

Cross-Departmental Teaming Exercise as a Teaching Tool for Efficient Student Learning and Advancement of Science and Engineering

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Abstract

A cross-departmental learning activity was conducted at California Polytechnic State University between Civil and Environmental Engineering (CE) 587 - Geoenvironmental Engineering and Materials Engineering (MATE) 232 - Materials, Ethics, and Society students. Both classes separately received a devoted lecture module on the environmental implications of nanotechnology. The different perspectives on synthesis of nanomaterials were highlighted in the project with regard to material performance (MATE 232 students) and with regard to fate in the environment (CE 587 students). The students in CE 587 were asked to provide guidance and recommendations to groups of students in MATE 232 for developing environmentally friendly methods for the synthesis of silver nanomaterials. Each student group in MATE 232 was subsequently required to respond and address two of the recommendations provided by the students in CE 587. The students engaged in this teaming exercise used the knowledge they gained from the lecture module along with their own expertise towards synthesizing sustainable solutions for an emerging environmental issue. A report containing the student recommendations, the student responses, and faculty perspective was developed and provided to all participants. Through this exercise, students were able to understand the connection and significance of life cycle of material production (i.e., from product development to potential release to the environment). In addition, pre- and post-lecture assessments were conducted using guizzes and examinations to evaluate student learning of the environmental aspects of nanotechnology. The assessment questions were designed to align with various levels of Blooms's taxonomy of cognitive achievement. Results of the assessment indicated that less than 10% of the students correctly answered the pre-assessment questions compared to more than 75% of the students for the post-assessment questions. The efficacy and the outcomes of the activity were not impacted by the difference in student levels (graduate students in CE 587 and undergraduate students in MATE 232). Selected suggestions and responses developed in the teaming activity provided research questions that could contribute to the healthy growth of nanotechnology. Adopting cross-departmental teaming exercises as a tool in engineering education provides opportunities not only from a pedagogical standpoint but also as a potential mechanism for generating research investigations that can contribute to the advancement of science and engineering. The teaming activity can be adopted for use in similar courses at other institutions as well as adopted for other pairs of courses.

Introduction

Teaming exercises in engineering education have been reported to: 1) improve student academic performance; 2) increase student involvement and participation; 3) foster critical thinking skills; and 4) prepare a trained workforce to work in real-world settings with requirements for collaboration and interaction on multidisciplinary projects¹⁻⁴. Nanotechnology is a "horizontal-integrating multidisciplinary science that cuts across all vertical sciences and engineering

disciplines⁵. Developing sustainable nanotechnology that adds value with minimal risks requires collaboration between engineers from various disciplines including materials engineers and civil and environmental engineers. This investigation is part of a broader curriculum intervention that is underway at California Polytechnic State University (Cal Poly) as part of a project bringing contemporary topics into the undergraduate STEM curriculum through developing and implementing teaching and learning tools in a wide range of disciplines from technical (e.g., science and engineering) to non-technical (e.g., liberal arts and business) fields.

The objective of this pedagogical investigation was to conduct a cross-departmental teaming exercise between civil and environmental engineering students in CE 587 (Geoenvironmental Engineering) and materials engineering students in MATE 232 (Materials, Ethics, and Society) at Cal Poly. This paper presents details of the cross-departmental teaming exercise, assessment of student performance, and faculty perspective on the pedagogical benefits for including such activities in the curriculum and challenges with this type of exercise.

Description and Implementation of the Teaming Exercise

The cross-departmental teaming exercise at Cal Poly was conducted between students in CE 587 and students in MATE 232. Students in CE 587 study the engineering properties of soils, geosynthetics, and solid wastes; the interaction between geomaterials and contaminants and wastes; beneficial reuse of wastes and byproducts; and waste containment facility design. CE 587 is a graduate level course that is available to undergraduate students as a technical elective. During the term that this exercise was conducted, 12 students (7 graduate and 5 undergraduate) were enrolled in CE 587. Students in MATE 232 study material properties and the impacts of materials and technology on society through the context of historical (e.g., Stone Age, Bronze Age, and Iron Age) and current events. Ethics and systems thinking are integrated in the course. Technical aspects include crystallography, phase diagrams, microstructures, processing techniques, and nanotechnology. MATE 232 is a required undergraduate course for all Materials Engineering students. During the term that this exercise was conducted, 51 students were enrolled in MATE 232.

The overall framework for the exercise was to first provide a focused lecture related to the environmental fate and toxicity of nanomaterials to the participating students from both classes. Then an assignment was provided to the CE 587 students to develop suggestions for responsible manufacturing of nanomaterials. Next, these suggestions were provided to the MATE 232 students as an assignment. The MATE 232 students responded to the suggestions from the CE 587 students with manufacturing strategies for minimizing the environmental impact of engineered nanomaterials. A final report was compiled and distributed to all of the students in

the two collaborating classes that summarized the findings from the exercise. Details of each step of the exercise are described below.

A guest instructor, a postdoctoral researcher with expertise in environmental implications of nanotechnology, was responsible for implementing and managing the various phases of the cross-departmental teaming activity. The guest instructor visited both classes and presented a devoted lecture on the environmental implications of nanotechnology. The lecture modules were a 2-hour format for CE 587 and a 1-hour format for MATE 232. The following topics were included in the lecture module: 1) overview of nanotechnology and the growing use of nanotechnology by a wide array of industrial sectors including energy; food and agriculture; medicine; construction; textiles; and electronics; 2) the release of nanomaterials to the environment; 3) the potential environmental and health risks associated with the growing use of nanotechnology; and 4) the current status of nanotechnology regulations. After briefly discussing these topics, the guest instructor dedicated almost half of the lecture time to provide detailed discussion related to the stability (i.e., resistance to aggregation) of nanomaterials, effects of stability on environmental fate and toxicological impacts of nanomaterials, and green synthesis of nanomaterials producing materials with weak electrostatic stability in contrast to strong steric stability. Stability is a proxy for the mobility and toxicological impacts of nanomaterials⁶⁻⁷. The stability of nanomaterials and synthesis methods were selected as the focus of the detailed lecture content as these factors govern the environmental implications of nanomaterials.

The lecture modules were structured to highlight the dichotomy of nanomaterials in terms of manufacturing versus end of life cycle (e.g., disposal and containment) aspects. The technical focal point for this distinction was the stability of nanomaterials (i.e., tendency for nanoparticles to remain as individual particles as opposed to aggregate into larger sized particles). From a materials engineering perspective, manufacturing with nanomaterials typically involves priority for developing stable nanomaterials to maximize efficiency in applications due to high surface area and transport properties. In contrast, from a civil and environmental engineering perspective, the large surface area and high mobility adversely impact containment and treatment of nanomaterials in the waste stream. When the size of nanomaterials become larger (through aggregation), the nanomaterials a) are more easily removed using conventional engineered systems for water and wastewater treatment and b) become less toxic to living organisms. The lecture modules provided balanced coverage related to the opposing perspectives on the stability of nanomaterials. Therefore, the lectures provided a unique opportunity for the respective groups of students to be exposed to the opposite end of the life cycle than what would be covered within individual departments.

The cross-departmental teaming exercise was facilitated following the lecture modules to allow students in both classes to collaborate to identify potential solutions to the complex challenge

associated with the dichotomy in the life cycle of nanomaterials. The students were required to explore the interface between product performance and fate of materials/contaminants in the environment through the structured interactions. After receiving the lecture module, a homework assignment was administered to each student in CE 587: "Please offer at least two suggestions to help a group of materials engineering students (taking MATE 232) working on the development of a new method for synthesizing silver nanoparticles to reduce the environmental risks associated with their new nanomaterial product." The objective of this assignment was to have CE 587 students apply the knowledge they attained from the lecture module directly to a practical problem. This assignment pushed the students outside of their conventional civil and environmental engineering framework of designing for a given waste stream and instead developing design recommendations for a stage well upstream in the life cycle of consumer products (i.e., the manufacturing phase) that eventually impacts waste containment. The students were provided one week to complete the assignment. All suggestions were compiled by the instructor and the guest instructor of CE 587. The suggestions were ranked for technical strength. Some of the language of the suggestions was slightly modified (i.e., rephrased) to provide clarity, while maintaining the intended technical meaning of the suggestions. The suggestions were selected and grouped to constitute 6 sets of 2 suggestions each. At least one suggestion from each student in CE 587 was included in the materials that were provided to MATE 232. Each set was assembled to include one suggestion of high technical strength and one suggestion of somewhat lower technical strength so as to not bias the workload for the MATE 232 students. The students in MATE 232 worked in a total of 12 teams of 4 to 5 students each on the collaborative exercise. Each set of suggestions from the CE 587 students was provided to two separate teams in MATE 232. The assignment (i.e., challenge to the MATE 232 class) was presented to the MATE 232 students in a session by the guest instructor. The students were required to respond to the suggestions with detailed manufacturing strategies for accomplishing the stated goals. The students were provided 3 weeks to complete the assignment.

Then, the suggestions provided by students in CE 587 and the responses received from students in MATE 232 were compiled by the guest instructor in a report that was distributed, by e-mail, to all students in the two classes. The report also contained a section presenting the perspective of the guest instructor on the overall exercise and a detailed description related to the accuracy, value, and robustness of the technical content of both the suggestions and the responses.

Finally, assessment exercises were conducted to evaluate student learning of the content of the lecture modules and to evaluate perception and motivation of the students. Pre- and post-lecture assessments were conducted using quizzes and examinations in both courses. The quiz format was used for the pre-assessment in both classes. For students in CE 587, the post-assessment was in the form of questions in a homework assignment and a single question on the final examination, while for students in MATE 232, post-assessment was in the form of midterm

examination questions. The assessment questions were designed to align with various levels of Bloom's taxonomy of cognitive achievement as presented in Table 1⁸.

Class	Assessment	Adopted Bloom's Level
CE 587	Homework assignment (contained ten	Knowledge, Comprehension,
	questions and one problem) based on the	Application, Analysis,
	lecture module and the teaming exercise	Synthesis, and Evaluation
	One quantitative problem on the final	Application
	examination based on the lecture module and	
	the teaming exercise	
MATE 232	Four questions on midterm examination	Knowledge, Comprehension,
	based on the lecture module and the teaming	and Application
	exercise	

Table 1. Adopted Bloom's Taxonomy

In addition to assessment of student learning through the direct assessment methods described in Table 1, the perceptions and motivations of the students in relation to nanotechnology were assessed using student selections for future technical electives and using a post-exercise focus group. The focus group was facilitated with several students that took part in the teaming exercise to evaluate student opinions and experiences in relation to the teaming exercise. Since (two quarters after) this teaming exercise was conducted, a Special Topics Course was developed and jointly offered by the Civil and Environmental Engineering Department and the Materials Engineering Department at Cal Poly. The course is at the 400-level, serves as a technical elective for undergraduate students of both departments, and is open to graduate students. Development of this course and enrollments of the course by students previously exposed to the teaming exercise were used to evaluate the impact of the teaming exercise on the curriculum and on student motivation.

Results and Discussion

Suggestions for Reducing Environmental Risks by Students in CE 587

The majority of the suggestions provided by students in CE 587 to students in MATE 232 were related to identifying and adopting green methods for manufacturing silver nanomaterials. Green synthesis methods have several advantages, which include using environmentally friendly reactants and avoiding the formation of harmful byproducts. Additional suggestions were related to: 1) avoiding, as possible, the use of chemical stabilizing agents that provide strong stability to

the nanomaterials as highly stable nanomaterials are difficult to aggregate in natural (e.g., surface water streams) and engineered (water and wastewater treatment plants) environmental systems; and 2) developing a synthesis method that generates silver nanomaterials that are more resistant to dissolution into silver ions to minimize toxicity due to the dissolution process⁷.

Analysis of the student suggestions indicated that students in CE 587 understood the main causes for the risk associated with the use of nanotechnology and applied this knowledge to the assignment. Most of the student suggestions represented current research topics on developing sustainable solutions to minimize the risks of nanotechnology and the student work demonstrated depth of understanding and evidence of having conducted literature review for the assignment. The guest instructor identified one of the suggestions as a topic that has not yet been investigated and represents a novel subject for a research proposal and a scope for a graduate thesis or theses.

Strategies for Responsible Nanomaterials Manufacturing by Students in MATE 232

The MATE 232 students responded to the suggestions provided by the students in CE 587. Several green synthesis methods and the use of biomolecules for synthesis and stabilization of silver nanomaterials were described in detail. Numerous groups in MATE 232 were able to identify and list stabilizing agents that could be used for electrostatically stabilizing silver nanomaterials for reduced environmental impacts. Electrostatically coated particles are sufficiently strong to maintain stability during use yet weak to be aggregated using conventional coagulating agents. Additional responses included solutions to overcome the dissolution of silver nanomaterials to silver ions. These solutions included coating the nanomaterials with polyethylene glycol to minimize oxidation and consequently minimize dissolution of silver nanomaterials and grafting the silver nanoparticles to another material to minimize oxidation and dissolution. Further research needs for determining appropriate substrates for grafting were identified by the students.

Analysis of the student suggestions indicated that students in MATE 232 understood the fundamental aspects of synthesizing nanomaterials including advanced topics such as passivation of surfaces to prevent oxidation. The responses overall had a strong scientific basis and represented research questions and potential science-based solutions that deserve further investigation and consideration by scientists evaluating the environmental implications of nanotechnology.

Assessment of Student Learning of the Lecture Module Content

The pre-assessment was conducted using the same question in both classes: *Please list three examples of environmental factors that influence the stability of nanomaterials*. Approximately

9% of the students in CE 587 and 2% of the students in MATE 232 correctly answered the preassessment question. The post-assessment questions were different for both classes and were designed to measure various levels of cognitive achievement (Table 1). The percentage of correct answers to the post-assessment questions was 79% for homework and 75% for final examination question for the students in CE 587 and was 86% for the midterm examination questions for students in MATE 232. The lower percentage of correct answers provided by students in CE 587 compared to students in MATE 232 was attributed to the higher level of difficulty of the postassessment questions given to students in CE 587 commensurate with a graduate course. In general, the comparison of pre- and post-assessment results indicated a significant increase in knowledge of students in both classes on the subject matter of the lecture modules.

Assessment of Student Perceptions

Student perceptions and motivation were assessed through enrollment trends and through facilitation of a focus group. Enrollment in the new Environmental Nanotechnology (Special Topics) course provided evidence of interest and motivation of students exposed to the teaming exercise. The Environmental Nanotechnology course had 21 students enrolled and 7 of those had participated in the teaming exercise. In addition, from a curricular and administrative standpoint, the teaming exercise facilitated multi-departmental support for offering the course. The focus group, including students involved in the teaming exercise, demonstrated enthusiasm for both the technical subject matter and the mode of inter-departmental teaming. Comments from students included "interesting", "eye-opening", "liked the exercise a lot", and "having to learn about the importance of stability was meaningful". The students indicated that this was the first multi-departmental learning experience in which they have participated. Based on the positive feedback from the students in terms of motivation, the research team is pursuing new and similar cross-departmental learning activities.

Faculty Perspective

Nanotechnology presents a significant environmental challenge: the novel physical-chemical properties of nanomaterials that caught the attention of various industrial sectors and led to the use of these materials for improving existing products or inventing new products are the same properties that are responsible for the growing concern with regards to the safe use of nanotechnology. The cross-departmental teaming exercise described herein was a highly instructive experience for students in CE 587 and MATE 232 where the students in both classes were exposed to the opposing perspectives on synthesis of nanomaterials with regard to material performance and fate in the environment. The teaming exercise created an environment for a constructive collaboration that made use of the expertise of both student groups to develop

synthesis methods for nanomaterials with minimal environmental risk without compromising the performance of the products containing the nanomaterials.

The cross-departmental teaming exercise represented a constructive development towards educating and training the future technical workforce about nanotechnology from both benefit and risk perspectives. Students in materials engineering and civil and environmental engineering are highly complementary for such training as materials engineers are responsible for developing the methods for manufacturing nanomaterials while civil and environmental engineers manage risks associated with the use and disposal of these materials. Therefore, this teaming activity provides a model that can be universally adopted to prepare engineering students for managing challenges and complex issues related to emerging technologies in a sustainable context.

The efficacy and the outcomes of the cross-departmental teaming exercise were not impacted by the difference in student levels (graduate students in CE 587 and undergraduate students in MATE 232). Through this exercise, students were able to understand the connection and significance of life cycle of material production (i.e., from product development to potential release to the environment). The assessment of this teaming activity demonstrated that some of the suggestions and responses by the students in both classes qualified as high level research projects that could contribute to the healthy growth of nanotechnology. Adopting crossdepartmental teaming exercises as a tool in engineering education provides opportunities not only from a pedagogical standpoint but also as a potential mechanism for involving undergraduate as well as graduate students in generating research questions and solutions that can contribute to the advancement of science and engineering. The outcomes of the crossdepartmental teaming exercise presented herein are generally in agreement with the main findings of other studies evaluating the importance of teaming exercises in engineering education. For example, Lamm et al.³ reported that team-based learning was an effective strategy for teaching problem-solving skills in engineering education. Hanson and Elton⁹ demonstrated that inter-university teaming exercises resulted in improving communication and interpersonal skills of the students.

Having a guest instructor to facilitate the activity was helpful for logistical support and more importantly, for the technical expertise of the postdoctoral fellow. However, the partnering faculty believe that the activity could be conducted successfully without a guest instructor.

In general, the method described in this paper for conducting and organizing the teaming activity was simple, efficient, and abundant in pedagogical benefits. An aspect that can be improved in future implementation of similar activities is to plan for an extra session in which students from both classes are provided time for a post-experience discussion with the guest instructor. Such a meeting would allow the instructor to provide comments and feedback on the overall experience

and answer any questions raised by the students. In addition, a portion of this extra session could be devoted to facilitating (through a third party) an assessment focus group. A second aspect for improvement would be incorporating a higher level of interaction and direct communication between the students in the different classes in completing the exercise.

Conclusions

Based on the cross-departmental teaming exercise related to nanotechnology, the following conclusions were drawn:

-The teaming exercise described in this paper provided an effective means for including contemporary technical content related to an emerging problem in an undergraduate course and a graduate course.

-The student suggestions and responses related to this exercise were at a level consistent with the state of the art. Incorporating challenging material to students, among other factors, fostered research-level innovation.

-The benefits of having students from different departments collaborate on a project were significant.

-The multi-departmental exercise benefitted both courses.

- -The different levels of students participating in the exercise (graduate versus undergraduate students) did not adversely impact the quality of the interactions.
- -Expansion of engineering courses to include conflicting priorities for design is beneficial for preparing students for a multidisciplinary workforce.
- -Identifying challenges and formulating solutions are both beneficial for the engineering curriculum.
- -The methodology described is well suited to adaptation and/or adoption by other courses in the same disciplines as described herein as well as by other disciplines.
- -For future applications, including synchronous interaction for cross-departmental activities is suggested.

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