Contributed Papers from Materials Science and Technology 2018 (MS&T18)
October 14–18, 2018, Greater Columbus Convention Center, Columbus, Ohio, USA

DOI 10.7449/2018/MST_2018_729_737

EXPERIENCES AND OUTCOMES OF TEACHING SENIOR CAPSTONE COURSE

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Abstract

The author taught a senor capstone design course during Fall 2017 in the Mechanical Systems design stream at Kettering University. The course duration for this course is approximately 11 weeks (Quarter system) that posed several challenges for handling the classes due to shorter academic term. The students are expected to perform detailed analysis and also validate the proof of concept of their designs by building prototypes. In all, there were 5 teams with 4 students each in each team. This paper discusses the course organization, topical selection policies and the final choice of a topic selected for each group to work on. Also, the appropriate assessment methods used to monitor weekly progress made by each group will be discussed. Finally, a brief description of work carried in each project along with the results from a sample project will be discussed.

Keywords: Capstone Design, ABET, Assessment

Introduction and Literature

Kettering University is a 4-year Degree College with a required co-op experience. Therefore, the students alternate between work and school terms (3 months). This means that there are two sets of students (called A-Section and B-Section) – one attending school, while the other on co-op work term. Around 2,000 total undergraduate students do co-op in 450+ different companies including the OEMs and their suppliers, UPS, and other health care manufacturers and providers, etc. Majority of co-op companies are in Michigan, Ohio and other surrounding states with a few in the Eastern, Southern and Western U.S. territories. Kettering is predominantly an undergraduate institution although graduate programs are available in Engineering and Business Departments. Mechanical engineering department is the largest with over 1,000 students total (> 50% of KU student population).

Capstone at KU and ABET

The capstone course is a 4-credit course spanning 11 weeks to complete. Capstone courses are offered in 5 specialties within mechanical engineering. These are: Mechanical Systems Design Project (which is what is discussed in this paper), Vehicle Design Project (for the Automotive specialty), Bioengineering Applications Project, CAD/CAM & Rapid Prototyping Project, and Energy & Environmental System Design. The average number of students in each capstone ranges from 20 to 25. Some of these capstone courses are offered twice in a year to cover the A- and the B-Section students.

As per ABET, one of the outcomes of a capstone design is for the students to demonstrate **an ability to design a system, component, or process to meet desired needs.** The capstone course is an assimilation of the knowledge gained in all undergraduate courses that the students take. The project topics should ideally cover all aspects of STEAM courses, including the Arts, Humanities and Social Sciences. In practice, however, it tends to be more focused towards only certain aspects of technical courses in the mechanical design stream. Most of the time, the students enrolled in capstone classes are in their final semester and ready to graduate. Therefore, the prerequisites for the capstone class are fully met to a great extent by all students, although some senior level courses such as Controls, Heat Transfer and Machine Design are taken by few students along with the capstone course, which creates some gaps in knowledge within a group needed for the capstone class. On the other hand, the gap created by a co-op term (at Kettering) also poses some problems although some students have already taken such prerequisites. Retention of knowledge or prerequisites is a challenge for some students which is overcome by the instructor reviewing critical areas and topics needed in the capstone class. It is usually understood that students enrolled in a capstone course have already taken Engineering Materials, Machine Design, and Computer Aided Engineering courses.

The catalog description of the Mechanical Systems Design capstone at KU is as follows:

"The fundamental topics of this course include: The engineering design process, ethics, teamwork, brainstorming, conceptual designs, design synthesis, alternative designs, product attributes, design criteria, engineering targets, proposal writing, project planning, project management, planning the fabrication of a physical prototype, virtual simulation, analysis techniques, bill of materials, bill of process, manufacturability, product variations, product quality, design reports and presentations."

If followed strictly, these topics and the above catalog description satisfies to a great extent the ABET requirements of a student's final learning experiences. Few of these topics were discussed at various intervals during the first few weeks of the term while the rest of the time was devoted to monitoring the individual, as well as each group's progress made on the project. Students were expected to self-learn details of some topics by referring to the engineering and management textbooks available in the library, as well as, by reading online resources. Due to their mandatory co-op experience, some of these topics, especially brainstorming, teamwork building, project management, etc., are 'naturally' understood and learned while they were at their co-op work. Budget-wise, the department provides an average of up to $300 per group for procuring materials and to fabricate the device. Technicians help is available for both fabrication and for testing of their prototypes. The usual safety and precautionary measures need to be followed by each group member when working in the machine shop, 3D printing lab or in the measurements lab. Students were encouraged to plan ahead of time to use the laboratory or workshop facility during the day time for any needed supervision by the faculty, technician or a fellow team member.

Capstone courses at other universities

Many engineering schools offer capstone classes for two semesters, or, for one full year for a total of 8 credits. Usually, students spend the first semester in attending first few classes to understand the topics on design process, synthesis and analysis, project management and developing team building skills, etc. They brainstorm their individual and group ideas to propose conceptual designs by carrying preliminary design calculations (by hand) and to further refine their conceptual ideas and initial designs before deciding one or two ideas for final design. They also develop CAD drawings and perform virtual simulations on the ideas they chose in order to narrow down further following the principles of DFMA (Design for manufacture and assembly). Math and CAE tools are used extensively during this phase to perform several iterations of their designs until feasible designs are identified. Term end presentations are usually required to receive a course grade for the work carried so far by each individual member and the group. Assessment tools such as peer grading, grading by an external examiner such as a sponsor of the project if any, and/or by the capstone team of instructors within the department. Weekly or bi-weekly progress reports are also used in the assessment.

During their second semester, student groups usually spend their time performing the final analysis of their idea, preparation of final drawings for fabrication, assembly and do the preliminary testing of their project. Fine tuning of their designs will become necessary due to unforeseeable hurdles and due to uncertainties in design. Students learn from failures how to minimize the several steps followed in the trial and error design process. Two-semester capstone, especially if sponsored by a participating industry, has more potential to produce better quality projects. Continuous monitoring by the instructor is necessary to help the students in case of problems. At Kettering, we are challenged by the shorter academic terms to handle the capstone courses. In other words, we are attempting to compact a 14 or 15-week semester, or even a 30-week (two semesters long) capstone work at other schools, in to an eleven-week long, 4-credit capstone course. Is it possible to maintain the same rigor and quality of work as other schools?

Project selection

Identification of the topic or the problem(s) for the project is always challenging, especially if it is left to the choice of the students. Some schools use the old or the current Design contests of NASA, ASME or other professional organizations and engineering societies, or the industry-sponsored projects, for their capstone. These are well thought out and challenging problems due to the time and efforts invested by the sponsoring industrial partners and the technical committees. In this scenario, the same problem statement is given to each student group and they work diligently and competitively to develop solutions of their own and produce their own but different final designs that satisfy the major requirements of the original problem statement. The general outcome of this kind of set up is that it involves healthy competition between the teams, team building, enjoying the fun, and in the end, learning from each other's ideas that fulfil the same original problem definition. Evaluation and documentation of all final designs for possible presentation at engineering forums and technical meetings is left as a task to the instructor.

In another scenario that the author followed, each individual student was asked to think and bring his/her own ideas (two or more), and present them to the entire class. They were asked to justify their own selection for its merits, foreseeable difficulties in the analyses (due to lack of enough subject knowledge, or tools), and the difficulties of procurement and fabrication, or the budgetary constraints (going over the limit of up to $300/group). In order to come up with their own ideas for the project, the students are encouraged to think individually using the 'pain-storming' approach, or think of non-confidential technical problems faced by them, their co-workers, or the employees at their co-op work. Additionally, they are asked to search on line resources to propose new ideas or design improvements of existing ideas and products. After this, each group will discuss among themselves to narrow down their individual choices (of 10 to 12 ideas for the entire group) to two or three ideas. These choices are discussed with the instructor for approval and for further brainstorming. Keeping more than one idea as a backup helps them in case of uncertainties that may happen along the way during the term. This kind of co-op experience is unique for KU students which is anticipated to provide value to the capstone course.

There are numerous papers available on ABET assessment of capstone design courses published in ASEE and IEEE and the other literature. Sibley School of Engineering outlined in a document the procedure they followed for assessing their capstone design courses [1]. Schmidt and Conrad developed a framework of instructions to be followed for satisfying the ABET-compliant capstone design courses [2]. Other departments such as electrical and computer science and engineering offer capstone classes and do the assessment following the ABET's criteria [3-5]. There are numerous other papers and references available on assessment of capstone design classes that the author used while teaching the class. Few of these will be discussed and presented by the author at the time of the conference.

Grading policies and Assessment

For the capstone, the instructor monitored students' progress throughout the term by weekly meetings of each individual group members. Grade break up was provided with the syllabus and detailed rubrics provided for the report. All in all, four editable documents were to be submitted by each group. These are: a formal report (as word file) using APA or other specified format for documentation, PowerPoint presentation slides, excel or matlab calculation files used for parametric studies, and the CAD/CAE part and simulation files that the instructor can edit, and/or reuse for other future capstone classes. Besides these, each group was asked to prepare neat posters for display at various campus events that take place at Kettering University. The fabricated devices are usually kept in a storage room for recycling of the material and/or to display the interesting designs in a show case for parents and other visitors. Some of these devices are also used for classroom purposes in other courses such as mechanics of solids, machine design, etc.

Grading Policy:

The final grade was to be based on:

- originality of idea and design, or, design improvements and/or modification(s) of an existing design, complexity of the problem chosen and its attempted analysis (i.e., multiple analyses – structural, dynamic (vibration), mechanisms & control, etc.), clarity of the work streams, and the quality of the communication (written & diagrammatic), etc. This was graded out of 300/400 points total.
- Good behavior, participation, punctuality. 100/400 points

Total: 400 points (100%)

Rubrics for the report:

The detailed rubrics for the assessment of the project have been discussed and posted on Black Board for the students' use. For each assessment category, the minimum 'requirements' and 'recommendations' were provided. These are:

- Cover page with proper title of the project, etc. 20/400
- Project brief containing team activities, topic selection, individual membership participation, and product design for analysis, etc. 60/400
- Project planning containing project complexity and work stream 100/400
- Analysis and report with CAD/CAE results, discussion of limitations, etc.100/400
- Design evaluation and conclusions 20/400
- Fabrication and testing of the device, comparison with simulations 90/400
- Peer and external evaluation by the technicians 10/400

Total: 400 points (100%)

The author followed similar grading policies and rubrics in the past and found this to be sufficient to evaluate each project report. It may be noted that the technician's evaluation based on the final presentations was very valuable since they were very familiar with the day to day progress made by the student groups in the shop along with the difficulties they faced while procuring the material, with the fabrication, assembly and testing of their design ideas.

Sample list of ideas proposed by each student for the project

Following is a partial list of ideas proposed by each member of two groups. In all, there were over 30 different ideas proposed by them. Their final choice was in bold face [6].

Ideas for project	Ideas for project
Drone position control	Closet hanging mechanism
Burr-less tube cutter	Automatic pet food dispenser
Fatigue modeling of differential	***Portable refrigerated cooler***
Extension cord power sockets	Pump action potato cannon
Portable washer/dryer	***Gooseneck hitch and tongue design***
Shower that reuses water	***2 DOF sun tracking solar panel***

Integrated stapler and date stamp	Portable desk
Solar powered charger	Slip clutch design
Adjustable kayak rack	Weighted rope machine

Sample project report

Adjustable and detachable Gooseneck hitch and trailer tongue for off-road vehicles [7]*:*

For the final project, one of the group's project work on gooseneck trailer assembly is presented here. Part of the work on this project was carried out by one of the group members as the final project for two independent studies [8]. Final project carried only 15% for each of those two course grades. One of the courses was advance machine design and the other was failure considerations in materials and design. Both these were taught by the present author and there was only one student who took those two courses for a total of 8 credits. Those courses covered many other traditional topics and assessed based on HW, exams, and a final project. Besides calculations and some finite element simulations, the main goal was to design the strength of the welded joints of the hitch structure, and then do the failure analysis using FMEA and other studies. For the capstone, redesign of the previous design ideas, detailed design of the assembly that is adjustable, finite element analysis (FEA) of the assembly including the welded connections, fabrication of the same and testing were the goal for the team. Each member of the capstone team contributed (although not equally) in brainstorming alternative designs, carrying more detailed machine design calculations of the final design, developing CAD and production drawings, fabrication of the assembly and testing. Figure 1 shows the final fabrication of the apparatus. No rigorous testing could be done due to limitation of facilities. However, they tested the integrity of the joints by hanging weights to the member on the right. Their report contained an outline of the testing procedure.

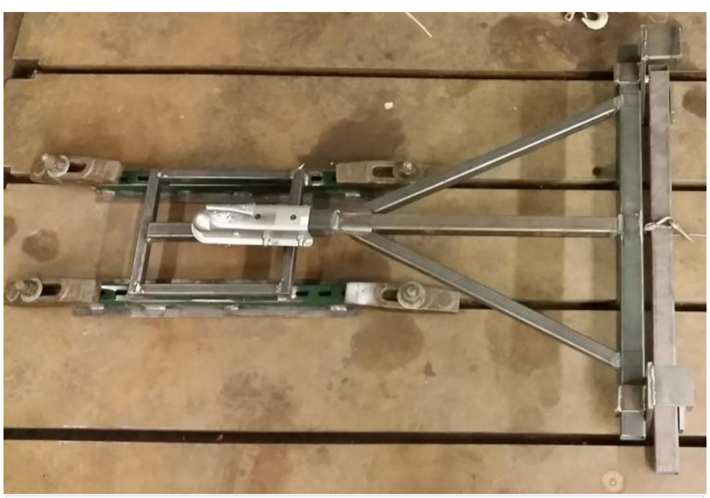

Fig. 1: Fabricated Gooseneck Hitch and Trailer [7]

Project description:

The gooseneck hitch and trailer tongue design will be utilized on off road vehicles, and will provide a convenient and easy way for the vehicles to tow if they do not already have towing capability. As mentioned before, parts of CAD and FEA were completed for the gooseneck hitch previously by one of the students of the group, so design changes were made and the trailer tongue was added on. Hand calculations were completed on the design, FEA analysis was completed, and then the design was fabricated and tested.

Figure 2 below shows the conceptual CAD design of the hitch.

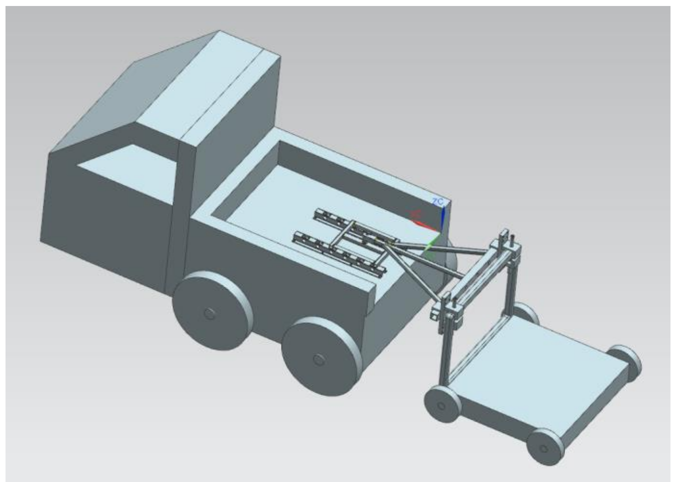

Figure 2: UTV attached to small trailer [7]

An example design of the hitch available in the market is shown in Figure 3 [9]. However, the gooseneck hitch and trailer tongue designed for this project allow for adjustable sizing and convenient use that is not currently available on the market. The previous gooseneck hitch design was completed by Blake White [8]. CAD and FEA work was completed on this design which can be seen in Figures 4 and 5. Several iterations of the work have been undertaken in all the projects and presented in the class on a weekly or bi-weekly basis. The students were also expected to document the knowledge used from other courses by listing those courses, knowledge gained from co-op work experience of each individual student, if any, new knowledge thru self-learning from the capstone project, and the overall lessons learned. Ethical issues behind producing safe designs and the impact of poorly designed projects on the society were also included in the report.

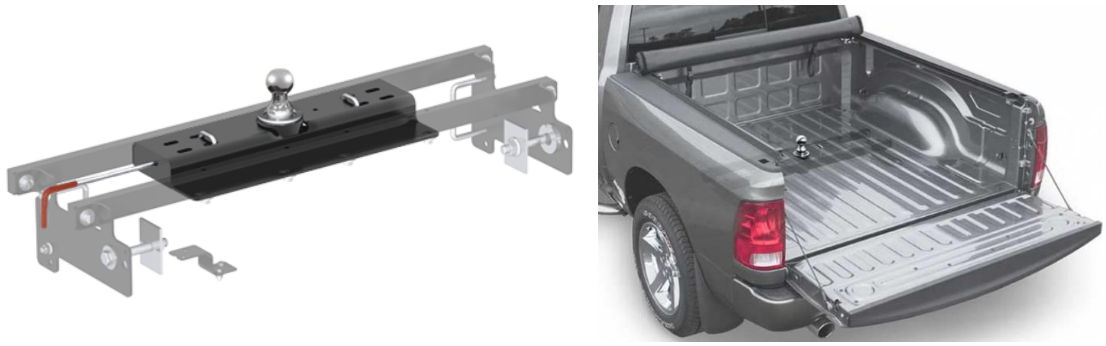

Figure 3: Gooseneck hitch before and after installation on a pickup truck [9]

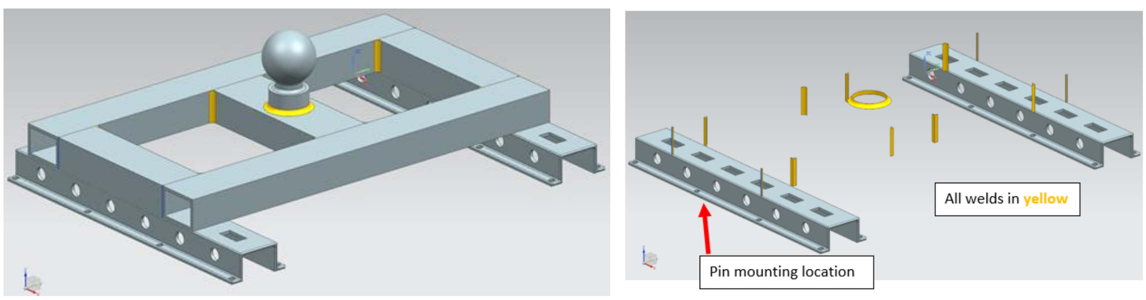

Figure 4: Previous gooseneck hitch design with welds [8]

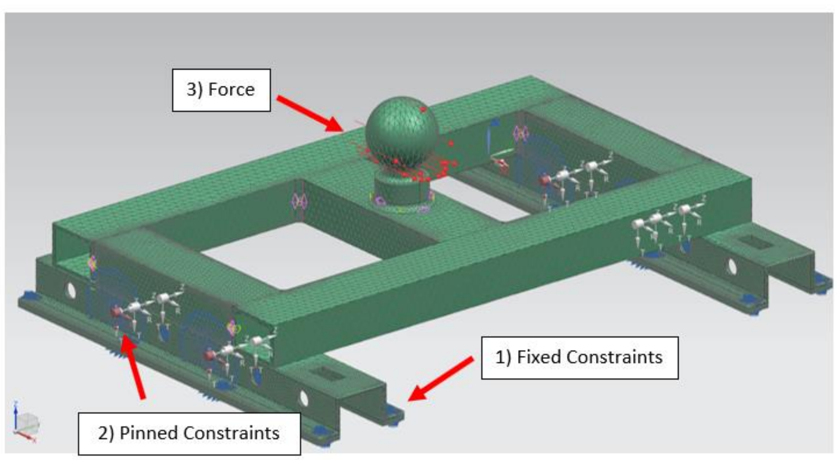

Figure 5: FEA analysis of the previous gooseneck hitch [8]

Assessment, observation and conclusions

The above concepts, topics and ideas have been carried in more rigor and content while teaching the capstone course. The overall average performance of the students was very good. Around 95% of the individual students participated in all aspects of the project. Being the first time this course was offered by the author at Kettering, more detailed assessment beyond what is presented in this paper could not be done. Also, more data may be needed for critical examination and to do better assessment in future.

Acknowledgements

The author wishes to acknowledge all students of the class. Thanks are also due to the laboratory technicians who provided full support to the students. Partial travel fund provided by Kettering University to attend the conference is sincerely acknowledged.

References

1. Sibley School Procedure for Assessing Capstone Design Courses – December 12, 2013.
2. Peter L. Schmidt and James M. Conrad (2012): "Capstone 101: A Framework for Implementation of an ABET-Compliant Capstone Sequence", Proceedings of ASEE 2012 Conference.
3. Ashraf Saad (2007): "Senior Capstone Design Experiences for ABET Accredited Undergraduate Electrical and Computer Engineering Education", Proceedings of ASEE 2007 Conference.
4. Paul Biney (2007): "Assessing ABET Outcomes Using Capstone Design Courses", Proceedings of ASEE 2007 Conference.
5. Phillips Agboola, et al (2012): "Assessing a decade old capstone senior projects through ABET accreditation program outcomes", Proceedings of Social and Behavioral Sciences, Volume 47, pp. 120 – 125.
6. Fall 2017 Mechanical Systems Design Capstone Class of Students.
7. Blake White, et al (2017), "Adjustable and Detachable Gooseneck Hitch and Trailer Tongue for Off-road Vehicles", Capstone final project, Fall 2017.
8. https://www.curtmfg.com/Category/56/Gooseneck%20Hitches
9. Blake White (2016-'17), Gooseneck Hitch Assembly Final Project Reports for MECH-412 and MECH-515 courses, Kettering University.