Project-based Guided Learning for Machine Elements Design Course

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Abstract

Project based learning (PBL) technique was adopted in Machine Elements Design course to motivate students enrolled in the course and better engage them in the process of learning. A project that links course learning outcomes with a topic of interest to industry and the community was selected. The project had two parts: design and fabrication. The field or topic of interest had to include all major parts and elements that are usually discussed in this course such as gears, chains, belts, shafts, bolts, bearings, etc. The project required the students to design and fabricate a garage door opening mechanism. Formal steps were followed by the instructor of the course to ensure consistency in the material delivered and the way it was delivered.

The students had the chance to experience real world problems and got engaged in a team oriented environment to design and fabricate the product. Basic project management skills were applied starting from feasible design and brainstorming, to conceptual and more detailed design before deciding on the final design. Detailed calculations were guided by the instructor to ensure the students were learning and understanding the new topics and material. When the design phase was completed, the students were required to fabricate a scaled prototype to check on the functionality of the product and experience the challenges that they might face in industry when trying to apply the design into real assembly and fabrication. Four teams and four different designs and products were obtained.

The grades of the students when following PBL teaching style were compared to previous grades when conventional learning was followed. The students’ performance and scores were significantly improved using PBL approach. The number of students scoring 80 out of 100 and higher was increased by 87.5%. Such active learning environments are expected to have other outcomes and impacts such as improved team working skills, communication capabilities, analytical reasoning in addition to project management skills.

Keywords: Engineering education, project based learning, students’ engagement.

Introduction

PBL can offer a better tool to teach and retain a concept providing a richer context in which subject matter can be learned and practiced. Project-based learning has the advantage of converting the learning process from being instructor-centered to student-centered approach. Various teaching styles are adopted and used in different classes in universities and vocational colleges to engage students in the learning process. Traditional learning techniques such as using
regular lecturing or presentations do not engage the students that often in the learning process. Innovative approaches to lecture a topic in class can include many forms of teaching and instructions such as demonstrations of experiments [1], students’ participation in a survey or multiple choice answers using rubbing answer sheets or clickers, group discussion, and other micro-insertion approaches [2].

According to Weimer [3], PBL starts with problem introduction and students are asked to solve these problems while learning the concepts in parallel with discovering new topics and material. Personal previous experience is a key factor in PBL. Different approaches are used by different students based on their prior experiences in the topic they are investigating. This creates motivation for students to link between what is new with what is already known. In this type of active learning environment, students are expected to do research, make decisions, prepare reports, and present their results.

PBL encourages students to challenge their skills and knowledge and develops lifelong learning skills that are not experienced with traditional teacher-centered approaches. However, guidelines and expectations must be set to prevent student failure and negative impacts. Weimer [4] discussed some risks and challenges associated with PBL environments.

Wlodkowski [5] indicated that analyzing and studying real-world problems are essential for any PBL environment in order to motivate critical thinking, collaboration, and professional skills. It is important to define achievable and reasonable rubrics that students can follow and accomplish successfully. Those rubrics should reflect a safe and successful environment where students are encouraged to participate instead of feeling embarrassed. It should promote an interesting and relevant experience, as well, where the students are allowed to fully engage in a professional role to fulfill the goal they are working on.

Student-centered environments can increase communication skills, ability to work with others in a team, practice logical thinking skills, while being innovative and creative [6]. This kind of learning environment encourages quantitative reasoning and complex problem solving skills as it is being routinely practiced in the work involved in this classroom pedagogy [7].

In this paper, PBL techniques used in Machine Elements course “MET21400” are presented. The predetermined set of learning outcomes for this course (CLOs) are as follows:

1. Apply principles and methods from statics, dynamics, and strength of materials to the selection of machine components.
2. Identify, define, analyze loads and stresses (tension, bending, torsion, and shear) operating on a structure.
3. Develop skills in using, reading, and interpreting necessary materials such as tables, charts, graphs, and industrial catalogues as part of appropriate problem solution.
4. Use the underlying concepts and theories of machine elements to select appropriate solution methods for specific problem solving.
5. Apply fatigue assessment methods (infinite life, finite life, and mean stress effects) in the analysis and design of mechanical bodies subjected to cyclic loadings.
6. Analyze, design, and select shafts, different types of gears, belts, chains, brakes, and other machine elements.

The specific outcomes that the instructor intended for the students to have by applying a PBL paradigm in addition to meeting the above learning outcomes were: 1) enhancing the level of learning to meet higher expectations, 2) preparing graduating students to work on world-like real applications and problems, 3) increasing retention of content and increasing students’ attitude towards learning, and 4) improving project management and implementation skills for students. These skills will ultimately lead to retaining students’ interests during class while covering the curriculum as set by the college and department.

Methodology

Project Based Learning (PBL) approach was used in this course. A project was designed to lead the course and meet the course learning outcomes (CLOs) listed above. PBL can be a powerful pedagogical tool, however it has its own benefits and risks. The time through which the teams implement their knowledge and learn new material should be well planned and guidance should always be available to prevent pit falls. For that, the instructor developed six formal steps to follow in the implementation of the PBL in this course. These steps are shown in Figure 1.

![Figure 1. Steps developed to drive the implementation of the PBL through the course](image-url)

The first step in Figure 1 was already established prior to the course initiation and the outcomes were set to meet the course CLOs in addition to other outcomes such as improving team work,
project management, communication skills, preparing the students to work on real world problems and increasing students’ retention in class.

The project was then selected to include topics in gears selection, shaft design, chains and/or belts, bearings and brakes. The target of the project was to help students meet the CLOs of the course and to improve students’ design skills, charts and tables reading and selection of appropriate machine elements. The instructor decided that designing a “garage door opening mechanism” would be an interesting topic for students. Most students have garages and know about the mechanism structure and operation. The target of the project was not to invent a new product, but rather to work on a project that would introduce the students to new concepts of the elements listed above and to learn how to design and select these elements to meet the project needs. The instructor then developed the course plan. Lectures were categorized for each machine element, such as gears, shafts, bearings, brakes, belts and chains and were recorded and made available to the students. Class time was then utilized to solve some applicable examples and to discuss some outstanding issues. The remaining time was then used to work on brainstorming the mechanism, discussing assumptions, conceptual design and final design. The instructor met each team separately on biweekly basis to discuss the progress of the projects. Five biweekly meetings were organized during the semester and the theme of each one was as follows: 1) brainstorming the basic structure and assumptions (conceptual design), 2) preliminary design, 3) critical and final design, 4) fabrication of a scaled product, 5) final report and product evaluation. A visual structure for the course is shown in Figure 2. The class was designed to meet twice per week for 75 minutes each (Tuesdays & Thursdays). These two class meetings were used to discuss outstanding issues, solve examples related to posted material and recorded lectures on one side (every Tuesday) and the other class period (Thursdays) was used to work on finalizing the project. Specific team meetings were done, as mentioned earlier, on biweekly basis.

Students were allowed to form teams on their own. No special techniques were used to set up the teams. Many techniques are available to match the qualities of the students in forming the best team, but the instructor decided to leave it open at this time since it was the first time this approach was implemented in this course.

For course evaluation, the students needed to submit homework assignments to ensure that they watched the recorded lectures and two exams were given during the semester. These assessment tools contributed to 50% of the final grade. The project evaluation included assessing (1) product design, (2) fabrication, and (3) team work evaluation all of which contributed to the other 50% of the course final grade. Team evaluation was done by cross self-evaluation for each team where each member evaluated himself and the other team members. The evaluation forms were confidential to ensure assessment transparency. In addition to self-evaluation, the instructor conducted individual oral assessments with each team member to ensure that he/she did participate towards the project.
The project required the students to design a full scale garage door and its accessories and then to scale down the dimensions to experience the challenges of fabrication and assembly. Some parts were not available after being scaled down so the students were allowed to use the closer dimensions or specifications of the part they were looking for.

**Results and Discussion**

Four different teams were formed in the class with 3 student members each. Three out of four projects used gears to transmit the power from the driving motor to the shafts and one used sprockets and a chain. All of the teams had the driven gear or the driven sprocket mounted directly on the folding shaft that would fold the door or turn it up and down to open and close. The teams designed the proper diameter of the folding shafts and selected suitable bearings to hold the shafts in its place as designed. Theories learnt through the recorded lectures and in other courses such as statics, dynamics, and strength of material were used to design and select the elements of this unit.

The teams approached the design in different ways, but all had to meet the objectives of the project which were designing a mechanism that opens and closes a garage door. The door material, opening speed, and construction were not restricted and were up to the teams to decide.
Some teams selected folding garage doors and others selected doors that rotate about its upper end.

In most cases, the students started analyzing the forces on the gears or the sprockets, then calculated the torques on the folding shafts, drew a free body diagram for the acting forces, calculated the forces acting on the supporting bearing, then calculated and drew the bending moments diagram on the shafts. The students then made their assumptions for the stress concentration factors and the loading type to design the shafts. The teams used equation (1) to estimate the shafts’ diameter.

\[
d = \left( \frac{32N_f}{\pi} \left[ \frac{(k_fM_a)^2 + \frac{3}{2}(k_fsT_a)^2}{S_f} + \frac{(k_{fm}M_m)^2 + \frac{3}{2}(k_{fsm}T_m)^2}{S_{ut}} \right] \right)^{1/3}
\]

where \(N_f\) is the factor of safety, \(M_a\) and \(M_m\) are the amplitude (fluctuating part) and mean moments, respectively; \(T_a\) and \(T_m\) are the amplitude (fluctuating part of the torque) and the mean torque, respectively; \(K_f, K_{fs}, K_{fm}\) and \(K_{fsm}\) are the fatigue stress concentration factors for bending, torsion, mean bending and mean torsional, respectively; \(S_f\) is the corrected fatigue strength and \(S_{ut}\) is the ultimate strength of the selected shaft material. Note that in order to be able to use equation (1) to estimate the diameter, the corrected fatigue strength needed to be found.

However, one of the correction factors needed to evaluate \(S_f\) was the size correction factor \((C_{size})\) that necessitated having the shaft diameter. This type of trial and error forced the students to use some skills in programming or spreadsheets to solve for the diameter using Newton-Raphson’s method by assuming an initial value for \(d\), solving for \(C_{size}\), estimating \(S_f\), calculating the new diameter and then checking on the difference between the initial and calculated diameters. Once the difference is quite small (< 0.01 mm), then the calculations were stopped. The students in this course were ready to carry out some iteration coding or had adequate experience using spreadsheets to solve such trial and error problem starting with an initial guess. Some groups struggled in getting the right initial guess, so the course instructor helped guide them as deemed necessary.

After estimating the shaft diameter, the teams were able to calculate the speed ratio and found the rotational speed of the shafts. To check for their project satisfaction, the linear opening speed of the door needed to be 1-3 fps (feet per second). If this was not met, then the initial assumption for the motor, the sprockets’ diameter, the gears’ number of teeth were revisited and the calculations were repeated till an acceptable speed value was achieved. The students then selected the bearings necessary to hold their shafts in place and other parts such as chains or belts. The four designed products are shown in Figure 3 through Figure 14.
Project # 1:

The team in this project decided to use a chain and two sprockets to reduce down the speed from the driving motor to the driven shaft. Flanged bearings were used in the design as shown in Figures 3, 4 and 5. Figure 3 shows the draw to scale model for the full door. Figure 4 shows more details for the driving mechanism. The full scaled door was successfully designed to open and close at a speed of 2.8 feet per sec (0.85 m/s). Figure 5 shows the final fabricated scaled down model which was scaled down by a ratio of 1:10 with respect to the designed model.

Figure 3. Project # 1 CAD assembly showing the driving motor and the driven shaft along with other accessories (details of the driving mechanism are shown in Figure 4)

Figure 4. Project # 1 CAD model for the driving motor, chain, designed sprockets, and one of the flanged bearing to be used in holding the shaft
Project # 2:

The team used a similar door to that done in project # 1, a folding type door, but instead of using chain and sprockets, used two spur gears. The folding door worked nicely and neatly around the shaft. Their brainstorming and initial design was done in 2D CAD drawings that were not shown here as most of the parts were similar to the scaled model shown in Figures 6 through 8. One issue with the fabrication was the gap between the door and the frame. All four teams actually had that issue in their scaled models. They did mention that they can use some kind of rubber to fill these gaps, but that would obstruct the folded door. In fact, they should have designed the door to be pulled back and then folded which would have required a retraction mechanism to be added to the door before starting to fold. Another issue with this team was the wrong switch selection; the team purchased the wrong electric switch which would not allow them to operate the door up and down using the same switch and, thus, had to add another switch. This was not a major issue for the project as this would not fall under machine elements design learning objectives. The door folding speed was slower than that achieved in project # 1 and was
approximately 0.3 ft/s (9 cm/s). This door needed to be folded at a slower rate as it was made up of thicker wooden pieces than what was used in project #1.

Figure 6. Project #2 showing the driving motor, gear assembly, and the folding door

Figure 7. Front side of Project #2 showing the door being folded up
Project # 3:

The team members used a set of bevel gears as shown in Figure 9 to operate the door. The door was initially designed to fold around the shaft, but due to some difficulties in the assembly, the team decided to change their folding door into the door shown in Figure 9 where it pivoted around its upper end. The team could not finalize their door design on time, so they used a simple door as shown in the final fabricated scaled model in Figure 10. However, everything else such as the gear, motor and electric switches worked perfectly fine as intended. The door was pivoted from its closed position to 90-degrees in approximately 2.2 seconds which was an acceptable opening speed.
Figure 9. Project # 3 CAD model

Figure 10. Project # 3 - Fabricated scaled model showing the gear-set, the electric switch, pivoting shaft and the representative door (for further details, zooming in would provide higher resolution view)

Project # 4:

The last team decided to use a set of simple gear trains to transmit the power from the driving motor to the pivoting shaft as shown in Figure 11 through Figure 14. The gears were selected to provide 1/5 speed reduction ratio to meet the intended door opening speed target which was approximately 2.3 seconds to open the door to 90-degree. An additional 1.5 seconds were needed to achieve 160-degrees from its closed position. The team used Lego parts to fabricate a small scaled model as shown in Figure 13 and 14. The team designed the gear train by trying adequate diameters and number of teeth to meet their intended speed reduction ratio. Although the Lego parts were ready, but this course-project was about designing a system without necessarily
fabricating the parts. In fact, one of the course objectives was selecting parts such as chains and belts, gears etc. so selecting ready to use, but correctly designed, gear sets was not an issue.

Figure 11. Project # 4 - CAD model showing the gear train

Figure 12. Project # 4 - Assembled design project in CAD (door is fully closed)
All four teams met the objectives of the project and the CLOs of the course. The project design phase required force analysis, bending moment and torsional effects calculations, fatigue loading calculation along with the associated concentrated stresses. To select appropriate gears, sprockets, chains and bearings, the teams needed to learn how to read the appropriate tables and charts which was one of the outcomes for this course.
To investigate the improvement in the students’ performance, the scores for the course when following PBL techniques were compared to previous scores obtained when the course was taught in a conventional manner. The percentage of students’ scores for both learning methods are presented in Figure 15. It was observed that the number of students with PBL learning paradigm were higher for scores 80 and above.

The change in number of students in each grade range shown on the x-axis of Figure 15 was further investigated by looking into the percent change. This was calculated as shown in equation (2) and the results were previously shown in Figure 4. It was observed that the number of students scoring in the lower two grade ranges, from 60-69 and 70-79, were reduced by 37.5% and 69%, respectively. The difference due to the decrease in the lower two ranges was seen as an increase in the number of students scoring in ranges between 80-89 and 90-100 where the increase in the number of students for both ranges was 87.5%; a very satisfying increase.

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\text{% Change} = \frac{\text{PBL result} - \text{Conventional result}}{\text{Conventional result}} \times 100
\] (2)

Figure 15. Students’ grades comparison between old-conventional lecture style and the new applied PBL course style

Figure 16. Percent change in number of students with respect to their final scores
Conclusions

Engineering courses and programs are intended to train and prepare students to be fully engaged with industry upon graduation, create well competent engineers, nurture research and development, foster technical innovation and contribute to society through engineering and technology. To increase students’ motivation, increase retention and improve their level of engagement and learning, a project based learning technique was applied requiring the students to design and build a garage door opening mechanism. In this paper, the project development and the products designed and fabricated by four teams were presented. The students’ performance was shown to increase due to the usage of the PBL approach by looking into the course scores when PBL was applied against conventional teaching class.

Upon the implementation of the PBL paradigm, the students met many of the required course CLOs by applying methods and principles learned in previous courses, analyzing the applied forces and drawing bending moments diagrams, navigating through various charts and tables to select gears, sprockets, chain and bearings, and finally applied fatigue loading analysis for the folding of pivoting shafts. An additional skill was CAD drawing and design. The second part of the project, project manufacturing and assembly, helped the students increase their fabrication and assembly skills. These outcomes and skills enhanced the level of learning for the students, as there was an increase of 87.5% in the number of students scoring 80 and above over conventional learning, introduced the students to real design and fabrication applications and helped improve other skills such as project handling and management.

PBL is a very powerful technique and it raises the level of education from knowledge and applying to analyzing and exploration. More improvement should be done in future. For example, teams should be teamed up based on their interests and a various list of projects should be allowed to better suit the students’ interests and experiences.

References