Infusing Computational Engineering Tools in Engineering Design Sequence Curricula

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ABSTRACT

This paper presents a project which aims at redesigning the curricula of engineering design sequence by infusing CAx tools in the design courses. Project strategies include the development of tutorials for the CAx tools, use of homework and projects to enhance students' skills in using the software and understanding of fundamentals, and use of Teaching Assistants (TA) to tutor students and to develop tutorials. Results of project evaluation show that the project activities are very effective in improving the students' learning of CAx tools and enhancing their understanding of theories. Feedback and future work are also discussed.

Keywords: CAD education, curriculum design, engineering design.
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1 INTRODUCTION

Graduating engineers in the 21st century are encountering more and more competitiveness because of the globalized economy. To reduce product cycle time and increase quality, many companies, like GM, Ford, Boeing, and 3M, have integrated simultaneous or concurrent engineering with help of computational tools into their corporate philosophies [8]. With the development of numerical techniques over the past 30 years, the engineering industries have reduced the use of experimental tests to the minimum by using modern Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM)/Computer Aided Engineering (CAE) tools [4]. The CAD/CAM/CAE tools are often called CAx tools, and CAx now is referred to various IT-systems which support all phases of the complete life cycle of a product. Today's industries demand that universities graduate engineers who are prepared with the skills both to apply the engineering fundamentals to the real-life problems using appropriate modern CAx tools [4]. A student who is not knowledgeable in using CAx tools will be placed in a distinct disadvantage after graduation in this highly competitive environment [8].

To meet this emerging need, Prairie View A&M University (PVAMU) has launched a project to infuse modern computational engineering tools (CAx) across and throughout engineering design curriculum since Fall semester 2008. This project is supported by a National Science Foundation grant and in part by PACE program (Partners for the Advancement of Collaborative Engineering Education). The project goal is achieved through the development of self-learning tutorials and introducing the closed-form and open-ended projects to reinforce the teaching of engineering fundamentals. The objectives of this project include:

- Provide students hands-on experience using a variety of CAx tools;
- Enhance the student learning of engineering fundamentals reinforced by using the CAx tools;
- Prepare students to be more competitive in job market and graduate schools; and
- Stimulate more under-represented students to pursue engineering degrees at PVAMU.

Although the advances in CAx tools have changed the practice of professional engineering, the curriculum for engineering education has not kept pace in adapting such technologies [4], [7]. According to a survey conducted by Ye et al. [13] on how industries evaluate the current CAx education in colleges and universities, 74 percent of the participants from the industries indicated that current CAx education is inadequate. The CAx education today mainly focuses on teaching students how to "point and click" software. The engineering curricula are still relying on the traditional pedagogy of training students to use the closed-form problems. As one commented in Ye's report [13], "CAx is just a communication tool for engineers. It does not make them better engineers."

Engineering education is challenged not only by the advances in the engineering design field and the demanding workforce requirements, but also by the Accreditation Board for Engineering and Technology (ABET) [5]. ABET Criteria require the engineering programs to develop students' skills by balancing engineering fundamentals, problem formulation, design and verification with the use of appropriate modern engineering tools [1]. According to a survey conducted by Center for the Study of Higher Education at Pennsylvania State University [9], half to two-thirds of the faculty have seen the need to increase the use of active learning methods, such as computer simulations, design projects, application exercises, open-ended problems, case studies, and group work in teaching (see Fig. 1).

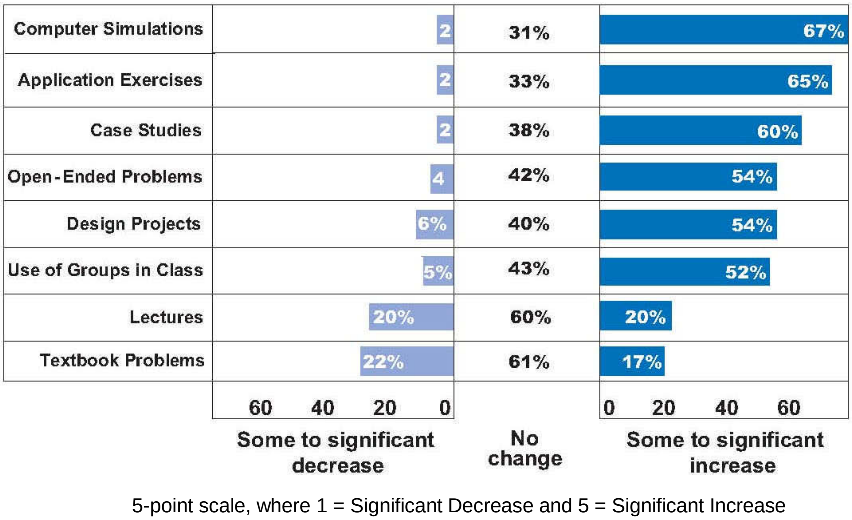


Fig. 1: Faculty's reports of changes in teaching methods [9].

2 PROJECT PLAN

2.1 Overview of Project Plan

Historically in the curricula of the Mechanical Engineering Department at PVAMU, CAD/CAE tools were only applied in the freshman level course MCEG1021 Engineering Drawing, and senior level course MCEG4093 Finite Element Analysis. There were a number of deficiencies with this sequence. First, students did not have opportunities to learn how to apply the CAx tools to tackle the engineering design problems throughout their four years' study. Second, the Senior Design course became the first time when students connect their knowledge of engineering science to an open-ended design problem.

When students enrolled in the Senior Design course where the CAx skills are mostly required, their CAx skills were rusty. Students performed poorly on applying CAx tools in their design projects.

To address these shortcomings, a project has been initiated to redesign the curriculum of engineering design sequence by infusing CAx tools in those design courses. As illustrated in Fig. 2, the CAx tools will be systematically integrated in the engineering design courses from freshman year to senior year. The targeted courses include “MCEG1021 Engineering Drawing,” “MCEG3053 Kinematics Design and Analysis,” “MCEG3043/4043 Machine Design I/II,” “MCEG4093 Finite Element Analysis and Design,” and “MCEG4073/4083 Senior Design I/II.” The CAx tools including Unigraphics.NX, MSC.ADAMS, ANSYS, and Altair.Hyperworks will be adopted to train students to design and analyze engineering problems.

The activities involved in this project include:

(1) development of tutorials for the software that will be integrated into the curriculum;

(2) use of homework to provide opportunities for students to practice using the software;

(3) use of projects to enhance students’ skills in using the software and understanding of theories addressed in the courses;

(4) use of Teaching Assistants (TA) to tutor students in use of the software and to develop tutorials.

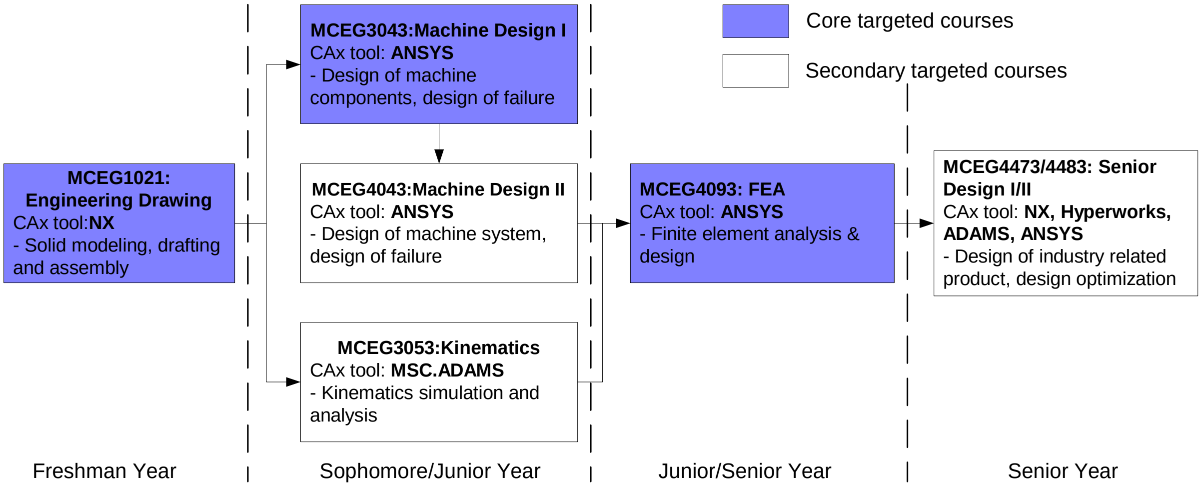


Fig. 2: The mechanical design sequence infused by CAx tools.

2.2 Project Issues

To achieve the goals of the project, several issues have to be addressed.

1. What are the appropriate courses to be integrated by CAx tools?
2. What are the CAx tools to be used in the curricula?
3. What approaches should be used to teach the CAx tools?

2.2.1 Issue One: Choose Appropriate Targeted Courses

The product design processes in the industry has proceeded more and more as a “virtual product” generation process enabled by the CAx tools [3]. Fig. 3 shows the typical life cycle of a product [14]. The whole design process is integrated by CAD/CAM/CAE/PLM systems. Our strategy is to identify appropriate design courses where the CAx tools can be integrated to develop students’ practical skills needed in the execution of the design process. As shown in Fig. 3, the current ME curriculum offer sequential design courses to teach students the theoretical fundamentals which are required in respective stages of the design process. The curricula developed by this project can be shared across the sequential design courses and even used by any CAD/CAE-related courses. For example, the tutorials developed in “Engineering Drawing” can be used by students in “Senior Design” to refresh their modeling skills. Through this sequential preparation, students will graduate with four years of solid experience in using CAx tools.

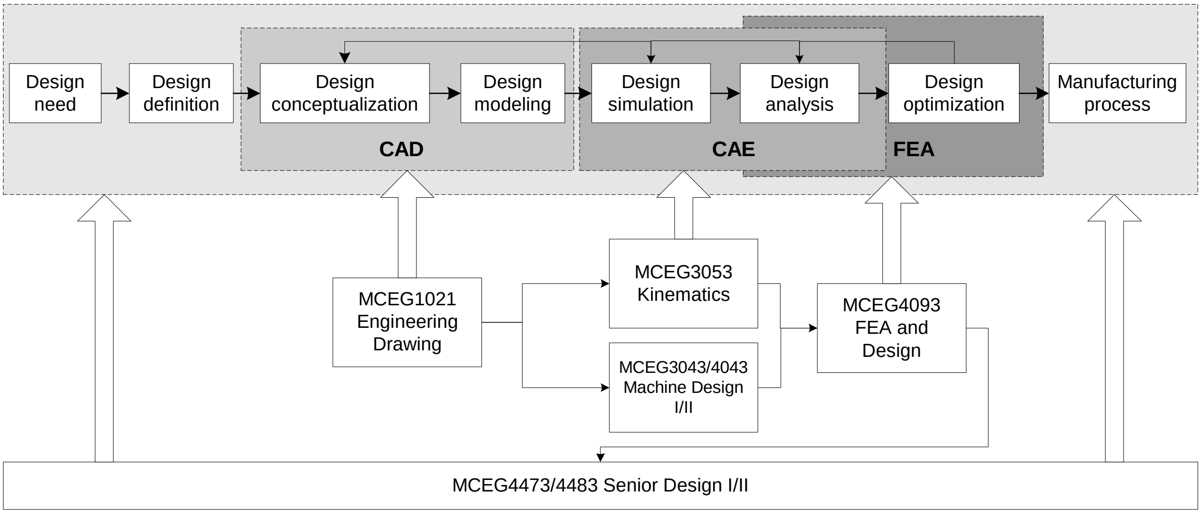


Fig. 3: Design process covered by engineering design courses.

2.2.2 Issue Two: Choose CAx Tools

Various CAx tools are available commercially. For example, for the CAD systems, there are high-end packages such as Unigraphics, Pro/Engineer, Catia, I-DEAS, and mid-range packages such as SolidWorks, Inventor, and SolidEdge [11]. For the CAE tools, there are ANSYS, Nastran, FLUENT etc. What packages should be used in the curriculum? The following factors have been taken into consideration. First, teaching students the high-end packages which are widely used in large corporations will increase students' future job market value. Second, the costs of the packages should be affordable. Although most of the vendors provide considerable discount for educational use of their products, the prices are still relatively high. PVAMU has the privilege to use the high-end packages at very low cost offered by PACE program. Therefore, Unigraphics.NX will be used as CAD package in the curriculum. MSD.ADAMS will be used as dynamics/kinematics simulation and analysis package. Altair.Hyperworks will be used as pre-processing (meshing) and optimization tool. ANSYS has been used as the FEA tool for many years at PVAMU. Except ANSYS, all the software packages are PACE software. Third, the resources of the training and technical support are also an important factor in selecting the tools. The PACE program offers substantial opportunities for training through cost effective manner.

2.2.3 Issue Three: Choose Appropriate Methods to Teach CAx Tools

As aforementioned, the goal of the project is to develop students the skills of using CAx tools in design process and to reinforce their knowledge of engineering fundamentals. It is a challenging task because the curriculum changes will inevitably increase the burden on the students given the facts that engineering students already have very heavy curricular schedule. Introducing CAx tools into "theory-heavy" classes can be cumbersome and time-intensive for faculty as well [7]. Furthermore, it is impractical to open a lab session for each course due to the packed program schedule. How can the project goal be achieved with a minimal impact on in-class lecture time? Self-learning tutorials will be developed and applied in the courses to guide students in solving engineering design problems. Literature can be found on the positive outcomes of using Web-based self-learning activities [10], [12]. Scholars have reported the effectiveness of using computer-based tutorials [4], [7], [15]. From those studies, it can be learned that the same outcomes can be achieved by using self-learning tutorial as conventional in-class learning. Tutorial-based learning has some advantages. Self-learning tutorials allow students' use on their own time and at their own pace and allow for remediation. The learning cycle is also more efficient; it requires less time for both the student and the instructor. In addition, it increases students' interest, engagement, and retention in the learning process. Furthermore, such tutorials will provide additional curricular tools which professors may adopt to implement inductive and active teaching techniques within their classes.

3 PROJECT IMPLEMENTATIONS

Three "**core targeted courses**" were identified in first phase of this project as shown in Fig. 2. These three courses are MCEG1021 Engineering Drawing, MCEG3043 Machine Design I, and MCEG4093 Finite Element Analysis and Design. In the first year, the project activities have been implemented as described below.

3.1 Student Teaching Assistants Training and Tutoring

Students have played an important role in this project. One undergraduate student was hired as teaching assistant for each targeted course. To be qualified as a teaching assistant, the student must have taken the course and received good grade. The TAs either knew how to use the CAx tools or were provided training opportunities. The TAs were assigned tasks to develop the tutorials and tutor the students. Involving students in the training, the development of tutorials, and tutoring has the following merits. First, the TAs obtained sufficient skills of CAx tools and high level understanding of the fundamental theories. This will enhance their competitiveness in the job market and graduate schools. Second, the TAs can bring their observations encountered in the learning to the development such that the tutorials will be more understandable to the students.

3.2 Development of the Self-learning CAx Tutorials

Series of tutorials have been developed for each targeted course since Fall 2008. Those tutorials were incorporated in the teaching of the targeted courses in Spring 2009. Each self-learning tutorial comprises two parts. The first part is to explain the detail steps of using the CAx tools to complete a design or analysis problem. The second part of the tutorial explicitly relates the functions covered in the first part to the theoretical fundamentals of the targeted courses. This feature distinguishes the tutorials developed in this project from the commercial tutorials provided by software companies. This additional information will strengthen students' understanding of engineering basics with the help of the visualization capabilities of the CAx software packages.

MCEG1021 Engineering Drawing		**MCEG3043 Machine Design I**
a. Primitives	1) Create a block with hole	1) Introduction
	2) Create a cylinder	2) Bending stress analysis
	3) Create model with positioning method	3) Safety factor
	4) Create model with moving method	4) Deflection
b. Remove Features	5) Create a block with boss	5) Counter shaft
	6) Create a block with pocket	6) Crane hook
	7) Create a block with slot	7) Bolt
c. Feature Operations	8) Create a bolt	8) Utility hook
	9) Instance	**MCEG4093 Finite Element Analysis**
	10) Taper, edge blend, and chamfer	1) Structural problems
d. Sketch	11) Sketch using dimensions	2) Simple truss
	12) Sketch using constraints	3) Swinging gate
e. Drafting	13) Drafting	4) Space truss
f. Assembly	14) Assembly using absolute positions	5) Buckle up
	15) Assembly using mating conditions	6) Heat transfer
g. Free Form Modeling	16) Free form model through curves	7) Flat plate
		8) Fluids
		9) Pipe
		10) Airfoil

Tab. 1: Subjects of tutorials developed for three courses.

The use of the tutorials varies among the targeted courses. MCEG1021 Engineering Drawing is a 3-hour lab class. It allows the instructor to cover the basics of engineering drawing and the practice of NX in the class. The NX tutorials are used as in-class exercises. The other two courses "Machine Design I" and "Finite Element Analysis" do not have lab sessions. Therefore, the tutorials are used as out-of-class assignments without devoting valuable class time to covering the specific uses of the software.

Sixteen NX self-learning tutorials were developed for MCEG1021 Engineering Drawing. Eight ANSYS tutorials were developed for MCEG3043 Machine Design I. Ten ANSYS tutorials were developed for MCEG4093 Finite Element Analysis. The subjects of the tutorials are listed in Tab. 1. As an example shown in Fig. 4, a tutorial "Bending stress analysis" using ANSYS was developed for "Machine Design I". The tutorial consists of "Table of Content", "Legend", "Problem Statement and Objectives", "ANSYS Instructions", and "Hand Calculations". The tutorial describes step by step how to use ANSYS to determine the maximum bending stress of a beam under two-plane loads. This exercise can be used to demonstrate theories of shear force analysis, bending moment analysis, and two-plane stress analysis. Students can follow the two-plane stress theory in the textbook "Shigley's Mechanical Engineering Design" [2] to validate with the analysis data output by ANSYS. It has been challenging for students to understand the stresses under multi-plane loads. The ANSYS output provides students the intuitive displays of where the maximum bending stress may act.

Title: **Bending stress analysis**

1. Table of contents

2. Legend

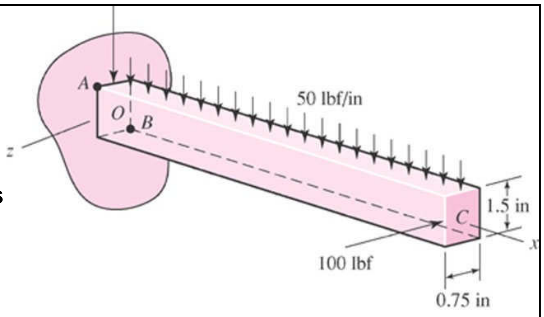
3. Problem statements and objectives

4. Step-by-step ANSYS instruction

5. Hand Calculation

ANSYS concepts:
a. Modeling;
b. Pre-processing;
c. Post-processing.

Fundamental theory:
a. Shear force diagram and bending moment diagram;
b. two-plane bending stress analysis.



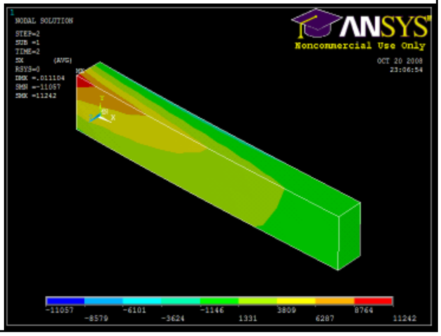


Fig. 4: Example of an ANSYS tutorial for "Machine Design I".

3.3 Development and Implementation of Homework and Projects

By completing the self-learning practice, students gain skills in using CAx tools and relate the skills with engineering fundamentals. The homework were developed and assigned that require students applying the skills learned in tutorials to solve a small scale problem. Closed-form and open-ended projects were designed and assigned to students which require them to apply the CAx tools in designing real engineering problems. In the projects, students need to apply the knowledge learned in the class to identify and formulate the design problems. Then they define the approaches and design parameters, and use the CAx tools to fulfill the design requirements. Using projects in the curriculum also enhances students' motivation and their retention in engineering [5], [6]. Fig. 5 shows an example of modeling and drafting project in "Engineering Drawing". The project requires students to apply the functions of primitives, remove features, feature operations, sketch, drafting etc. in designing and drafting a bracket. The final project in "Engineering Drawing" is an open-ended group project. The students were given the freedom to design any consumer product/mechanical machine with at least 10 subcomponents. Fig. 6 illustrates a Jet-turbine engine designed by one group of students.

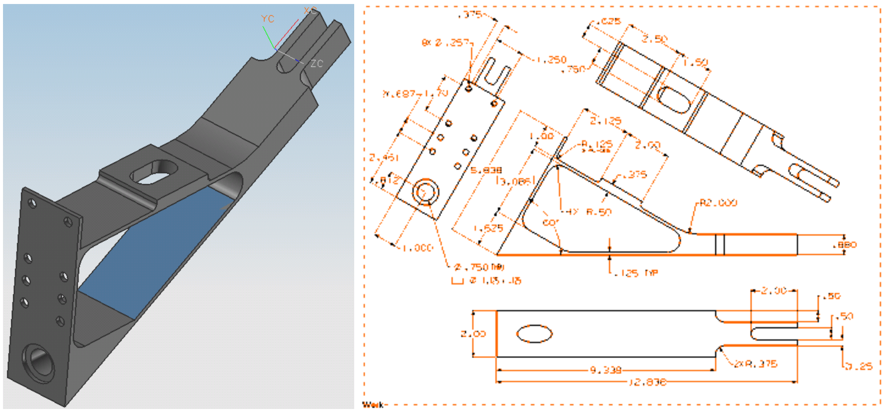


Fig. 5: Modeling and drafting project in "Engineering Drawing".

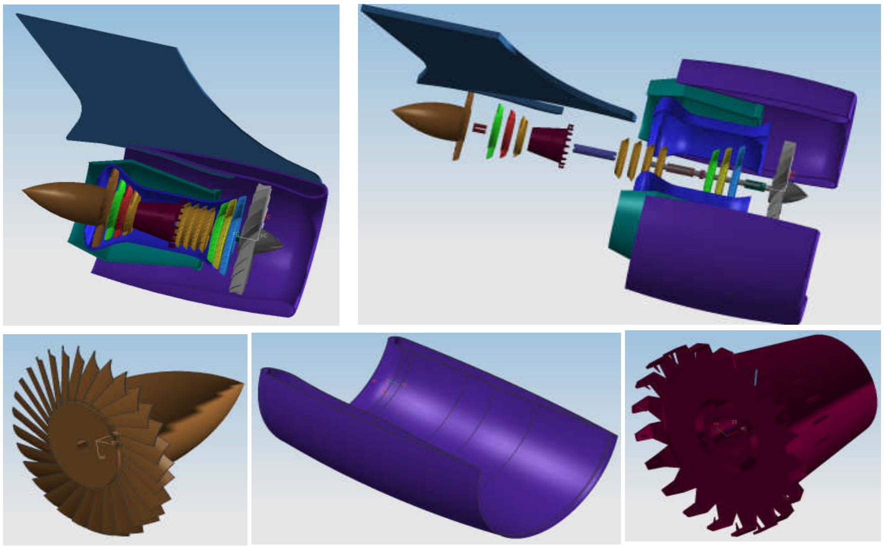


Fig. 6: Jet turbine engine.

4 PROJECT EVALUATION

The project evaluation is conducted by the collaboration of external evaluator West Texas Office of Evaluation and Research (WTER) and the project management team at PVAMU. The evaluation targeted on assessing the project outcomes, identifying appropriate modifications that are needed in implementation of project strategies, monitoring project progress and attainment of project goal. The project outcomes are identified as:

(1) Series of self-learning tutorials and closed-form and open-ended assignments will be delivered and infused in the sequence of engineering design courses.

(2) Students will gain solid hands-on skills on using various CAx tools in different phases of design process.

(3) Students will have strengthened understanding of the engineering fundamentals.

(4) The motivations and retentions of students in STEM disciplines will be increased.

In Year One, the following external evaluation tasks are completed:

- Conducted surveys in three targeted classes (MCEG1021 Engineering Drawing, MCEG3043 Machine Design I, and MCEG4093 Finite Element Analysis) at the end of the Fall 2008 semester to collect baseline information before full implementation of project strategies began.
- Conducted surveys at the end of the Spring 2009 semester in MCEG1021 and MCEG3043 to collect information about implementation and impact of project strategies. (MCEG4093 was not offered this semester.)
- Conducted focus groups with students in MCEG1021 and MCEG3043 at the end of the Spring 2009 semester to collect additional information about implementation and impact of project strategies.
- Conducted expert review of tutorials to determine strengths, concerns, and suggestions for improvement of the tutorials.
- Conducted interviews with the project TAs at the end of the Spring 2009 semester to get their perspective about their role in implementation of project strategies and about student impact.

4.1 Project Surveys

Only the survey results of MCEG1021 are presented here due to the page limitation. At the end of the Fall 2008 semester, 29 MCEG 1021 students completed surveys which asked students' perceptions of:

(1) how much the homework and projects added to their skills in using NX;

(2) how much the use of NX, homework, and projects increased their understanding of the theories of engineering drawing;

(3) the impact of the classes on their confidence in using various NX features;

(4) their current level of confidence in using NX features.

These survey data are used as baseline data. Comparisons of these data with data collected in Spring 2009 are presented in this section. In Spring 2009, the tutorials and TA tutoring were implemented. 19 MCEG1021 students completed surveys which addressed the same questions as in Fall 2008 with the following additional questions:

(5) how much the use of tutorials added to their skills in using NX;

(6) how much the tutoring by TAs added to their skills in using NX;

(7) how much the use of tutorials increased their understanding of the theories of engineering drawing;

(8) how much the tutoring by TAs increased their understanding of the theories of engineering drawing.

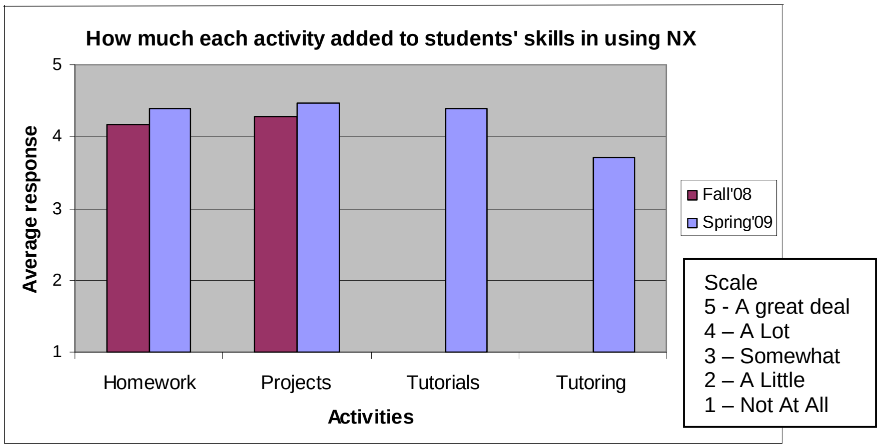


Fig. 7: Survey on "how much each activity added to students' skills in using NX".

As shown in Fig. 7, all the activities have significantly added to the students' skill in using NX. In spring 2009, students perceived that the projects have the most significant impact. Tutorials and homework have slightly less impact. Tutoring has the least impact among the activities. At least 2/3 of the students indicated each tutorial increased their skills using NX "a great deal" or "a lot." (NOTE: Selection of "a great deal" or "a lot" to describe the amount of the increase will be indicated by a great increase.) Comparing the data in Fall 2008 and Spring 2009, students had more positive response on that the homework and projects would add to their skills in using NX.

Fig. 8 shows the survey data about the impact of each activity on their understanding of theories taught in the courses. The students agreed that the use of NX increased their understanding of Engineering Drawing "a lot". The average response on the impact of homework, projects, and tutorials are all over 4 point. The students were more skeptical on the tutoring by TAs. At least 79% of the students indicated great increases in their understanding of engineering drawing theories using each tutorial. The average points on homework and projects increased by 17% and 9% respectively between Fall'08 and Spring'09.

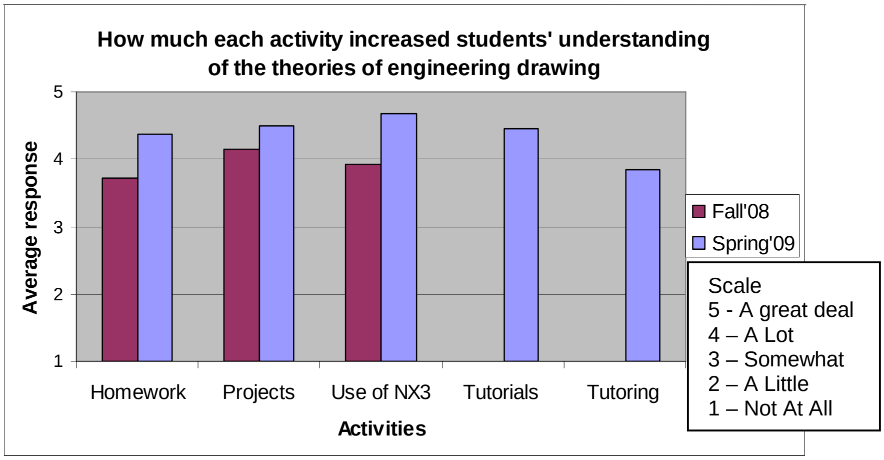


Fig. 8: Survey on "how much each activity increased understanding of engineering drawing theories".

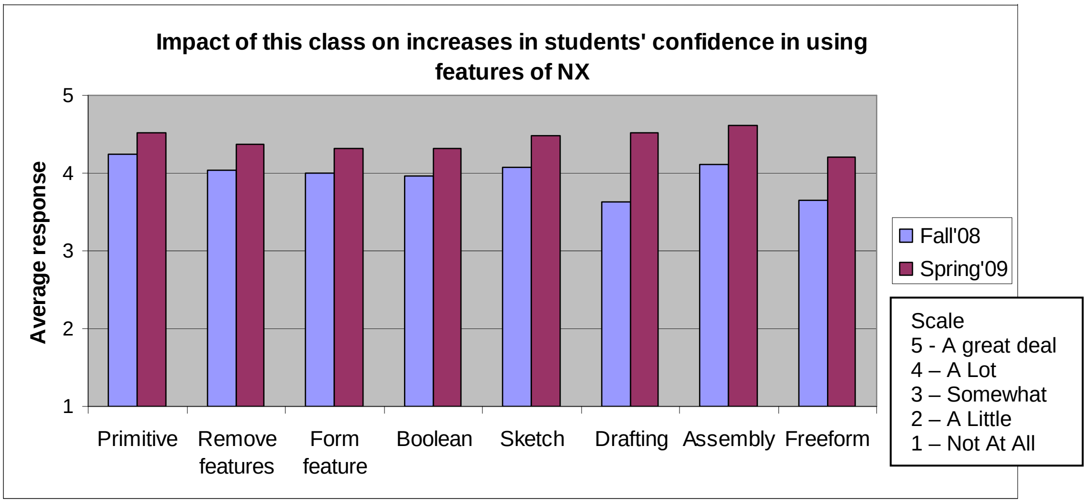


Fig. 9: Survey on "impact of this class on increases in students' confidence in using NX".

On the surveys, students were asked to describe the increases in their confidence in using each NX feature as a result of this class. As shown in Fig. 9, there was a larger degree of agreement on the Spring'09 survey indicating increases in confidence in using all eight features than on the Fall'08 survey. The differences between average response of the Fall'09 and Spring'09 surveys on the eight features ranged from 0.28 to 0.91.

MCEG1021 students were also asked to describe the current level of confidence in using each of the eight features of NX. As the Spring'09 survey data shows in Fig. 10., students were more confident in using primitives, remove features, and sketch than using form features, assembly, and freeform feature. In the future, more attention will be paid when teaching those features where students are less confident in. Fig. 11 illustrates the comparison of the confidence level between Fall'08 and Spring'09. The percentage of students indicating "very confident" increased from 43% to 51%. The percentage of students indicating "confident" increased from 28% to 30%.

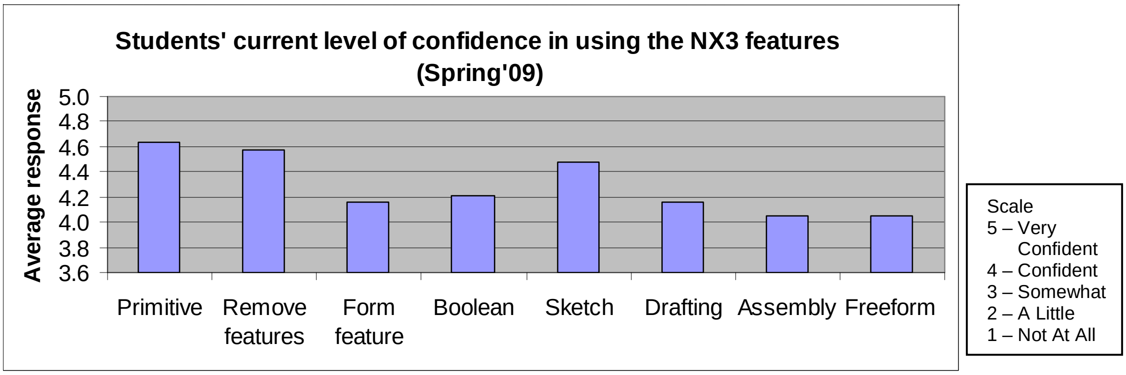


Fig. 10: Students' current level of confidence in using NX.

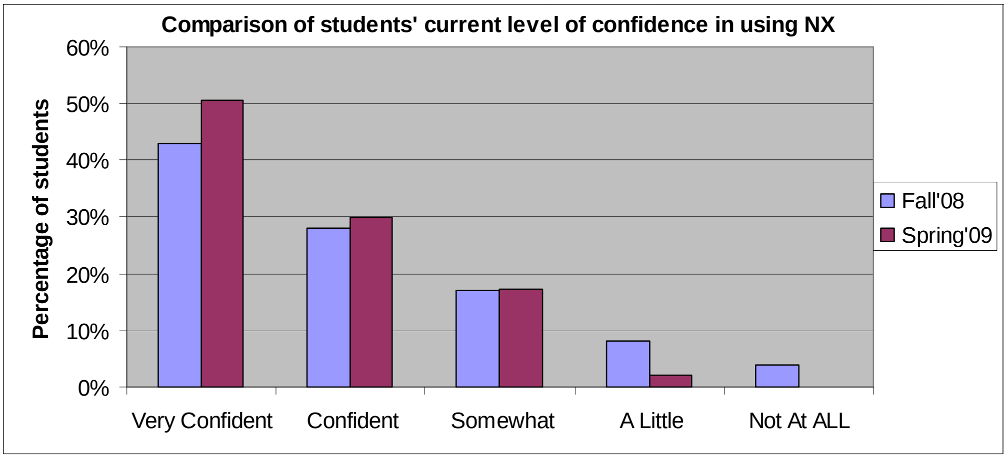


Fig. 11: Comparison of students' level of confidence.

4.2 Focus Group Feedback

During focus groups, MCEG1021 students indicated the usefulness of tutorials. However, they indicated the tutorials needed more details, pictures, diagrams and intermediate steps. They also indicated that homework was good preparation for their class projects. However, students did express concerns about the amount of time required for homework. They pointed to the fact that this is a one-hour credit course, but the time required is more like what would be expected for a three-hour credit course. Some students indicated that even though much time was required, they still believed learning to use the software was very important and worth the time.

When asked about how the impact of TAs on student learning could be increased, students suggested more TAs, more hours for TAs helping students, and more tutorials for TAs to use in helping students. Some felt that the TA was very helpful, but others indicated the TA lacked knowledge about the software and tutoring skills.

The following are some of the students' comments:

- "Doing project made me feel like an engineer."
- "Having the visual display makes a big difference in my understanding the theories."
- "Learning how to use the software has been good for me and will look good on my vita."
- "I like teaching. I might want to get a PhD so that I can teach."

5 CONCLUSIONS

A project has been launched to infuse modern computational engineering tools (CAx) across and throughout engineering design curriculum at PVAMU since Fall semester 2008. In the first year of the project, NX and ANSYS have been adopted in three "core targeted courses" including MCEG1021 Engineering Drawing, MCEG3043 Machine Design I, and MCEG 4093 Finite Element Analysis and Design. Project implementations include the development of tutorials for the software, use of homework and project to enhance students' skills in using the software and understanding of theories addressed in the courses, and use of Teaching Assistants (TA) to tutor students and to develop tutorials. Project evaluations were conducted at the end of each semester. Survey data show that the tutorials and tutoring are very effective for improving the learning of CAx tools. The assignments have increased students' skills in using engineering software and enhanced their understanding of theories. This project has significant impact on increasing students' confidence in using engineering software.

Future work will include improvements to develop the tutorials and projects. The project strategies will be expanded in the teaching of more design courses. Dissemination of the curricula developed in this project is also called for the future plan.

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