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Implementation of a Project-Based Learning Approach in an Upper Level Course in Engineering Technology

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Abstract

Project-based learning (PBL) is characterized as one of the most efficient approaches to engineering education during recent years. It has been applied from elementary education to higher education courses in diverse areas. In this study, the reader will find brief information of specific areas where the PBL approach has been used, advantages, and challenges to PBL. Although the source of project definition is not the main goal of this study, the reader can find a section on it. The focus of this study is on the methodology applied to enhance PBL in a linear programing course. The methodology helps identify where student work supported the desired learning components and where remediation in the curriculum needs to be focused. Accordingly, sections on student assessments and outcomes, conclusions, and future studies are included.

Introduction

Historically, learning in engineering curricula has been very technically focused. This style in no way reflects an engineer's requirement in their job which includes teamwork and multi-discipline problem solving skills [1]. Project-based learning (PBL) is a part of a pedagogical practice that involves a wide range of engineering requirements methods. However, this learning method has not been holistically implemented [2]. To help with this issue, ABET, in its most recent guidance is pushing for more PBL which research has shown as key and most prevailing attribute among successful graduate engineers within the industry [1]. The prevalent method for teaching in engineering disciplines is the "Chalk and Talk" approach. The instructor will lecture and the student will be a passive learner, not a student centered method [1]. These authors argue the need to do more using student centered approaches. Other authors too have identified the need to use student centric approaches but there has been little adoption of these approaches in many science and technology areas [3]. In their papers [3] and [4] argue that PBL has a student centric approach. The purpose of this study is to present a methodology used in a linear programming (LP) course in the Department of Engineering Technology at a teaching university.

Background

Project-based learning has been used in different courses or areas with different approaches. The study by Mills and Treagust [1] comparing problem-based and project-based approach in engineering education with specialization in civil, electrical, mechanical, and computer engineering at Central Queensland University applied a 50% method for both cases in a single semester. The finding shows that the understanding level from student evaluation at the end of the semester in project-based learning was higher compared to the problem-based, accordingly the student stated that the use of real world and case scenarios helped. Though it was identified that continuous training of students and faculty in this regard will help increase the capacity for PBL to become more effective. Accordingly, [5] found the same in the study of freshman mechanical engineering students in an introductory course and the report was based on the application of a unit consisting of a microproject. Students shared that they benefitted by thinking over the problems without prior encounter and solving problems through group thinking. This comes with regular visits to the instructors to stay on track and not defeat the purpose of PBL. In the same light [6] reports his experience in the area of Engineering Technology, drawing from his experience as a faculty advisor for an experimental vehicle program and used areas of total quality, engineering design process, and engineering solutions as topics for his Engineering Fundamentals class. Engineering Technology students were then invited to participate in the vehicle projects which added hands-on experience to the students. In addition, [6] comments that 36 (most) of his students enjoyed working on projects. Applications in areas other than engineering or engineering technology can be found and [7] provided a review of the application of the PBL approach using a breakdown for preschool and primary school, secondary school, and in higher education including preservice teacher training. In their review they explored several efforts in different countries such as United Kingdom, Spain, Lima, Portugal, Australia and Ireland. The review resulted in six recommendations for successful adoption of a PBL approach. The PBL approach has even been applied in music studies [8]. The researchers also gave an overview of the positive and negative experiences a group of lecturers experienced during this pedagogy approach. According to authors [7] and [8] research on instructors' role on successful implementation of PBL in the United States and Lithuania several themes were identified: time management, culture establishment that stresses student self-management, student grouping, working outside their reach, using technology, getting started, and assessing student promptly. This is important information that can be used to achieve success by applying the PBL approach. One publication that addresses the importance of using PBL with the knowledge generated throughout several years of experience is that of De los Rios et al [9]. Drawing on 20 years of experience and several applications that extended to rural development areas and engineering applications among others, sharing the evolution of the strategy of using PBL in the classroom in three phases: 1. the implementation and use of PBL approach; 2. expansion of the approach to other courses; and 3. where authors link additional competencies from PBL approach to project management. The concept for using a PBL approach relying on industrial projects for computer science majors was elaborated by [10]. The study emphasis that using industry projects results in students being ready for real word capabilities vs cases or projects derived from cases where exposure to all capabilities may be limited and not expanded to all the intricacies of real life as happens in industry.

Linear Programming and Project Based Learning

Project based learning continues to gain significant attention in education, especially for the effectiveness in improving deep learning, critical thinking, and problem-solving skills for students [4], [11], and [12]. According to [12], within the realm of PBL integrating linear programming techniques improves students experiences to become more relevant, challenging, and increases the ability to address complex decision making problems. It is highly fundamental that engineering students leverage the skill set while in school to help them succeed within the global market space. Graduates have to deal with challenges and continuous advancement that globalization is bringing to their professional fields [12]. The demands of the 21st century are within the confides of communication, collaboration, critical thinking, problem solving, creativity, and innovation [13]. Accordingly, [11] and [13], states that project based learning integrating linear programming is a learning and a teaching method that guides students to learn and a guide to their learning process. LP is a mathematical optimization technique that follows the concepts of these demands as compared to the traditional mathematical courses that only allows students the knowledge of concepts and theory without linking to real problems [12], [13]. Integrating LP and PBL is an approach that helps student with meeting these demands, [12] stated that linear programming courses can be taught by assigning the following procedures: gathering information, problem modeling, and result analysis and documentation. These methods comprise four variables in each section that begins with understanding the problem in the information gathering section and ends with result documentation in the result analysis and documentation section. According to [12], this framework has been used by other researchers but a further research work was done to develop a proposed framework for soft skill application in linear programming using PBL activity sequence. The author stated that, the PBL activity sequence proposes a feedback loop that allows the students to learn as they work using a set metric and rubric to assess each work stage. LP integration with PBL is grounded in the desire to afford students with authentic and real-world solving experiences that helps to bridge traditional practice knowledge providing a systematic approach for modeling and solving decision making problems [12], [13]. As the preparation of students for the complexities of the modern workforce is necessary, it has become more prevalent to equip engineering graduates with the ability to use real-world context to approach holistic problems by integration LP with PBL to promote deeper conceptual understanding and higher thinking skills [11], [12], and [13]. Lastly, limited sources of similar works to our project are available. No other work on a similar course has been found except for the application of optimization techniques such as integer programming, linear programing and transportations problems to an undergraduate industrial engineering course. However, thee work presented by [14], used real research projects with application to a health care system. The instructor concludes the approach improved several student's outcomes all related to engineering accreditations. Listed in the paper include communication, team working and learning of subject matter plus others.

Advantages of a PBL Approach

According to [4] and [11], some of the attributes found among top performing engineers with project-based learning experience are effective communication, exceptional teamwork ability, critical thinking, data management and analysis, problem solving, etc., which aligns well with the employer's needs. Project-based learning is a combination of several approaches that help students in the areas of constructivism, cognitive psychology, situated learning theory, and concept of integration through teamwork and scientific problem solving methods within a balanced constructive team [2], [5]. Teamwork is an essential aspect of PBL which brings individualistic character requirement resulting in successful task delivery with team members expressing their various perspective to solving problems [5]. The teamwork setting has been found to positively increase student's learning attitude towards technology and science applications, shaping their skill development, knowledge compilation, and general ability as they move from college to industry [2]. It is becoming necessary to get students up to the level required to easily settle into industries upon graduation. According to [4] and [12] "project-based learning is the best way to fulfil industry needs" and PBL is a fundamental approach to reaching this plight. There is a common agreement in studies where it was identified that students were able to build their own knowledge through active learning, environment interaction, and collaborating in teams with the instructor's guidance to deliver an intended product [1], [5]. Team selection seems to be an issue, but if done properly, it is one of the great strengths when implemented. Others report individual motivation, the motivation to learn is enhanced and the responsibility for own activities to strengthen self dependence [8]. In the study by [10], it is reported that another benefit is the "positive impact on students" allowing a better understanding of the problems students will face in industry.

Challenges of a PBL Approach

In addition to the problem of selecting the team members, one of the challenges using the PBL approach deals with is communication. This is an issue that [4] and [13] agrees on that unhappy employers arises due to unsatisfactory skills at writing and speaking. Writing and oral presentations are key to delivering the student's accomplishments. Some include in their teaching approach tutorials for Excel and Word. Elements such as subscripts, superscripts and equation editor in Word and for Excel computation and graphing [6]. Insufficient preparation of students, lack of time, lack of lecturer's experience in the project is reported by [1]. According to [3], "disciplinary egocentrism" is referred to as one of the challenges to implement projects, a challenge on the instructor side. While [3] define disciplinary egocentrism as "unable or unwilling to engage in alternative approaches to their discipline," and the term can equally be applied to students. Accordingly, [8] report that negative experience is the difference in expectations between an instructor and students. Additionally, they experienced "some students tend to shift responsibilities for the quality of the studying to the group of the project implementation, to avoid assuming responsibility for the outcome of activities of the whole project group, to insufficiently communicate with the study colleagues". The authors went on to express in the previous study that there is "lack of student's social and leadership competencies." [4], [11], and [14] explain a diverse team is essential and the instructors play a major role in helping to formulate the team in the right complexity where no single group have a combination of all like minds.

Methodology

The course selected for this study is a second semester, senior level optimization (linear programming) class taught to engineering technology (ET) majors. The course focused on applying linear programming to manufacturing and supply chain problems. It covers mainly linear topics though some non-linear topics and heuristics are also covered. As part of the program, all students have been required to complete four writing intensive courses and are expected to understand the basics of writing as well as all students have taken integral and differential calculus. This class is used to provide summative assessment for the ET program's ABET requirements. Specifically, the course is being used to evaluate ABET ETAC SLO 1: *Ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly defined engineering problems* and SLO 2: *Ability* *to design systems, components or processes meeting specified needs for broadly defined engineering problems*.

The projects defined in this study originated from an NSF (National Science Foundation) call for proposals that the authors were interested in and to support the department's push for assessment and accreditation. To ensure that the projects were aligned with the NSF call, a three-plane diagram was created to help focus the projects. Three-plane diagrams are a strategic planning tool that is being used by the Engineering Research Centers to help support a top down approach to planning out systems and identifying enablers and barriers to the implementation of these systems. The diagrams have three ascending planes: knowledge base, technology base, and systems base, hence the name, three-plane diagram. Each level requires an increased level of understanding of the topic being researched. The three-plane diagram used in this project was previously developed by one of the authors and the diagram used for this research is shown in Figure 1. This graphic shows what the author felt were the topical knowledge needed to support future factory. This diagram shown in Figure 1 is incomplete to protect some of their work. Through the three-plane diagram, eight potential topic areas were identified for the students to research:

1. Optimal location for EV charging stations in Texas
2. Are staffing issues due to a reduced workforce or due to inefficiencies in scheduling
3. Based on energy production, when should companies utilize wind and solar farms versus utilizing fossil fuel generation
4. Optimal layout of residential areas around cities
5. Optimization of space base/station layout
6. Optimal layout of energy systems in cluster types
7. Development of neural network pathways in manufacturing environments
8. Evaluate digital twins approaches to determine their effectiveness in optimizing their modeled simulation

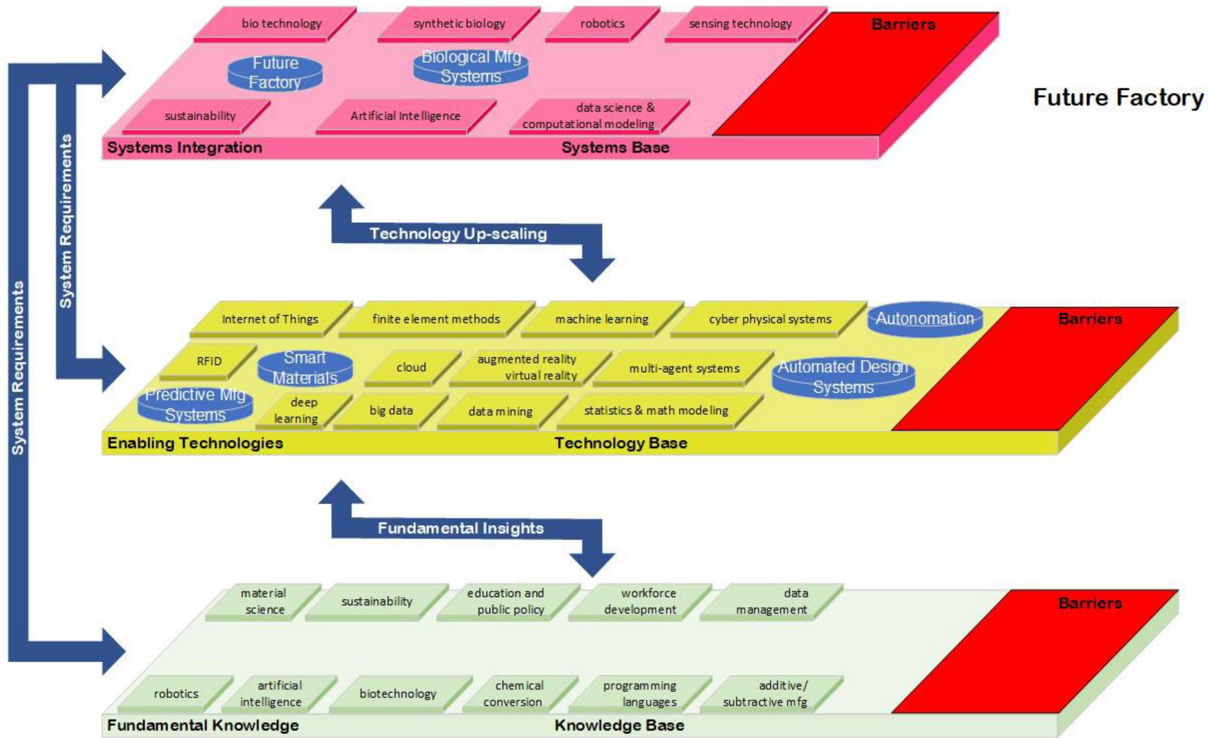


Figure 1. Reduced version of 3-plane diagram

There were three project deliverables staged to build up to a completed project and paper submission by the end of the semester. Teams were comprised of 3 to 4 students chosen at random. The scale for all rubrics was a 3 point rating scale with 1 being needs intervention, 2 below expectations, and 3 meets expectations.

The first deliverable was for students to write two article reviews and write a 200 word abstract for the project. The intent was for the students to be exposed to journal articles and their components and to use the abstract as a preliminary guide for their projects. They were also required to begin looking for data sources and have at least two data sources and five journal articles identified for this portion of the project. Students were provided further instruction on the expectations of the abstract and the grading rubric for the project. Upon grading and return, students were advised to meet with the faculty member to discuss their progress. For this deliverable, the rubric is shown in Table 1.

Table 1. Basic rubric for deliverable #1

Abstract	- Statement of Engineering Problem - Explanation of the approach used to solve the problem - Expected Results
Article Review	- Purpose - Methodologies - Results - Conclusions - Takeaways

The second deliverable consisted of writing an introduction, background, and methodology. Additional references were required for a total of 10 journal articles. The second deliverable also required the use of a journal template provided to the students. The format of the journal template is based on the IEEE format. In this portion of the project, focus was given to defining the problem being studied and why it was important, what work had already been performed in the field leading up to the students' work, and defining how the work for the project was going to be structured and performed. Since the course is based on linear programming, the methodology required definition of the models and assumptions used in the project. Upon grading and return, students were advised to meet with the faculty member to discuss their progress. Table 2 displays the rubrics for the second deliverable.

Table 2. Basic rubric for deliverable #2

Introduction	- Statement of Engineering Problem - Explanation of why the problem is important enough to work on - Hypothesis
Background	- Provided a comprehensive background of the problem - Identify what others have done in the field - Identify gaps in the research
Methodology	- Define variables, models, and methods - Define data types and sources - Propose an analysis method that corresponds to the models used

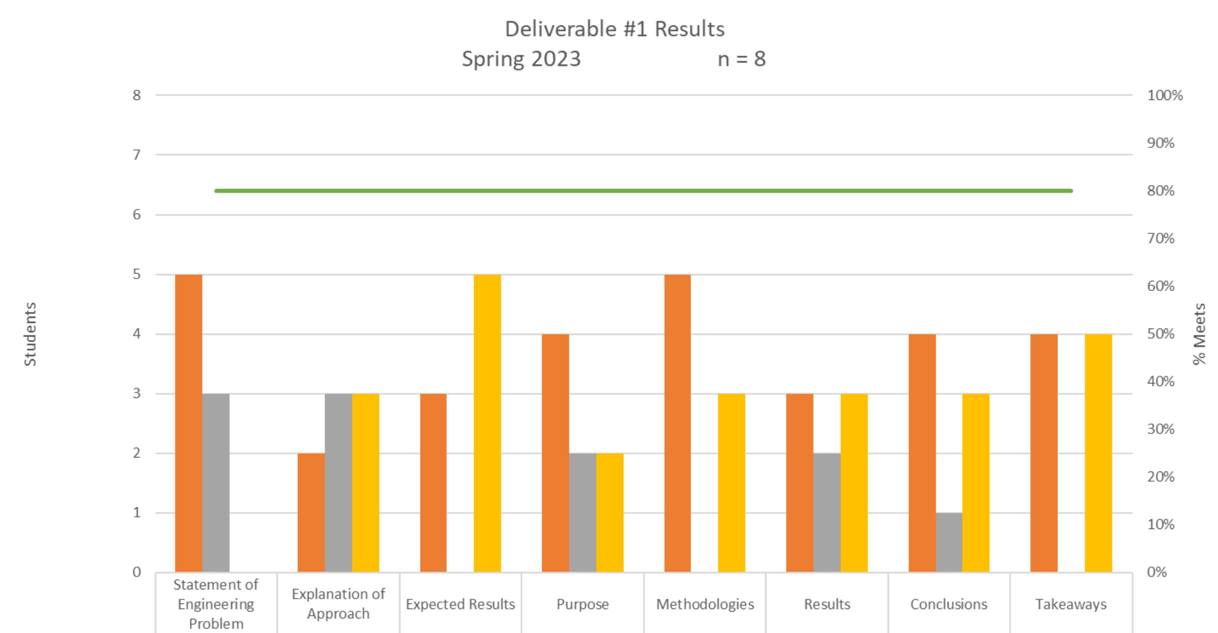
The third deliverable allowed students to make corrections to the previous work but also required them to submit sections discussing the results and conclusion of the project. These sections were used to evaluate how the students showed data in tables and graphs, how they interpreted the data meaning, and what information they took away from the data. Final papers were graded and returned to students. Students were advised to continue to meet with the faculty member. See Table 3 for rubrics used in the third deliverable.

Table 3. Basic rubric for deliverable #3

Results	- Data appropriately shown in tables - Figures and graphics are appropriate to the data and relevant - Figures and tables are descriptive of the data and supported by the interpretation of the results
Conclusions	- Conclusions are reasonable and discuss how the project addressed the engineering problem and hypothesis - Limitations and next steps are discussed

Results

The following graphs show the project performance against the rubrics provided to the students.



	Statement of Engineering Problem	Explanation of Approach	Expected Results	Purpose	Methodologies	Results	Conclusions	Takeaways
Meets	5	2	3	4	5	3	4	4
Below	3	3	0	2	0	2	1	0
Intervention	0	3	5	2	3	3	3	4
Target	80%	80%	80%	80%	80%	80%	80%	80%

Figure 2: Student performance on deliverable #1

For Deliverable #1, students submitted an abstract and discussed the articles that they had begun reviewing. The student work was evaluated against the rubrics with the intention of making sure that the students could properly identify the problem they were working on and beginning to formulate a plan to approach solving the problem based on documented practices in the literature. This is explained to the students in the context of defining a problem they will work on in industry, properly determining the scope of that problem, and evaluating common practices that others have taken to solve similar problems. Figure 2 shows how students performed against the rubric. For example, the first rubric looks at how well the students fully defined the problem that they were working on. In this cohort, 5 of the 8 groups met the expectations and 3 of the 8 performed below expectations. The targets of 80% were arbitrarily set for this semester but will be updated for future semesters. The authors' assumptions were that at least 80% of the student projects should be able to meet these criteria.

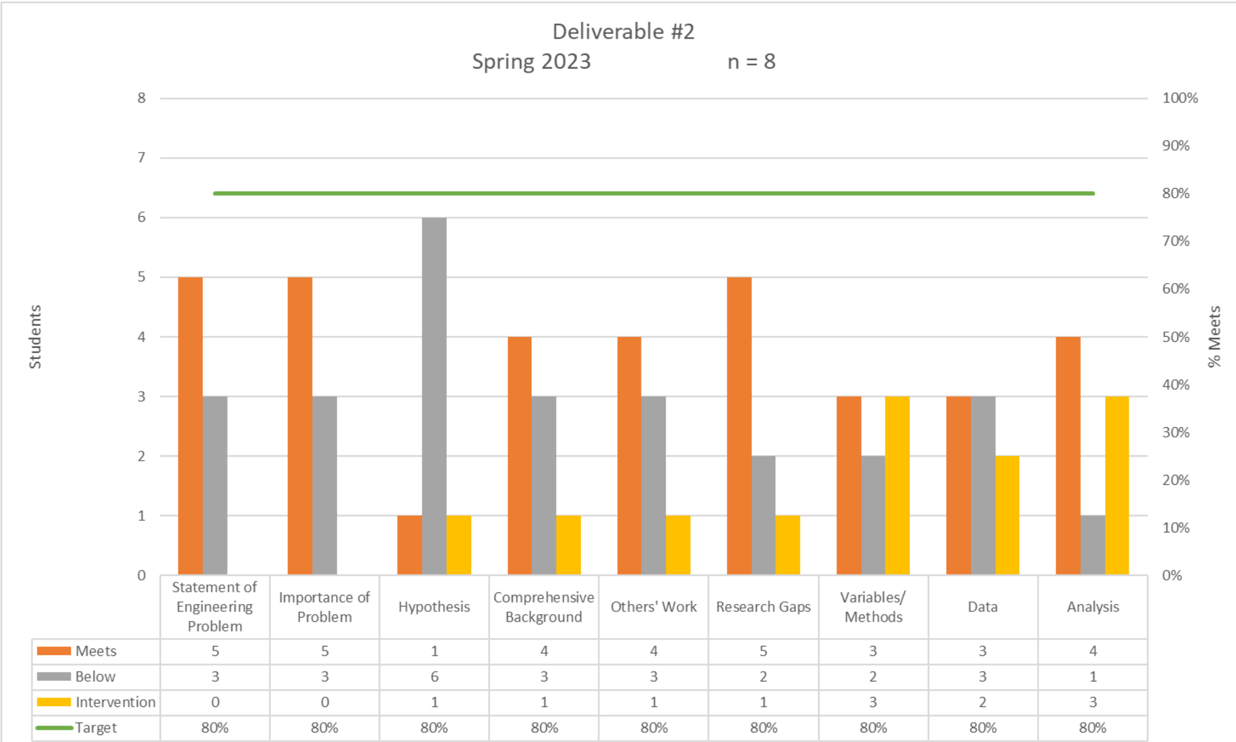


Figure 3: Student performance of deliverable #2

For Deliverable 2, students continued their work to develop an introduction to the problem, write a background, and develop a methodology to solve their problem. The discussion with the introduction expands on their previous work and includes defining why the problem is important enough to solve, what it is they expect to solve, and how they will know if they solved the problem they were working on. They are expected to pull references to discuss how others have resolved similar problems. This is expected to equate to them working through a benchmarking process in industry. The students were expected to identify holes in the research and use those as potential opportunities for their work. The students were also tasked with defining variables, data, and their proposed models that they expected to use in their projects. Figure 3 shows how the students performed against this rubric.

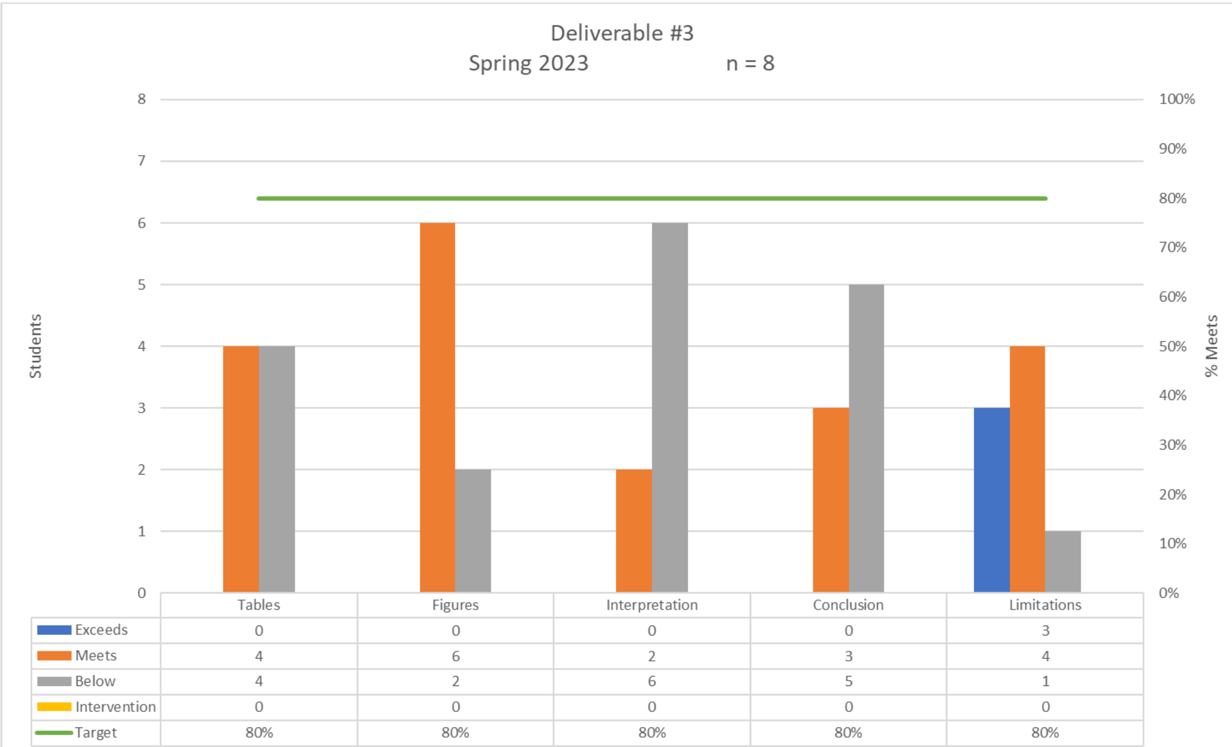


Figure 4: Student performance on deliverable #3

For Deliverable 3, students were to clean up comments from previous work, but the assignment focused more on how they presented their data and information, how they interpreted their results, and what they would plan to do with the results. The rubric for Deliverable 3, shown in Figure 4, adds the category of “Exceeds Expectations”. This category was only relevant to the “Limitations” rubric as all other rubrics ended with “Meets Expectations”. Future works will include the “Exceeds Expectations” as there has been some opportunity to introduce graduate students into this course as a primer for their coursework. The authors expect the requirements for these student projects to be higher.

Discussion

Students did not take full advantage of using the instructor’s feedback. For Deliverable #1 students did not actually discuss their work results once they were graded against the provided rubric. Many students then assumed that the problem that they were working on was not correct, so they changed their problem. When the students began working on Deliverable #2, it was found that since they did not fully understand the problems they were working on, they were not able to develop an appropriate methodology. After the instructor intervened in the project, the students were offered guidance in addressing problems noted in their previous work and how to proceed with the project. The main concern with the output of Deliverable #3 centered on papers that had incomplete or insufficient conclusions. Work continued to clarify some of these issues prior to the presentation of the materials, which is not covered in this paper.

Conclusion

Though the outcomes against the rubrics were not as good as were expected, the information has been valuable in several ways. The methodology used in this project can be used for research and for helping faculty develop projects for their courses relevant to their research and related to community needs. The 3-plane diagram that was actually used has more details and the information that the students were able to bring forward in their projects supported the faculty member's work.

As Engineering Technology students, this approach allowed the students to see how their education is not only valuable to engineering and manufacturing but also to the larger community. Most of the topics were foreign to them and many did not understand how their education would even allow them to work in these fields. Through discussions and interactions, the common threads of their coursework could be discussed to help them become more informed.

The work has also helped the department identify and begin to understand areas of opportunity, where coursework can be refined and changes implemented earlier in the students' academic careers, and what the students are retaining. As the department continues to work towards accreditation, it is expected that this will help strengthen the work that is being performed.

Future work on the project includes continuing to refine the rubrics. For most criteria, there is not an exceeds expectations. As improvements are implemented earlier in the curriculum, the expectation is that more students will perform better on their projects. There are also opportunities for some of our graduate students to take these courses so there is the expectation that the work is of higher effort.

Changes are also planned to increase the involvement of the instructor with the student projects. Some of this involvement is to help force students to begin their work sooner, as opposed to waiting until the due dates to start. The involvement will also help reinforce the problem and possible solutions to the problem earlier in the project as some projects had a hard time correlating what they knew to the problem. This interaction should also ease apprehension that students have with interacting with the professor outside of class times.

Lastly, the faculty are looking at methods for students to provide feedback on their projects during the semester, whether this is through discussion boards, sticky notes, or surveys. This would help provide students with different mechanisms to reach out for help during the project and during the semester.

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