Newly Introduced Capstone Design Course for Mechanical Engineering Technology: Lessons Learned From Two Cohorts and Two Types of Projects

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Biographical Sketch

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Professional Preparation B.S., Mechanical Engineering, Yarmouk University, Jordan, 1987 M.S., Mechanical Engineering, JUST, Jordan, 1990 Ph.D., Mechanical Engineering, the University of Iowa, 1997 EMBA, (courses only, no degree) The University of Iowa, (2004-2005)

Appointments Academic: Assistant Professor Central Michigan University 07/14 - present Visiting Faculty Central Michigan University 01/14 – 06/14 Dean of Accreditation PMU, Al-Khobar, KSA 08/09-12/14 Adjunct Assistant Professor The University of Iowa 2000-2005 Lecturer National Community College, Jordan 1990-1992 Industry: Director of Engineering Gail Industries, Cedar Rapids, Iowa 1993-1997 Senior R&D Manager HNI Corporation, Muscatine, Iowa 1997-2005 Mgr., Product Dev. Eng. A.O. Smith Corporation, Tennessee 2005- 8/2009

Closely Related Publications • Emad Tanbour and Suleiman Ashur, Gap Analysis of Engineering Course Learning Outcomes using NCEES FE Exam, Abstract submitted and accepted to ASME 2015 International Mechanical Engineering Congress and Exposition, Huston, Texas Nov.13-19, 2015 • Butler, P. B., Tanbour, E., Rahman, S., and Smith, T. F., "Virtual International Design Teams," Proceedings of 2002 ASEE Midwest Section Meeting, Madison, WI, September 2002 Significant Other Publications • M. F. Alzoubi, E. Y. Tanbour and R. Al-Waked (2011), Compression and Hysteresis Curves of Nonlinear Polyurethane Foams under Different Densities, Strain Rates and Different Environmental Conditions, IMECE11 2011, Denver, Colorado, USA • E. Y. Tanbour (2011), Institutional Effectiveness, the Point Of View of Southern Association of Colleges and Schools (SACS), King Saud University, Feb 2011 • Emad Y. Tanbour, Rafat Al-Waked and Mohamed F. Alzoubi, Experimental Study of a Waste Heat Recovery System for Supplemental Heater, Energy and Sustainability, April 2011, Spain • Ramin K. Rahmani, Anahita Ayasoufi, Emad Y. Tanbour and Hosein Molavi, Enhancement of Temperature Blending in Convective Heat Transfer by Motionless Inserts With Variable Segment Length, Journal of Thermal Science and Engineering Applications, September 2010, Vol. 2 • Ramin K. Rahmani, Emad Y. Tanbour, Anahita Ayasoufi and Hosein Molavi (2009), Enhancement of Convective Heat Transfer in Internal Compressible Flows by Stationary Inserts, Journal of Thermal Science and Engineering Applications MARCH 2010, Vol. 2 • Emad Y. Tanbour, Ramin K. Rahmani and Anahita Ayasoufi (2009), Large-Eddy Simulation of Turbulent Flow Through Small Gage Gas Appliance Orifice, Proceedings of IMECE 2009, Lake Buena Vista, Florida, USA • Emad Y. Tanbour and Ramin K. Rahmani, (2009), Enhancement of Temperature Blending in Convective Heat Transfer by Motionless Inserts with Variable Segment Length, IMECE 2009, Lake Buena Vista, Florida, USA • Emad Y. Tanbour and Ramin K. Rahmani, (2009), A Numerical Study of the Thermal Performance of Two Stationary Insert Design in Internal Compressible Flow, ASME Summer HT2009, San Francisco, CA, USA

Awards and Honors • Arch T. Colwell Merit Award, Society of Automotive Engineers (SAE) USA, 2001 • Ph.D. Scholarship Award, JUST, 1992-1997

Synergistic Activities • Introduced Computer Aided Design for elementary and middle school children (2005-2009) • Supervised 30+ design/research projects involving 83+ undergraduate students • Hosted numerous outreach programs for 2000+ pre-college students • Combustion Institute KSA Country Chapter founding member • Supervised three annual teams of international design exchange students from France conducting research/design at U of Iowa and Industry • Served as industry liaison between U. of Iowa and HNI Corporation for nine years • Served as a member of industry advisory board for College of Engineering at the U. of Iowa representing HNI • Reviewer for Energy and Sustainability Journal since 2010 • Developed and implemented three strategic plans to earn KSA national, ABET and SACS accreditation for PMU, KSA (2009-2013) • Conducted Specialized ME training on numerous industrial applications for major oil/gas corporations worldwide (2009-2013) • Serving on the advisory board of Center for Computer Aided Design, U of Iowa (2003-present) • Tens of industry consulting services in the areas of product design, development over the past 25 yrs.

Dr. Molu O. Olumolade, Central Michigan University

An Associate Professor of Engineering and Technology with Central Michigan university; received first and second degrees from NCA&T and doctorate degree from the University of Calgary. He has been engaged in teaching for more than a decade and has more than 20 years of industrial experience in plant engineering. His research and publications are in the areas of manufacturing scheduling, design for manufacturability and assembly (DFM/DFA) and preventive maintenance.

Dr. Oumar Rafiou Barry, Central Michigan University

Dr. Barry graduated with a Bachelor degree in Mechanical Engineering with Honors in 2008. In June 2008, he joined Hydro One Inc. where he worked as design Engineer for seven years. During his employment at Hydro One Inc., he obtained a Master of Applied Science (MASc) and a PhD degrees in Mechanical Engineering in 2010 and 2014 from Ryerson University and the University of Toronto, respectively. Dr. Barry's research has been focused on mechanical vibrations; including wind induced vibrations, energy harvesting using piezoelectric materials, optimization of engine mounting systems for noise and vibration reduction. In July 2015 he joined the University of Central Michigan as an assistant professor in the School of Engineering and technology.

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Abstract

This paper demonstrates the experience of teaching newly introduced capstone design course for two consecutive Mechanical Engineering Technology graduating cohorts at the authors' School of Engineering and Technology. The newly introduced capstone design course was taught for the first cohort utilizing one internally sponsored project assignment for the entire cohort, while the second cohort experienced five different project assignments three of which were industry supported, and the remaining two projects were internally supported. The paper highlights the methodology of delivering the capstone design course during both years and compares and contrasts design experiences between internally and externally sponsored capstone design projects. It will be shown quantitatively, in this study, that industry sponsored projects provided better opportunities for students to receive real-life project experience while introducing a different level of challenges for faculty and school. Classes were divided into teams and the team-based assessment used is also captured in this work. Assessment instruments embedded into the capstone design course are also discussed and level of success is demonstrated in view of ABET a-k outcomes emphasized throughout the course. The paper concludes with recommendations to continuously improve industry-sponsored capstone design projects with an emphasis on Mechanical Engineering Technology cohorts.

Overview of the Capstone Design Course

This capstone course was approved through the curriculum system of the School of Engineering and Technology in 2013. The course is a one-academic semester course usually offered during spring semester and is offered as a required course for Engineering Eechnology undergraduate programs. The programs include Mechanical Engineering Technology (MET), Product Design and Development, and industrial engineering technology majors. The first cohort went through this new course in the spring of 2014. The second cohort was in the spring of 2015. Although the class is a mix of all technology majors, MET constituted more than 80% of the students due to enrolment distribution in the School of Engineering and Technology. As a standard capstone assessment course, this newly introduced course was aimed at assessing the following learning outcomes[1]:

1. Analyze an industrial-based problem,
2. Describe and apply decision-making processes appropriate to industrial problems.
3. Apply and exhibit an understanding of tooling design, prototyping, process planning, production planning and control, quality control, safety, and project management with regard to an industrial project.
4. Develop an effective working relationship with team members with different technical backgrounds and with an industrial client to determine how to solve problems.
5. Synthesize solutions to industrial problems in order to develop designs and build prototypes.
6. Develop technical reporting skills (oral and written) as they apply to the industrial environment.
7. Develop a systems approach to solving industrial problems.
8. Demonstrate ability to incorporate standards and industry compliance requirements in the engineering design process.
9. Demonstrate understanding of ethics in engineering and technology practice.
10. Demonstrate ability to apply sustainability analysis to engineering design.

The above learning outcomes were mapped against ABET a-k for ETAC criteria of 2014-2015 cycle[1] and recently revised for the 2016-2017 cycle criteria by the MET assessment committee with the School of Engineering and Technology (SET).

Course Curriculum Focus Skills

The curriculum of the capstone course is developed to satisfy assessment of the level of success of the technology programs in satisfying ABET ETAC a-k criteria[1] that are not assessed thoroughly by other program required courses. Although the list of learning outcomes are assessed during the course delivery, the following major areas of earned skills are emphasized and assessed in reference to best practice research [3, 4,5, 6]:

1- The process of design of mechanical components and assembly as it is applied to an industry sponsored project
2- Practical application of taking a design project from concept to production
3- Ability to work in teams
4- Oral and written technical communication skills
5- Safety, sustainability, engineering ethics and applying standards during the design process

In spring 2014, the entire cohort was assigned one design project. Class was divided into teams and each team was working on the same design project assignment. The teams were asked to design and prototype a metal work bench vise. The above five areas of skills were assessed and teams used SET machine shops to prototype the projects. The experience of industry sponsored projects was not available due to the fact that there was little time between approving the course into the curriculum and offering it that spring. Due to the one project assignment, assessment process undergone a standard course experience and no external feedback (third party) assessment of the success was possible.

During spring of 2015, five projects were assigned three of which were industry sponsored. The other two projects were internally assigned with one assigned to SAE Formula 1 car and the other was assigned to Baja team of SET. The three industry sponsored projects were tapped from regional manufacturing companies. The breakdown of the five projects were as follows:

Internally assigned:

1- SAE Formula 1: This project aimed at designing pillow blocks for main bearing on the SAE Formula 1 car.
2- Baha car: Design, prototyping and testing of the suspension system

Industry sponsored:

1- Redesign of a knife grinding machine for wood chipping equipment
2- Design of diecast aluminum office table's legs
3- Reverse engineering methodology for perforate and expanded sheet metal

Course Management Approach:

The capstone course was managed using the following approach:

During spring of 2015, the class met twice a week for two hours sessions dedicated to team related project tasks and one time a week for class related lectures and course management. Industry sponsored project teams were engaged in biweekly teleconference with the sponsoring company, and when possible, on-site visits were facilitated at least for sponsors within reasonable driving distance from SET. The weekly breakdown of tasks for the class are listed in table 1 and the following are major definitions of assessment instruments that were embedded into the course:

- **Project Journal:** The maintenance of a bound design project journal is a requirement of the course by each team member.
- **Teamwork (Peer-assessed):** At least twice in the semester students are requested to complete a written evaluation of team members' performance.
- **Project Portfolio:** This is an ongoing maintenance of a project portfolio. Records of team meetings, and updated plans for upcoming work are maintained in the portfolio, and

are reviewed in project meetings with the instructor and industry's sponsor. Standard contents of the portfolio reflects all proceedings of the team work on the project. Such proceedings include weekly design review meeting notes, conceptual ideas and sketches, diagrams or pictures of the design progress throughout the project, weekly project progress one-page reports, Gantt charts, intermediate and final reports, presentations and all relevant project planning, communications, and execution documentation.

- **Formal Documents:** Throughout the semester, **Formal Documents** are required by each team. Such documents should be formatted with professional style and carry a team logo, a cover page, and serve as a building block towards the preparation of the Team's final report. Professional technical writing styles are observed in these **Formal Documents**.

- **Final Project Poster**: Each project team prepares a final project poster to be submitted and exhibited during week 16. Guidelines and templates for the poster are provided during the course lectures.

- **Professional Topic Assignment:** Two professional topics assignments are given to each student. Assignments targets three areas of learning outcomes which are: Safety and engineering ethics, sustainability and using standards in mechanical design.

Table 1: Weekly Schedule of Course Delivery

Week	**Activity**	**Comments**
Week One	Introduction to IET 499 Assignment of Team and Projects Ethics in Engineering and Technology Rough Gantt Chart For the Project	• Possible Meeting/teleconferencing with Industry Sponsor (if applicable) • Rough Gantt Chart due by Wednesday 5 PM
Week Two	Standards and Compliance in Engineering Design Team Status Review and Project Plan, Refinement of Problem Statement, Refinement and formalizing of requirements Bi-Weekly Design Review meeting/teleconference with industry sponsor	• Start building project portfolio binder • Bring project journal bound notebook • Bi-weekly review with industry sponsor is to be completed before Wednesday 4PM • Weekly one page progress report due Wednesday 4 PM
Week Three	Sustainable Engineering Design Status Review and Process Coaching **Formal Documents Submission:** Design Problem Statement Conceptual and Detail Design - Ongoing	• Weekly one page progress report due Wednesday 4 PM • **Formal documents** due Wednesday 4 PM
Week Four	Conceptual and Detail Design - Ongoing	Weekly one page progress report due Wednesday 4 PM

	Bi-Weekly Design Review meeting/teleconference with industry sponsor 1st Professional Topics Assignment is distributed	
Week Five	**Oral Presentation: PPT on the following:** • Project Status Review • Conceptual and Detail Design - Ongoing	• Weekly one page progress report due Wednesday 4 PM • Attach your Oral Presentation PPT to your Weekly one page progress report
Week Six	Detail Design – Ongoing Bi-Weekly Design Review meeting/teleconference with industry sponsor **Formal Document Submission:** • Refined Statement of Success Points • Attach exhibits of success points	**1st Professional Topics Assignment Due by Wednesday 4 PM**
Week Seven	**Formal Document(s) Submission** • Bill of Materials • Dimensioned Part Drawings • Midterm Peer Evaluation Survey	• Weekly one page progress report due Wednesday 4 PM • Midterm peer evaluation surveys are due Wednesday 4 PM
Week Eight	Critical Parts Review **Midterm Review, Written and Oral** Bi-Weekly Design Review meeting/teleconference with industry sponsor	• Weekly one page progress report due Wednesday 4 PM • Midterm Project Report and PPT due Wednesday 4 PM
Week Nine	SPRING BREAK	
Week Ten	Status Review and design refinement Prototyping (if applicable) 2nd Professional Topics Assignment is distributed	• Weekly one page progress report due Wednesday 4 PM
Week Eleven	Status Review and design refinement Prototyping (if applicable) Bi-Weekly Design Review meeting/teleconference with industry sponsor	• Weekly one page progress report due Wednesday 4 PM
Week Twelve	Status Review and design refinement Prototyping (if applicable)	• Weekly one page progress report due Wednesday 4 PM • **2nd Professional Topics Assignment Due by Wednesday 4 PM**

Week Thirteen	Status Review and design refinement Prototyping (if applicable) Bi-Weekly Design Review meeting/teleconference with industry sponsor	• Weekly one page progress report due Wednesday 4 PM
Week Fourteen	Status Review and design refinement Prototyping (if applicable)	• Weekly one page progress report due Wednesday 4 PM
Week Fifteen	Finalizing Project Plan Work on Team Final Report and PPT Presentation Final Peer Evaluation Survey	• Weekly one page progress report due Wednesday 4 PM • Final peer evaluation surveys are due Wednesday 4 PM
Week Sixteen	**Formal Document(s) Submission:** • Final Report, PPT, Final Project Poster and Oral Presentation • Presentation to Industry's Sponsor (if applicable)	**Formal Documents** Due Wednesday 4 PM

Summary of capstone projects used in the spring of 2015:

Five projects are assigned in the spring of 2015, three of which were industry sponsored, one SAE Formula 1 and One Baja car project. The following is a brief summary of the five projects:

Knife Grinder Redesign: This is an industry sponsored project aimed at providing a redesign of a knife grinder used in industry to sharpen knives used in wood chipping equipment. The redesign requires students to come up with a more efficient mechanism to mount knives on the grinder and to provide a simpler method to articulate certain mechanisms within the grinder. Figure 7 shows a pictorial of the final assembly of the grinder redesign. Students were able to spend quality time at sponsor's location and made frequent visits to the sponsor. A lead engineer from the sponsoring company was assigned to interface with the team. Lessons learned from this project are captured in following sections.

Reverse Engineering of Expanded Sheet Metal: This was the second industry sponsored project and it was aimed at developing a reverse engineering methodology for perforated expanded sheet metal. Students interacted virtually with industry sponsor since it was an out of state company. The project was executed by utilizing precision visualization and magnification measurement process that is automated to produce CAD content from actual perforated and expanded metal samples. Lessons learned are captured later in this paper. Figure 8 shows a pictorial of the final assembly

Diecast table's legs: This is an alternative material design project sponsored by a major office manufacturing company. Students were tasked to design a commercial grade table legs from diecast aluminum alloy originally made from fabricated steel components. The sponsor is an out of state company and virtual interaction with the sponsor was the method used in this project. Figure 9 shows a pictorial of the final assembly

Baja and SAE Formula 1: These are the two projects internally sponsored by SET. Figure 10 and 11 show a pictorial of the final assembly designed for Baja and Formula 1 respectively. Lessons learned from this project are captured later in this paper.

Assessment Methodology and Outcome:

During the spring 2014 first experience with this capstone course, standard breakdown of course tasks were employed. Professional topics (safety, ethics, sustainability and standards in design), peer-reviews and midterm and final oral presentations were emphasized during spring 2015. Table 2 shows the breakdown of assessment parts used in spring 2015. Although the assessment methodology focused on having part of the assessment individually assigned, majority of the assessment outcome was driven by team progress to emphasize team work learning outcome.

Table 2: Assessment breakdown of tasks:

Assessment	**Individual**	**Team**
Final Report (written)		30%
Midterm Report (written)		10%
Project management and schedule conformance		15%
Professional Topics Assignments	15%	
Final Design Report (oral with ppt)*	10%	
Teamwork (peer-assessed)	10%	
Midterm Report (oral with ppt)*	10%	
Total	**45%**	**55%**

**Student individual Journal is included in the assessment of the grade*

Project teams outcome of the above assessment methodology for four teams in spring 2015 are summarized in Figures 1 to 6 shown below. The fifth team is removed from these figures due to the fact that the team was comprising of only two students who had diverging performances during this class.

Figures 1 to 3 indicates individual student's performance under the three assessment instruments of two professional topics and midterm oral presentation. Student's midterm oral presentation is aimed at following best practice of mentoring capstone projects[3]. Student's performance on peer review has improved between midterm and final review questionnaires indicating the importance of peer review on improving student team work contribution. Best practice[3] and recent research on semester-long engineering capstone projects[4] were followed in the spring of 2015. There is a little compelling evidence in Figure 5 that students tend to perform better in project management instruments than other individual instruments. The individual student benefited from project management activities more than getting individual instruments satisfied. The final presentation individual performance indicates the independence observed in figures 1 to 3.

Figure 1: Assessment Outcome of Professional Topic 1: Engineering Ethics

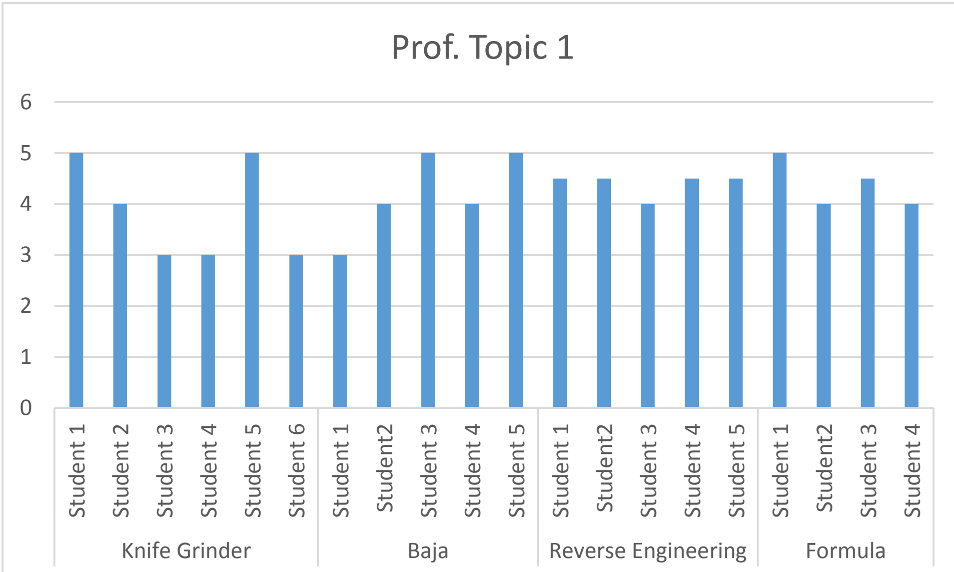


Figure 2: Assessment Outcome of Professional Topic 2: Sustainability in engineering Design

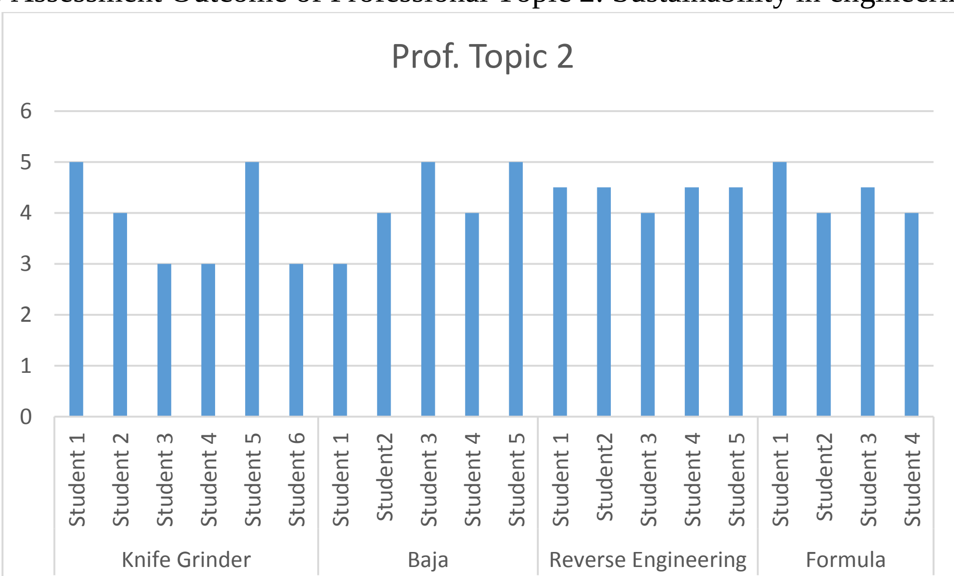


Figure 3: Assessment Outcome of Midterm Oral Presentation

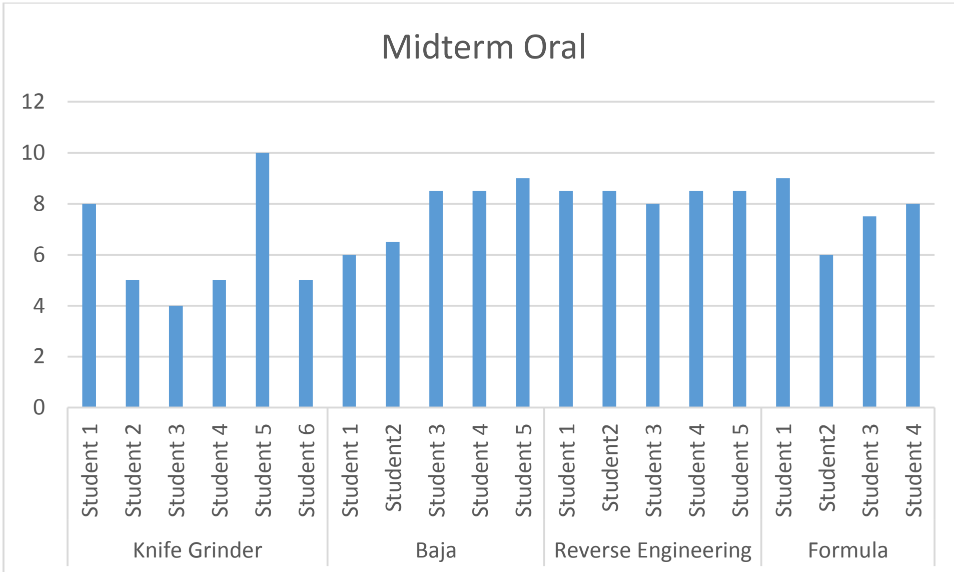


Figure 4: Assessment Outcome of Peer Review Questionnaire

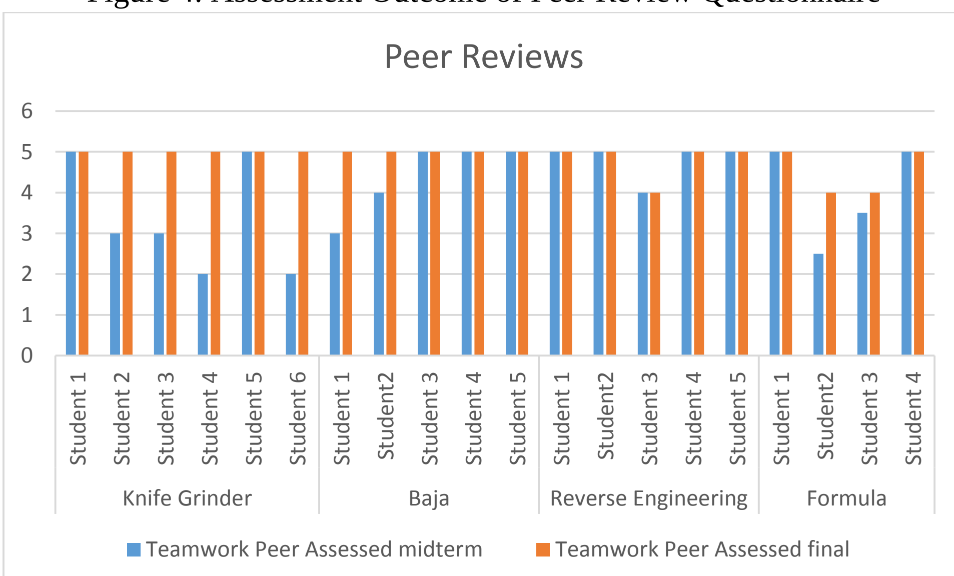


Figure 5: Assessment outcome of team project management

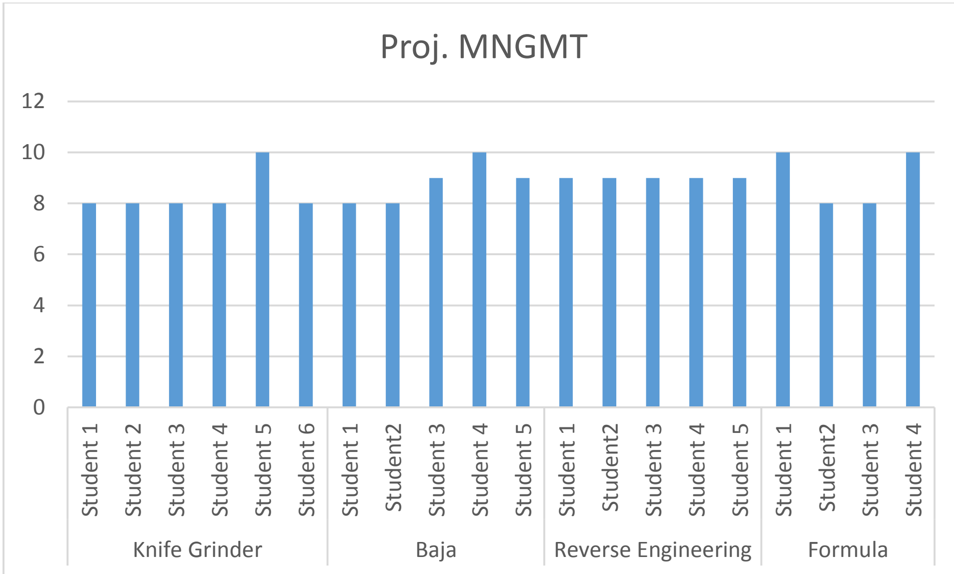
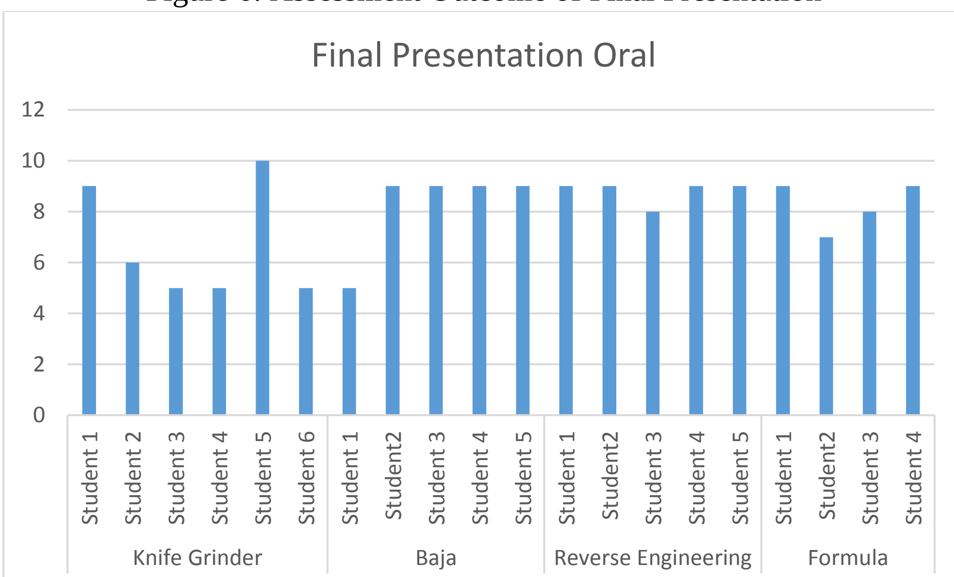


Figure 6: Assessment Outcome of Final Presentation



Lessons learned from the two cohorts:

Although the first time offering of the capstone, in the spring of 2014, was instructed by a senior member of SET faculty with strong background in manufacturing, the fact that industry sponsorship was absent made it difficult to assess other learning outcomes of this course. In specific, the third-party industry sponsor feedback on the level of success of the project was missing. To improve the course delivery, industry-sponsored projects are emphasized during the spring of 2015 to secure third-party feedback on the success of the capstone project. This is also called closing the loop of continuous improvement of curriculum development process[2]. The following are observations of the level of success in each the 5 focus skills listed earlier in this paper of the capstone projects of the spring of 2015:

1- The process of design of mechanical components and assembly as it is applied to an industry sponsored project:
   This applied to the three industry sponsored projects listed before. In all three projects, students demonstrated the ability to design mechanical components and assembly using engineering approach. The project that allowed students to visit the industry sponsor on a frequent basis made more progress on getting to a production level detailed design and prototyping while projects that interacted virtually produced satisfactory outcome design details but with limited ability to see the final production process.
2- Practical application of taking a design project from concept to production:
   This focus skill was assessed throughout the semester for all five projects. Most impact on the success on this focus skill was observed through documentation of weekly design review meetings, using individual student project journal and team portfolio build up. Successful outcome in this skill was observed in all five projects. Lesson learned in this skill is to mentor the students of all projects on week 1 of the semester on the importance of translating ideas of design into an evolution of conceptual illustrations. Instructors and project mentors with strong abilities to illustrate design ideas play an important role to kick-start conceptualization process for project teams.
3- Ability to work in teams:
   This focus skill was emphasized in all five projects. Lesson learned from this cohort is that instructors and mentors should detect team moral variation as early as possible and intervene to remedy any sources of lowering team moral. Teams made out of more than five seniors tend to increase the possibility of unequal distribution of project burden. This can force some team members to evolve into least contributing to the team outcome.
4- Oral and written technical communication skills
   Midterm and final oral presentations provided excellent assessment opportunity for instructors and industry sponsors. Feedback half-way through the project provided improved performance for 80% of team members across the cohort in regard to presentation skills and leadership skills.
5- Safety, sustainability, engineering ethics and applying standards during the design process
   This set of skills was assessed through individual student assignments in addition to assessing team adherence to applicable standards pertaining to the specific project. Lesson learned from this cohort is that most projects selected were having great opportunity to seek applicable engineering and industry standards to implement during the design process. One project had challenges in finding applicable standards due to the fact that the design is related to a process narrowly controlled by few players in the industry. To remedy this challenge, students were mentored to utilize applicable standards pertaining to over the shelf items that were included in the completed assembly of the design.

Conclusions:

This paper highlights the challenges of mentoring a fairly large cohort of engineering technology seniors during the capstone design course. The paper emphasizes the outcomes of the second cycle experience due to the diversity of projects assigned to the spring of 2015 cohort and the application of lessons learned in spring 2014 cohort. In the process of delivering new introduced capstone design courses, engineering technology programs should consider best practices published in the literature such as ASEE and other sources to increase the learning curve of the program and to improve the success rate of project teams. This paper presented out SET's experience in rolling out a new capstone design course and reaping strong indicators of success in just two consecutive cycles. Thanks, in part, are due to applying best practices in curriculum development and mentorship of graduating engineering technology seniors.

Pictorial views of capstone projects of spring 2015:

Figure 8: Pictorial view of the knife grinder project:

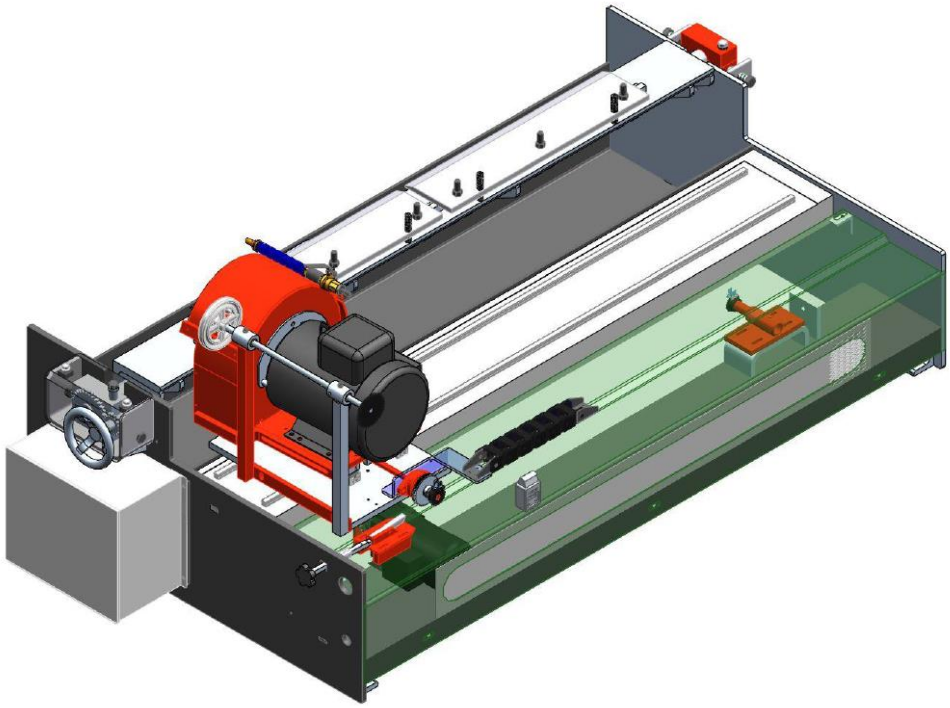


Figure 9: Pictorial view of the reverse engineering CAD model:

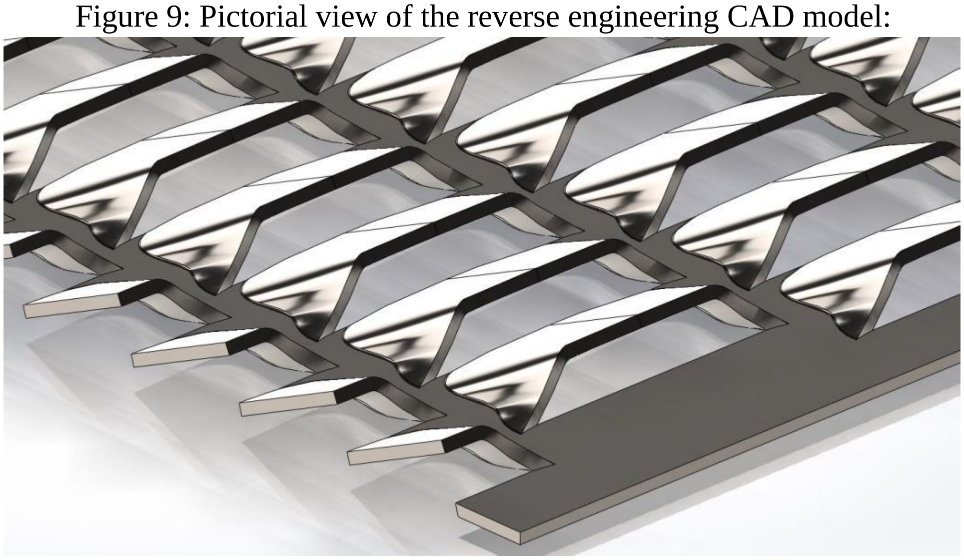


Figure 10: Pictorial view of the diecast table legs:

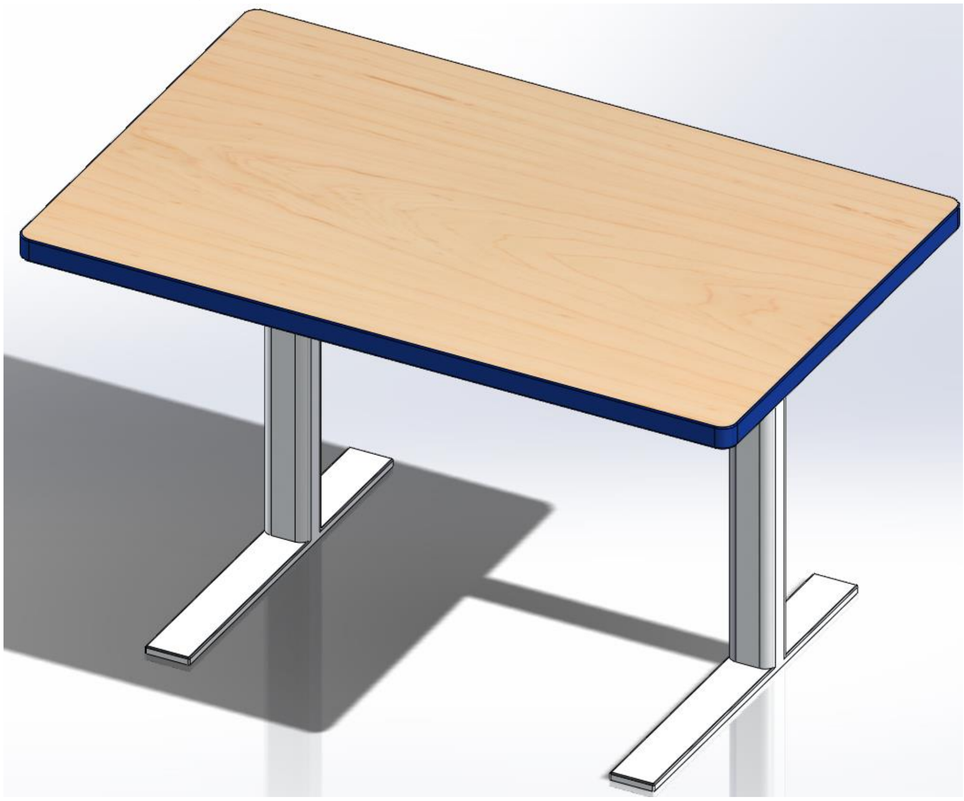
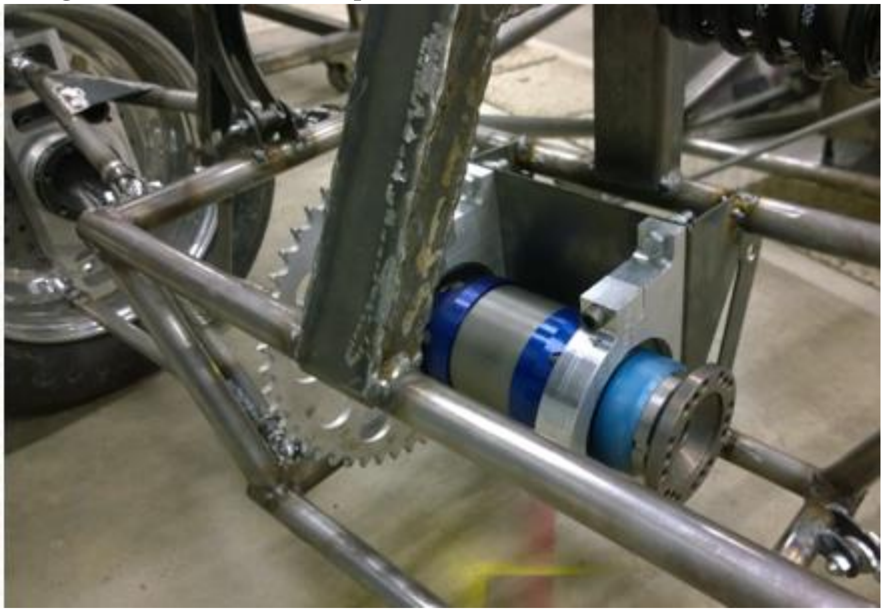


Figure 11: Picture of the Baja car showing suspension:

Figure 12: Picture of the pillow block for the SAE formula one:



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