Senior Mechanical Systems Design Capstone Projects: Experiences and Assessment

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Abstract

Organizing and completing an undergraduate senior design capstone project course that lasts only ten to eleven weeks (one quarter term) is challenging for both the instructor and for the students. In this paper, the experiences and assessment of few senior capstone design projects in the mechanical systems area is discussed in detail. The present author is the coordinator of this capstone course. One of the senior lab technicians helps the students outside the class hours with refining their design drawings, procurement of material, fabrication and testing phases. He helps the author instructor with the assessment of students’ work by providing constant feedback about the progress the student groups make at various intervals of time.

In this paper, sample capstone design projects and their outcomes will be presented. In particular, this paper gives an overview of the developed devices specifically by focusing on the design and development aspects of the prototypes. Rubrics for grading were provided at the beginning of the term and their progress monitored on a weekly basis. The student involvement includes understanding the strengths and weaknesses of their prerequisites knowledge needed to successfully complete the chosen project. Since Kettering is a co-op university, students alternate between academic and work terms. They have working knowledge and good time management skills. Industry interaction in the capstone courses is highly desirable but not always easy to secure due to various practical reasons that the companies have, one of which is short duration of the class (10 to 11 weeks).

Introduction and brief literature review

There is no doubt that capstone courses are very important players of the final program outcomes of an academic department, and the university as a whole. Capstone courses provide ultimate academic experience to students at the exit of their academic career. Capstone courses build up on the learning outcomes from majority of the courses they take as undergraduate level. According to Tomorrow’s Professor Postings on Teaching and Learning (Stanford University) [1], "Introducing [undergraduate] students to content that could make a contribution to their field has potential benefits to the students, faculty, institution, and discipline. From the student perspective, completing a research project with even the potential for publication provides a competitive advantage in gaining admission to graduate school or demonstrating discipline-related skills for the job market.”
The main objectives of the capstone course are to choose a topic for the project, brainstorm conceptual ideas and develop preliminary designs, perform analysis, procure material and fabricate the prototype, test the device based on the original objectives, and finally, discuss (assess) the strengths and weaknesses of their design work and the performance of the fabricated prototype. The above process by no means is a serial activity, but it is iterative by revisiting the main stages of the design, manufacturing and testing cycles to make modifications to the thought process and to get closer to reality of a design. Students are expected to perform parametric studies and comment on what if design scenarios. They are expected to discuss the scalability of the project idea to other potential applications. Finally, they are expected to document the difficulties and hurdles if any, faced during any stages of their product and process cycles, and what steps and changes are needed to be done at which design process stage, to overcome the difficulties faced.

There are numerous papers available in the literature and published in ASEE and other educational conference proceedings, posters, and journals. Funding agencies such as NSF also encourage inter-collegiate capstone projects and classes coordinated both from within USA and between US colleges and colleges abroad. Now-a-days, many capstone classes in engineering and in business departments are undertaken keeping in view the needs of the communities and the societies we live in, and not necessarily only targeting the growth of engineering products for companies.

There are several views expressed by many educational researchers on what capstone classes are. Moore [2] views that a capstone course gives an opportunity to the students to demonstrate that they have achieved the goals for learning as established by their academic departments and the educational institution as a whole. Davis et al [3] produced a set of ten holistic roles of an engineer. These are categorized under three main roles such as technical role, interpersonal skills role, and professional role. Also, it is anticipated that each student takes the behavior role of an analyst, problem solver, designer, researcher, etc., as outlined by Davis et al [3]. Similar ideas are expressed in Learning Professor [1], namely, “…capstone projects that are real to students help address the major student impediment we have noted: motivation. This is one of the premises of problem-based learning and internships and practicums as well. When students believe in the importance and legitimacy of the task, their psychic investment is higher and their motivation improves. Finally, a discipline can benefit by accumulating greater knowledge through student participation.”

El-Sayed and Beyerlein [4] discussed how to develop a capstone design course to achieve program outcomes of a discipline. Plumley, et al [5] discussed the learning outcomes of assigning a common capstone project involving freshmen and senior students in the mechanical engineering department. There are many papers on undergraduate senior capstone design that are
multi-disciplinary in which students from the same discipline (example, mechanical) working on a project that involves both mechanical, electrical, computer science and even business disciplines, projects involving group of students from other engineering, science and business departments, and finally, projects that involve group of students from various other colleges both from within USA or global. Managing multi-team and global capstone projects require lot of planning between the instructors and also need support from the respective college administrations.

In a recent paper, Lutz, et al [6] pointed out that real capstone courses should mimic authentic open-ended, real world engineering experiences involving an interaction with real clients and industry professionals. While this is very desirable and may be true to some colleges (for example, Harvey Mudd College, etc.), it is not easy for others. Sometimes, it is a ‘hit-and-miss’ in the sense that occasionally an industry approaches a college to do a short term project work involving students. The work may be to design and develop a new engineering system and test it on campus, or to carry out extensive experimental work at the industrial facility. Coordinating the latter with student groups will be very challenging due to class schedules and safety issues both in commuting and at work.

Past ASME Design Contests traditionally used to propose a design idea (Ingersoll Rand Contest) and the students (from various colleges and various disciplines) participate in it. Funds for this are mainly borne by the respective colleges although students and faculty advisors manage to involve industrial sponsors to augment the expenses. These are year-long commitments similar to Formula SAE competitions. While a capstone course (or an equivalent final learning experiences course), which is required for ABET accreditation, earns academic credits, the ASME and FSAE type contests mostly do not get any academic credit. Students learn a lot in working with team members from different disciplines to participate in ASME and FSAE type contests. On the other hand, most capstone classes are traditionally well organized and assessed. The present paper falls in to this category. Most recently, the present author discussed a brief paper at a conference on the experiences and lessons learned from some of the previous capstone design classes and projects [7]. In this paper modification to the course organization and the new lessons learned from the recent capstone classes is presented. In particular, technical details of one exceptional project, and a brief outline of the other projects is presented. All projects have the same student learning outcomes (SOs), and the students were informed to show evidence in fulfilment of these SOs.

**Background and present work**

Kettering University holds the First Robotics for different high schools, and quite a few of them choose our university to pursue their undergraduate degree in engineering. We also hold several other STEM related events and workshops on campus. Within the mechanical engineering
department, we have a junior level hands-on mechatronics lab course in which students work in a team to design, build and test a device using wood as the primary material. They are expected to only use the provided materials including wood, small motors, batteries, etc. Other purchased materials are not allowed. Competition rules and grading rubrics are disclosed in advance as each group diligently works mostly during the 2-hour class period to complete their project. Background knowledge is mostly physics, basic mechanics (pulleys, levers, mechanical advantage, RCA circuits, etc.), and manufacturing (machining using lathe, drills, grinder, filing, or 3D printing, etc.). Test track is already built by the lab technicians as each group enters in to competition at the end of the term. There are other details about this course (teaching safety rules, patents, etc.) that are not discussed in this paper. However, this course provides motivation and skills needed to prepare for the senior capstone classes.

**Capstone class:** As per the senior capstone class, we have 5 different capstone courses that are offered in a year: Bioengineering Applications, CAD/CAM and Rapid Prototyping, Energy & Environment, Mechanical Systems, and Vehicle Design. These are divided by the area and expertise by the available individual capstone instructors (i.e., there are 5 different capstone instructors). Also, these are based on students’ interest and their specialties. The present author is the sole coordinator of Mechanical System Design Capstone Project. Not all capstones are offered during the same term; but year-round we offer one or two different capstones for the students to choose. Being a co-op college, we need to offer the same capstone twice a year to accommodate both sections of students (when work term students come back to school, and vice versa). Many times the scope of the projects under each capstone use common knowledge areas (bioengineering, mechanical design, thermal fluid, dynamics and controls, electrical circuits, etc.), although the Vehicle Design capstone project sometimes involves testing or doing experimentation on existing engines and engine systems with minimal or no additional fabrication. Many times, some students of the Automotive and Mechanical Systems design capstone courses undertake projects related to FSAE or Mini Baja. On the other hand, some projects in Mechanical Systems and other capstones may only be simulation based. The mechanical engineering department provides token funding of up to $250 for each group of a capstone. So, with around 150 to 200 graduating seniors each year, the department keeps a budget of around $10,000 or so only for capstone classes. All the lab facilities for machining, joining and 3D printing are available to the students, although few students carry fabrication at their own facilities.

**Course Learning Objectives (CLOs):** The CLOs for this course are listed as follows.

1. **Creative thinking in design:** Students will be able to brainstorm and think creatively both individually and collectively as a group, to achieve alternate design solutions.
2. **Teamwork and communication skills**: Students will be able to form and work in teams to effectively communicate their ideas and design alternatives in written and oral formats.

3. **Project planning and management**: Student will be able to use project-planning tools to plan tasks, timing and coordinate design activities.

4. **Identify product attributes and design criteria**: Student will be able to use systematic design process thinking to analyze the conceptualized product attributes and transfer these attributes to design criteria and engineering targets.

5. **Product simulation and synthesis**: Student will be able to apply their education and co-op experiences to simulate the conceptualized product in the intended environment and synthesize to achieve targets and attributes.

Out of the 7 Student Outcomes (SOs) per ABET (listed below), the most relevant ones to the present and other capstone classes are being discussed by our department in consultation with other capstone instructors. For each of these SOs, 2 to 3 levels of performance indicators (PIs) are needed as evidence that the SOs are satisfied to a great extent. These indicators should be simple, meaningful, measurable and manageable [8] that any instructor teaching this class can provide from their assignments (weekly project progress reports, quiz(izes), design, analysis, fabrication and testing of the device, and the oral and written communication of their final project reports). These indicators are similar, and roughly aligned with, Bloom’s taxonomy. For capstone courses, ideally all seven (7) ABET SOs are appropriate as these are meaningful and measurable. However, some of them are more important than others. These are being finalized by the department.

**Student Outcomes (per ABET):**

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

As mentioned before, performance indicators (PIs) (for example, draw free body diagrams, calculate gear tooth bending stress in fatigue, etc.), and their level (ranging from being simple (Level 1) to more rigorous performance (say, Level 4), as well as the evidence of attainment (assigning and collecting sample assessment tools such as homework, quiz, exam, mini-project, etc.), are under development.

Course organization: As mentioned before, this course is in the mechanical systems design area, and it carries 4 credits. The class meets twice a week with 2-hours of duration for each class. This gives ample time to discuss the progress of each group by taking turns between each group, while other groups continue to actively engage in project planning and doing work. There are usually 12 to 18 students in the class with 3 or 4 students in each group (4 to 6 groups). Thus, it is easy to manage the class and to expect fair amount and quality of work from each group. Sometimes, if a student drops the class, one group may have only two students, although attempts will be made to pull one student from a 4-member team (if there is any).

Procedure for choosing and assigning projects: Conventionally, there are two main ways of selecting or assigning a topic or an idea for a capstone project. One method is to assign the description of an open-ended problem that is common to all groups of the class, and each group competitively brainstorm ideas to design, build and test their own device. This is similar to ASME Design Contests and FSAE motorsports competitions, and also somewhat similar to our junior level mechatronics course. While majority of the junior students like the mechatronics course, being the first time hands on course, for some, they want to build a device based on their own ideas, or from experiences gained at work (co-op).

The second method, which is what the author followed, is to encourage the students to bring their own ideas and topics for the project and the instructor decides for their suitability (rigor and content) before approving the idea/topic with modifications, if any. The students’ feedback shows that almost all of them like the freedom to think an idea of their own for the project. A third way might be a combination of both the above two options. One of the limitations of the second method is that not all project ideas they brought were well-thought out, or, are suitable either because they are mostly out of scope of the course (heavily on thermal fluids side), or, the rigor and content. An example of this was to program a (fully purchased) drone to do certain tasks using a controller. Another idea was to design and build a simple pull-up bar suitable for short (height) people, etc. such proposals were randomly thought lacking details of whether they are new designs or new fabrications, or a combination of both. Such ideas were rejected by the instructor.
Prior preparations for the course:

a) Students, who are on their work (co-op) term, are contacted 1 to 1.5 weeks prior to the start of the classes by sending an email via Black Board (BB), which is the communication system used at our university. Course syllabus and previously completed list of capstone projects (with brief reports) are uploaded on BB and also by email sent to all students. Also a list of relevant capstone ideas from other schools was also posted on BB for the students to get an idea what problems to choose.

b) Expected attributes of choosing a capstone project are also posted on BB (see later for more details).

c) The students are asked to propose 3 to 4 individual new ideas of their own while still work (co-op) that are good candidate topics (in their view) for the capstone project. They are encouraged to identify problems from their work experience, and those that might be useful to their company (if they are not confidential). They are also notified that this is a required first task of the course for credit. Each student needs to submit this list along with sketches via email, but no later than the first day of classes. Almost all students were enthusiastic and came prepared to discuss their own ideas to the class.

Expected attributes for choosing an idea for the capstone project: Keeping in view that a capstone course is an assimilation of the knowledge gained from several of the undergraduate classes that they took, the students were given guidelines for choosing a project idea. Some of these are: (a) is it a new or original ideas and design of the system? Or, (b) is it based on design improvements and/or modification(s) of an existing design? (c) complexity of the problem chosen, (d) relative complexity of projects chosen between the teams, number of members in a group (work load), (e) anticipated depth of analysis using math and CAE tools to carry out multiple analyses – structural, dynamic (vibration), mechanisms & control, etc., (f) anticipated work streams (processes), and (g) quality of the communication (written, oral & diagrammatic). These guidelines also map in to the CLOs for this course. Students were told that these attributes would be used in the final assessment.

Activities during first day (2-hour) and other class periods during the term:

a) All individual project ideas were collected from each student for the instructor to go over those. At the same time, each student (following an order decided by the instructor) makes power point slide presentation of each individual idea they thought, to the class. This carries a credit that counts towards the final grade. With each student taking 5 to 6 minutes for presentation of their multiple ideas, it takes about 1.5 hours for everyone to complete their presentations. The senior lab technician (and other technicians if they are free) will also be present to witness the presentations.
b) After a short break (on first day), the instructor gives feedback to the students, and asks them to come prepared for the next class by narrowing down their ideas to 1 or 2, and the strong reasons for their final selection. This is done for credit as they refine their presentation with new or revised sketches containing more details.

c) During the remaining class period the instructor reviews basics of prerequisites knowledge – statics, solid mechanics & design. Responsibility to review the math and CAE tools is rested on them to refresh since they already took several classes that use both math and CAE tools.

d) During the second period of the class (Week 1), students quickly present their narrowed down ideas to the class, while the student audience critique their ideas to see to what extent if any, their narrowed down ideas fulfil expected attributes of the project. They are then broken down to form groups of their own or as decided by the instructor. This is a very tough activity; however, the instructor attempts to identify after consultation with the students of the class their individual expertise and skills to take turns as a leader, researcher, analyst, manufacturer, tester and communicator. For example, students who are leading a fraternity/sorority club, or a professional student organization on campus (as president or secretary, etc.), or leading a community organization during their co-op term are interested in assuming the role of a leader of a group. Similarly, those who are really good at using CAD/CAE tools can be good analysts of a team. Likewise, a manufacturer has hands-on skills of their own or at co-op work. Although a systematic approach has not been taken to identify individual skills of each student to form a well-balanced team or a group, it is assumed that each individual student within each group takes more than one role and responsibility. During the same class period, selection of an idea for the final project is decided and justified. During this phase, each student of the group brainstorms, competes and convinces other members of the group that their idea is the best overall. Both the instructor and the technician play a role in guiding the students in their preliminary selection of the project ideas from analysis, design, material procurement (BOM, cost estimates), manufacturing and testing perspectives. If none of the ideas are well-thought (which is rare), then the group is asked (loosing part of their grade) to revisit the list of ideas already posted on BB from other colleges, and to select an idea of their interest from among those (or modification of those). Otherwise, at this stage, each group would have selected one or two candidate ideas to brainstorm further. They are asked to modify their power point slides if needed and make presentation to the class of their ideas, along with the justifiable reasons for their final selection.

e) During Weeks 2 to 6, each group discusses the progress they made during each week in terms of preliminary design, analysis, material procurement plans (including use of recycled materials from within the department and university), contacting the lab technicians for manufacture and testing. This is done as a weekly presentation to the
instructor and at appropriate time, to the lab technician(s). Assessment of each week’s progress is done based on meeting the originally proposed objectives and activities in the form of Gantt chart. Preliminary design calculations, framework of the written report, power point presentations, excel sheet or matlab calculations and CAE analysis simulations are part of the assessment tools used to monitor their progress. Students undertake several parallel activities during this time as they progress with excitement and enthusiasm to complete the project.
f) During 3rd or 4th Week, an individual quiz is given to assess each team member’s familiarity with the overall scope or activities of the project – design, process and testing. This will ensure that they are not just responsible for only one or two parts or activities of the project. Every member is required to contribute to the technical aspects of the project and not just be responsible to a single activity such as report writing and preparation of presentation materials. This will reduce ‘compartmentalized’ mind among some students who are not aiming high to get good grades. This may harm the other members of the group, leading to misunderstanding among themselves (group dynamics).
g) Weeks 7 to 9 are crucial and critical for each group as they accelerate their energy to fabricate the device, perform testing, repair and complete the documentation, ready for final presentation to the class.

Assessment tools used:

a) Overall project work – 250/400 points
b) Quiz – 50/400 points
c) Class participation, attendance, Impression of instructor and technician – 100/400 points
d) Total 400 points: 100%

The above overall grade is divided per rubrics provided to the students at the beginning of the class. These are based on the following table of contents. Additionally, students were given detailed instructions on requirements that are mandatory in the project and in the report writing, as well as, recommendations and guidelines that are also needed but some may be optional.

Rubric/item for grading of Project work

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<th>Rubric/item for grading of Project work</th>
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<tr>
<td>b) Market Analysis</td>
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<td>c) Knowledge from on Campus Courses Used in Project</td>
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<tr>
<td>d) Description of the Design Process</td>
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<td>e) Hand Calculations / Engineering Assumptions</td>
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<td>f) CAD/CAE/FEA/Simulations</td>
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<tr>
<td>g) BOM/Fabrication</td>
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<tr>
<td>h) Important Technical Specifications of the Fabricated Device</td>
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Sample capstone project work:

There were 4 projects completed during the Fall 2018 Capstone class [9]. Details of one of the example projects (Project #4: Swerve Cart) is presented later. There were 3 members in this group. This project was sponsored by the company that one of the students does co-op with. This is the first time a company sponsored a capstone project for this class, which proved to be very good experience for both the instructor and to the students working on this project.

List of the other approved projects and the number of members in the group is given within parentheses. Sketches are also provided for these.

1. **Design modifications and analysis of an electric skateboard** (2): The goal of this project is to (a) build an inexpensive, short-range electric skateboard with remote control capabilities, (b) modify the existing non-powered longboard rear truck with electric motor mount, and (c) add battery pack with controller under the board. Almost all parts are off-the-shelf items, except for the mount which is a 3D AM part. Figure 1 shows the photograph of the skateboard used for the project.

![Photograph of the existing non-powered skateboard](image)

**Fig. 1: Photograph of the existing non-powered skateboard**
2. **Electric wire stripper** (3): The goal of this project (Fig. 2) is to (a) design and fabricate an adjustable wire stripper that should accommodate a 16-gage to larger outdoor extension cords, and (b) fabricate the machine for less than $200. The current methods for stripping wires are not good for long lengths of wire. Also, they are expensive.

![Fig. 2: View of the fabricated wire stripper machine](image)

3. **Lift-assist roof rack** (3): The goal of this project is to design and develop a prototype model of an automobile roof rack system. Figure 3 shows the view of the system

![Fig. 3: View of the fabricated lift-assist roof rack system with motor](image)
4. **Swerve Kart** (3): The project goal was to fully design, manufacture, assembly, and testing of a go-kart featuring 4-wheel independent steering. Not all items listed here follow the same order of table of contents presented above. This was a sponsored project.

*New features of the design:*

a) Vehicle not restricted in motion like those with 2-wheel steering Cars vs HiLo’s;

b) Directions of Motion: Forward/Reverse (Longitudinal motion); Left/Right (Lateral Motion); Pure Rotation; Any Combination of these

*Work Distribution:*

Member 1 (Group Leader): Designer of “Pods”; Coordination with Sponsors; Program Developer; Machining

Member 2: Design + Finite Element Analysis (FEA) of Frame; Assist with Design of “Pods”; 3D Printing

Member 3: FEA of “Pods”, Purchased Components; Design Calculations (Structural and drivetrain)

Preliminary cart design is shown in Fig. 4.

![Wheel Pod](image)

**Fig. 4: Preliminary CAD Design of the Go Cart**
Sample FEA results of the gear and chain drive is presented in Figure 5. Students used NX 11.0 software for the CAD and FEA of all components.

![Sample FEA results of the gear and chain drive](image)

Fig. 5: Comparison of FEA Results (von Mises) for Chain in Contact with 4 Teeth (left) and 8 Teeth (Right)

Budget allocation was planned well by this group as they continuously approached their sponsors for material support. All materials were shipped by the company along with stamping of some parts done at the company. Figure 6 shows list of parts procured.

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Total Sponsor: $1,168.07

![Budget Allocation of BOM](image)

Fig. 6: Purchasing and Budget Allocation of BOM [9]
Almost all custom made components are 3D printed using the facilities available at our university. Original plan was to TIG weld the aluminum frame; however, the students had to resort to using nuts and gusset plates due to no TIG welding facility available here. Aluminum frame is shown in Figure 7. Students also completed the process flow diagram (not shown here).

The testing procedure included the following activities:

Test single module; Uphill Climb; Uneven Terrain; Full Forward -> Full Reverse; Parallel Park; Ease of control

The students tested the final fabricated device (not shown here) but experienced noise problems due to improper mesh between the chain and gear drive mechanism. They discussed the reasons for this problem and suggested alternative methods of design and assembly. First conclusion was the gearing ratio for the steering motor was not padded enough to account for real world forces, such as friction, in the system. This caused the motors to hit stall torque and stall current before it was able to turn the wheel direction. This has been rectified with additional planetary gear stages that were not available until after the semester was over. Major recommendation of the group was the meager fabrication facilities and the allocated budget of $200, whereas the cost of this device exceeded $1,100. This project was allowed to be undertaken since they were successful to get the sponsorship from the company. At the end of the term, the students took their project away with them.

Fig. 7: Final frame and cart design assembly with electronics and drives [9]
Overall teaching and learning experiences of this capstone course:

a) 10 to 11 Weeks for a capstone course is challenging for the students without compromising on quality and content. However, they worked very hard to meet the deadlines and targets. Some of them have heavy course load of 3 other classes to take.
b) Assistance provided by the senior lab technicians when needed was very helpful as they participated in the fabrication of the devices.
c) Managing the different groups of their progress was not that difficult. However, the author has full load of teaching that kept him busy throughout the term.
d) Choosing the right idea for the project is challenging.
e) The overall quality of ideas and designs were acceptable with most of them having some innovation.
f) Design and simulation activities with less of fabrication and testing may be better but may not fit in to the expectations of a capstone course in which the students should design-build-test their ideas.
g) Some works are of publishable quality at educational and research conferences [7].
h) Monitoring to balance workload within a group is always challenging.
i) Overall satisfaction of the students is good.
j) Time frame to complete the project is acceptable but very challenging.
k) Final report, CAD/CAE files, math tool programs, power point slide presentation and poster preparation were used as assessment tools besides weekly progress reports and the quiz. Rubrics provided by the instructor helped the students immensely to meet the expectations of the outcomes.

Conclusions

In this paper, outline of how the Mechanical Systems capstone project class at Kettering University is discussed in details by providing the background of the students (co-op), and the university calendar (11-week Quarter system). Course organization and content are posted using the Black Board system of the university. Course learning objectives (CLOs) and the students outcomes as per ABET (SOs) are presented. Based on the assessment of all the projects, all CLOs are satisfied to a great extent as the students brain-stormed the individual ideas before selecting a final topic for their project. Using their project management, team working and time management skills, the students identified the project tasks and divided the work load. Synthesis of several design ideas before developing conceptual design has been carried by all groups, although in one project the individual contribution of each member towards the assigned and agreed up on tasks was not carried out fully. Weekly progress of each group of students is monitored via presentations and progress reports.
Advanced Math and CAE tools have been used to carry out the hand calculations and finite element analysis of critical components. Process design charts were prepared that shows iterative steps between different design stages. Detailed analysis of the critical components of their designs using solid mechanics and machine design principles could be improved. The knowledge gap due to co-op term seems to have played some role in this although the instructor tried to review the pre-requisites knowledge.

Procurement of the material and fabrication activities of each project design has been very satisfactory. Execution of the planned testing procedures of their prototypes needs some improvements due to lack of time and limitation of availability of data acquisition and measurement equipment and instrumentation (for example, strain gages). Most of these are primarily dedicated for graduate student research activities. Efforts are being made to procure more such instruments for use by the capstone classes.

Students identified and documented the knowledge and knowledge gaps from the previous courses taken at the university. Final learning outcomes and safety issues along with the impact of poor designs on the society were discussed as well. Sample project report with assessment tools is provided.

Overall, it was an enjoyable but challenging experience both for the instructor and the students. Recommendations for future include consultation with various other instructors both from within and outside the department to identify potential project topics from their ongoing applied research projects. More employee sponsored projects will be explored so that the practicing engineers can be involved in the assessment process which adds value to the course.

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