USING TRIZ, PARAMETRIC MODELING, FEA SIMULATION, AND RAPID PROTOTYPING TO FOSTER CREATIVE DESIGN

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Abstract *- Fostering creative design within the curriculum in engineering and engineering technology is often both daunting and time-consuming. This paper describes the efforts in the Engineering Technology Department at Western Washington University to foster creative design within the curriculum by using TRIZ, parametric modeling, finite element analysis (FEA) simulation, and rapid prototyping. First, the paper describes how assessment enabled the faculty to create a collaborative environment. Second, the introduction to the design process using parametric modeling and 3D printing rapid prototyping technology during the freshman experience is described. Next, the paper describes TRIZ, the Theory of Inventive Problem Solving, in detail and how that philosophy can be used within an academic setting to foster both creativity and efficient product and process design. Then the paper details how TRIZ, FEA simulation and Fused Deposition Modeling (FDM) are actually used in the senior year. The paper concludes with the results of the department's assessment efforts and plans for future.*

INTRODUCTION

Fostering creative design within the curriculum in engineering and engineering technology is often both daunting and time-consuming. However, it is also extremely important given both industry's growing need for discerning, quick creative problem solvers and the resulting ABET criteria and assessment requirements in design. Currently engineers, designers, analysts and technologists are all seeking methods to decrease the time from concept to market while simultaneously improving quality and maintainability. More often than not, products are now created in a collaborative business environment enabled by the widespread use and availability of the Internet. Universities too must respond to this changing environment to effectively educate students who will become technical members of product development teams. Students who have not used the newest generation of technical product development tools or who have not learned how to be effective team members will not be ready to function in modern collaborative business environments. To respond to this changing environment for graduates, the Department of Engineering Technology at Western Washington University has emphasized concurrent or collaborative engineering principles and team based projects during the last two years within the curriculum. Similarly, individual classes are structured with laboratory projects that emphasize teamwork and creative endeavors. Creative laboratory experiences are part of most classes within the three engineering technology programs: Electronics Engineering Technology [EET], Manufacturing Engineering Technology [MET] and Plastics Engineering Technology [PET], and the three other technical programs within the department: Industrial Design, Industrial Technology and Technology Education. Since there are six different programs with the Engineering Technology Department serving 450 majors, it is relatively easy to structure collaborative team based projects. Often, classes contain students from more than one discipline so that cross-discipline projects and teams can be accentuated. Students from the Industrial Technology programs and from the Industrial Design program are often used as "student" consultants to a wide variety of projects to add to this cross-disciplinary approach.

INITIAL ASSESSMENT EFFORTS

In order to respond to these industry concerns and upcoming accreditation issues (ABET as well as at the university level) the Engineering Technology Department began a detailed assessment effort two years ago and recently created a five year plan to effectively measure the expected outcomes of our programs and courses. The effort began with several brainstorming sessions for the entire department faculty. From those brainstorming sessions, the faculty decided upon a list of essential core skills that all graduates from any of the six programs should possess. Then, the group decided to ask each faculty member to rate each of their courses on a scale of 1 to 5 for all the core skills. However, it was apparent that listing the skills and accurately assessing course content for them is quite different. While the survey was completed, the group noticed that each faculty member could rate the courses differently and interpret each skill differently. Thus, a common definition for both the skill level and the rating was needed. Initially, a faculty committee drafted the details of the ratings and the faculty as a whole refined them. It is essential for any assessment effort that the faculty fully participate in both the definitions and the rating system. Failing to agree on the basic premise of the assessment definitions certainly assures eventual failure of the system and dooms any meaningful outcomes assessment too.

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The faculty produced the following basic skill levels and definitions:

Analytical Skills Ability to: logically analyze and solve problems from different points of view; translate scientific and mathematical theory into practical applications using appropriate techniques and technology.
Oral Communication Skills Ability to: verbally present ideas in a clear, concise manner; plan and deliver presentations; speak and listen effectively in discussions based upon prior work or knowledge.
Visual Communication Skills Ability to: utilize appropriate technology to create drawings, illustrations, models, computer animations, or tables to clearly convey information; interpret and utilize similar information created by others.
Written Communication Skills Ability to: present ideas in clear, concise, well-structured prose; choose appropriate style, form, and content to suit audience; utilize data and other information to support an argument.
Project Management Skills Ability to: Set goals; create action plans and timetables; prioritize tasks; meet project milestones; complete assigned work; seek clarification of task requirements and take corrective action based upon feedback from others.
Teamwork Skills Ability to: work together to set and meet team goals; encourage participation among all team members; listen and cooperate; share information and help reconcile differences of opinion when they occur.
Creative Problem Solving Ability to: apply a design process to solve open-ended problems; generate new ideas and develop multiple potential solutions; challenge traditional approaches and solutions.
System Thinking Skills Ability to: understand how events interrelate; synthesize new information with knowledge from previous courses and experiences.
Ethics and Professionalism Ability to: understand and demonstrate professional and ethical behavior; understand social and ethical implications and interrelations of work, and respond in a responsible and professional manner.
Technology Skills Ability to: properly use industrial-quality technology appropriate to field; adapt to new technology; integrate existing technology to create new possibilities.
Business Skills Ability to: accurately estimate production costs; calculate the cost effects of alternative designs; predict the effects of quality control, marketing, and finance on product or process cost.
Self-learning Skills Ability to: learn independently; continuously seek to acquire new knowledge; acquire relevant knowledge to solve problems.
Programming Skills Ability to: use higher level, structured programming languages to write effective and efficient code to complete a task such as modeling or calculation, or control equipment; understand and adapt existing structured programs.

PARAMETRIC MODELING AND 3D PRINTING

With financial support and technical advise from our industrial partners, the Engineering Technology Department began a substantial restructuring of its core curriculum two years ago. Last year, the use of high end CAE tools, such as Pro/Engineer, CATIA and IDEAS, was integrated into the freshman experience. This year a new rapid prototyping facility was added to that freshman experience. Starting with the first class in Engineering Graphics, the students use the same modern CAE tools now found in industry. All students within the department are required to take this introductory engineering design graphics course. Visualization and creative design are emphasized in that first course, while more traditional engineering graphics subjects such as assemblies and geometric dimensioning and tolerancing are taught in the second course. Starting this academic year, the freshmen complete a project using creative design on the Stratsys® Genisys® Fused Deposition Modeling (FDM) 3D printer. In the second engineering graphics course, the same project is created so that it could be manufactured using Design for Manufacturing (DFM) principles and Pro/Engineer's assembly functionality. This academic year the project was a working flashlight.

TRIZ

Classes and Projects Similarly, the upper division courses are in the process of restructuring to accommodate an increased emphasis on creative design and team projects. Once engineers and technologists worked in isolation and were taught in individual university classes that emphasized individual problem solving. Today, engineers and technologists work as part of collaborative engineering teams and must posses the team skills needed to function effectively in that environment. Continuing to educate technologists in an atmosphere emphasizing the individual is not longer adequate. Thus, the curriculum is being transfomed to emphasize team-based projects and more creative problem solving with open-ended design problems. The TRIZ methodology of creative, but systematic problem solving is emphasized.

One such course that has been restructured significantly is the Computer Integrated Manufacturing (CIM) class that emphasizes the new Internet based Product Data Management (PDM) systems and high-end simulation analysis tools. It is the class where the upper division students use ANSYS® to complete a team based detailed finite element analysis project and use the Stratsys® high end FDM machine to produce a functioning product model. The pre-requisites for the course include CNC Machining, Statics and Strength of Materials. Next year the plan is to continue the project from the Strength of Materials course into the CIM course. This year the project for the course was to produce a functioning snap-fit box and to prove with basic engineering mechanics that the design is sound and within all design parameters. The results from the project are presented to a faculty team and are produced in an Internet ready format.

Team size is 2 to 4 students per project per CIM lab section depending on the number of students enrolled in any particular section. Student teams are encouraged to use other students within the department or university as team consultants to obtain a particular expertise necessary for successful completion of the project. Bonus points are given both for identification of the needed expertise and for actual utilization of the necessary expertise. For example, Industrial Design majors are often sought to gain further team expertise in human factors and ergonomics when the team is designing a product for the differently-abled community or for the work environment. Electronics students provide expertise in the controls area and Vehicle Design students provide expertise in transportation type issues. Manufacturing Management majors from the College of Business and Economics provide meaningful input regarding project management issues and facilities layout. The faculty member selects the team members, with input from the class participants, so team characteristics are as balanced as possible within a given team. Effective team attributes include such items as: open, spirited and respectful communications, respect for and acceptance of others and their ideas, clarity in the roles for all team members, clarity in missions and goal statements, understanding of the decision making process within the team, individual responsibilities and accountabilities, sound team leadership, clarity of time-lines, acceptance of team assessment methods, and balanced composition of abilities of team members [10,11,12].

Student team members are given the opportunity to rate both themselves and other team members on a scale of 1 to 5 on items identified by the teams as attributes being important to the success of the team. Student team members are also given the opportunity to evaluate the team as a whole, on the same scale [1 to 5], on agreed upon objectives for the team. Since the students have agreed upon both the attributes of a "good" team member and have also agreed upon the attributes and objectives for their teams at the beginning of the design exercise or project, this works well. Rating of themselves and other team members have been found to be important for effective teamwork [12], but can also cause suspicion and dissention within teams [10,11]. However, the rating system in this particular course has worked very well and has not caused any obvious or serious team difficulties. In addition, this does not eliminate the difficulty the faculty member has assessing the actual performance of the team or completely eliminate complaints from students surrounding individual workload issues within teams. Even in the "best" team, not all individuals perform at identical levels; this usually causes concern, especially with students who will be graded on this team performance. This, of course, simulates the workplace of today. Members of collaborative engineering teams work at different levels, but the success of the company is determined by the collective success and all team members either benefit or lose as a result.

The TRIZ method of encouraging creative solutions to design problems was used during this academic year [5,6,7] in the CIM class. The point of adding the TRIZ material to the design/teaming content of the course was to foster creativity in the student teams. A TRIZ book [5] that was written for practicing engineers was used to supplement the traditional course text materials. The student feedback from using this material was very positive. The TRIZ method enables creativity by showing how innovative and "new ways of thinking" can be used to solve what at first seems to be insurmountable technical problems. TRIZ is simply a method of looking at design differently – "do it inversely, do less, do it sooner, do it later, change the state of matter, etc. There are numerous short design examples to illustrate how to examine problems with "new eyes" while trying to forget about traditional or obvious solutions. Several problems and associated solutions are given so that the student teams can practice brainstorming while assisted by the TRIZ methodology.

This year one the projects for the course was to produce a functioning snap-fit box and to prove with basic engineering mechanics that the design is sound and within all design parameters. The attributes that were used this academic year to evaluate these projects are based upon agreed upon desirable attributes by the faculty of the Engineering Technology Department at Western. This approach eliminated much of the individual faculty members concerns over team based instruction since all faculty have agreed upon objectives and goals.

After considerable thought and debate, the students were given the choice of using either Design Space or ANSYS (or both) for their comprehensive final projects in CIM. However, for the first six weeks of the quarter, the students learn the basics of FEA with ANSYS using the conventional interface. The class begins with ANSYS labs in the following areas: a simple cantilever beam problem, a solid cantilever beam problem, a plate with a hole problem, a mechanical strain gage amplifier, and a hollow beam strength monitor problem. For the last introductory lab before the project, the students solve the cantilevered beam, but completed in Design Space with Pro/Engineer modeling. During the initial labs, the students are solving problems for which they can either calculate the answer directly or closely estimate the solution. It is also during that time that the students learn the basics of element selection based on solution goals, modeling for FEA, sensitivities to mesh refinements and element selection and how to determine if the FEA model accurately represents the behavior of the part. For each they must write a lengthy lab report that addresses each of these issues and basically prove they have enough knowledge to know that their FEA model accurately represents the behavior of the part. They solve each problem multiple times so that they can understand the complex issues surrounding FEA modeling.

For the first several weeks the software and complexity of the issues involved in appropriate modeling using FEA usually overwhelm the students. The students are introduced to FEA basics in lectures and are also given numerous reading assignments from their lecture text "Building Better Products with Finite Element Analysis by Adams and Askenazi [1]. Kitto wrote their lab manual at Western Washington University. The complexity of the ANSYS interface coupled with the complexities of FEA modeling for Engineering Technology students made it necessary to produce a separate lab manual. By the end of the introductory ANSYS only period, the students have a good understanding that FEA is simply not just adding loads and constraints to detailed assembly geometries. They are well aware that the modeling is sensitive to a number of issues – even in Static, Linear cases. They are also now prepared to do basic part design for function using FEA as a learning tool as well as analysis tool. It is interesting that novice designers start to use multiple load cases to understand part behavior. Even a simple concept as bending stress distribution across the cross section and length of a beam is clarified as they work with the FEA modeling. The students are always anxious to add various loads and see if they can predict and understand how the part behaves. This represents a significant step beyond completing rote textbook problems for them. As novice designers, they can use ANSYS as a very important learning tool and do so – without prompting from the instructor.

As the final introductory exercise, the students are finally introduced to the combination of Pro/Engineer modeling and Design Space. Design Space is introduced at this point rather than at the beginning so that the students gain an appreciation and understanding of FEA modeling first. While Design Space is a wonderful and easy to use product, it also "hides" many of the fundamental issues in FEA. Of course, it does so deliberately, but the students must first understand the what and how, before they can understand how to use Design Space correctly. Certainly, this is the same concern that fundamentally confronts the simulation industry today. As designers are able to use a product such as Design Space to gain a fundamental but not detailed understanding of part behavior, there are also opportunities to also mis-understand the product and the solutions it produces. At this point the students are also shown the Mechanical Toolbar in ANSYS and its auto-report functionality.

Some of the most interesting projects that the students completed this academic year involved designing a small snap-fit container that they could produce on the new FDM rapid prototyping machine that uses ABS material. Although the students are not sophisticated enough to complete a Non-linear analysis, they can learn a great deal about fundamental behavior of the part or assembly by completing a Static, Linear analysis. Recall that at this point the students are novice designers. Before completing this class, the students complete mostly text book problems and moving to a complete open-ended design problem where they must also set the basic design parameters is a difficult transition.

Photos of some of the students' team project FDM models of the snap fit containers are shown in Figures 1-3. An example of a project that illustrates what students can learn from completing such a project is shown in the models in Figures 3-6. This team completed a container as snap-fit pill-box that is opened by adults with limited mobility by the adult squeezing it in the palm of one-hand. The final design of the container works very well, but the students needed both the Design Space models and the FDM model to learn about the behavior of the container. The container was designed in Pro/Engineer and imported into Design Space. The change in the bottom of the box design is shown in Figures 5 and 6. The Design Space results are shown in Figures 7 and 8. An example of a design of a snap-fit that was not as successful is shown in Figure 9. The snap-fit is neither large enough for the size of the container nor deep enough to engage the other side of the snap-fit adequately.

FUTURE DIRECTIONS

After our first detailed alumni and employer survey this academic year, it is clear that work remains to be done within the curriculum. This information coupled with our own internal assessment and our senior exit survey gave us interesting insights into our evolving curriculum. For example, even though we thought we were teaching many team-based projects within the curriculum, the students were still exiting the program without a clear understanding of the team based design methodology. Clearly, then we need to introduce design and, in fact, team based design methodology in that first freshman experience. Too much class time is devoted across too many different courses to unstructured or less than ideally structured team-based design experiences. In that environment, the students never really grasp the underlying fundamentals of good team based design and understand the methodology. Thus, we will be adding structured team based design and design methodology in that first course and continue it on the next three courses. Thus, they will be better prepared to use that methodology in the upper-division courses. Thus, valuable upper-division course time will not be taken up teaching the same approach across many different classes.

The other main lesson learned from our alumni and their employers is that our students are not that well prepared to understand the business world and the environment surrounding commerce. At the same time, they rate the management courses that they take on campus as excellent although there are more plant and manufacturing management topics in those courses. Project management skills is the only other area that the alumni and employers related as needing improvement. How we are going to address these issues is complex. How do we give the students a better understanding of the world of business, commerce and the associated politics in a course or in the curriculum? Project management skills should be addressed by a more structured approach to team based design and a more structured approach to the senior capstone courses. Project management will be the topic addresses during the next academic year. We will be seeking advise from our Industrial Advisory Committees regarding the larger commerce and business issues.

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