Campus Integrated Project-Based Learning Course in Civil and Environmental Engineering

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***Abstract*—A hybrid project and service based learning course has been introduced in the Department of Civil and Environmental Engineering (CEE) at the University of Illinois. The primary objectives of the course are to develop engineering problem solving, professional, and business skills earlier in our CEE undergraduate curriculum by having student teams identify open-ended, ill-defined campus/community problems or opportunities, develop a feasible project scope, and propose sustainable solutions.**

The unique features of our course include (1) a blend of service and project learning with faculty instructors partnering with the campus engineering staff to assist with team project mentoring, campus data collection, local field trips, and case studies, (2) formal course assessments through pre and post-class survey and student focus group interviews, and (3) weekly instructor meetings that consist of faculty, teaching assistants, department administrators and engineering staff updating the course during the semester and planning major changes for the next course offering. In this paper, we describe the course organization and its curricular evolution along with evaluation data from student surveys and focus groups as well as the impact of routine instructor community of practice meetings.

Keywords—project based learning, interdisciplinary team projects, case study, field trips, service learning

I. Introduction

With a new generation of highly motivated engineering student who yearn for hands-on experiences, project and service based learning curricula are a key asset for preparing engineering students for solving 21st century societal challenges as well demonstrating the importance of the university campus experience. Project-based learning (PBL) involve student engagement in open-ended, complex problems and direct student activity towards producing an end product [1]. Student projects are based on challenging problems that parallel similar activities of practicing engineers [2]. Successful exposure to open-ended problems, which present students with conflicting goals, are integral to the development of the ability to apply the principles of engineering while serving within their profession [3]. In addition, students are able to work more autonomously in generating realistic products which allows them to construct and reflect on their own learning. Chinowsky, Brown, Szajnman, and Realph [4] note "by empowering students to learn outside of classroom lectures and developing contextual situations in which they can apply content, universities are much likelier to produce graduates who are able to apply their knowledge in the real world and continue to build upon it in the absence of lectures".

PBL courses are not new to engineering [5]. One of the motivators in wider adoption of PBL courses within engineering programs has been the industry. Gaps between graduates' knowledge of principles of engineering and their ability to apply and synthesize these principles were noted [6], as well as a fragmentation of their knowledge [7]. More recently, employers have demanded greater development of students' non-technical skills such as written communication, project management, and teamwork [8]. Several studies have found gains in these “in-demand” skills from active participation in both problem and project-based learning [9]. In addition to improvement in non-technical skills, students engaged in PBL score higher on performance assessments, skill-based assessments, and long-term knowledge acquisition as compared to traditional didactic instruction [10-11].

Service learning (SL) courses simultaneously engage students in academic activities and community service experiences, which provide non-structured academic content and develop non-technical skills, such as, communication, and community engagement. [12-13]. SL experiences were also found to improve professional skills such as decision making, ability to make presentations, and improve interpersonal skills [14]. Webb and Burgin [12] found “significant parallels between factors contributing to successful community engagement and effective teaching and learning by students”. SL was also linked to greater retention of students within engineering programs, particularly for students who are members of minority groups [9].

Fully integrating PBL or SL into large, historical engineering departments are challenging because of the inertia in changing the significant quantity of fundamental science and engineering classes as well as campus level minimums for the number of humanity and social science classes. Therefore, Civil and Environmental Engineering (CEE) curricula evolution has generally lagged updates seen in newer departments (e.g., bioengineering, systems engineering).

The University of Illinois’ Department Civil and Environmental (CEE) continues to be a top-ranked program in the U.S. For years, the college of engineering and CEE undergraduate curriculum has provided students with very strong background in the fundamentals of science and engineering but with limited integrated exposures to team projects accept in the senior year as required by ABET. Based on alumni surveys, observations of other institutions engineering curricula, need for greater professional competency, and the literature [15-17], several faculty recognized the gap in our curriculum to provide a team-oriented project or service experience for early-year undergraduate students that could fulfill multiple learning objectives such as developing interdisciplinary problem solving, professional skills (leadership, project management, and entrepreneurial), and business skills (communication, interpersonal, and teamwork). In 2013, a hybrid project and service based learning course was launched to fulfill the aforementioned objectives with four instructional components: (1) self-selected team projects, (2) faculty presented case studies, (3) field trips to local civil infrastructure facilities, and (4) regular assessments through weekly instructor meetings, formal surveys, and student focus groups.

Through an intimate collaboration with the campus facilities and services engineering group, this course is "intrapreneurial," giving it a unique flavor of service learning mixed with projects that are more constrained in scope. This course provides a unique experience for our early year undergraduate in civil engineering by combining project and service based learning. Through this integration, we hoped to realize gains in both content knowledge and non-technical skills such as writing found in traditional faculty led project courses while also finding gains in interpersonal skills found in traditional service learning courses.

II. Course Overview and Assessment

Our hybrid CEE project and service based learning course offers a blend of team-oriented semester projects, discussion-driven case studies, and instructor-led field trips to local infrastructure facilities. Students collaborating in teams of three to four select a campus problem or opportunity of interest. With mentoring from a team of interdisciplinary faculty from Departments of CEE, Agricultural and Biological Engineering, English, and the campus engineering staff, teams define and scope the problem, develop a realistic project management plan, and eventually propose a sustainable solution. Project themes revolve around engineering sustainability, which engages teams in learning opportunities and creates synergy across many disciplines. Table I is an example of several of the projects students accomplished over the past two years. Through team project work, receiving peer-to-peer team project reviews, and instructor feedback, students develop necessary life-long learning, professional, and business skills that are under-emphasized in our current engineering curriculum.

TABLE I. TEAM PROJECTS

2014 Project Tiles	2013 Project Titles
Feasibility of Green Wall Building Retrofit at Krannert Art Center	Evaluation of algae-based bio-binder for asphalt replacement
High efficiency toilet upgrades and water management	Energy production from swine manure
Feasibility of Solar Panel Parking Lot	Evaluation of the possibility of using raw water on campus
Introducing LEED Lab Campus Course	Business Instructional Facility (BIF) energy assessment – LEED Platinum Certified
Grey Water Collection and Use in Campus Buildings	

Formal student surveys and focus group data collected by evaluation professionals in the College of Education, combined with the weekly instructor meetings, and collaboration and mentoring from faculty with engineering education expertise, helped refine the course over a two-year period. A result of these formative evaluation activities and discussions during the weekly meetings led to the conclusion that students' writing/communication and project management skills need strengthening, and thus the course evolved to formally include these objectives. In addition, significant class time is allotted for students to conduct their team project work and receive guidance and mentoring from course faculty and campus engineering staff, teaching assistants, and other subject matter experts.

III. Unique Course Features

This hybrid course combines aspects of project and service based learning experience while encouraging engineering faculty and campus facilities and services engineering staff (i.e., course instructors) to collectively mentor student teams. An instructor's community of practice was established from the initial course development and implementation in order to foster ownership among multiple faculty members so that longevity of the course is assured. Research has demonstrated that regular meetings and broad faculty engagement along with departmental leadership involvement is the most significant factor in maintaining the stability of a course. Course changes are done in conjunction with formal student feedback from surveys and focus groups, as well as feedback from the engineering education on how to adapt evidence-based reforms in the course (e.g., use of active learning with i-clickers and successful practices adopted from other PBL and SL courses). Additionally, the case studies instruct students in the process and skill of solving engineering problems that are required for their team projects. Field trips provide an exciting student experience on the complexity of engineering infrastructure and a connection to their career studies and projects. Finally, the second hour of the weekly class was reserved primarily to establish regular interactions between the student teams and faculty/engineering staff mentors.

IV. Course Background and Format

The hybrid PBL and SL course in CEE is two credit hours and meets once per week. The course is designed for sophomore students in CEE but is broadly advertised throughout the campus to include any engineering or non-engineering disciplines. The class is organized with a faculty course director, multiple faculty instructors who present case studies, lead field trips, and provide expert feedback; engineers from the campus facilities and services (F&S) department; and two teaching assistants, who actively participate in weekly classroom activities. Several additional professors and community professionals contribute to several case study lectures throughout the semester. A professional writing instructor from the English department is also now part of the course, providing students with formal feedback on their semester project reports and presenting technical writing tips.

Throughout the semester, seven case study lectures (see Table II) are presented by faculty on contemporary topics covering a particular area in infrastructure engineering and sustainability. The main case study objective is to teach students the process of engineering problem solving by examining real engineering challenges and opportunities. Prior to each case study lecture, students are expected to read background material on the lecture topic and take a ten-question quiz. Each case study is designed to be interactive with the faculty delivering probing questions via i-clicker technology in order to lead to facilitate faculty-student dialogue and promote additional inquiries.

Several case studies are integrated with field trips to local civil and environmental infrastructure facilities. The four field trips, listed in Table II, combined with the case study lecture, provide students with opportunities to actively participate in a complex engineering problem and solution in the classroom and in the field, experiencing live and the multidisciplinary nature of designing and building civil infrastructure facilities.

Team projects are key to teaching students how to define a problem or opportunity, propose a solution or feasibility study to their problem, identify what component can be solved in a semester time span, execute a plan of action, and communicate the results in various formats (proposal, interim report, presentations/poster, and final report). This team format is intended to acclimate students to working across disciplines at an earlier point in their undergraduate educational experience than what is normally required in our CEE department. One of the course's goal is to transform our more traditional approach of solving problems in early years of CEE education from a compartmentalized and individual approach into multidisciplinary problem solving team with students from different CEE concentration areas and across the campus.

TABLE II. Case Studies and Field Trips

Case Study Lectures	Faculty / Expert	Field Trips
Urban Stormwater Management and Green Infrastructure	Professor, Environmental Hydrology and Hydraulic Engineering	Urban stream passing through campus and designed for city stormwater management and visual amenity
Wastewater Treatment and Biofuel Production	Professor, Agricultural & Biological Engineering	Champaign-Urbana wastewater treatment plant
Power Generation and Infrastructure	Director, Campus Facilities and Services	Campus Cogeneration Abbott power plant
Building Information Modeling (BIM) and 4D Visualization for Construction	Professor, Construction Management	Construction project of new student residence hall integrated with BIM
Construction Material Recycling – Resource not Waste	Professor, Transportation and Construction Materials	
Structural Health Monitoring of Railroad Bridges using Wireless Smart Sensors	Professor, Structural Engineering	
Urban Design and Human Health	Professor, Landscape Architecture	

Teams are formed after several weeks of formal and informal project idea exploration. Students take an initial pre-semester survey on project themes that they are most excited about and then during multiple organized sessions, students communicate with each other and campus experts and instructors to better define project themes. During the next step, students draft a three-page proposal laying out project objectives, scope, tasks, required resources, and project timeline. As the semester progresses the students gather project information and data via the literature, interviews, observations, and interactions with mentoring from the course faculty and experts. An interim project report is required two-thirds into the semester that provides valuable feedback to teams and allow for changes to projects to meet end of the semester goals. At the end of the semester a final project report is submitted summarizing the findings and accomplishments by the teams. The course culminates in a team project poster presentation that is judged by practicing engineers from the campus and local community.

Informal technical feedback is provided weekly by student-instructor interactions and by the teaching assistants during class and office hours. Technical writing comments are first provided by the English instructor for all deliverables, secondly through peer review, and finally during final grade assignments for each deliverable by course faculty. Students have verbal communication opportunities during periodic three-minute presentations given by each team to communicate project objectives, status, and key findings.

V. Course Assessment and Evolution Strategy

Several key components of the course development and reformation actively utilize student assessment and evaluation data along with weekly instructor meetings. To assess the effectiveness of the course in accomplishing its learning objectives and gather formative feedback to inform course improvements, students were asked to complete questionnaires at the beginning and end of the semesters as well as volunteer for an end of the semester focus group discussion. A complementary WIDER grant from the National Science Foundation, focusing on evidence-based active learning reforms for science, technology, engineering, and math courses, was instrumental in providing expertise from an external evaluation team from the College of Education. This team led development of the survey instrument and focus group guide and conducted the data collection and analysis activities with approval by the University of Illinois Institutional Review Board.

The course was designed to include a cooperative teaching environment with weekly meeting of primary instructors (faculty and campus engineering staff), teaching assistants, and teaching pedagogy experts during the semester and monthly meetings off-semester. This enables necessary changes to the course during the semester while also giving time for strategic planning and changes for inclusion in the next course offering. All instructors were invited to participate and provide feedback to the instruction team. The weekly instructor meetings assessed the previous week's case study activities, including the field trip and project progress, and provided mid-course adjustments as needed. Long-range planning and course refinement occurred primarily in the off-semester course meetings.

A. Student survey

At the beginning and end of the semester, students were asked to anonymously and voluntarily complete an 18-question pre/post-survey, which included both close- and open-ended questions. Survey questions were designed to assess the following: 1) students' perceptions of the helpfulness of course activities and the course overall for their engagement and learning; 2) changes in students' perceived level of engineering, professional, and business skills and perceptions of engineering as a profession; and 3) influence of the course on students' future engineering-related career plans. Additionally, student demographic data was collected including gender, race/ethnicity, international and language status, and academic standing. Pre-post changes in students' responses to select survey items before and after students completed the course helped provide evidence of the effectiveness of various components of the course for developing students' knowledge and skills and perceptions of engineering as a profession. The surveys were completed by 61% of the students. Both survey results were analyzed by course instructors and teaching assistants. Post-survey results were analyzed by the external evaluation team.

B. Student focus group

At the end of the course, all fifteen students were invited to voluntarily participate in a focus group discussion conducted by the external evaluation team who had not previously associated with the students. Two forty-five minute group interviews of 7 (4 male, 3 female) and 6 students (4 female, 2 male) were held during class time. Open ended questions were given to spark feedback and discussion regarding general topics such as the course structure, the students' assessment of what they learned, skills they used, and how this course has influenced their understanding of the engineering profession and their role in it. Interviews were audio-recorded, with permission from all participating students, and anonymous transcripts were analyzed by the external evaluation team and summarized for the course instructors [5].

VI. Assessment Results

In this section, we provide brief descriptive information regarding students who participated in the 2014 survey, focus group interviews, and changes to the course made based on the evaluation data. We provide the survey mean on a 1 to 4 point scale, where 1 means either poor, not interested or not important and 4 means excellent, very interested or very important. A sample of the some of the key results are summarized next.

A. Course Format

Students reported that all aspects of the course enhanced their learning experience. Students scored the best components of the course to be field trips (3.88), research experience (3.75), project-based learning (3.63), and developing their project-management skills (3.63). Additionally, in both the questionnaire and focus groups, students reported that interacting with practicing engineers was helpful because these interactions exposed them to different areas of engineering. They also reported that the field trips were helpful because they provided hands-on, experiential learning, and the project proposals were helpful for learning project management skills, e.g., start a project, set a timeline, and technical writing as noted in the student quote below:

I find the opportunity to develop and pursue a project to completion the most helpful. This class exposes underclassmen civil engineering students to the field because they choose a project to tackle and complete the project in a given period of time. Just like they would in the industry. It is a unique class that allows students to develop technical and applied skills rather than the theory that is learned in most other classes. – Student

Students valued having multiple instructors for hearing a diversity of perspectives, especially at the beginning of their projects, and for learning about a variety of engineering subfields as noted in the following quotation.

The four consistent instructors that we had, they each specialized in something different, so if we went to one instructor and asked them for advice, it would be different than what another instructor would say. That's good because it helped us get different views, and we decided which view we wanted to integrate for our own proposal. It was really good to have multiple resources to go to. – Student

B. Learning and Engagement

Students rated the course most helpful for thinking about the material rather than just memorizing it (3.75), understanding what it means to be a professional in this discipline (3.63), building on prior knowledge in this discipline (3.63), taking ownership over what I learn rather than only relying on the teacher (3.63), feeling excited about learning (3.63), and working with peers to solve problems (3.63). Students noted that they developed a variety of important skills related to project development and management including how to write proposals, how to interact with other professionals in the field, communicating data, and working with others. Additionally, several students stated that this course helped them realize the value of doing projects that had a real impact on people and society.

I think starting a project from the beginning, and trying to imagine where it's going to go two months from then was really helpful because that's not something we'd done before, but it's going to really pertinent to our careers. – Student

Survey results taken before and after completing the course, shown in Figure 1, show the change in overall student self-rating of their project, communication, and teamwork skills. Collectively, the students self-assessed an improvement from mostly fair (2.79/4.0) to (3.52/4.0) good/excellent in their own project, communication, and teamwork skills, most significantly in their written communication. Overall, the student focus group responses had mixed reactions about the writing instructor despite strong self-assessment of the importance of technical writing. International students felt the writing instructor support was helpful and improved their proposals.

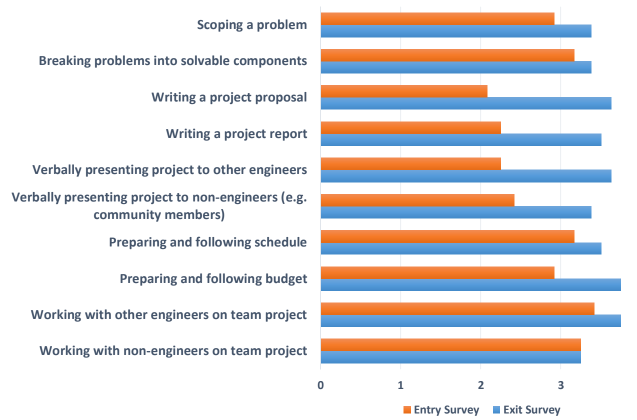

Fig. 1. Students' self-rating of project, communication and teamwork skills before and after completing the course in fall 2014

VII. Synthesizing Course Assessment Information

Results of the student feedback relative to the overall course objectives, fostering improved student-instructor engagement, and implementing a collaborative teaching and feedback environment within a community of practice was largely successful. Multiple instructor involvement with their own particular specializations was an effective method for discussing a wide range of topics and added a layer of confidence that students were receiving exposure to the latest research and trends in many fields. As one student put it "*it's really nice having each topic presented by someone that knows it really well–and specializes in it*." Another student benefit of involving experts to present case studies is that data being presented about real projects familiar to the expert hold students attention and sparks discussion.

The critical mission of campus division of F&S is to support the academic engine of university, and a connection to F&S was a critical component of this course. The partnership with F&S connected students to their projects with data sets and campus F&S engineering professionals. One student said, "*One of our ideas could actually be implemented in the university–knowing that, that's pretty cool.*" F&S has been instrumental in refining problem statements, providing data, mentoring students, and presenting a case study and hosting the field trip at power plant and their continued participation in our course is critical.

When students were asked what the most important skill that they learned in the course was, their overall comments expressed how important professional writing is and the value of good communication skills, which validates keeping a technical writing aspect to the course as well as continued opportunities for student presentation of projects. Field trips were ranked as the most interesting aspect and the most helpful for understanding the roles of engineers. Although arrangement and supervision of field trips are time consuming, clearly students gain tangible experience from them and thus they are an essential part of the class. Case studies provide an early opportunity for many students to learn what engineers do and show students how to frame a problem, which in turn assists them in their team projects and future classes.

VIII. Course Changes Stemming from Student and Instructor Feedback

The student and instructor feedback led to changes between the first and second year of the course. The main changes included adding a case study on structural health sensing and monitoring as well as adding an English department instructor to provide formal technical writing feedback to students prior to instructors grading the delivered reports. Teaching students how to write clear project objectives, how to define a problem, and how to establish tasks and distribute them among team members during the course's first offering was not overly successful but during the second offering formal training was given and the students responded positively. The course schedule was also altered to give more in-class time during the beginning of the semester for students to develop their project ideas. Finally, time was given at multiple points in the semester for students to orally present their project progress both for both their benefit, and so that teams could learn what the other teams were doing.

Modifications to the next offering of the course in the fall 2015 will include refining the project identification process to include assignment for individual students to generate project ideas based on campus needs, presentation of each student's top two project ideas, and delaying team formation and initial project proposal deliverable. Several case studies will be introduced earlier in the course to accommodate more time given to project idea development. A learning management system software (Scholar™) will be implemented to allow for online collaboration across and within the teams, a semantic writing tool for project reports, pre-class quizzes, peer review, instructor grading, report editing statistics, permanent archiving of the team projects, and scaling the class to larger number of students. The introduction of this course into CEE is currently only an elective but effort is underway to make it a core requirement for sophomores in our undergraduate CEE curriculum. Finally, the pedagogical innovations and lessons learned from this course is already impacting senior design course in our CEE curriculum.

IX. Conclusions

The development of a hybrid project and service based learning course at the sophomore level for the Department of Civil and Environmental Engineering at the University of Illinois provides a major shift from the traditional faculty lecture format used in most CEE courses. Additionally, transforming students' traditional way of solving problems from an individual, compartmentalized approach to a multidisciplinary problem solving team approach at earlier years in the undergraduate curriculum will acclimate students to think like an engineer and allow them to work across disciplines more efficiently in the junior and senior years. The primary objectives of this course are to teach students problem solving, professional competency, and business skills as well as to identify as a CEE. The objectives are met through intimate collaboration with the campus engineering staff, discussion-driven case studies led by the course instructors, field trips to local civil infrastructure facilities, and most importantly through student-defined team projects related to a problem or opportunity observed on our campus through hands-on learning experience.

Current successes in the course derive from a strong instructor community of practice that facilitate activities such as weekly meetings during the semester and monthly meetings when the class is not in session, discussions of improvements, and incorporation of research based instructional strategies. Formal course assessments rate student-instructor interactions and subject expert feedback as an important aspect of the course. The course's success is also intimately linked to the expertise provided by campus engineering personnel, evaluation experts, engineering education experts, and English writing expertise. Additionally, the collaborative teaching environment ensures that the course reforms are sustainable over the long term.

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