A PROJECT-BASED CAPSTONE ENGINEERING DESIGN COURSE FOR ASSOCIATE DEGREE MECHANICAL ENGINEERING TECHNOLOGY STUDENTS

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Abstract:
All the associate degree mechanical engineering technology (2MET) students at The Pennsylvania State University, Altoona College are required to take a capstone engineering design course during their fourth semester in the two-year degree program. This project-based three credit-hour course is titled “Product Design with Writing Skills” (MET 210W). In this course students are taught design and selection of spur gears, shafts, helical compression springs, chains and sprockets, keys and fasteners, through team-based assignments and mini projects. These activities prepare students for the major design project to be conducted near the end of the MET 210W course.

The major design project assigned to the MET 210W students involves design and analysis of a transmission system for an SAE Mini Baja vehicle. Each student design team consists approximately of 10-12 students. It is expected that the use of large groups to conduct their design project would mimic a real-life industrial engineering design situation.

This manuscript describes the instructional approach used to teach this project-based capstone engineering design course. Detailed information regarding the activities conducted in MET 210W is provided. Finally, the assessment techniques used in this course are described.

Introduction
The engineering education community has shown increasing interest in project-based learning approaches. The benefits of project-based learning include enhanced student participation in the learning process, enhanced communication skills, addressing of a wider set of learning styles, and the promotion of critical thinking.\(^1\) The authors feel that the use of engineering design and analysis projects provide students with a wider context to the material presented in the lectures. A literature survey provides information regarding implementation of project-based instruction into several freshmen engineering/engineering technology type courses.\(^2,3,4,5,6\) Teaming skills are also taught and learned through completion of group projects.

Product Design (MET 210W) is a fourth semester writing intensive capstone engineering design and analysis course for students enrolled in the 4\(^{th}\) semester of an Associate Degree Mechanical Engineering Technology Program offered by The Pennsylvania State University. In this three credit-hour course, engineering design and analysis principles are taught through team-oriented design projects supported by communication skills: graphical, oral, and written.

The major goal of the course is to provide each student with the procedures to properly design and select machine elements normally found in mechanical systems. These elements include key design and analysis, roller ball bearing selection and analysis, chain
and sprocket selection and analysis, linear helical compression spring design and
analysis, spur gear design, selection and analysis, transmission power shaft design and
analysis, clutches and brakes selection and analysis, and bolts/fasteners selection and
analysis. A final Speed Gear Reducer Design/Analysis Project for possible use in the
SAE Mini Baja vehicle is assigned mid semester with a completion date during the last
week of classes. A written project proposal with function and design requirements and
progress reports must be submitted by each group. A detailed final report is also required
by each group. The final capstone project requires students to apply almost all learned
course knowledge and techniques in the completion of the design and analysis of the
speed gear reducer. Interaction with commercial vendors is also encouraged in selecting
components.

This paper focuses on the instructional activities used to teach this project-based capstone
engineering design course. Descriptions are given of each activity with assessments and
feedback techniques. Special emphasis is placed on unique features that other faculty
may find helpful in their own endeavors of teaching engineering design and selection of
machine elements for mechanical systems.

MET 210W Course Structure and Assessment
MET 210W is a three credit hour course that meets for 5 hours a week and is divided into
lecture and laboratory time. As stated above it is the goal of the course to provide each
student with the necessary concepts and procedures to properly design and perform
analysis of common machine elements in mechanical systems. Prerequisites for the
course include statics, strength of materials, kinematics, and dynamics. Some sort of
AutoCAD or Pro-Engineer software experience is also necessary along with MS-Office
skills in creating engineering drawings and reports.

The text book used in the course is *Machine Elements in Mechanical Design, 4 th edition*,
by Robert L. Mott, 7. The authors feel this text does a great job in addressing all the
issues involved in mechanical design and analysis of machine elements and is very
readable by the students. The authors have even received comments from past graduates
praising the text and how they are still using it in their present positions. Moreover, there
is an extensive reference section at the end of each chapter if further information is
needed on the subject matter. Mr. Mott’s text begins with the initial steps in the design
of a speed reducer transmission with explanations of function statements, design
requirements for evaluation criteria and builds to the compete analysis of all the
components of the speed reducer including spur gears design and analysis, shaft design
and analysis, bearing selection criteria, bearing mounting and speed reducer housing
construction.

Grading for the course is based on weekly quizzes related to individual course topics,
group project reports related to individual course topics, and a final capstone design
project that includes a group project proposal, 2-3 group progress reports and the final
group report covering all the steps in the design and analysis of the speed gear reducer.
Students all receive the same grade for group reports of individual topics.

For the capstone design and analysis project of the speed gear reducer, students are given
a chance to evaluate individual group members through the use of an assessment form
that lists all group members. The students are asked to assign a number between 0-10 for
each group member and write any comments concerning other student’s performances.
within the group on the form. The results are kept confidential and are used in
determining the percentage of the each student’s grade for the final capstone project. The
capstone project normally is 10-15% of the student's final course grade.
The authors have found the students to be honest in assessing other student’s
performance in their own group. We did not find evidence of the buddy system where all
group members would give each other overly high marks in group participation. Instead
the author’s consistently found that if one or two group’s members were lacking in their
effort toward finishing their assigned portion of the project, several group members
would give them very low marks in the 0-5 range, with 10 being a prefect score. Extra
consideration was given to comments made by group leaders about individual group
members. We also ask students to write about their experiences of working on a large
group design project in the form of an inter office memo. The authors found that most
comments were favorable in nature with students emphasizing the real world feel the
project had and the large group interaction skills they developed during the project. Also
in large groups the students seem better prepared to help each other in understanding the
technical material used in the project.
Lastly students are required to write 2-3 short papers during the semester with topics of
their own choosing provided the topic is related to machine elements and design.

**SAE Mini Baja Vehicle**
The Penn State Altoona College has a Student Section of American Society of
Mechanical Engineers (ASME). It is this student organization each year that designs and
builds from scratch an off road type vehicle called the Mini Baja. This vehicle is powered
by a 10 hp. Briggs and Stratton 4 cycle engine. The event is actually organized and
administered by Society of Automotive Engineers (SAE). The car must meet specified
safety regulations and is equipped with a roll cage. The car is raced in early June of each
year over a two day period in 4 different events. These events include an acceleration
test, a tractor pull test, a hill climb test and a 4 hour off road endurance race.
Approximately 100-130 engineering and engineering technology schools compete in this
event each year. The Altoona College Baja vehicle uses commercial shock and springs,
wheel and tire assemblies, torque converter, drive chain and sprocket system, and brakes.
The frame, suspension system, steering linkage, brake and accelerator pedals, seating
compartment and roll cage are all designed and fabricated by the students from steel
tubing and welded and bolted together. There is a multidisciplinary approach used in
building the car at the Penn State Altoona College with Art students creating and building
fiberglass body coverings for the car. The Mini Baja Vehicle Competition also requires
the students to submit a report showing their design calculations.
Students are initially exposed to the Mini Baja Vehicle in their first semester of the two
year Mechanical Engineering Technology program through an introductory engineering
graphics course. The students are required to design an accelerator pedal for the car and
create a set of working drawings using AutoCAD software. The students usually see the
Mini Baja car again in their third semester through a three credit hour kinematics and
dynamics course, MET 206. In this course the current transmission system of the vehicle
is used as a class example. Lastly during their fourth and final semester of the MET
program, students once again visit the Mini Baja car within the confines of the MET
210W Product Design course. In this course students study the multiple sprocket chain
secondary reduction system, and also the helical compression springs of the suspension system.
The Mini Baja Vehicle affords a unique opportunity for the faculty to introduce and show actual examples of course theory through strength and engineering analysis of existing components of the car such as the helical compression springs used in the suspension and the sprockets and drive chain secondary reduction system. Original design of the Mini Baja speed gear reducer transmission system or analysis of an existing transmission system is also done in MET 210W using the Mini Baja car.

**MET 210W Description of Topics Activities**
The topics covered in MET 210W Product Design course include the following: key design and analysis, rolling contact ball bearings selection and analysis, roller chain and sprocket selection and analysis, linear helical compression spring design and analysis, spur gear design and analysis, ANSI power transmission shaft design and analysis, bolt and fastener selection and analysis. A capstone design project speed reducer combining most of the above machine elements is also completed and is described in the section below. Other topics also covered but not specifically related to machine elements are Mohr’s Circle of Stress, theories of failure, and combined loading of beams structures. In covering these above topics the authors normally cover the material in a standard lecture classroom setting and then assign a small group project that requires the student teams to perform an analysis of an existing machine element component. Where needed a class visit is made to the Engineering Project Laboratory to see the Mini Baja vehicle and use it as a class example, showing the machine component being studied in the lecture class. The students really seem to enjoy getting to touch actual examples of the machine components they just studied in the classroom. We also require the students to research and locate commercial vendors of selected machine components such as spur gears or helical compression springs and then perform suggested analysis and sizing as listed in the manufacturer’s product literature. The manufacturer’s literature sizing or strength analysis results are then compared with their textbook theoretical analysis results. In most cases the two methods show good agreement and hence the students gain confidence in their abilities as design engineers.

We have even taken this technique one step further by having the student teams phone the manufacturer and discuss their calculations and findings with actual engineers from the component manufacturer. It was extremely exciting for the students to talk with professional engineers about topics they were studying in class. This exercise seemed to generate much enthusiasm and gave many students a great deal of self motivation for the remainder of the project. This experience also gives students good practice in developing oral communications skills needed in real world engineering and manufacturing environment where parts will need to be sized and ordered from commercial vendors.

The students also realized through this exercise that not all sizes of components are available and compromising is sometimes necessary in producing a finished product. It is also hoped that this will help engineering students move away from the common pitfall of looking for the one right answer to a given problem as taught in their prerequisite science and math courses. We feel this exercise will help students understand and realize that there are sometimes many acceptable solutions to a given
engineering problem and economics can and do enter into design decisions and component selections.

**Capstone Design Project**

The capstone design project is the design of a speed reducer for possible use in the current or future Mini Baja vehicles. The final project may also take the form of an analysis of an existing speed reducer gearbox already in use on the Mini Baja vehicle. One unique feature of this final project is the large group size that is employed in completing this project. The MET 210W class of 20-25 students is divided into two large design teams of 10-12 students. In using large groups to conduct their final design project, the authors are attempting to mimic a real-life industrial engineering design situation in scope, logistics, and people management. It should be noted that most of the large groups decided to divide themselves into smaller sub-groups and assigned individual components of the projects to these smaller sub-groups.

The project begins with the design teams selecting group leader and/or project managers. Guidance is given to the students about what makes a good group leader or project manager. The student stereotype of a group leader being the person that does all the work is corrected. The students are told that the group leader or project manager is the person responsible for delegating the work and seeing that all jobs are done in a timely fashion.

The Penn State Altoona College engineering technology programs are made-up of approximately a 30% returning adult student population. Many of these students have prior management experience. These older students have historically made very good group leaders and seem to have a positive influence on the younger traditional students. Management styles used by various student team leaders varied from a hands off encouragement style to a very authoritative style. The students strongly seem to prefer the more non dictatorial style of management. The authors have even had one group elect not to have a group leader and this group’s performance was found to be well below average. No attempts were made to divide the groups up in terms of the academic strengths of the students, although this practice would seem to eliminate the super groups and extremely weak groups.

After groups selections were made, the groups were required to formulate a short project proposal that included a function statement, design requirements and evaluation criteria. A detailed treatment of project management techniques including project time lines was not covered in the project due to time constraints. However, this is a topic that we hope will be included in future offering of the course.

The students groups were given several hours per week of dedicated class time to work on completing all the tasks in the design of a new speed gear reducer or the analysis of an existing speed gear reducer depending on the Mini Baja vehicle state of readiness that particular year. The authors feel that giving students in-class time ensures all group members will be able to meet as the chances of all 10-12 group members finding a common time outside of class is very unlikely. The sequence of design of the speed reducer begins with the spurs gears. Tangential and radial gear forces are calculated and then loaded onto the shaft where shear and moment diagrams are generated to find total bending moments at critical sections of the shaft. This information is then used in the ASTM equation for standard power transmission shafting in bending and torsion. The bearing reaction components are found and then used in calculating the total bearing
reaction. This and expected bearing design life are used in sizing rolling ball bearings for each shaft of the speed gear reducer. Lastly, power transmission keys and a speed reducer housing are designed. The level of design detail related to the housing has been kept to a minimum with just basic dimensions being all that is required. A simple cost analysis of the machine components is included with the report.

During the project, 2-3 group progress reports are completed and collected as this mimics a real world industrial project. These short reports allow the faculty to gage the pace of the groups and help the groups in meeting intermediate goals. The authors usually allow 3-4 weeks to complete the entire process with a due date the last week of classes or early finals week. The final report has normally been very extensive in nature requiring 25-35 pages to document all the steps necessary in the design process. Pro-Engineer and/or AutoCAD Drawings are required with the final report showing the speed gear reducer. To date the authors have not required formal presentations using MS PowerPoint by the groups due to time constraints but feel this would be a good addition to the course. Please refer to appendices A-C to view examples of hand drawn conceptual speed reducer designs, and completed designs using AutoCAD and Pro-Engineer.

Within this project, probably one of the most difficult concepts for the students to grasp are shear and moment diagrams in three dimensions which are required for shaft design and bearing selection calculations. Only through using many class examples have the authors felt successful in getting students to understand this concept well enough to have students perform their own shaft design and bearing selection procedures. All course material is also assessed through individual student weekly quizzes. No overall exam covering all phases of the speed reducer project has been given to date.

As stated above, student comments in the form of an inter office memo concerning their experiences in the large group environment were submitted by the students. Again, the inter office memo was an attempt to simulate a real world environment. By far, most of the students found the experience very favorable and enjoyed the larger group size. They also enjoyed the real world flavor to the design project and the connection between theory and actual machine components manufacturers. These same students also found larger groups made for more reasonable work loads for such an extensive project. Limited negative student comments seem to center around the feeling of too fast a pace for the project or a lack of understanding between individual group members of not knowing what has to be done. We feel these short comings could be addressed by stronger group leaders and instruction in project management skills. The large majority of students also responded favorably to the use of the Mini Baja Vehicle as a class example. A few of the students even went so far as to become part of the Mini Baja Design Team and helped complete the construction of the car. There were however a few students who made comments to the effect that during their last two years within the MET program, they feel they have had enough exposure to the Mini Baja Vehicle. It should be known that it was the original intent of the faculty at Penn State Altoona College to integrate some sort of common theme throughout the engineering programs and courses and the Mini Baja Vehicle was thought to be a good venue. The authors however can fully understand maybe a second option or even a changing theme may need to be considered in the future.
Conclusion
This paper describes details of a writing intensive capstone engineering design course for associate degree mechanical engineering technology students. In this three credit-hour course termed Product Design (MET 210W), engineering design is taught through team-oriented team design projects supported by oral, graphical, and written communication skills. The project based learning approach used in teaching MET 210W is described in this paper. The authors believe that project based learning is very helpful in providing an effective learning experience for students in the development of problem solving skills, promote collaboration, and allow for the synthesis of multi disciplinary skills. Students comments regarding the use of project based instructional approach in MET 210W revealed that they found projects an effective and rewarding addition to the course.

Appendix A
Conceptual Drawing of Two Speed Transmission Concept for SAE Mini Baja Vehicle
Appendix A

Input speed 1490 RPM
Gear Ratio 8:1
Output Speed 185 RPM

Appendix B
AutoCAD Drawing of Single Speed Gear Reducer for SAE Mini Baja Vehicle

Appendix C
Pro Engineer Drawing of Single Speed Gear reducer for SAE Mini Baja Vehicle
Bibliography


Biography

Eric Granlund holds a M.E. degree in Engineering Mechanics from The Pennsylvania State University and a B.S. degree in Mechanical Engineering from The Pennsylvania State University. He currently teaches in both the baccalaureate engineering and engineering technology programs at The Pennsylvania State University, Altoona College. He is faculty advisor of the engineering honor society Tau Alpha Pi student chapter at Altoona College. He has developed and taught numerous children’s engineering courses and is a member of ASEE and ASME.

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Sohail Anwar holds a Ph.D. degree in Industrial and Vocational Education from the Pennsylvania State University and a M.S. degree in Electrical Engineering from the University of Texas at Arlington. He completed additional graduate coursework in control theory and applied mathematical sciences at the University of Texas at Arlington. He is currently serving as an associate professor of Engineering and the program coordinator of Electrical Engineering Technology at The Pennsylvania State University, Altoona College. Since 1996, he has also served as an invited professor of Electrical Engineering at IUT Bethune, France.