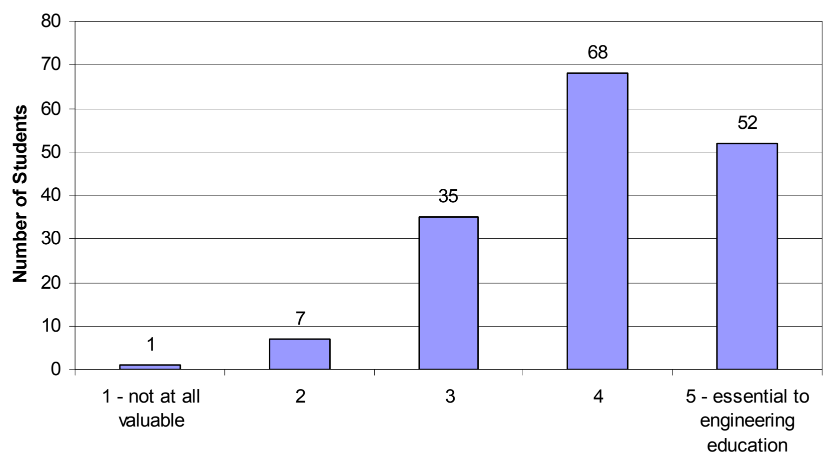


Figure 6
Student responses to “How valuable do you think the facilities of the Keck Engineering Analysis Center are in Engineering Education?”

students perceive CAE to have the potential for valuable contributions to engineering education. Furthermore , 32 percent of the responses claim that CAE is essential to engineering education.

To investigate a possible connection between student interests and motivation, students were queried regarding their interest in learning additional CAE analysis techniques and of their motivation to work on homework requiring the use of CAE resources in comparison to textbook assignments. With an average of 3.9 on the 1 – 5 scale shown in Figure 7, the distribution of responses suggests that students are generally interested in CAE. Although the distribution is biased considerably towards a response of 5 – very interested, at least 4 percent of the students reported that they were not at all interested. When students are queried regarding their work motivation during the semester, results shown in Figure 8, a nearly symmetric distribution about a response of 3 – equally motivated suggests that an interest in CAE does not necessarily serve as a strong motivator for working homework problems.

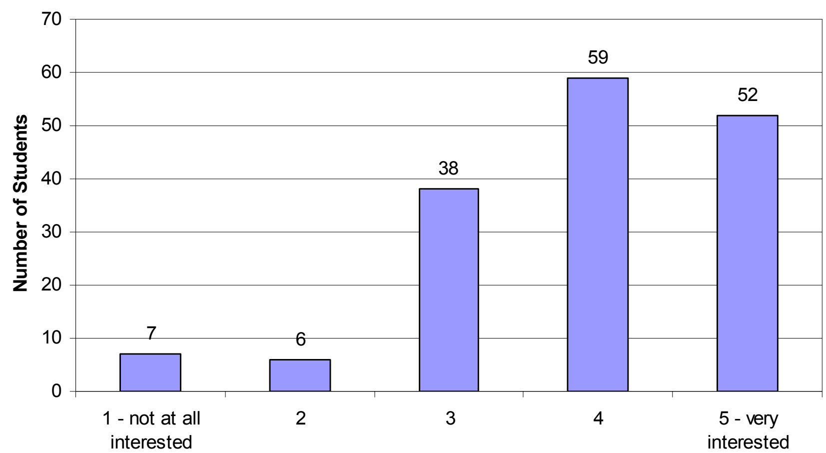


Figure 7

Student responses to "Are you interested in learning more about the analysis capabilities of the Keck Engineering Analysis Center?

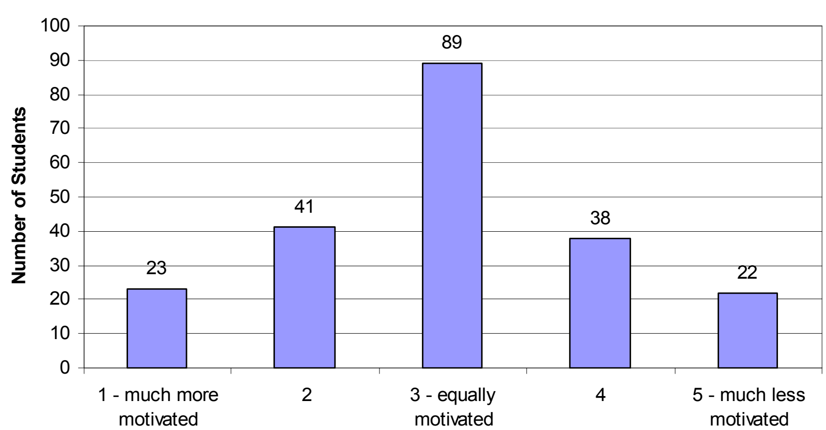


Figure 8

Student responses to "Were you better motivated to work on course assignments that required use of the Keck Engineering Analysis Center facilities compared to traditional textbook homework?

Summative assessment of the third project goal to enhance the analysis capabilities of students was initiated via a student survey. Senior design students were questioned regarding the contributions of CAE resources to project success. This component of summative assessment provided results for the first time at the midpoint of the three year project. Survey results from 57 senior design students in the Fall semester of 2004 indicate that 42 percent of all senior design students utilized CAE resources in the Keck Center and 96 percent made frequent use of a personal computer.

Conclusions

The project details presented attempt to provide a practical structure for the implementation of active learning techniques utilizing CAE resources. Strategies center on the use of learning modules and address several concerns of engineering education. Assessment efforts focus on project goals, teaching effectiveness concerns, and on the overall project impact on the students. Preliminary assessment results suggests that students are interested in CAE and view it as a valuable component of engineering education. This perception, however, does not seem to influence student motivation towards homework assignments. Although final summative assessment findings will not be available until the conclusion of the project, practical avenues are presented to incorporate CAE and perhaps other technologies into engineering education and support the gradual development of student capabilities with CAE analyses.

Acknowledgements

The project described above was funded in its entirety by the W. M. Keck Foundation. Borrowed figures and private communication with Dr. Hodge Jenkins at MUSE are greatly appreciated.

References

1. Nygren, K., "New Technology and the Need to Change the Focus in Engineering Education," Proceedings of the 2004 ASEE/IEEE Frontiers in Education Annual Conference, Savannah, Ga., October 20-23, 2004.
2. P.S. Steif and E. Gallagher, "Transitioning Students to Finite Element Analysis and Improving Learning in Basic Courses," Proceedings of the 2004 ASEE/IEEE Frontiers in Education Annual Conference, Savannah, Ga., October 20-23, 2004.
3. Baker, Capece, Lee, "Integration of Finite Element Software in Undergraduate Engineering Courses," Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition, 2001.
4. Thilmany, J., "Analyzing up front," *Mechanical Engineering Magazine*, Vol. 122, No. 10, October 2000.
5. Thilmany, J., "FEA finds its place," *Mechanical Engineering Magazine*, Vol. 124, No. 10, October 2002.
6. Gessel, Rieder, and Tennyson, "Integration of microcomputer based finite element analysis into the undergraduate mechanical engineering curriculum', Computers in Education Journal. V 7, n 2, 1987.

7. Rogge, Burtner, Sumner, "Formative Assessment of a Computer-Aided Analysis Center: Plan Development and Preliminary Results," Proceedings of the 2004 ASEE/IEEE Frontiers in Education Annual Conference, Savannah, GA., October 20-23, 2004.
8. Jenkins, H., "Increasing student interest and understanding in a first mechanics course through software modules," Proceedings of the 2004 International Mechanical Engineering Congress and RD&D Expo, Anaheim, CA, November, 13-19, 2004.
9. Keeton, M. T., *Experiential Learning*, Jossey-Bass Publishers, 1976.
10. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Prentice-Hall, New Jersey, 1984.
11. Mahaney, J., "A drafting course for practicing engineers," Proceedings of the 2004 International Mechanical Engineering Congress and RD&D Expo, Anaheim, CA, November, 13-19, 2004.
12. Ekong, D., "Using OPNET modules in a computer networks class at Mercer University," Proceedings of the 2004 ASEE Southeastern Section Conference, Auburn, AL, April 4-6, 2004.
13. Sumner, L., "An interactive learning module in preparation for integral methods in fluid mechanics," Proceedings of the 2005 ASEE Southeastern Section Conference, Chattanooga, TN, April 3-5, 2005.
14. Felder, R. and Brent, R., "Cooperative learning in technical courses: Procedures, pitfalls, and payoffs," ERIC Document Reproduction Service, ED 377038, 1994.
15. Rutz, Eckart, Wade, Maltbie, Rafter, and Elkins, "Student performance and acceptance of instructional technology: Comparing technology-enhanced and traditional instruction for a course in statics," Journal of Engineering Education, April 2003, p. 133-140.