

Group Projects to Induce Active Learning in Introductory Material Science Courses for Chemical and Mechanical Engineering Students

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Abstract. While an introduction to Material Science and Engineering (MSE) course is part of the core curriculum in many Engineering fields such as Mechanical and Chemical Engineering, many students often display a lack of interest in the subject matter, and struggle to see the relevance of the material to their Engineering field. To address this issue, the authors adopted a project-based learning approach in two introductory material science classes. The goal is to stimulate interest in the subject matter by providing students with the opportunity to apply fundamental Materials Science and Engineering (MSE) principles learned in the classroom to a material of their choice and interest. The student learning outcomes of this project are: (1) apply key concepts of the Material Science tetrahedron (processing, structure, properties, and performance) to their material of choice; (2) organize research material obtained from internet and book resources into a cohesive written report and oral presentation (including hands-on demonstrations); and (3) demonstrate good teamwork and interpersonal communication skills between group members. In this paper, the effect of group projects on stimulating students learning interest and improving their learning effectiveness is evaluated based on the direct outcome (reports and presentations) of the group projects, questionnaires, and student performance in exams. Our results suggest group project is an effective complement to traditional classroom lectures to improve student learning motivation and performance for introductory MSE courses.

Introduction

Materials Science and Engineering (MSE) is a discipline that focuses on the structure-properties-processing-performance correlations of materials. An introductory MSE course is often a required class in the curriculum of many engineering fields. For example, at University of Minnesota Duluth (UMD), an introductory MSE course is required in both the Chemical Engineering (ChE) (typically taken by Juniors) and Mechanical Engineering (ME) (typically taken by Sophomores) departments. However, we have observed many students display a lack of interest in the subject matter, and struggle to see the relevance of the material to their Engineering field, leading to poor performance in exams. To address this issue, the authors adopted a project-based learning approach in these two introductory MSE classes. The goal is to stimulate interest in the subject matter by providing students with the opportunity to apply fundamental MSE principles learned in the classroom to a material of their choice, and to improve student learning effectiveness by stimulating peer-to-peer learning and group discussions outside the classroom while developing better teamwork and interpersonal communication skills.

In recent years, project-based learning (PBL) has attracted increasing interest in engineering education communities.¹⁻⁵ PBL has often been adopted to engage students through active learning, which has been demonstrated to enhance student learning compared to traditional lecture-based learning.⁶ In this paper, the effectiveness of group projects on stimulating students learning interest and improving their learning effectiveness is evaluated. Our results suggest

group projects are an effective complement to traditional classroom lectures to improve student learning motivation and performance for introductory MSE courses.

Method

For both courses, the classroom lectures discuss primarily the general concepts and principles of materials science and engineering. The content includes: the structure of materials (bonding, crystal structures, defect, diffusion, phase diagrams and phase transformation), mechanical properties (stress-strain behaviors, strengthening and failure), and processing and applications (performance) of metals, polymers, ceramics and composites.⁷⁻⁸ As one-semester courses, these classes do not discuss in-depth about thermal, electrical, optical and magnetic properties, or modern materials such as semiconductors, biomaterials, and smart materials. Students are encouraged to engage in independent study of these topics if necessary to complete their group projects.

In the first week of the semester, each group of three or four students is tasked to pick any engineering material of their choice and submit an abstract consisting of a brief description of the material, and their plans to present this material to the class. Subsequently, students spend the next eight weeks investigating their material of choice in detail and complete a written report. The required sections of the report include an overall introduction of the history and current status of the engineering material, and an in-depth description of the structure, properties, processing, and applications (performance) of the material. To encourage a higher level of critical thinking, the students also evaluate current research applied to their material (either in processing, or altering its microstructure), and, in the process, gain an appreciation and understanding of recent advancements in their material using new technologies. In the second half of the semester, each group gives an oral presentation with hands-on demonstrations in class. The presentation date depends on the relevance of the selected material to the class lectures. For example, a group researching on polyethylene will give their presentation during the weeks when the lecture material is on polymers.

This group project is a mandatory assignment that accounts for 20% of the overall grade for the class. The project reports are graded by the instructors based on overall quality and completeness of each required sections, while the oral presentations are graded by both the instructors and the student audience based on presentation quality, education content, hands-on demonstrations, and group performance in the question and answer (Q&A) session.

In one of the ChE classes, the group projects are managed slightly differently. Students turn in different sections of their report with deadlines staggered throughout the semester, corresponding to the lecture material. For example, after concepts on Structure has been covered, students are given a week to complete their section of the report on the structure of their material. In addition, to ensure equal contribution to the research report among group members, each member is responsible for researching and writing one specific section, with mandatory draft submissions to the other group members for comments and edits. The final section of the report involves reading and summarizing a recent journal article (< 5 years) related to their material of choice. A final

comprehensive report of the entire research is turned in at the end of the semester, incorporating the instructor's comments for improvements for each section.

Assessment of Outcomes

The students came up with variety of materials for their group projects, covering all four categories of the engineering materials: metals, ceramics, polymers, and composites. For example, in the ChE class in spring 2016, the selected materials were copper, stainless steel, silicon carbide, Indium antimonide, Aerogel, high density polyethylene, asphalt, neoprene, and Kevlar. In their written reports, most groups demonstrated the ability to apply fundamental MSE principles to understand the different aspects of the materials, even for the materials and properties not covered by the class lectures. For the oral presentation, each group gave a 20-min talk based on Powerpoint slides, online videos, and a few hands-on demonstrations to show the properties of the materials, followed by a 5-min question and answer (Q&A) session. Most of the presentations were well prepared and received good grading from both their instructor and peer students. Generally the teams who presented good hands-on demonstrations tended to receive better grading from students. For example, the Kevlar group who invited a police officer giving an excellent demonstration of a bulletproof vest made of Kevlar received a nearly perfect grade for their oral presentation. The group projects obviously helped the students to develop good teamwork and interpersonal communication skills which were demonstrated in the oral presentations. Those oral presentations also served as a good complement to the instructor's lectures for engaging students in the class.

At the end of the semester, we assessed teaching and learning effectiveness through a questionnaire handed out in class, which included three questions directly related to the group project:

1. *Do you agree that the group project is a good way to learn the fundamental concepts of materials science?*
 - a. *Strongly agree*
 - b. *Agree*
 - c. *Neutral*
 - d. *Disagree*
 - e. *Strongly disagree*

2. *Which of the following has been the best source(s) for you to learn the course materials?*
 - a. *textbook*
 - b. *Lectures*
 - c. *Homework*
 - d. *Group project*
 - e. *Quizzes and midterm exam*

3. *Which of following has been the most useful in helping with self-evaluation of your performance in the course?*
 - a. *Homework*

- b. Quizzes
- c. Midterm exam
- d. Group project

Students were allowed to choose multiple options as response to the questions. The questionnaire also included an open question:

- 4. *What do you like and dislike about the course?*

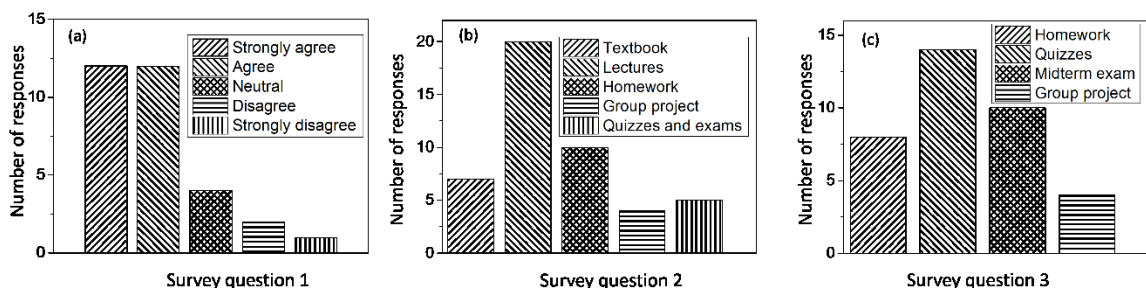


Figure 1. Distribution of the number of student responses to question 1 (a), question 2 (b), and question 3 (c) in the survey questionnaire. The survey was done with a ChE class in Spring 2016.

Figure 1a-c presents the results of student responses to the first three questions, respectively. As shown in Figure 1a, the majority of students (77%) agreed or strongly agreed that the group project was a good way to learn the fundamental concepts of materials science. However, only 9% of the students chose group projects as the best source (s) to learn the course materials (Figure 1b), behind lectures (43%), homework (22%), textbook (15%), and quizzes and exams (11%). Figure 1c shows that more students believe quizzes (39%), midterm exam (28%) and homework (22%) provided them better evaluation of their performance in the class than group projects (11%). In response to the open question 4, 28% of the students mentioned that they liked the group project, with only 4% claiming they disliked the group project. In summary, the survey results suggest the group project is welcomed by the students as a supplementary source to learn the course materials and evaluate their performance in the class, while the traditional means of learning (lectures, homework, etc.) still seem to be favored by students.

We also retrieved some statistical results from our university's official student evaluations for the ME classes to assess student's learning outcomes and instructor's teaching effectiveness in classes with and without incorporation of group projects. The two following questions that are relevant to our outcomes were selected.

- 5. *The course assignments, exams, and projects were a good measure of my learning.*
- 6. *Overall, I learned a lot in this course.*

Students rating options for the two questions include 6 (very strongly agree), 5 (strongly agree), 4 (agree), 3 (disagree), 2 (strongly disagree), 1 (very strongly disagree). The results from four semesters between 2013 and 2016 are retrieved. In two of those semesters, group projects were implemented in the MSE classes, while in the other two semesters there was no group project incorporated in the classes. Figures 2(a) and (b) show the comparison of mean evaluation rating of questions 5 and 6 between these two sets of classes, respectively. The sample size was between 20 to 35 students. The figures clearly show better evaluation rating for the classes with incorporation of group projects, which suggest these projects may have enhanced student learning and level of interest. To further study the student performance, we also compared the student average overall grade in these classes, as shown in Figure 3. The average grades in classes with group project incorporation improved significantly. These statistical results indicate the group project was effective in improving the students' learning outcomes.

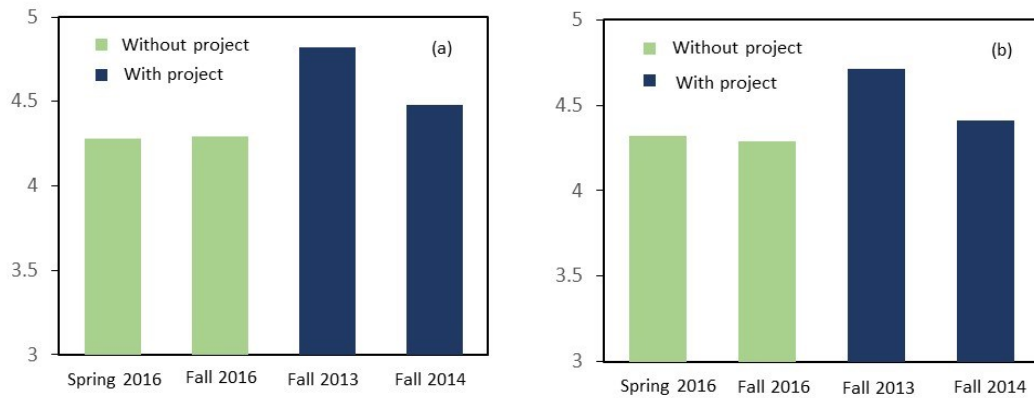


Figure 2. Comparison of mean evaluation rating of question 5 (a) and question 6 (b).

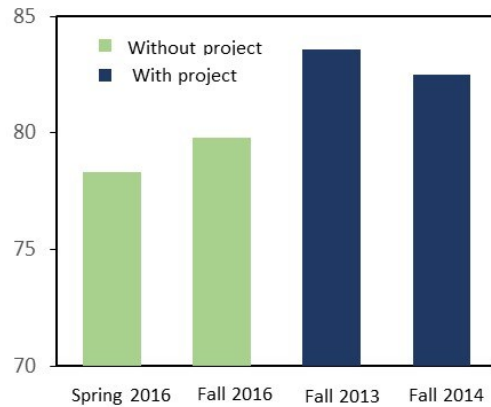


Figure 3. Comparison of average grades between the classes with and without group project incorporation

For the ChE class administered with staggered deadlines coordinated with the lectures, we believe this format offers less tangible improvements to student learning. First, the staggered deadlines provide accountability for students to work on the research project throughout the semester. Second, peer editing of reports among group members require students to assess critically others' writing. Third, students improve their writing skills by re-writing individual sections of the research for the final report, based on comments and feedback from the instructor. While no data is available to quantify this format's effect on this research assignment, anecdotal evidence based on better quality final reports (compared to other reports from other classes taught by the same instructor), as well as informal conversations with students, suggests positive enhancement to student learning overall.

Conclusions

In this paper, we documented the implementation of a group project in introductory MSE classes in two engineering departments. Our results suggest that, in general, this form of active learning enhances overall learning of essential material science concepts. This approach also provides a platform where students can conduct material research outside classroom and develop their interpersonal communication and teamwork skills. One caveat, however, is that students still value learning through traditional means of classroom lectures and homework assignments. Hence, our formal and informal assessments suggest that utilizing a combination of new active learning techniques with traditional lectures is an effective way of enhancing student learning, by giving them the opportunity to apply classroom knowledge to an open-ended research project requiring independent learning and team cooperation.

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