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Longitudinal Study of a Project-based Learning Methods Replacement for Lecture Based Courses

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Introduction

Incorporating project-based learning into first year experiences for engineering students has been shown to improve student motivation and success [1], [2]. Using hands-on projects [3], interdisciplinary projects [4], or implementing project-based learning approaches in courses [5] during the first-year of an engineering curriculum also improves student retention [6]–[8]. Project-based learning enhances student learning, improves student self-efficacy [9] and better prepares students for workplace challenges [10]. However, outside of the first year and the final capstone project course, project-based learning has not been effectively incorporated into typical engineering curriculums. A project-organized curriculum, as defined by Heitmann [11], where the majority of the curriculum is focused around project-based learning is relatively uncommon and requires significant restructuring of the entire curriculum. **Upper-level engineering courses may include instructor defined projects focused on implementing the course material in a more realistic fashion than typical homework problem.**

To incorporate more project-based learning into the upper-level undergraduate engineering courses a novel curriculum for the sixth semester (second semester junior year) in a four-year Mechanical Engineering B.S. degree was created. This curriculum replaced three traditional, lecture-based engineering science courses with a project-based learning environment. The students followed the traditional curriculum their fifth and seventh semester, with only the sixth semester being changed. Students not involved with the modified curriculum continued in the traditional, lecture-based courses, as shown in Figure 1.

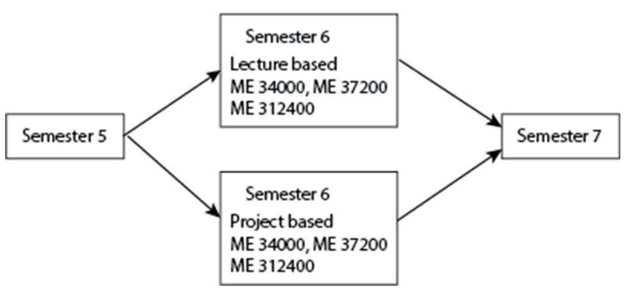

Figure 1. Schematic showing intervention during 6th semester.

The modified curriculum replaced the following traditional courses with the project-based environment: ME 34000 *Dynamic Systems Analysis and Design*, ME 37200 *Design of Mechanisms*, and ME 31400 *Heat and Mass Transfer*. These three courses cover fundamental components of mechanical engineering science concepts (mechanics, heat/thermodynamics, controls) and are relatively difficult courses in the traditional Mechanical Engineering curriculum. Real-life design and analysis problems were incorporated in the modified curriculum by utilizing the existing academic design competitions available in the Department. The SAE Clean Snowmobile Challenge, the Shell Eco-marathon, and the SAE Formula Hybrid academic design competitions provided ideal projects with multidisciplinary design challenges that included well defined requirements, goals and the need to fabricate working components.

The project-based learning environment included a laboratory workspace with access to the competition vehicles, online instructional materials covering the course material and required weekly meetings. Rather than presenting the theory in a traditional lecture format, subject based modules were available for the student to learn the material. A recommended, but not required, schedule for using the modules was provided. Tasks that required content knowledge from the replaced courses which also furthered the specific academic design competition goals were assigned. For example, a task was to design a curing oven to fabricate composite components used on the competition vehicles. To accomplish this task the students needed to acquire the knowledge typically found in a heat transfer course and a controls course and apply that knowledge in the development of the real-life design problem. Thus, providing the students in the modified curriculum with a hands-on, project based, self-motivated process for learning theoretical concepts based on the design and analysis goals of the academic competition project.

Any junior level student could participate in the modified curriculum if they had fulfilled all the prerequisites for the replaced courses and they had not already taken one of the replaced courses. This way the participants were prepared to learn the material but had not already been exposed to it.

Perrenet et al. [12] lists the three main objectives of education as "(1) acquisition of knowledge that can be retrieved and used in a professional setting; (2) acquisition of skills to extend and improve one's own knowledge; (3) acquisition of professional problem-solving skills." The use of the extracurricular academic design competitions as a nexus for engineering education reinforces these concepts and creates a significant, multi-disciplinary project-based learning experience.

Assessment

A cross-sectional and a longitudinal study was performed. The cross-sectional study was a direct comparison of the students' performance on written exams taken from the associated courses as compared to the traditional lecture-based course students' performance on the same exams. The longitudinal study consisted of tracking the research-students' grades in subsequent courses in the curriculum and comparing them to the average grade of their peers in those courses. In addition, a survey about their educational experience and their self-efficacy with engineering topics was given to both students in the modified curriculum and in the traditional curriculum.

Results

Fifty students in the Mechanical Engineering program agreed to participate in the study. To be eligible to participate in the project-based curriculum the students needed to have fulfilled all required prerequisite courses and not have completed any of the three replaced courses. Twenty-nine of the fifty students were eligible to participate in the project-based curriculum, however only eight students chose the project-based curriculum. The remaining forty-two students who agreed to participate in the study remained in the traditional lecture-based curriculum. The student demographics are provided in Table 1. N indicates the number of students in each group. The prior GPA is the average GPA of the students in each curriculum before the start of the project-based curriculum. In general, the students with the highest GPA in the Department chose not to participate in the project-based curriculum probably because traditional lecture-based courses work well for them. Minority students were better represented in the project-based curriculum.

	Students in Traditional Curriculum (N=42)	Students in Project-Based Curriculum (N=8)
Prior GPA	3.22 ± 0.55	2.92 ± 0.63
Gender	78% Male	87% Male
Race/Ethnicity	77.5% White	36% White

Table 1. Demographics

Students in the project-based curriculum took the same exams at the same time as students in the traditional lecture-based course. The exams were graded by the instructor of the lecture-based course (three different instructors) with no difference in grading scheme. There was effectively no difference in exam performance between the two groups. Table 2 shows the average exam grades for each group.

	Students in Traditional Curriculum	Students in Project-Based Curriculum
Heat Transfer Exam 1	84 ± 16.5 (N=30)	84 ± 12.4 (N=8)
Heat Transfer Final	99 ± 1.7 (N=30)	99 ± 0.9 (N=8)
Design of Mechanisms Exam 1	94 ± 7.9 (N=41)	94 ± 7.3 (N=8)
Design of Mechanisms Final	95 ± 3.8 (N=41)	95 ± 3.6 (N=8)
Instrumentation Exam 1	82 ± 14.2 (N=25)	77 ± 7.0 (N=8)
Instrumentation Final	83 ± 8.9 (N=25)	84 ± 6.9 (N=8)

Table 2. Exam performance during the intervention

As shown in Figure 1, students in the project-based curriculum return to lecture-based courses in the traditional curriculum at the beginning of the following semester. Performance of the students in the traditional curriculum and students in the project-based curriculum in the subsequent semester was evaluated by comparing the student's cumulative GPA prior to the intervention to the semester GPA following the intervention. There was no statistically significant difference in the results, indicating the retention of the material, at least at the level required for subsequent courses in the curriculum, was the same for both groups.

In addition to the academic performance, the students in each curriculum were surveyed about their attitudes and self-efficacy. The survey consisted of Likert scale questions and free response questions. The Likert scale questions can be broken down into five categories. Tables 3-7 below show a synopsis of the results from the Likert scale questions. In all cases the difference is small and, in most cases, not significant, but trends can be identified. In each of the tables a "+" indicates the project-based learning had a higher average score, "-" indicates that project-based learning had a lower average score by the amount indicated.

Question	**Difference**
Can master courses this semester	-0.1
Good Grades in Engineering Courses	0
Can master challenging courses	+0.1
Courses are boring	+0.1
Curriculum is preparing for career	+0.1

Table 3. Questions about Course Confidence

Question	**Difference**
Excellent Job on Tasks	+0.2
Leadership Role	-0.1
Good Oral Communication	0
Career will use course content	+0.4

Table 4. Questions about Career Confidence

Question	**Difference**
Independently perform experiments	+0.2
Analyze Data	+0.3
Challenges are appealing	+0.2

Table 5. Questions about Experimental Confidence

Question	Difference
Design Novel Things	+0.2
Identify design need	-0.1
Evaluate a design	+0.1
Recognize required changes	-0.1

Table 6. Questions about Design Confidence

Question	Difference
Use Computer Tools	+0.4
Use Technical Concepts	-0.1
Use Fabrication tools	+0.1

Table 7. Questions about Solving Problems

In general, the students in the project-based curriculum indicate more confidence in designing but less confidence in identifying a design need than students in the traditional curriculum. This could be a result of the students in the project-based curriculum being faced with the open-ended, multidisciplinary, design problems associated with the competition projects. Students in the traditional curriculum typically will not have that experience until the capstone design course. Students in the project-based curriculum also believe they will use the course content in their future career and have more confidence in using computer tools.

Table 8 shows the qualitative results from analyzing the open response questions for each group. The analysis indicated much better-defined career goals and a difference of perceived barriers from experience to connections in the industry.

Open Response Questions	Traditional Curriculum	Project-Based Curriculum
Describe Your Career Objective	Not Well defined	Well Defined
Describe Barriers to Obtaining Your Career Objective	Experience in the field	Connections in the industry
What Motivates You to be in Engineering	Problem Solving	Problem Solving

Table 8. Analysis of free-response questions

The survey given to the students in the project-based curriculum included an additional section asking about their opinion about this novel curriculum. The Likert scale ranged from “5-

Strongly Agree” to “1 – Strongly Disagree”. The students in the program thought the program was effective and would recommend more courses be converted to this style.

Question	Score
I Learned topics better in the program	3.4 ± 1.2
The program took more time than the associated class	3.0 ± 1.0
More classes should be converted to this type of program	4.1 ± 1.2
I would recommend friends to take this program	4.1 ± 1.0

Table 9. Opinions about the program

Conclusion

Three lecture-based, engineering-science courses in the junior year of a traditional Mechanical Engineering curriculum were replaced with a project-based learning experience. Thestudents in the project-based learning experience produced real-life designs, solving problems from extracurricular academic design competition projects in the Department. The students demonstrated equivalent mastery of course topics by achieving similar scores on the course exams. The self-efficacy of the students in the project-based curriculum was slightly higher than students in the traditional curriculum in all cases except for their confidence in identifying a design need. All students involved in the project-based curriculum indicated that more courses should be converted to this format and would recommend the program to their friends. Future career goals of the students in the project-based curriculum were better defined and perceived barriers shifted from experience to connections in the industry. Incorporating a strong project- based learning experience prior to the capstone design experience can give students a better learning experience, more self-efficacy with engineering topics, equivalent content mastery and better-defined career expectations.

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References

[1] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, “Engineering Design Thinking, Teaching, and Learning,” *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, 2005, doi: https://doi.org/10.1002/j.2168-9830.2005.tb00832.x.

[2] M. J. Prince and R. M. Felder, “Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases,” *J. Eng. Educ.*, vol. 95, no. 2, pp. 123–138, 2006, doi: https://doi.org/10.1002/j.2168-9830.2006.tb00884.x.

[3] R. Freuler, A. Fentiman, J. Demel, R. Gustafson, and J. Merrill, “Developing and Implementing Hands-on Laboratory Exercises and Design Projects for First Year Engineering Students,” *ASEE Annu. Conf. Proc.*, Jan. 2001.

[4] A. Dirsch-Weigand, F. Koch, R. Pinkelman, M. Awolin, J. Vogt, and M. Hampe, “Looking beyond one’s own nose right from the start: Interdisciplinary study projects for first year

engineering students," in *2015 International Conference on Interactive Collaborative Learning (ICL)*, Sep. 2015, pp. 729–732, doi: 10.1109/ICL.2015.7318119.

[5] J. Froyd, A. Srinivasa, D. Maxwell, A. Conkey, and K. Shryock, "A Project-Based Approach to First-Year Engineering Curriculum Development," in *Proceedings Frontiers in Education 35th Annual Conference*, Oct. 2005, pp. T3H-T3H, doi: 10.1109/FIE.2005.1611955.

[6] D. W. Knight, L. E. Carlson, and J. F. Sullivan, "Staying in engineering: Impact of a hands-on, team-based, first-year projects course on student retention," *age*, vol. 8, p. 1, 2003.

[7] C. A. Whitfield, R. J. Freuler, Y. Allam, and E. A. Riter, "An Overview of Highly Successful First-year Engineering Cornerstone Design Projects," p. 9.

[8] N. L. Fortenberry, J. F. Sullivan, P. N. Jordan, and D. W. Knight, "Engineering education research aids instruction," *Sci.-N. Y. THEN Wash.-*, vol. 317, no. 5842, p. 1175, 2007.

[9] J. Michael, J. Booth, and T. E. Doyle, "Importance of First-Year Engineering Design Projects to Self-Efficacy: Do First-Year Students Feel Like Engineers," *Proc. Can. Eng. Educ. Assoc. CEEA*, Jun. 2012, doi: 10.24908/pceea.v0i0.4650.

[10] M. A. C. Pereira, M. A. M. Barreto, M. Pazeti, M. A. C. Pereira, M. A. M. Barreto, and M. Pazeti, "Application of Project-Based Learning in the first year of an Industrial Engineering Program: lessons learned and challenges," *Production*, vol. 27, no. SPE, 2017, doi: 10.1590/0103-6513.223816.

[11] G. HEITMANN, "Project-oriented Study and Project-organized Curricula: A Brief Review of Intentions and Solutions," *Eur. J. Eng. Educ.*, vol. 21, no. 2, pp. 121–131, Jun. 1996, doi: 10.1080/03043799608923395.

[12] J. C. Perrenet, P. a. J. Bouhuijs, and J. G. M. M. Smits, "The Suitability of Problem-based Learning for Engineering Education: Theory and practice," *Teach. High. Educ.*, vol. 5, no. 3, pp. 345–358, Jul. 2000, doi: 10.1080/713699144.