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Incorporating a Milestone-Based Project Based Learning Method in a Foundry Course

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Abstract

The objective of this study was to investigate the impact of a milestone-based project-based learning (PBL) methodology incorporated in a metal casting (foundry) course. The course, which contains a hands-on laboratory portion, was designed as a full semester learning experience for students, which integrates a PBL pedagogy to facilitate learning. The students worked in teams throughout the semester, constantly contributing to the completion of their projects. The intervention of this teaching and learning strategy was compared to a control version of the course in which a conventional end-of-semester exam rather than project was used. The PBL (intervention) version of the course, examines the impact of having the course project become the main learning mechanism and considers and attempts to measure the ways in which PBL affects student performance. Implementation of the PBL pedagogy was enabled by adopting a milestone formatting technique [1]. The project was proportioned into different milestones (assignments) that assisted the growth of the final project. The project required the students to (1) design a metal casting, (2) design and produce tooling to make the casting, and (3) produce and evaluate the casting. Instruction was aimed and targeted to provide essential background information so that students were able to complete each milestone in a timely manner. Each milestone allowed the students to gain more experience and additional feedback towards their developing project. To investigate the impact of this PBL implementation, pre and post questionnaires were administered probing students' perceptions of learning and development. Objective based assessment was made comparing students' overall semester grades from the intervention to the control semester. Student perception of learning improved in both years of the intervention and although confounded by course delivery changes brought on by COVID-19, course grades improved in the semesters the intervention was administered as compared to the control (no-intervention) year.

Introduction

Project-based learning (PBL) is a teaching method that encourages students to solve challenging real world problems in groups, while focusing on one major project [2]. PBL can be a very effective teaching method because students must learn soft skills such as working in groups, managing time and information, and searching for information necessary to complete the project successfully in addition to the necessary hard skills, that are related to the course learning outcomes. PBL in the classroom also provides students an opportunity to begin to think and act professionally to solve challenges and pitfalls experienced in design problems that one would encounter in the real-world. PBL has been shown to not only be effective, but a preferred pedagogical method by students [3], especially in courses that use engineering design principles. Engineering design, by its very nature provides, challenging open-ended problems for students to solve. Therefore, classes that incorporate engineering design projects are an ideal fit for a PBL methodology. This is particularly the case when the engineering design project has a physical component that needs to be produced/manufactured as the students can first design the item on paper or computer software, then they can produce/manufacture it in a lab setting and gain a hands-on learning experience. One particular emphasis of PBL is that the project needs to drive the learning, as opposed to merely having a project assigned at the end of the semester. The majority of the class, if not the entirety, should constantly focus on the project. This typically involves in-class discussions, lectures, homework assignments, and possibly even exams that are focused, or are closely related, to the project.

In order to effectively administer a PBL pedagogy, one research team, Torres *et al*. [1] developed a milestone-based PBL pedagogy, in which the entire class was partitioned into five major sections. Each section corresponded to a section of the project, such that the first section of the project was due early on in the semester (first few weeks), shortly followed by the second, and so forth. Each section was termed an individual project "milestone", hence the milestone-based delivery method. This delivery system allowed the project to stay relevant throughout the year and the learned knowledge from the project culminates as the course progresses. This methodology also allowed the students to immediately apply what they just learned on a portion of the project, as opposed to having to recall information learned weeks or months prior. Another unique aspect of this PBL methodology, is that, at the end of the semester an overall final project was due, which contained the five milestones. These five milestones were previously graded and returned to the students shortly after they were due, therefore, the students were given the opportunity to reflect, and learn from their mistakes in their initial attempt at the individual milestone. Allowing the students, a second attempt, creates an additional learning experience, and boosts their confidence and comprehension [1].

In the current study, the milestone-based PBL technique developed by Torres *et al.* [1] was incorporated in a metal casting (foundry) course at Texas State University with the goal of improving student comprehension of the course learning outcomes. Torres *et al.* [1] demonstrated that their technique was effective at improving student comprehension, and–most importantly–the students preferred the teaching method. Therefore, this study will not only further the insight to implementing PBL, but it will also demonstrate another iteration of the milestone-based PBL technique in a completely different type of course, particularly a course that contains a hands-on laboratory portion. Therefore, the successful implementation of this study will demonstrate the effectiveness that a milestone-based PBL methodology has on a different class than the one for which it was developed, and one that contains a hands-on engineering design problem.

Background

The philosophy of PBL dates to 1897 when John Dewy established his pedagogical creed of "learning by doing". However, its implementation in the modern classroom began in the early 2000s, when Thomas Markham established and defined PBL as a pedagogical technique that integrates knowing and doing [4]. He elaborated that PBL students learn knowledge and elements of a course curriculum, but also apply what they know to solve authentic problems and produce results that matter. In the modern classroom, PBL students take advantage of modern digital tools to produce high quality, collaborative products. Markham further articulates that the focus of PBL is not on the curriculum, such that information is simply regurgitated back to the student, but the focus is put on the education of the student, which rewards intangible assets such as drive, passion, creativity, empathy, and resiliency [4]. It is understood that these traits are not grown from following procedures or solving textbook problems, but are activated through experiencing the core principles of the class in a collaborative setting.

PBL has been used in all educational stages from primary school, secondary school, and undergraduate education, as well as in graduate-level courses [5]. Moreover, PBL has been used in different fields of study, including the humanities [6] social sciences [7] natural sciences [8] formal sciences [9], and applied sciences [10]. In regard to PBL in STEM education, PBL can be understood as an educational approach such that students learn and develop deeper STEM skills by working in teams on meaningful real-world engineering design projects [11]. These engineering design projects may have different goals, such as creating products or services, solving a problem, or answering a research question [4]. In a typical STEM based PBL course, students are challenged to learn by getting their hands dirty by discovering the necessary skills and materials to accomplish the project by themselves [12]. Students are also required to reflect on the learning process [13] and present the project outcomes to an audience [4]. In a PBL-centered course, students typically follow a pre-coordinated schedule with clearly defined deliverables and milestones [14]. Researchers indicate that PBL use can bring benefits such as improving students' motivation to learn [15] and fostering skills development [16].

Foundry and Heat Treatment is a senior level course taught in the Department of Engineering Technology at Texas State University. The course attracts a diverse group of students with various backgrounds. The course is required for students in the Manufacturing Engineering Technology and Environmental Engineering Technology majors (up to catalog year 2020). The course is an elective for students in the Environmental Engineering Technology program in the Department of Engineering Technology and the Manufacturing Engineering program in the Ingram School of Engineering. The course format consists of two credit hours of lecture accompanied by one credit hour of laboratory instruction. The course content consists of an overview of metal casting processes, properties of foundry sand systems, solidification of metals and alloys, design of gating and risering systems for metal castings, and properties of commonly used foundry alloys. At the end of the course, the students are expected to be able to:

- Demonstrate an understanding of various casting processes and their key aspects.
- Design and produce sound castings by using the principles and best practices in metal casting.
- Use casting simulation software to perform the detail design of a casting feeding system that provides tranquil filling and minimizes defects.
- Identify, evaluate, discuss, and propose recommendations to metal casting problems.

The milestone-based PBL was first introduced in the Foundry and Heat Treatment course in the Fall 2020 semester and again in the Fall 2021 semester with minor changes to account for lessons learned during the first implementation. The motivation for implementing a PBL methodology in this course stemmed from the instructor's (who is also the first author of this study) experience teaching this course. The instructor hypothesized that student interest, comprehension, and understanding would significantly improve if the course contained a semester-long design project. However, the instructor predicted problems could be encountered during the implementation of the project based on the instructor's prior experience incorporating projects into other courses. The second author, in a discussion over pedagogy, proposed the idea of a milestone-based PBL format as a solution to problems the instructor had experienced implementing projects in those courses. One issue that could be particularly overcome with the technique was that students often put off the project until the very last moment, either due to general procrastination, or they felt as though other assignments took more precedence over the project. As this course focuses on metal casting with a hands-on laboratory component, the project was inevitably to design and produce a casting of the students own making. Due to the nature of this project, a large amount of previously learned knowledge and design review is required to have a successful day casting the students' projects. It was quite evident that with a lack of a detailed design review and students attempting to work on their project in a short period of time at the end of the semester would result in failed casting attempts. Due to the nature of the foundry laboratory, it is not trivial to get the furnace up to temperature, make molds, and pour a casting. Therefore, students typically only get one attempt to produce their castings within the lab time allotted. This manner of delivery also limits student learning because meaningful feedback cannot be given in a timely manner–castings are often removed from the mold the next day. In order to improve learning and prevent these issues, the authors concluded that implementing a milestone-based PBL methodology that would use the project to drive the learning in the classroom would be the best approach. This would also create multiple opportunities for the students to complete each step of a thorough and well thought out design, including design review, such that the students will have a more successful day producing their castings in the laboratory.

The demographics of the implementations are as follows. The participants include the instructor who is male, and 49 years of age at the time of the first implementation, and the students, who have an age range of approximately 21-35. During the first implementation, the students comprised 18 males and 2 females, while in the second they comprised 13 males and 7 females. The course was taught in a conventional lecture room and a metal casting laboratory. There were two 50-minute lectures and one 170-minute lab session each week during the Fall 2020 and Fall 2021 semesters. As previously stated, these students are typically at the rank of senior and have taken and passed the course pre-requisites (Introduction to Materials Science and Manufacturing Processes). For the project, students were randomly assigned to groups of two.

Research Methodology

The intervention in this milestone-based PBL methodology consisted of a semester-long project in which students designed a metal casting and the corresponding pattern to produce the casting. This required the students to learn hard skills such as being able to design a gating and risering system by hand and how to perform the detailed gating and risering system design using a commercial metal casting simulation software package (Altair Inspire Cast). Following the design phase, the students were then required to physically produced the metal casting in the Texas State University foundry laboratory. These were the primary goals of the course with the PBL methodology. However, in order to improve student learning, understanding, comprehension as well as solve the issues encountered in previous course projects, a milestone-based PBL methodology was implemented such that the project drives the course learning outcomes. Throughout the project, students had milestones that were required to be completed to guide them through the design process, which provided the instructor the opportunity to provide feedback. The course lectures were timed in such a way that information critical to the completion of the project was introduced approximately one to two weeks before it was needed to complete the project deliverables. The project deliverables, which followed steps used to make commercial castings, are as follows:

- Description of the metal casting they intended to produce
- A Computer-Aided Design (CAD) model of the metal casting, which would be used to produce the pattern
- Preliminary gating modeling
- Preliminary gating and risering calculations
- A casting simulation showing gating of the casting from an ideal location, the solidification dynamics, and potential locations for casting defects
- A matchplate pattern to produce the casting
- The final casting itself
- A presentation outlining the process the students went through to produce the casting
- A final report detailing the design and production process

In addition to the inclusion of the project and timing of topics according to the milestones, additional structural changes were made to the course. With the implementation of the milestone-based PBL methodology, the comprehensive final exam was dropped as students would now be demonstrating their cumulative learning through performance on the project. In addition, in Fall 2020, the course delivery was changed to hybrid. This change was made based on the COVID-19 pandemic teaching protocols. Most student assessment including quizzes, homework, and exams was conducted online. With the online administration of exams, the instructor made the exams open-book and notes, under the assumption that students would have access to outside materials during the exam, which otherwise would be difficult to control. The course delivery was face-to-face during the control semester in Fall 2019 and once again during the second iteration of the intervention in Fall 2021. Closed-book exams were given in the both semesters the course was taught face-to-face (Fall 2019 and Fall 2021).

To gauge the success of the intervention, pre- and post-surveys were administered to the class measuring their understanding of the design of foundry tooling and the metal casting process. Table I shows the questions used in the pre and post surveys. Questions 1 – 6 were presented on the pre-survey, while all questions were presented on the post-survey. Students indicated their agreement with each statement on a Likert scale of 1 to 7 with 1 being “strongly disagree” and 7 being “strongly agree.”

After the first implementation of the PBL intervention in 2020, the instructor realized that as engineering design is often an iterative process, and to improve student learning and comprehension, students needed to be given an opportunity to implement the concepts learned in class, learn from the failures and successes of the first iteration and then be given a second iteration to improve their designs and products. This realization came after seeing many of the students’ castings fail at the end of the semester during the first implementation of the project. Most of the groups came to the foundry laboratory to produce their castings with incomplete tooling and tooling that did not incorporate all of the design features needed to make a successful casting. Only two of the ten castings were considered a success, and the instructor surmised that most of the students ended the course with a feeling of disappointment. With that in mind, in the second implementation of the PBL intervention (Fall 2021), students were given two attempts separated by two weeks to produce their project castings. In order to provide enough laboratory time to achieve this, the project timeline was shifted forward by two weeks. This allowed enough time for students to attempt their castings for the first time, implement design revisions based on lessons learned from the first attempt, and then to come back to the foundry laboratory two weeks later for a second and final attempt at producing their castings.

Table I. Questions used on pre- and post-surveys. Questions 7, 8, and 9 were only used on the post survey.

Question
1. I can describe at least three common metal casting processes.
2. I can design a part to be made by metal casting.
3. I understand how metal flows into a mold and solidifies.
4. I can design the runner system for a casting.
5. I can design risers for a casting.
6. I can use casting simulation software to design a gating and risering system for a casting.
7. How satisfied are you with the casting project in this course?
8. How well did the casting project help you understand how to properly design a pattern and gating and risering system for a casting?
9. Please provide any comments you would like to add.

Results

The primary mode of assessing the effectiveness of the milestone-based PBL intervention was the administration of pre- and post-surveys as previously discussed. Participation in the pre- and post-surveys was completely voluntary. Participation rates for the pre- and post-surveys are shown in Table II. The results of the pre- and post-surveys are shown in Table III.

Table II. Pre- and Post-Survey Participation Numbers and Rates

Semester	Enrollment	Pre-Survey		Post-Survey	
Fall 2020	20	18	90%	14	70%
Fall 2021	20	17	85%	14	70%

Improvements in perceived student learning were shown across all survey areas for both semesters of the intervention. The largest improvements were for Questions 2, 4, 5, and 6, which are all related to the design of a casting and its associated filling system. This appears to be indicative of the success of the design-centered project that led students step-by-step through the process of designing and producing the casting, filling system, and the pattern used to produce them. The increase also seems to indicate that students gained confidence in the design skills they developed through the project. The particularly large increase in scores related to Question 6, which asks about the student's ability to use casting simulation software, is expected because none of the students had prior experience with casting simulation software prior to taking the course. However, the students were given some exposure to the design of gating and risering systems in the prerequisite manufacturing course. The smallest gain was observed for Question 3, which dealt with a student's ability to understand how metal flows into a mold cavity and solidifies. This was thought to be a significant educational benefit of using casting simulation software because this is shown in the simulations, whereas one cannot see metal flowing or solidifying in the mold during laboratory casting sessions. Therefore, this modest gain came as a surprise.

Table III. Pre and post questionnaire results for semesters the intervention was applied.

	Fall 2020 Treatment		**Fall 2021 Treatment**		**Aggregated Results**		
Question	Pre-Survey	Post-Survey	Pre-Survey	Post-Survey	Pre-Survey	Post-Survey	Percent Improvement
1. I can describe at least three common metal casting processes.	5.67	6.14	3.94	6.00	4.83	6.07	25.7
2. I can design a part to be made by metal casting.	5.11	5.86	3.59	6.07	4.37	5.96	36.4
3. I understand how metal flows into a mold and solidifies.	5.56	6.07	4.41	5.71	5.00	5.89	17.8
4. I can design the runner system for a casting.	4.50	5.43	2.94	5.71	3.74	5.57	65.3
5. I can design risers for a casting.	4.44	5.29	2.88	5.50	3.69	5.39	46.1
6. I can use casting simulation software to design a gating and risering system for a casting.	3.11	5.79	2.65	6.21	2.89	6.00	107.6
7. How satisfied are you with the casting project in this course?	–	5.21	–	5.86		5.54	–
8. How well did the casting project help you understand how to properly design a pattern and gating and risering system for a casting?	–	5.71	–	6.21		5.96	–
9. Please provide any comments you would like to add.	–	–	–	–	–	–	–

Student comments from Question 9 were generally positive and expressed most students' enthusiasm for the project. Following are comments obtained over the two interventions. The comments were lightly edited for readability. Comments not pertaining to the project or learning outcomes were excluded. The comments from the first intervention in Fall 2020 semester were:

- Great class this semester! I learned a lot of different things that I hope I can use in the future.
- Gating and risering system is one of the most important parts. You mess that up and there isn't a mold made.
- A lot of information, but taught well.
- I enjoyed this course and I will value the lessons I have learned through here.
- This was my favorite course this semester, thank you!

- Was a great class!
- Not really anything else to add.
- I enjoyed how the project helped us see everything that we have been learning throughout the semester.

The comments from the second intervention in the Fall 2021 semester were:

- We need more pours, different alloys and more room for error. I want to be taught how to account for failures and make sure that my casting comes out well. If there is anything to fail I want it to be the surface finish.
- The example problems in class were helpful for the design of our project at the end.
- Overall this was a great course. I learned way more than I expected and if I was asked to take this class again I definitely would. He created a great learning environment and always pushed for us to learn and think critically.
- Great class. Like all others, there's just not enough time to go really in depth into the material and trial and error. Overall a great intro in a large and important industry in the modern world. Thanks Dr. Trueba.
- Very fun project to work on.
- I learned so much from the class and it definitely cleared up things I was confused on about the casting process. Some classes I have taken as an Engineering Technology major were very badly constructed and not much was taught. The opposite goes for this course. I feel like I have learned more than enough and am satisfied with the outcomes of the course. Thank you for caring!
- Professor was one of the best I've had. Difficult class but learned a lot and had a great time doing so.
- I wish we had more time in the lab because I strongly believe that casting knowledge gets better with practice. It was really fun to be at the lab, it help me better understand some theoretical [concepts] that was difficult for me to get.
- Professor Trueba is an amazing instructor, leading us all the way to the path of successfully understanding the material.

The aggregated pre- and post-survey results were analyzed to determine if the increase in scores for each survey question over the semester was statistically significant. For this purpose, a Student's *t*-test was applied to the responses of each survey question to evaluate the null hypothesis H_0 that there is no difference in the populations of student responses to the pre- and post- surveys. The null hypothesis was evaluated at the $p = 0.05$ significance level. At this level, the differences observed between the pre- and post- survey responses for questions 1-6 were found to be statistically significant, and the null hypothesis was rejected.

In order to provide direct assessment (as opposed to indirect, such as the questionnaires), the average overall course grades were used and are presented in Table IV for the two intervention semesters as well as a control semester, which was taught the semester immediately prior to the intervention semesters. All courses were taught by the same instructor.

As shown in Table IV, the average course grades increased by four percentage points when the course was taught using the PBL methodology intervention, as opposed to the traditional course delivery (control semester). The significance of the improvement in scores is confounded by a change in assessment brought on both by the change in pedagogy and the COVID-19 pandemic as previously discussed. The course was delivered hybrid during the first intervention (Fall 2020). During the second iteration of the intervention (Fall 2021), the class was taught face-to-face again, along with the exams once again being closed-book. It is interesting to note that there was no apparent change in course grades accompanying this change.

Table IV. Average course grades over three semesters

Semester	2019	2020	2021
Control/Intervention	Control	Intervention	Intervention
Average Score	78.7	82.6	82.6

Discussion

As previously discussed, during the first administration of the intervention in this course it was observed that many students did not arrive at the first project casting session prepared to produce a successful casting. The reasons varied from improper pattern designs that ultimately cause the mold to break to pattern features that are too large or fine to reproduce on the casting. In the first intervention, the instructor did not anticipate this being an issue and had the students produce their castings during the last week of class. Unfortunately, a large majority of the castings failed and were not completed, and because there was not sufficient time left for a second casting attempt, the students finished the course with a high level of frustration. Additionally, the instructor had to assess these projects differently than was planned, due to the unsatisfactory casting results. Therefore, the course schedule was adjusted in Fall 2021 to allow a second attempt for the students to produce their castings based off lessons learned from their first iteration. As anticipated, most students arrived for their first attempt ill prepared, and none of the castings were a success. Students modified their patterns based on the lessons learned in the first casting attempt, came back two weeks later, and nearly all the groups (~80%) produced successful castings upon the second attempt. Although a significant improvement was observed, the goal in future iterations is to have 100% of the groups have a successful casting within two attempts.

The instructor believes the change in the project schedule allowed the students to learn about the design process more deeply and with a significantly lower level of frustration. Examining the results of post-survey questions seven and eight support this conclusion. The averages of the responses to question 7 in 2020 and 2021 were 5.21 and 5.86, respectively, representing an increase of 0.65 points. Similarly, a 0.5-point increase was observed in the responses to Question 8 from 2020 to 2021 (5.71 vs. 6.21). The null hypothesis H_0 that there was no difference in populations of survey responses to questions 7 and 8 between the years 2020 and 2021 was tested using a Student's t-test. Unfortunately, the hypothesis could not be rejected at the 0.05 significance level. Nonetheless, the instructor feels like the difference is meaningful, and the modified project schedule will be maintained going forward.

As this was only the second iteration of the milestone-based PBL intervention, the author plans to continue implementing and improving on the methodology. As previously discussed, there are still aspects in which improvements can be made, such as having 100% of the student groups produce a successful casting. Another major change the authors plan to make in future iterations is incorporating additional assessment methods in order to fully ascertain if the milestone-based PBL methodology is in fact improving student learning and comprehension. Planned methods for this are embedded test questions, quizzes, homework assignments, and other possible direct (non-subjective) assessment methods that all focus on the project, and most importantly the course learning objectives.

Conclusions

Implementation of a milestone-based PBL pedagogy was found to have several benefits:

- The pedagogy increased student perception of learning outcomes in a metal casting course with a hands-on laboratory portion over the two years in which the intervention was implemented.
- The pedagogy appears to improve student confidence in their design abilities as students are guided step-by-step through the design and redesign process with constructive feedback along the way.
- Learning from mistakes can be powerful. Providing a second opportunity to successfully design and produce a prototype may improve outcomes and student satisfaction in projects requiring the design and production of a prototype.

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