Exposing Sophomore Students to Engineering Design Using an Innovative Project-Based Learning Approach

Dr. Hamed Samandari, Miami University

Dr. Hamed Samandari is a Visiting Assistant Professor at the Mechanical and Manufacturing Engineering Department at Miami University. Dr. Samandari also serves as an Adjunct Faculty member at the Engineering Technology Department at the Miami's regional campus. Prior to his appointment with Miami, he spent a year as a Postdoctoral Research Fellow at the University of Massachusetts at Amherst. Hamed received his B.Sc., M.Sc., and Ph.D. degrees, all in Mechanical Engineering, form Isfahan University of Technology in Iran, University of Tabriz in Iran, and Middle East Technical University in Turkey, respectively.

Dr. Banafsheh Seyed-Aghazadeh, Miami University

Banafsheh Seyed-Aghazadeh is the James A. Myers Endowed Assistant Professor at the Department of Engineering Technology at Miami University. She received her B.Sc. and M.Sc. degrees from University of Tabriz, Iran, and her PhD from University of Massachusetts, Amherst, all in Mechanical Engineering. Prior to joining Miami University, she spent a year as a postdoctoral research associate and a lecturer at the Department of Mechanical and Industrial Engineering of the University of Massachusetts, Amherst.

Exposing Sophomore Students to Engineering Design Using an Innovative Project-Based Learning Approach

1. Abstract

This study presents a teaching methodology developed through a 3-year-long iterative-study in order to incorporate hands-on experiences in engineering courses and expose sophomore students to engineering design. Sophomore engineering technology students enrolled in a 200-level Computer Aided Design course participated in this study. An innovative Project-Based-Learning (PBL) approach with an embedded Agile Project Management (APM) is implemented to promote skills such as critical thinking, problem solving, communication, and self-management. These are skills that students need to have to succeed in senior capstone projects or in professional practice. APM is used to respond to students' struggles with PBL's project management. APM is an iterative approach with ability to respond to issues as they arise throughout the course of the project. In this approach, students performed a series of agile rituals such as showcases, retrospectives, stand-up meetings and iteration reviews.

2. Introduction

The implementation of Project-Based Learning (PBL) in science, technology, engineering, and mathematics (STEM) education has gained much interest in recent years [1-3]. PBL is a dynamic classroom approach in which students actively explore real-world problems and acquire deep content understanding by taking over the ownership of their learning. PBL is different from Problem-Based learning. The outcomes and tasks are well defined in Problem-Based learning, whereas, in PBL, only the outcomes are well defined and students need to define the tasks [4]. In PBL, students work in collaboration with their peers to identify the problems and find strategies to solve within activities with no or minimum instructional help from instructor [5].

Studies have shown that PBL is a much more effective education methodology to respond to industries demand for engineers with multidisciplinary skills compared to traditional teaching pedagogies. It promotes a collaborative learning environment that can enhance students' social and problem-solving skills [6]. PBL has been successfully used to teach higher-level undergraduate and graduate courses in engineering curriculum. Examples include but not limited to courses in structural and materials failure mechanisms [7], renewable energy courses [8], and senior design mechanical courses [9].

However, in PBL approach, student learning is significantly correlated with quality of implemented PBL. Students, who are provided with low quality PBL, even show a negative learning growth [10]. High quality PBL has six criteria, each of which must be at least minimally met in a project in order for it to be considered *high quality*. These six criteria are [11]:

1. Projects should not just be “fun activities” or “hands-on experiences”. They should require intellectual effort.
2. Projects should be experienced as “real.”
3. Students make their work public by sharing it not only with the teacher but also with other students.
4. Students should work in collaboration.
5. Students should manage their project and time.
6. Students should learn to assess the quality of their work.

The Framework based on the above criteria is the accumulated experience of many researchers/educators who have shared their ideas and critiques [11].

This study presents a teaching methodology based on high quality PBL developed through a 3-year-long iterative-study to promote essential 21st century skills between students. These skills directly fulfill industry’s and ABET’s requirement to train engineers who can handle the ambiguous design problems by thinking critically. Our initial experience with PBL has shown us that it is very challenging to satisfy criteria 3-6 of high quality PBL in typical classroom settings. This becomes even more challenging working with sophomore students who lack the essential skills such as teamwork. Hence, we embedded the Agile Project Management (APM) into PBL to respond to students’ struggles with criteria 3-6 of PBL.

Agile Project Management is an iterative approach to planning and guiding project processes with ability to respond to issues as they arise [12-13]. APM methodology has received much attention in the 21st century, particularly from software development companies. However, in the recent years, owing to its numerous benefits, it has been modified to be used by non-IT focus industries as well. In traditional project management methods, requirements are fixed in an effort to control time and cost, whereas, in APM, time and cost are fixed in an effort to control requirements. APM breaks down projects into small pieces that are completed in iteration cycles. In this approach, iteration goals are achieved through performing a series of agile rituals such as showcases, retrospectives, stand-up meetings and iteration reviews [14]. Following APM methodology results in a rapid deployment of solutions, efficient use of resources, and an increased collaboration between team members and consumers. There are some potential drawbacks to APM methodology, including a tendency for projects to go off track and a lack of documentation.

3. Description of the Course

Sophomore engineering technology students enrolled in a 200-level Computer Aided Design course participated in this study. This is a course where students gain the ability to create detailed drawings of parts and assemblies using a computer aided drafting software. This is an introductory course in freehand sketching and computer-aided drafting/design. Students are taught basic CAD commands, tools, multi-view drawing and dimensioning techniques. Even though students learn how to create the drawing views and 3D dimensional models, they do not get the chance to produce any tangible products. The non-modified course outcomes are as follows:

- Demonstrate the ability to create multiple view detail drawings of parts and assemblies.
- Demonstrate proficiency in solid modeling using Autodesk Inventor software to facilitate engineering problem solving.

With a goal to expose students to engineering design, the following additional outcome was introduced to the course

- Students will work in teams to design a mechanical system and fabricate a prototype of their design using 3D printing and additive manufacturing resources.

Based on this new outcome, students were tasked to design and fabricate commonly used engineering mechanisms, by which they get exposed to practices in the real engineering world. A broad variety of mechanisms were selected including but not limited to a 4-bar linkage, oscillating lever with quick return, ordinary crank, or crank slider. The feedback of instructors from upper-level courses was used in selecting mechanisms and mechanisms that have been traditionally used in upper-level courses are favored in the selection process. Figure 1 shows samples of such mechanisms. Students were only provided with the base 2D schematics and were tasked to design and fabricate mechanisms using only 3D printing and additive manufacturing resources that were available to them at the department level, free of charge. No additional documented guidelines were provided to the students and the projects were kept open-ended.

It is worth highlighting that this course is an introductory 200-level course and it is not the objective of the course to teach students all the engineering design principles. Many of these students have not taken core-engineering courses such as Statics, Dynamics, and Strength of Material. The goal is to engage students in a design activity to improve their appreciation for the engineering topics with minimum increase in the course load.

4. Implementation

The new teaching methodology was developed through a 3-year-long iterative-study. Following an agile mindset at the end of each academic year, authors performed retrospectives fine-tuning the developed teaching methodology. The covered content and the textbook were kept the same. The same instructor was asked to teach the course following the same content. The same assignments and exams were used to evaluate students' work through these 3-year long study.

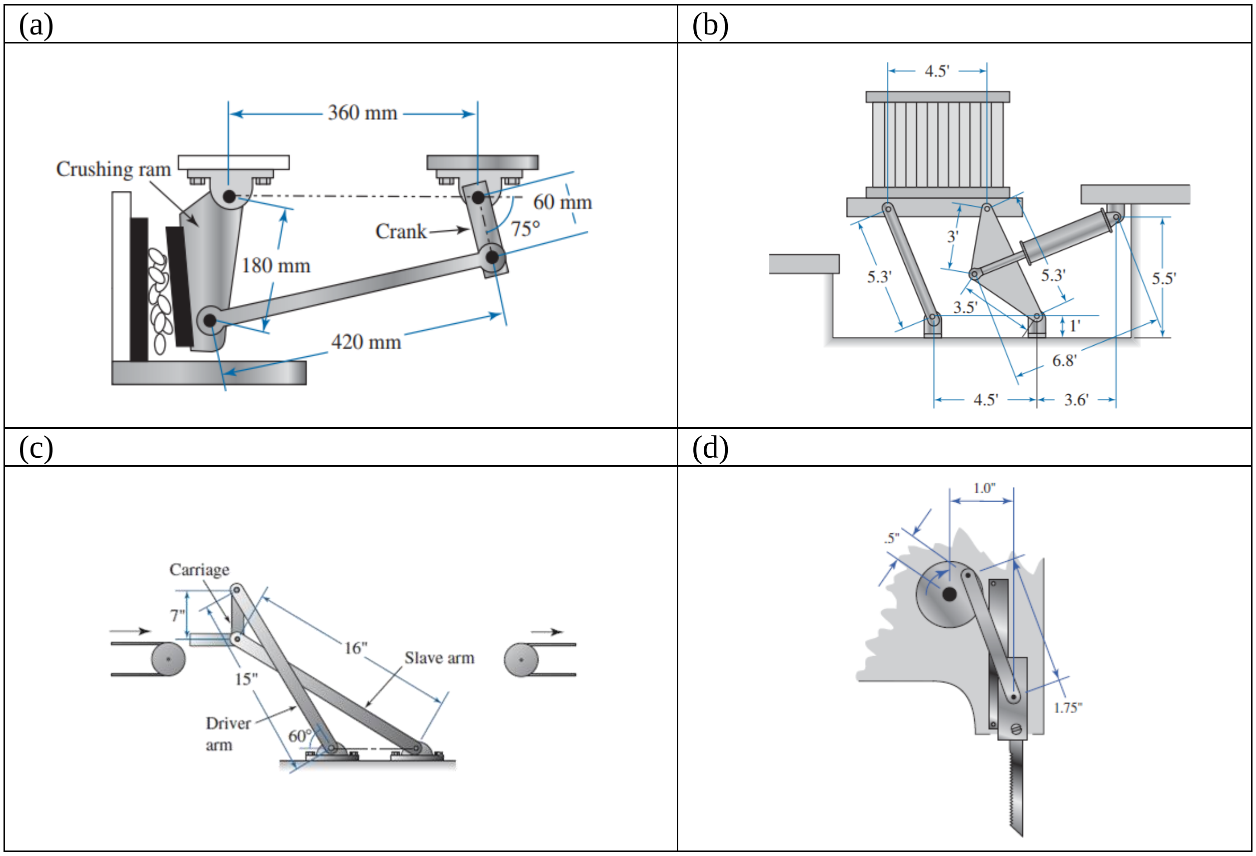

Figure 1. Schematic of commonly used engineering mechanisms a) rock crasher b) transfer mechanism c) mechanism to turn over cartons d) reciprocating saber saw [15]

The first year data was used as the baseline for the study. During the second year, PBL approach was used to introduce students to design project. Students worked on a series of projects on a self-paced schedule and reported their work at the end of semester as a group presentation. At the beginning of semester, students were allowed to self-select team members (four members per team). In the third year implementation of PBL, project management techniques from agile methodology were introduced to address challenges observed with implementation of criteria 3-6 of PBL. Followings are the details of agile rituals that were used by students to address the criteria 3-6 of PBL.

4.1. Daily Stand-up

Daily Stand-up was modified to be used as a weekly stand-up by students since the class met once a week. Students were asked to stand-up in the presence of other students and the instructor to inform the class about team’s ongoing activities for a duration no more than two minutes per team. Standing up helped to keep the meetings short! Students were not asked to provide any detailed status and they were advised to use a light and informative tone.

4.2. Iteration review

Iteration reviews known as showcases were used to display the work of the team at the end of each iteration cycle. Students were asked to use a more formal structure for their presentations. Cycles were planned to happen every two weeks. During the review, each team had 10-min to celebrate their accomplishments, show finished work within the iteration, and receive immediate feedback from other students and instructor (stakeholders).

4.3. Retrospective

Providing early and often feedback plays an important role in agile methodology. Retrospectives were used at the end of each iteration review to help the students to understand what worked well–and what didn't. Students were asked to focus on what was working well and seek for solutions for the areas where things were not working well.

Appendix A includes the course syllabus. The changes introduced in the second year are highlighted in the *blue* and the changes that introduced in the third year are highlighted in the *red*. The instructor information and the names are blacked out.

5. Results

The end of semester survey and students final grades are used to evaluate the effectiveness of the new introduced teaching methodology. Table 1 Provides statistics on student enrollment at each year. One student dropped the course during the second year due to family issues and another student dropped the course during the third year due to financial issues.

Figure 2 shows samples of students' work during the second and third year. It was interesting for us to see students' ability to come up with different designs (solutions) for the same schematic (project).

An end of semester questionnaire was designed and employed to gather students' opinions. The survey contained questions about students' learning, satisfaction, and understanding of material. Table 2 summarizes the questions used in the survey. Students were asked to indicate their agreement with each statement. The following ratings were used: 0.0 - Strongly Disagree; 1.0 - Disagree; 2.0 - Neutral; 3.0 - Agree; 4.0 – Strongly Agree.

Table 1. Student enrollment statistics

	Year 1: Baseline	**Year 2: PBL**	**Year 3: PBL+Agile**
Number of students enrolled	18	12	12
Number of students dropped the course	0	1	1

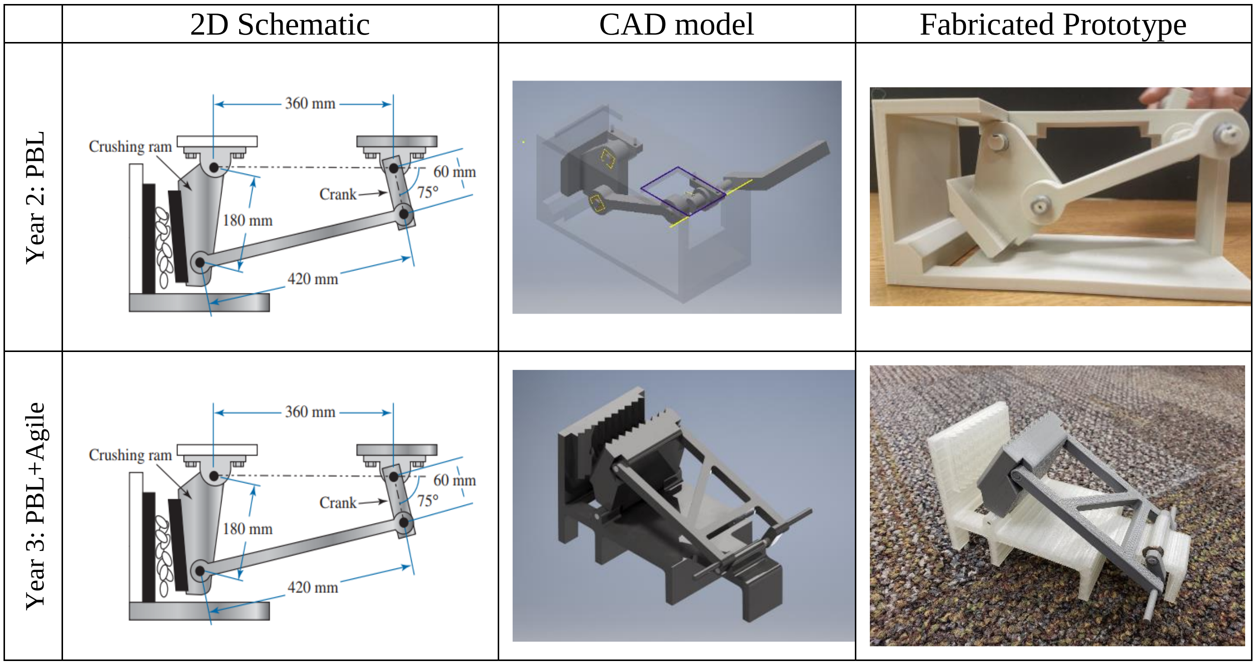

Figure 2. Sample of students' work

Table 2. Student's survey questions

	Statements	Abbreviation
Q1	I have gained an understanding of this material.	Understanding of material
Q2	In this course, I learned to analyze complex problems or think about complex issues.	Analyze complex problems
Q3	The instructor employed effective tools for learning (e.g. lab activities, homework, projects, in-class and on-line activities, etc.)	Effective tools
Q4	What is your overall rating of your learning in the course?	Learning
Q5	What is your overall rating of the instructor?	Instructor Rating
Q6	The material covered in this course will help further my career and/or life goals	Furthered my career/goals

Figure 3 summarizes the results of the end of semester survey collected each year. Results from Q1 indicate that students believed they have gained a better understanding of material when PBL is implemented. Q1 rating for the third year when APM is implemented do not show a significant difference when it is compared to PBL year only. Students were also asked to comment on how this project helped them to analyze complex problems or think about complex issues through the course (Q2). Results from Q2 show that students found the new teaching approach effective, helping them to analyze complex problems in overall. However, a significantly higher rating for the second year (i.e. PBL only) compared to the third year (PBL+Agile) is observed. This was interesting since participated students worked on the exactly same projects with the same level of difficulties during the second and third years. A potential cause for this drop can be found in the fact that tools from APM such as iteration reviews helped students to break down the design difficulty levels, which has shown itself as a lower difficulty rating in the third year.

Results from Q3 show that students did not find PBL to be an effective tool on its own (3.33/4.00), whereas with the addition of Agile, they found it to be a very effective tool (3.71/4.00). In Q4, Students were asked to rate their overall learning in the course. A small drop in the rating is observed in the second year, which we believe is due to the fact that all the high quality PBL criteria were not satisfied properly. This is also reflected in the students' comment as they found the group project to be more stressful: "Not sure that the group project for us did much more than added more stress." With addition of Agile in the third year, the overall learning rating shows a promising improvement indicating that the management skills helped student to manage their projects to learn more.

Students were also asked to provide an overall rating for the instructor (Q5). The department average for this score is 2.90/4.00. Survey results show that the instructor score has improved with introduction of the new teaching approach. Instructor did not use any new resources. The only difference in the second year (PBL only) was that students worked on a project and reported it at the end of semester. The increase in the rating can be possibly associated with the fact that students have taken the ownership of their learning working on group projects. This can be observed in student's comments as well : "instructor was very helpful. clear on explaining. great final group project."

With addition of weekly stand-ups, iteration reviews, and retrospectives when APM was introduced during the 3rd year, students engagement in the class were increased significantly. The students were surveyed on the following questions regarding agile practices:

> Q-A1: "Working in pairs on this project was challenging."
> Q-A2: "Having bi-weekly gate presentations to briefly discuss the progress in team project helped me to be more engaged in the group's progress and makes team work and communication between the students and the instructor more transparent."

The survey results show that only 20% of students found working in pair to be challenging, which was previously pointed out by students as a main challenge during the second year implementation of the design project (only PBL). This was complemented by the results of the second question where 80% of students found the bi-weekly gate presentations to be very effective in facilitating the communication between students. Iteration cycles decreased project risk factor helping students to focus more on learning. This can be found in students' comments as well:

> "*The group project required us to overcome challenges and rework designs as a team throughout the semester and was a very effective learning experience. The lectures were well paced and the instructor made sure we were up to date on the tools we learned*."

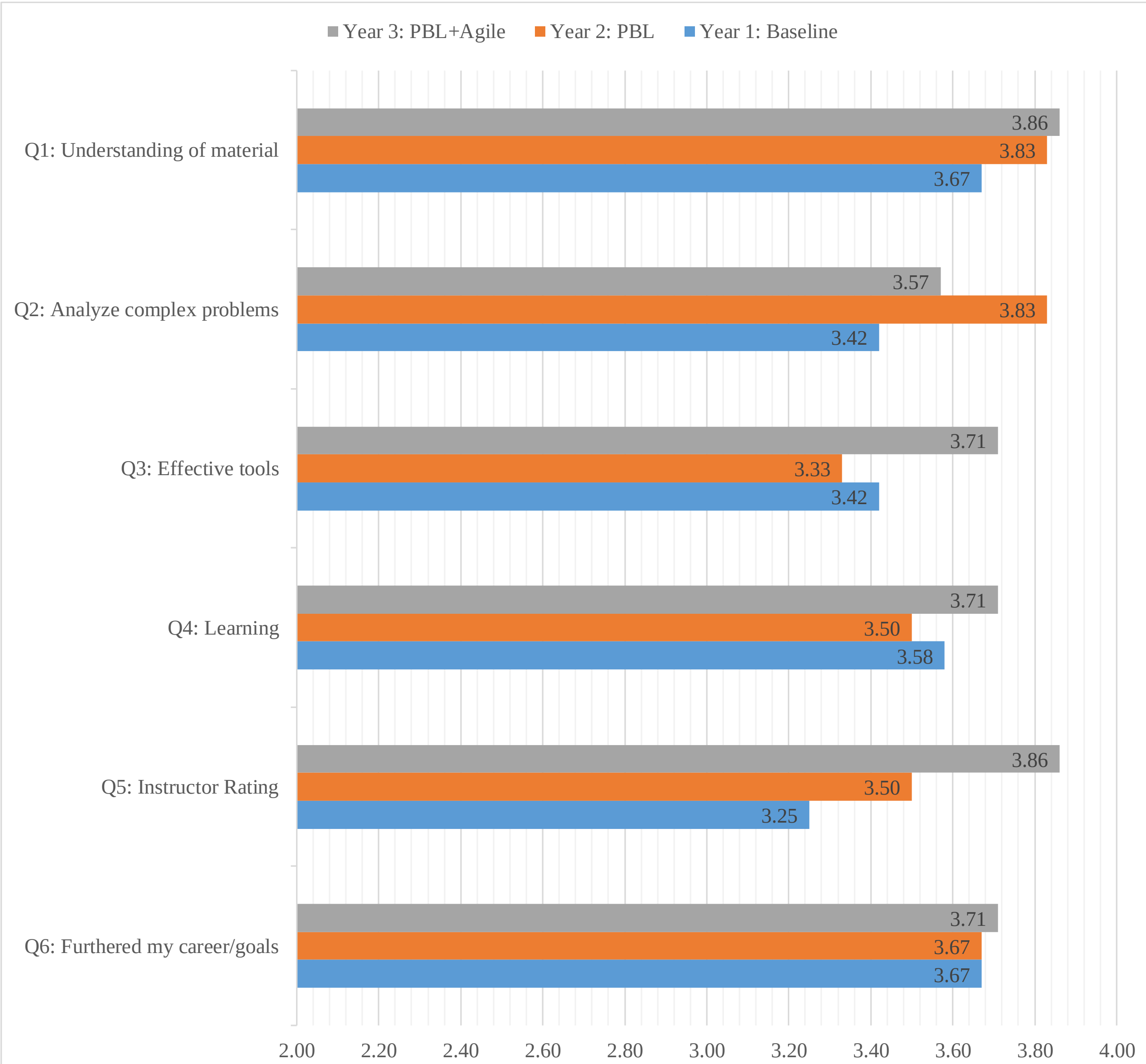

Figure 3. Student survey results (the max score is 4.00)

Students grades did not show any significant statistical change throughout the implementation of the new teaching approach. The small size of the cohorts limits use of any direct assessment method such as course grades. A small drop in the class overall average is observed, but it was not significant once compared to years before implementing the new teaching methodology.

Table 3. Student final grades

	Year 1: Baseline	Year 2: PBL	Year 3: PBL+Agile
Mean (SD)	85.89 (8.98)	82.42 (13.59)	80.38 (11.50)

6. Conclusions

We found PBL to be a very effective tool when combined with APM. PBL, when it is implemented properly, has the potential to help students to achieve a higher level of development in the cognitive domain. APM helps students to manage their time, be active in the class, and celebrate and take the ownership of their work.

Results from an end-of-year questionnaire showed that working on an-open ended design project with tangible end-results had significantly increased students' appreciation for the topic. It is anticipated that lessons learned from this will provide the framework for cross-curriculum collaboration with instructors of other higher-level courses to identify projects that can be readily used in the sequential courses. A student can design and fabricate a mechanism in one course and analyze and simulate it in other higher level courses. Such a framework can provide the students with the vision that all the fundamental courses are well connected to each other.

References

1. Jamieson, L. H., & Lohmann, J. R. (2012). Innovation with impact: Creating a culture for scholarly and systematic innovation in engineering education. American Society for Engineering Education, Washington, 77.
2. Lattuca, L. R., Bergom, I., & Knight, D. B. (2014). Professional development, departmental contexts, and use of instructional strategies. Journal of Engineering Education, 103(4), 549-572.
3. Thomas, J. W. (2000). A review of research on project-based learning.
4. Slough, S. W., & Milam, J. O. (2013). Theoretical framework for the design of STEM project-based learning. In STEM Project-Based Learning (pp. 15-27). SensePublishers, Rotterdam.
5. Capraro, R. M., Capraro, M. M., & Morgan, J. R. (Eds.). (2013). STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. Springer Science & Business Media.
6. Martínez, F., Herrero, L. C., & De Pablo, S. (2011). Project-based learning and rubrics in the teaching of power supplies and photovoltaic electricity. IEEE Transactions on Education, 54(1), 87-96.
7. Lanning, D., Lestari, W., & Waterhouse, S. (2010). A unique undergraduate laboratory-based course in engineering failure. In American Society for Engineering Education. American Society for Engineering Education.
8. Chen, R., Goodman, D., Izadian, A., & Cooney, E. (2010). Teaching renewable energy through hands-on project-based learning for engineering technology students. In American Society for Engineering Education. American Society for Engineering Education.
9. Echempati, R., & Dippery, R. (2010). Teaching and assessment experiences of an undergraduate Mechanical Engineering Design course. In American Society for Engineering Education. American Society for Engineering Education.
10. Capraro, R. M., Capraro, M. M., Scheurich, J. J., Jones, M., Morgan, J., Huggins, K. S., ... & Han, S. (2016). Impact of sustained professional development in STEM on outcome measures in a diverse urban district. The Journal of Educational Research, 109(2), 181-196.
11. Mergendoller, J. R. Defining High Quality PBL: A Look at the Research. [Online article]. Available: https://hqpbl.org/wp-content/uploads/2018/03/Defining-High-Quality-PBL-A-Look-at-the-Research-.pdf [Accessed Feb. 20, 2019].

12. Beck, K., & Gamma, E. (2000). Extreme programming explained: embrace change. addison-wesley professional.
13. Cohn, M. (2005). Agile estimating and planning. Pearson Education.
14. Inayat, I., Salim, S. S., Marczak, S., Daneva, M., & Shamshirband, S. (2015). A systematic literature review on agile requirements engineering practices and challenges. Computers in human behavior, 51, 915-929.
15. Myszka, D. H. (2004). Machines and mechanisms. Prentice Hall.

Appendix A

[redacted]

Department of Engineering Technology

ENT 235	**Computer Aided Design**	**3**
Course Number	Title	Credit Hours

Instructor:

Name: [redacted]
Office location: [redacted]
Office location: [redacted]

Lecture:

Thursday 6pm – 9:55pm - 08/27/18 to 12/15/18 – [redacted]

Group activity:

Refer to group activity schedule

Description:

This is an introductory course in freehand sketching and computer-aided drafting/ design. Students will be taught basic CAD commands, tools, multi-view drawing and dimensioning techniques.

Prerequisites:

ENT 135

Text Material:

Autodesk Inventor 2018, by Sham Tickoo, Publisher: CADCIM, 2018

Downloading the Student Edition of the Software

Students can download a copy of Autodesk Inventor Software from the web page of "Autodesk Student Engineering & Design Community". You need to create an account to download and install the software.

Download link: http://www.autodesk.com/education/free-software/inventor-professional
Installation instruction: https://knowledge.autodesk.com/customer-service/installation-activation-licensing/install-configure/single-computer-installation/stand-alone-installation
Software help: http://help.autodesk.com/view/INVNTOR/2018/ENU/

Student Learning Outcomes:

Upon completion of the course, students will be able to:
Demonstrate the ability to create multiple view detail drawings of parts and assemblies.
Demonstrate proficiency in solid modeling using Autodesk Inventor® software to facilitate engineering problem solving.
Students will work in teams to design a mechanical system and fabricate a prototype of their design (3D printing)

ENT Departmental Standard for Awarding Letter Grades:

Each faculty member will use the following scale in assigning letter grades in their courses, with the following allowances:

The end (or ends) of any range can be adjusted (rounded) by +/- 0.49 point

A+	A	A-	B+	B	B-	C+	C	C-	D+	D	D-	FAIL
100-98	97-94	93-90	89-87	86-84	83-80	79-77	76-74	73-70	69-67	66-64	63-60	59-0

Topical Outline:

Please note:

The instructor may make changes to the topic and the entire syllabus as deemed necessary.
The instructor reserves the right to change the 'order' in which topics are presented.

Week	Date	Topic	Chapter(s)
1	August 30, 2018	Introduction, Drawing Sketches	1,2
2	September 6, 2018	Drawing Sketches	2
3	September 13, 2018	Adding Constraints and Dimensions	3
4	September 20, 2018	Editing, Extruding and Revolving	4
5	September 27, 2018	Sketching and Modeling Options	5
6	October 4, 2018	Advance Modeling Tools I	6
7	October 11, 2018	Editing Features	7
8	October 18, 2018	Advance Modeling Tools II	8
9	October 25, 2018	Assembly Modeling I, 3D Printing	9
10	November 1, 2018	Assembly Modeling II	10
11	November 8, 2018	Working with Drawing Views I	11
12	November 15, 2018	Working with Drawing Views II	12
13	November 22, 2018	Thanksgiving Holiday (no class)	-
14	November 29, 2018	Presentation Module	13
15	December 6, 2018	Stress analysis and Group Presentations	

Group work schedule

There will be six sessions of group activity during the semester. Refer to the schedule below and the provided calendar for the ***tentative*** dates of these sessions. Please be aware that in order to adjust for variances in the pace of coverage of material in class, it may be necessary to shift a scheduled date. These sessions will be prior to the class on the given dates between 6-7 pm. The regular class will start on 7pm.

#	Date	Title
1	September 13	Introduction and Deciding about the group project
2	September 27	Part design I
3	October 11	Part design II
4	October 25	Assembly I
5	November 8	3D printing
6	November 29	Assembly II

We will use *Trello*, a web-based management application, to track team's progress incorporating *Agile values and principles*. At the end of each session, teams will do presentations to showcase the work of the team and will submit a report describing the day's activity.

What is Agile?

Agile is an iterative approach to project management that helps teams deliver value to their customers faster and with fewer headaches. An agile team delivers work in small, but consumable, increments. Requirements, plans, and results are evaluated continuously so teams have a natural mechanism for responding to change quickly.

Links to learn more on Agile management skills:

- https://www.atlassian.com/agile/project-management
- https://www.forbes.com/sites/stevedenning/2016/09/08/explaining-agile/#61d571b2301b

3D Printing

3D printing resources are available at Middletown and Hamilton campuses. You can print in paper, ABS, PLA Nylon and a powder. To 3D print, your design has to be sent as a .stl file. You can E-mail it to [redacted] or take file to [redacted].

Notes:

Copy your instructor in the email and have ENT 235 on subject line
.stl files do not come with dimensions so include the dimension info (mm, inch).
You cannot select the color of material.
Do not wait until the last minute to send a print job.
Depending on the size and detail of the object, the printing can take hours to manufacture.

Grading Policy

The following is the tentative distribution of credit for the required tasks:

Attendance, punctual, attentiveness, and collegial in group work	5%
Computer Laboratory and Homework Assignments	55%
Group project	20%
Final term project	20%

Class Attendance

Every student is required to attend all the classes and is required to stay for the entire period of the class. Therefore, make sure that you schedule your work accordingly.

Points will be taken off for every unattended class.
If you are unable to attend more than **two** classes, you will be automatically dropped.
You are expected to be in class and ready to start work at **6:00 pm**. If you are regularly late for class, points will be taken off (from the item: "Attendance, punctual…").

Please see the Student Handbook for more information in this regard.
[redacted]

Lab and Homework Assignments

View each week's homework assignment as an opportunity to get ready better for your career.

POLICIES FOR SUBMITTING YOUR ASSIGNMENTS

In-lab Practice Work:

On the class day, you will submit your lab practice work online on Canvas.
You need to show your finished in-lab practice work before you leave the class.

Homework Assignment:

Similarly, you need to submit printed copy and files of your homework latest by **6:00 pm** of the due date, in order to get full credit for completed assignments.

Late Submission:

Late submission of the in-lab practice work and homework assignments is acceptable until a week after the deadline but will come with a **50%** penalty.

Printing Your Models:

One simple method of printing your work is using Alt+print-screen option of MS Windows to copy your work. Then you can paste it in MS Window's Paint program.
If the model is 3D, rotate the model in Inventor and then repeat it at least two more times. Put all views in one paper sheet if possible.
Make sure that your print cards have enough credit before you attend the class.
A sample report file can be found at Canvas/assignments

Submitting Your Files:

Upload them under Canvas/Assignments. You SHOULD NOT submit the files by email.
Note that the date and time of an uploaded file is shown to me next to your file, and should you have submitted it after the due date and time, it will notify me and a penalty will be applied.
Combine all Tutorial models in one file and submit that file.

Name of Submitted Files:

Use this format for naming your files. Also use the same format the top of your submitted prints
For Tutorials: "Last name, first name, Ch number, TU number"
For Exercises: "Last name, first name, Ch number, EX number"

Other guidelines:

- If you are submitting more than 1 paper sheet, staple them, otherwise **5 points** will be reduced from each assignment.
- You may submit your modified assignment several times prior to the due.

Attention to Weekly Lectures

Students should follow instructor's lecture and simultaneous practice. No student should work on any Tutorial or Exercise during that period. After the lecture is over, you will have time to spend on your in-class tutorials.

Communication Methods

Primary communication will be via email. However, some of the course materials such as the syllabus, announcements, handouts, solution of tests, HW assignment, etc. will be posted on Canvas. Canvas of the course can be found under your "[redacted]". Upon addition or change in the course materials, I will send a notification email about those updates.