AC 2010-1855: AN INNOVATIVE METHOD PROVIDING AN ALTERNATIVE TO CAPSTONE COURSES USING EXPERIENTIAL LEARNING

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AN INNOVATIVE METHOD PROVIDING AN ALTERNATIVE TO CAPSTONE COURSES USING EXPERIENTIAL LEARNING

Abstract

The Mechanical Engineering Technology program at Rochester Institute of Technology (RIT) has implemented an alternative to the capstone project technique commonly used to satisfy the ABET Criterion 5 Curriculum section d. *(Capstone or other integrating experiences must draw together diverse elements of the curriculum and develop student competence in focusing both technical and non-technical skills in solving problems.)*[1]

A majority of Engineering Technology and Engineering Science programs rely upon a capstone project for providing an integrating experience which, by their very nature, are burdensome to the program resources and invariably suffer many disadvantages in their operation. Due to the size and complexity of capstone projects, the objective in the Mechanical Engineering Technology (MET) program at RIT has been to provide an alternative to the current capstone technique that will provide a superior integrating experience through a series of connected experiential projects integrated into the core classes.

This paper will present a method, based on a scheme for experiential learning and innovation, that is a viable and robust alternative to the capstone technique which is easier to implement, will reduce the burden to the program, and provides a more complete integrating experience to the student while strengthening the MET program here at RIT.

Introduction

The MET Program at RIT has met the ABET Criterion 5 requirement (Integrating Experience) by demonstrating a strong Co-op program supporting over 250 companies with every student requiring five quarters (50 weeks total) of industrial experience or equivalent for graduation. However, in the spirit of continuous improvement, an enhanced integrating experience is being sought. An overwhelming majority (8 out of 10) of Colleges have committed to a traditional-style Capstone Project in order to meet Criterion 5. In investigating the logistics and implementation scheme of a Capstone Project, it became apparent that a substantial burden is placed upon the faculty and staff with a projected increased workload of approximately 10% to 20%. Using a Product Design approach to problem solving a method was identified that 'met the customer's needs'. The MET program is labeling this as the 'Backbone Concept' where a series of highly-integrated projects are completed through the first to the senior year of a student's experience that generates an increasing level of mastery to problem solving.

MET Definition of the 'Integrating Experience'

ABET requires engineering technology programs to provide students with a capstone or other integrating experiences.

> *"Capstone or other integrating experiences must draw together diverse elements of the curriculum and develop student competence in focusing both technical and non-technical skills in solving problems."*[2]

The requirement implies the need to prove that the experiences whether capstone or otherwise include diverse aspects of the program. Since curricula are defined by both technical and non-technical program outcomes, program outcomes can be used as means of qualifying integrating experiences. In the MET program at RIT, there are 24 program outcomes. Ten are modeled after the ABET a through k requirements, ten after the ASME requirements and the rest based on input from program constituents. All program outcomes support the overarching theme of problem solving.

One of the goals of the MET program at RIT is to provide students with multiple opportunities to develop problem solving skills while working on opened ended problems Open ended problems are necessary as they are more like that encountered by practicing professionals in industry where problems are posed, but solutions are not. The program controls the process without imposing solutions by exposing students to proven tools and techniques of effective problem solving. The solution to these problems require students to be creative and innovate as they apply knowledge gained from previous courses and experiences. Furthermore, these activities extend them beyond course material covered in traditional courses. To accomplish this, several integrating experiences in required coursework that are focused on developing student problem solving skills have been developed. The program qualifies these as integrating experiences as follows.

1. The activity must involve solving an open ended problem.
2. The activity must require students to create a solution to a problem that extends them beyond what they have been taught in coursework at their level in the program.
3. The activity must involve diverse aspects of the program as defined by program outcomes. These are:
    a. At least 3 program outcomes from those identified as technical
    b. At least 4 program outcomes from those identified as non-technical.

The intent of the program is to provide students with the opportunity to work on as many of these problems as possible and to have them experience problem solving that integrates all program outcomes by the time they have finished the program.

Traditional methods –Capstone Projects

A Capstone Engineering Education survey was conducted by Brigham Young University. This survey provides an understanding of practices in Capstone education. Responding to this survey were 173 schools with 96 % of these schools reporting a Capstone course. It should be noted that the authors found that schools who did not offer a Capstone course were less likely to complete the survey.

Based on the survey, some general attributes of a Capstone course can be described. At 48 % of the institutions that Capstone project is completed in conjunction with a related course. The remainder of the schools, a class followed by a project (28 %) and a project only (26 %) were the second and third most common description of the course. The duration of the capstone course is most often one or two semesters in length (45 % and 36 % respectively) where the number of hours of faculty time spent instructing the course ranged from 1 – 3 hours per week and the average number of hours of formal instruction per week was 2.9 hours. Faculty were also involved in non-instructional roles such as mentors, consultants and evaluators. The majority of departments reported that faculty to student ratio was less than 1:10 with 41 % having a faculty ratio of 1:5. Most project teams involved 4-6 students with a faculty member overseeing the project. With an average of 40 % of the faculty participating in capstone courses and low faculty to student ratios, this results in a "heavy toll on faculty loading."[3] In addition, faculty have reported that "the manpower commitment to support a really effective, professional process-design course….requires at least twice as much time to teach as an ordinary lecture course."[4]

Funding for capstone projects ranges from $40-$33,000 with the survey showing that 87 % of the projects required less than $1000 of funding. Funding sources included institute finding (81 %), sponsor funding (64 %) and student funding (47 %). Because funding could come from multiple sources the sum of these sources is greater than 100 %.

Industrially funded projects are a common source of student capstone experiences. It has been reported that when using industrially sponsored projects it can be difficult to align the project with course learning outcomes. "Having taught the engineering senior design class in a multidisciplinary context for the past ten years using several different project approaches, I find the one consistent unknown from semester to semester remains the quality of the client student interaction in externally-based, client-supported design experiences."[5].

Industrial projects can also vary widely in their technical content, there may be difficulties in matching the student team to the skill set required to complete the project and "in general industry is not able to provide the consistency in objectives and quality of consulting to assure a satisfactory result."[6] One university reported that the ABET auditors noted a lack of consistency in the quality and scope of Senior Projects.[7] "Gathering appropriate projects for capstone design courses is a recurring, labor-intensive activity. The process is complicated by issues such as whether to charge a fee for the projects, ownership of intellectual property, and the required time and effort required to solicit, qualify, and "close the deal" projects."[8] .

Another disadvantage of a Capstone project, often completed during a student's last semesters at an institution, is that if students have poor performance related to any of the learning outcomes there is little or no time for the student to improve in this category. [9] Furthermore, it was reported by California Polytechnic State University that before redesigning their capstone project "less than one third of senior projects were completed in two quarters and was the main cause of graduation delays."[10]

Alternative Method

From investigating the issues of providing an integrating experience via traditional methods, it is clear that an alternate method of needs to be explored. Selecting those issues considered to be of most importance gives:

1. *Effectiveness of Delivery* – Must give the student an experience that meets and can grow to exceed expectations of the integrating experience.
2. *Consistency of Delivery* – The delivery system needs to provide a robust and consistent pedagogy that covers all intended learning objectives yet allows the flexibility of project variation for experiential learning.
3. *Cost* – Not only does the cost of yearly operations need to be minimized but the variability of cost needs to be managed also.
4. *Resources* – The impact on space and peripheral resources need to be integrated with other activities for efficient utilization. Faculty time required needs to be assessed and minimized where possible.
5. *Safety* – Safety currently is not identified as a problem and this is a good thing. However, many projects are independently developed using Institute resources with many teams working at unsafe speeds in the machine shop and elsewhere. Better control and management need to be a priority.
6. *Multiple Experiences* – An integrating experience should be used to help the student grow throughout their entire time at college and not be used as a final gradable moment. Students need more time to practice. *(Capstone projects usually do not give much leeway with regard to starting over thus promoting a 'one-shot-and-you're-done' methodology).*
7. *Intellectual Property* – The integrating experience needs to be separate from intellectual property if at all possible. *(Working with industry will involve contracts around intellectual property which places as much work if not more on hammering out an agreement as it does completing the project).*
8. *Graduation Success* – It should reduce the percentage of graduation delays experienced in previous models.

The integrating experience is important but is just a part of the 'product delivery system' where the actual product being the student experience and with the students being the direct customer. Any product delivery system can be segmented into specific phases within a timeline and in looking at the MET Program the same can be accomplished. Shown below is the roadmap of the delivery system being developed and implemented at RIT.

Each year is labeled as a phase or a theme in which student expectations are formed. In the first year, discovery is the central focus. That is not to say that discovery is exclusive to the first year. For example, in phase 3 (or year 3) there is the expectation of practicing mastery in their discipline but Discovery is there also. Each new course must provide discovery in order to move the intellectual process forward. However, in the same sense, there is enough knowledge garnered by the 3rd year student that it is expected some repeated knowledge is now in the mastery phase. For example, a 3rd year student is expected to have a mastery of report and presentation skills and is graded at that level with smaller errors less tolerated. Expectations are simply held to a higher standard as the student progresses.

One of the strengths of an integrating experience is that it leads to experiential learning through smaller, more manageable projects. Projects start early in the course and are expected to be worked on in teams within and outside of the class time with formal, more organized coverage of topics such as team behavior/management, project planning, and technical content within the class time. Mentoring outside the classroom is accomplished not only by office hours but also by upper class students hired as lab assistants and teaching assistants (TA's). Usually, the process of successfully completing a project is more important than the project itself with a strong emphasis on creativity and critical thinking. This methodology is repeated in several courses within each of the phases of the program which provides several opportunities for the student to be involved in the integrating experience.

The Mechanical Engineering Technology Effort

The MET program has implemented this idea into an incremental set of core courses starting from the first year and into the 4th year student courses. Listed below are outlines of the curriculum phases (Discovery through Refinement) with the Performance phase given more detail as an example of the specifics of how it is implemented.

Phase 1: **Discovery** - This starts in the first year Materials Testing course and continues in Statics. There is a fair amount of discovery in Materials Testing such as material properties, the affect of heat treatment, and developing quality lab reports. In the past, students were instructed on the subject matter and given a detailed outline of how to perform the experiment. Currently, the emphasis is on discovery and the connection between foundation theory in class and experimental methods.

- Primary course - Materials Testing. Program Outcome's (PO's) Integrated – Materials Technology, Experimentation, Communication, Teamwork, Quality

Phase 2: **Foundation** - Strength of Materials is the first course students learn the foundation skill of integrated problem solving with a design, build and test project. Communication and teamwork are integrated into the projects.

- Primary course - Strength of Materials. PO's Integrated – Strength of Materials, Statics, Materials, Electrical, Problem Solving, Computer Skills, Manufacturing Processes, Problem Solving, Application of Science and Math, Experimentation, Communication, Teamwork, Quality

Phase 3: **Mastery** – Principles of Mechanical Design gives the student their first experience in detailed machine components and their integration.

- Primary course - Principles of Machine Design. PO's Integrated – Problem Solving, Computer Skills, Manufacturing Processes, Problem Solving, Application of Science and Math, Experimentation, Communication, Teamwork, Quality. *(This course is a work in progress at this time).*

Phase 4: **Performance** – In Failure Mechanics, students are tasked to determine the fatigue characteristics of a given type of steel within a statistical confidence level. They are responsible for not only performing experiments, previously learned in materials testing, but also responsible for performing new experiments such as fatigue testing, profilometry, and nitrogen furnace anneal. Also, they are responsible for managing external testing from an outside lab.

- Primary course – Failure Mechanics. Integrating Experience: A team project that requires the design of a series of experiments to investigate, evaluate and statistically define the fatigue characteristics of a specific steel.

Phase 5: **Refinement** – This is experienced in machine design where students are required to develop a design of a machine and prototype it for proof of concept.

- Primary course – Machine Design. Integrating Experience: A team project that requires the design of a machine mechanism along with the development of a prototype and the testing of one of its requirements.

Selecting a course and showing how this process is applied gives a more detailed example of the five levels. Failure Mechanics is the fourth out of five sequential core courses in which students cover static and fatigue failure theories along with applying their knowledge to validate the fatigue characteristics of a specific steel sample. They are responsible for the design of the experimental process including running a series of six or more material tests such as fatigue, tensile and heat treating to name a few. The project runs eight weeks and they, as a team, are responsible for a technical report and presentation on their findings. Selected presentations are presented to the IAB members for industrial evaluation. Listed below are the five levels applied to the project and what is expected of the student along with Instructor issues.

Discovery:

- Design and perform a fatigue test on a specific set of samples of low-carbon steel.
- Collect and analyze the data from the above test and report any unusual variances from published values.
- Exposure to industry-level 'report-outs'
- Exposure to conflicting lab results requiring explanation and proof of 'why'

Foundation:

- Develop a plan involving a series of experiments that will validate any discrepancies in the tests.
- Work with other teams other classes and other years of data to communicate effectively and statistically strengthen their data.
- Provide an industry quality report in an acceptable format.
- Statistically determine variances and results.

Mastery:

- Presentation skills.
- Teamwork and cross-team involvement
- Cost analysis of work performed

Performance:

- Utilize course material and testing procedures previously learned in earlier courses
- Run new experiments independent of class.

Refinement:

- Extensively use software. MathCAD, Minitab, Excel, Word, Powerpoint, Project.

- Responsible for project planning.

Instructor emphasis on experiential learning:

- Driven by ‘Why?/How?/Prove it!’ Must defend any test requested to be run and prove its need and reason including an approximate cost. What will it buy you?
- Heavy emphasis on networking and citation requirements.
- Competitive trading of experimental data between groups. Example, only one run on furnace for phase III annealing of parts.
- Extensive freedom to select tests.
- Heavy coaching and mentoring. Course is ½ group work.
- Extensive interaction with lab technicians, department faculty, and outside contacts such as industry and laboratories.

Providing a living backbone experience

Currently, there are a series of core courses in which our integrating experience has been implemented with enough detail as to ascertain a reasonable experience as to the effectiveness of this new ‘backbone’ process.

Benefits:

1. Can cover more and have more face time with instructor. Capstones are usually 20 weeks with minimal student/ instructor time and a great deal of independent/group time.
2. Exposure to several instructors through several courses.
3. Allows greater detail of topics such as the student being responsible for independently designing an experiment, statistically validating the results and presenting their findings.
4. Integrates not only the technology of the courses but also greatly enhances the soft skills.
5. Gives more infusion time. Opportunities for students to try alternate approaches to problem solving with a fresh start each time. Lets students experience growth. Enhances opportunities for diversity.
6. The ‘Why? / How? / Prove it!’ concept is more hard-wired into the student.
7. Gives the student more time to ‘pick themselves up and try again’. This offers reiteration and reflection before moving onto the next phase.
8. There are more distinct gradable moments and more refinement in the detail.

(Having had personal experience with a traditional senior capstone project both as a student and an industrial representative for several projects, the author can say without a doubt that the deficiencies stated in the above sections are real and actually understated.)

The following table illustrates the courses currently wired into the RIT MET Integrating Experience and how they support the ABET Program Outcomes. The focus has been on core courses in which are mandatory for all students in the program. As lecture-based courses are converted to project-based courses, the integrating experience will become stronger. Technical elective courses will be the next phase of implementation, however, are not critical to the core experience. It is desirable to have all courses with an integrating experience but may not be realistic in all electives but the ones that do will support and enhance the core effort.

Table showing the course to PO mapping:

	Program Phase	Discovery	Foundation	Mastery	Performance	Refinement	Refinement
	Course Number and Name	0610-304 Materials Testing	0610-303 Strength of Materials	0610 -305 Prin. of Mech. Des. *	0610-403 Failure Mechanics	0610-506 Machine Design	0610-465 Thermo-fluids Lab *
	Year Level	1	2	2	4	5	5
Program Outcomes	Mfg. Processes	X	X	X	X	X	
	Engineering Materials	X	X	X	X	X	
	Statics		X	X	X	X	
	Strength of Materials		X	X	X	X	
	Dynamics				X	X	
	Fluid Mechanics						X
	Thermo-dynamics						X
	CAE Tools			X	X	X	X
	Mechanical Design		X	X	X	X	
	Electrical, Hydr.& Pneu.		X	X	X	X	X
	Apply Current Knowledge	X	X	X	X	X	X
	Exper-imentation	X	X	X	X	X	X
	Apply Creativity		X	X	X	X	X
	Teamwork	X	X	X	X	X	X
	Solve Tech. Problems	X	X	X	X	X	X
	Com-munication	X	X	X	X	X	X
	Lifelong Learning	X	X	X	X	X	X
	Ethical & Social Resp.				X	X	X
	Diversity, Societal,				X	X	X
	Quality, Timeliness, CI	X	X	X	X	X	X
	Computer Tools		X	X	X	X	X
	Project Management			X	X	X	X
	Codes & Regulations			X	X	X	X

Program Phase	Discovery	Foundation	Mastery	Performance	Refinement	Refinement
Course Number and Name	0610-304 Materials Testing	0610-303 Strength of Materials	0610 -305 Prin. of Mech. Des. *	0610-403 Failure Mechanics	0610-506 Machine Design	0610-465 Thermo-fluids Lab *
Year Level	1	2	2	4	5	5
Meaningful Work Exp.			X	X	X	X

Measures

The purpose of the integrating experience is to improve student's ability to solve open ended problems in their chosen field that are also realistic in the industrial settings. The problem selections have been reviewed by the MET IAB to gauge their relevance to industry. In addition, IAB members have attended some oral reports by students on their integrating experience and have rated their performance relative to industrial expectations. Feedback is provided to students raising their awareness of the level they should aspire to achieve in solving problems and communicating results.

The MET program has co-operative education component that requires students to work in industry in their field for more than one year in total in 5 separate work blocks. This affords students the opportunity to gain valuable experience, but also provides the program with an opportunity to obtain independent feedback on the performance of students in the work place. Employers and students fill out a questionnaire on-line at the end of each work period. As a result it is possible to follow the student's progress as measured by employers 5 times prior to program completion. Performance based on data collected over the last 6 years shows little change in most categories until very recently. Though still small, many performance measures are trending slightly upwards. Though it cannot be confirmed, there are no other identifiable differences in the program that can explain the apparent improvement. The goal is to sustain and continue this improvement by implementing additional experiences.

Future

The goal of the MET program is to infuse integrating experiences throughout the program including all technical and non-technical program outcomes. While experiences implemented to date support all non-technical program outcomes, they have focused on the technical areas of Materials, Applied Mechanics and Machine Design. None have been implemented in Thermo-fluids and Manufacturing. Current plans are being developed to include such experiences in the near future.

As projects are implemented, student awareness in subsequent years grows. This creates the need to continually modify projects and develop additional ones to maintain a fresh approach. This has been done by a combination of strategies that include revising objectives and increasing requirements making projects both different and more difficult and of course coming up with entirely new experiences. For example, the first student project in Strength of Materials required student to design build and test a simple force gage hard mounted to a fixture. The next generation of projects will focus on measuring torque with subsequent experiences that have the goal of measuring forces in the tension and compression members of structures.

Currently, there are additional opportunities for assessment of all program outcomes as well as the value to students of participating in integrating experiences. These include more direct assessment of several program outcomes such as teamwork, communication, and ethics along with the increased involvement from the IAB and alumni in reviewing project proposals and providing independent assessment and feedback during project review meetings with students.

Conclusion

The enhancing the MET Integrating Experience by a backbone of project-based coursework has provided a more efficient and effective experience for the students as well as the faculty. The projects are flexible enough to allow student ideas as well as the projects from industry to be integrated into the program. Of particular note, the intellectual property issue has been much easier to overcome with not only less conflicts but more time to resolve IP issues at the institute level.

This effort is considered an evolutionary work in progress and is expected to be constantly in a 'continuous improvement phase' especially in the assessment and measurement phases. Of greatest interest has been in the students themselves and how they have converted to a 'you lecture – I listen' mode to 'what is the problem – now let me figure it out…' mode. This change in the student's involvement seems to greatly increase their inquisitiveness and gives a purpose to integrating their previous coursework into the current problem. This has been a desire of industry in which they want to see greater inquisitiveness and creativeness from the co-op students and even the new hires.

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