

Project-Based Learning (PBL) in a course on mechanisms and machine dynamics

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ABSTRACT: Currently, engineering education is undergoing significant changes worldwide. The educational community is showing increasing interest in Project-Based Learning (PBL) approaches, which promise to lead to heightened student motivation, stimulate student self-learning and promote communication skills. Stevens Institute of Technology (SIT), Hoboken, USA, is currently transforming all its educational offerings. Several courses were selected for pilot implementations of PBL methodologies. This paper presents an initial assessment of the experiences gained from the revision of a junior-level mechanical engineering course on mechanisms and machine dynamics. The centrepiece of this revised course is a group design project that aims at developing a realistic product.

INTRODUCTION

Currently, engineering education is undergoing significant structural changes. The rapidly evolving technological landscape forces educators to constantly reassess the content of engineering curricula in the context of emerging fields and with a multidisciplinary focus. In this process, it is necessary to devise, implement and evaluate innovative pedagogical approaches for the incorporation of novel subjects into educational programmes without compromising the cultivation of traditional skills. The educational community is showing rapidly rising interest in Project-Based Learning (PBL) approaches.

Felder and his co-workers developed an Index of Learning Styles as an instrument that can classify different dimensions of learning [1][2]. While the traditional lecture-based teaching approach is considered as conducive only to certain learning styles, design projects are recognised as a means of providing the student with broad context to the particular body of information presented in the lectures, and thus these projects are likely to be especially effective for global learners. Furthermore, students are encouraged to assume responsibility for their learning experience and to shift from passive to more active learning patterns. This is likely to improve knowledge retention as well as the ability to integrate material from different courses. In addition, by adopting a project-based teaching approach, the teacher is enabled to create a more cohesive course structure, where the course moves more fluidly from topic to topic [3]. Brown and Brown traced the roots of project-based education back to the early 1980s and discussed its critical attributes [4].

Over the last few years, project-based instruction has rapidly gained acceptance by the educational community and is now being applied in a wide spectrum of engineering disciplines, at various types of academic institutions and throughout the different phases of the educational programmes. This is witnessed by a continuously expanding body of related information in the educational literature, some of which is briefly summarised below.

Roedel et al developed a freshman course that combines and integrates material from introductory courses in calculus, physics, English composition and engineering, whereby engineering projects were used to teach design and modelling principles [5]. Lopez implemented a series of small team-based design projects into a manufacturing course to strengthen the ties between theory and practice [6]. Weller et al implemented a project-based manufacturing laboratory that culminates in the manufacturing of a functional Stirling engine [7]. Sener applied PBL to construction engineering and opined that, in contrast to traditional lectures that mainly convey information, this approach leads to knowledge, which is gained by using information for particular applications [8]. Rubino presented the implementation of PBL into a freshman engineering technology course [9]. Genalo discussed the application of a PBL approach for teaching design of experiments in the framework of a materials science course [10]. Haik reported the development of an engineering mechanics course based on a term project that also involved building the designed product [11]. Adams discussed the enhancement of a statistical quality control course by incorporating projects that synthesise the information presented in the lecture and aim at solidifying and expanding the students' understanding of the material covered [12]. Rasheed et al applied a project-based self-instruction approach to a course on multimedia production [13]. Miner et al used projects as the vehicle to introduce students to the FEM, as well as a means to enhance the students' enthusiasm for their major [14][15]. Newell and Shedd discussed the implementation of team projects into a heat transfer course and compared their method with the traditional teaching approach [16]. McCreanor adopted a PBL format in a hydraulics course and used a just in time teaching mode that kept the students focused on why they were learning a certain topic [17].

Richardson et al emphasised that projects can serve as a powerful tool for attracting students to and retaining them in engineering programmes by demonstrating the diversity of skills needed to practice engineering [18]. Similarly, Wood and Craft reported a dramatic improvement in student retention of an engineering technology programme through the introduction of PBL [19]. Going one step further than the above-summarised implementations, Wood describes an entire engineering technology curriculum for the freshmen year where mathematics, science, technology and communications are taught in an integrated fashion using group projects [20]. In a similar development, Clark et al presented the design, implementation and evaluation of an entire project-based curriculum for chemical engineering that addresses a series of shortcomings of traditional curricula [21].

Stevens Institute of Technology (SIT), Hoboken, USA, is currently in a phase of dynamic transformations of all its educational offerings in light of an institute-wide strategic initiative. As part of this restructuring, a new undergraduate engineering curriculum was recently implemented that reflects the latest trend towards innovative pedagogies. Several courses were selected for pilot implementations of PBL methodologies, and this paper discusses the related revision of a junior-level mechanical engineering course on mechanisms and machine dynamics and a preliminary assessment of the outcomes.

OBJECTIVES OF THE COURSE REVISION

Previously, the course was taught with two 75-minute lectures and one 3-hour lab per week for a total of three academic credits. The syllabus followed the standard sequence of topics that have traditionally been part of similar courses nationwide. A more detailed description of the course outline and a discussion of the performance criteria used in the assessment of the related learning outcomes was given elsewhere [22]. In addition, a portion of the laboratory component has recently been based on remotely accessible experimental set-ups [23-25]. In this particular course, a fair number of analytical tools need to be introduced before students can be engaged in synthesis-based design activities that tend to better resonate with students' preferred mode of knowledge acquisition. In previous offerings of the course, this often led to insufficient student motivation for acquiring analysis skills and an ensuing lack of prerequisite skills for meeting the analytical challenges involved in design projects towards the end of the course.

At the outset of the course revision through implementation of PBL techniques, a number of project requirements were identified. Realistic project topics had to be chosen to ensure that the students would recognise their relevance and consequently identify themselves with the tasks at hand. This requirement takes into account that one of the key incentives for introducing the PBL approach was to stimulate excitement of students and to motivate them to take an active interest in their own learning rather than mainly focus on obtaining a certain grade by acquiring just enough knowledge to achieve this goal. In addition, the project had to seamlessly integrate all topics that are typically covered in the course and, at the same time, exhibit the appropriate scope and level of complexity.

As was discussed by Eder, engineering practice does not simply represent applied science but rather involves societal, aesthetic, legal, economic, marketing, management and coordinating considerations [26][27]. In acknowledging this reality, Walker et al developed real-life projects for a course in environmental engineering that were designed not only as a method to foster teamwork and improve open-ended problem-solving skills but also enhanced students' understanding of societal impacts and contemporary issues [28].

In recognising the importance of students' awareness about non-technical issues for their future professional success in the corporate environment, it was decided in the course revision described here to focus the projects to be developed on the design of specific products, which included a variety of business considerations. A similar approach had been taken earlier by Ross, who designed a course where students participated as employees of a fictitious design company. The student teams explored the imperfections of actual systems and the design tradeoffs related to existing products and finally created their own product designs [29]. This product-oriented approach ensures the open-ended nature of the projects and requires students to make certain assumptions relating to the product to be designed on their own. It complements the analysis activities typically associated with traditional, lecture and homework-centred courses not only with the synthesis-type tasks involved in the more traditional, well defined design projects with narrower scope, but also trains students in the integrative thinking used for reflecting on and evaluating existing alternatives. By aiming the projects at the design of an actual product, they were made relatively complex, thus requiring true teamwork and efficient communication and helping to impart skills and strategies associated with collaborative planning, executing and monitoring of project progress. The interdisciplinary nature of the projects was introduced in order to overcome the compartmentalisation of knowledge that often results from students taking various courses on what appears to them as being disconnected subjects and thus failing to realise their interconnectedness. Therefore, this educational model attempts to reflect the realities of the corporate work environment.

COURSE STRUCTURE AND PROJECT DESCRIPTION

In the revised course, the total number of contact hours remained unchanged. Also, the general technical topics that were covered previously were not altered in the revised version. The course content was organised into six 2-week educational modules that essentially corresponded to the principal subjects. The amount of traditional homework problems assigned was reduced approximately by half. The design project was structured correspondingly into six parts that were integrated with the educational modules. This was assigned to groups of three or four students at the start of the course. Handing out the project immediately at the outset of the course, where students are largely unfamiliar with the material required for the completion of the project, renders the learning process goal driven. This approach is in support of the life-long learning scenario for which students ought to be prepared and where the learning typically occurs on a needs basis in an active and often collaborative learning mode. The submission of a written progress report was required after the completion of each of the six parts of the project in order to guide students through the design tasks and to enforce due progress throughout the entire semester.

At the start of every lecture period, approximately 15 minutes were devoted to unstructured discussions of project-related issues and problems. In addition, a total of three full class periods throughout the semester were allotted for two progress presentations and a final presentation by each student team. Thus, the class time used for interaction on issues related to the project required a reduction of material covered in the lecture component by approximately 25% compared with the traditional syllabus. Therefore, the removed content had to be covered through independent learning associated with the project activities.

An overview of project components for each of the educational modules is given in Table 1. The technical components are identical with the topics presented in the lecture and represented roughly three times as many individual project tasks as the associated business components. The latter were not covered comprehensively in the lecture but were part of informal discussions. In addition, they draw on the students' previous exposure to these topics in a variety of other courses.

Table 1: Components of the modular project.

Module No.	Technical Components	Business Components
1	Mobility of mechanisms	Project planning
2	Kinematic analysis	Patents & trademarks
3	Gear design	Market analysis
4	Linkage synthesis	Societal impact
5	Force analysis	Cost analysis
6	Vibration analysis	Business plan

The four candidate products shown in Figure 1 were presented to the student teams as possible project selections. Contrary to examples typically used in popular textbooks for related courses, a theme of significant relevance to society was selected. Triggered by a rapidly aging population and facilitated by recent technological advances, devices to assist older citizens and people with disabilities will become more and more prevalent. Many related products involve simple mechanisms and thus represent valid candidate course projects.

Figure 1: Products (clockwise from top left: hand-held therapeutic massager; wheelchair lift to be retrofitted into a minivan; arm prosthesis, and stairway lift to be installed in homes of the elderly.

The project description given to students included the following elements: a concise statement of project objectives, explanation of teaming issues (team forming procedure and team member responsibilities), breakdown of the six modules into a sequence of specific tasks, list of deliverables with associated deadlines, and outline for grading and evaluation procedures. Distributing an explicit task breakdown to students may initially seem to contradict the fundamental philosophy of open-ended PBL, but this class was the first exposure of this particular group of students to this approach, which indisputably requires a certain amount of training and experience. After assessing the outcomes of the recent pilot implementations and making the necessary adjustments, SIT is planning to propagate the PBL approach into a number of other classes. In the future, the students will be exposed to this approach as early as in the freshman year, and thus they will be enabled to gradually build up the skill set required to function in this active learning environment. At that time, the level of detail included in the project description is likely to be reduced.

LESSONS LEARNED

Upon assessing the first pilot implementation, a few findings can be identified. Firstly, the introduction of PBL changed the interaction between the instructor and students significantly. While the learning environment before the revision was very teacher-driven, the revised course was much more focused on the students' needs. This required some flexibility on the instructor's part in responding spontaneously to the project-related problems surfacing during the unstructured discussions and in adjusting the lecture pace to the project's progress. In the next offering, some adjustments to the schedule will have to be made. The planning on which specific subjects to cover in the lecture and which ones to move to independent learning through the project will require some adjustments in the future.

Secondly, letting students determine the composition of the project teams entirely on their own turned out to be an inadequate choice. Based on this procedure, three of the teams formed through mutual agreement of all members, while the remaining fourth team essentially consisted of those students who, for some reason, were unable to form alliances. The result was a group that over the course of the semester significantly underperformed the other teams. While it is rather clear that equal teams with culturally diversity and similarly distributed talent would be desirable, it is much less obvious how such a balanced distribution could be achieved. A team selection by the instructor based on grade point averages would not necessarily result in equally strong teams since other qualifications such as previous co-op experience or leadership skills are just as important for the group success, as are analytical abilities and factual knowledge. Dennis, for example, described the use of students with prior work experience as team leaders to promote peer-to-peer teaching and learning [30]. Incompatibility, due to work schedules and personality conflicts, might also turn out as further impediments to the feasibility of team selection by the instructor. Therefore, during the next offering of the course, a random procedure will be adopted.

Another challenge associated with team-based educational activities is the evaluation of both individual contributions and achieved skill levels of the team members. Student groups often covered for underperforming team members unless forced directly into peer evaluation. Arce suggested using peer evaluation in the final project presentations as a significant component of the grading procedure for project-based courses [31]. In the course described here, team members were asked to evaluate and rate each other's work as documented in the final group presentations, as well as complete an anonymous questionnaire judging the contributions of all team members. In cases of obvious extreme discrepancies in the level of contributions, a differential to the project grade of the group was assigned for individual students.

CONCLUSIONS

A PBL approach was implemented into an existing junior-level mechanical engineering course on mechanisms and machine dynamics. The course content was reorganised into six 2-week educational modules. The group design project was also structured into six parts. It was assigned to the students right at the start of the course and aimed at developing a realistic product, thus including both technical and business aspects. Written progress reports required upon completion of each individual module, as well as two oral progress presentations, helped to guide students in the timely progression towards the final project goal. An initial assessment of the experiences gained from the implementation of the project-based teaching methodology is given and potential modifications for future offerings of the revised course are discussed.

REFERENCES

1. Rosati, P.A. and Felder, R.M., Engineering student responses to an index of learning styles. *Proc. 1995 ASEE Annual Conf. and Expo.*, Anaheim, USA, 739-743 (1995).
2. Felder, R.M., Matters of style. *ASEE Prism*, 6, **4**, 18 (1996).
3. Felder, R.M., Woods, D.R., Stice, J.E. and Rugarda, A., The future of engineering education II: teaching methods that work. *Chem. Engng. Educ.*, 34, **1**, 26-39 (2001).
4. Brown, B.F. and Brown, B.F., Problem-based education (PROBE): learning for a lifetime of change. *Proc. 1997 ASEE Annual Conf. and Expo.*, Milwaukee, USA (1997).
5. Roedel, R.J., Kawski, M., Doak, R.B., Politano, M., Duerden, S., Green, M., Kelly, J., Linder, D. and Evans, D., An integrated project-based, introductory course in calculus, physics, English and engineering. *Proc. 1995 25th Annual FIE Conf.*, Atlanta, USA, 530-535 (1995).
6. Lopez, D.A., Project based instruction in manufacturing: a new approach. *Proc. 1997 ASEE Annual Conf. and Expo.*, Milwaukee, USA (1997).
7. Weller, J.E., Kumar, V., Grove, S. and Bordia, R.K., The development of a project-based instruction to manufacturing laboratory involving a Stirling engine. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
8. Sener, E.M., Design of the learning environment: professional project-based learning in construction engineering. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
9. Rubino, F.J., Project based freshman introduction to engineering technology courses. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA, Session 3547 (1998).
10. Genalo, L.J., A project-based approach to DOE in materials. *Proc. 1999 ASEE Annual Conf. and Expo.*, Charlotte, USA (1999).
11. Haik, Y., Design-based engineering mechanics. *Proc. 1999 ASEE Annual Conf. and Expo.*, Charlotte, USA (1999).
12. Adams, S.G., Project-based learning in a statistical quality control course. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA (2000).
13. Rasheed, H.A., Nestorovic, S. and Elhassan, S., Designing a self-instructed, project-based multimedia course in engineering education. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA (2000).
14. Miner, S.M. and Link, R.E., A project-based introduction to the finite element method. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA (2000).
15. Miner, S.M. and Tyler, T.N., A project based introduction to mechanical engineering. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
16. Newell, T. and Shedd, T., A team-oriented, project-based approach for undergraduate heat transfer instruction. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
17. McCreanor, P.T., Project based teaching: a case study from a hydraulics class. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
18. Richardson, J., Corleto, C., Froyd, J., Imbrie, P.K., Parker, J. and Roedel, R., Freshman design projects in the Foundation Coalition. *Proc. 1998 28th Annual FIE Conf,*, Tempe, USA, 50-59 (1998).
19. Wood, J.C. and Craft, E.L., Improving student retention: engaging students through integrated, problem-based courses. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA (2000).
20. Wood, J.C., An interdisciplinary problem-based engineering technology freshman curriculum. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
21. Clark, W.M., DiBiasio, D. and Dixon, A.G., A project-based, spiral curriculum for chemical engineering. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
22. Esche, S.K., Pochiraju, K. and Chassapis, C., Implementation of assessment procedures into the mechanical engineering curriculum. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
23. Esche, S.K., Prasad, M.G. and Chassapis, C., Remotely accessible laboratory approach for undergraduate education. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA (2000).
24. Esche, S.K. and Hromin, D.J., Expanding the undergraduate laboratory experience using Web technology. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
25. Esche, S.K., On the integration of remote experimentation into undergraduate education. Submitted to *ASEE J. of Engng. Educ.* (2001).
26. Eder, W.E, Problem solving is necessary, but not sufficient. *Proc. 1997 ASEE Annual Conf. and Expo.*, Milwaukee, USA (1997).
27. Eder, W.E., Einstein got it wrong (for once) - some consequences for problem-based learning. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
28. Walker, H.W., Coleman, S. and Gaberell, M., Incorporation of project-based learning in an environmental engineering course at the Ohio State University. *Proc. 1999 ASEE Annual Conf. and Expo.*, Charlotte, USA (1999).
29. Ross, J.T., A microelectronics curriculum designed with industry input and project-based laboratories. *Proc. 1998 ASEE Annual Conf. and Expo.*, Seattle, USA (1998).
30. Dennis, N.D., Experiential learning exercised through project based instruction. *Proc. 2001 ASEE Annual Conf. and Expo.*, Albuquerque, USA (2001).
31. Arce, P.E., Group projects-based final exams. *Proc. 1999 ASEE Annual Conf. and Expo.*, Charlotte, USA (1999).