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Future K-12 Teacher Candidates Take on Engineering Challenges in a Project-Based Learning Course

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Abstract: This paper documents new engineering focused curricula for an undergraduate Liberal Studies course directed at future K-12 teacher candidates. The engineering design process is introduced to students within the context of a Project-Based Learning environment. Students are presented with engineering design challenges for which they must generate possible solutions, ask questions, seek information, reflect on project directions, and finally develop an artifact representing their design solution. Course learning objectives are centered on applying the engineering design process, approaching problem solving as an effective team, and becoming more reflective and skilled in providing actionable feedback in team settings while applying K-12 content. Students exhibited excellent sustained inquiry, experienced the cycles of the engineering design process, added to their previously acquired content knowledge and developed teamwork skills. The curriculum development and course evaluation contribute to construction of a rigorous Project-Based Learning Framework incorporating engineering design.

Introduction/motivation for new course

K-12 teachers represent the most direct and consistent influence on students' access to engineering knowledge. Teacher understanding and demonstration of engineering's problem solving power and its relationship to society offer a highly effective vehicle for motivating student interest in engineering and other STEM fields. Additionally current science standards – Next Generation of Science Standards (NGSS)[1] - incorporate engineering design into the learning objectives of science in grades K-12. However few classroom teachers have had the benefit of exposure to engineering design before beginning their teaching career. Just like their students, early exposure in the undergraduate curriculum that enriches future teachers' knowledge of engineering and technology and its relationship to the world would benefit these candidates.

Project based learning (PBL) and the engineering design process are a natural pedagogical fit. PBL is focused on knowledge and understanding of key content standards partnered with 21st century skills including the ability to work well with others, to solve problems and be a self-motivated learner. The Buck Institute for Education[2] describes the essential project design elements as stimulated from a challenging problem or question, characterized by sustained inquiry, set within an authentic context, offering students voice and choice, providing opportunities for reflection.

The engineering design process may be expressed a number of different ways. One model is cast as a cyclic process, with progress going in either direction in the cycle and sometimes shortcutting from one step to another, as is consistent with the iterative nature of engineering design. The process is composed of steps which begin with the identification of the problem, followed by postulating and evaluating possible solutions. Engineering is Elementary[3] expresses these steps as Ask, Imagine, Plan, Create, Improve, Figure 1.

Your first mission is to design a ramp that will fit one of the identified spaces.
To do so, we will provide opportunities for you to explore wheelchair navigation firsthand, existing ramps and accessibility options on campus, and other important features that you may identify along the way.

You should also be sure that your ramp is physically feasible, complies with ADA legal and practical requirements, and other important considerations for individuals with accessibility challenges.

Figure 1. Engineering Design Process

Figure 2. Text of the first Design Challenge.

Within the context of the collaborative work of university education and engineering faculty and a local school district on an ongoing grant focused on improving teacher preparation for application of common Core standards and Next Generation Science standards, a liberal studies course was designed to introduce undergraduate students interested in entering the teaching profession with engineering design experience. While courses for non-engineering majors have been developed to expand literacy in technology and engineering very few courses focus on teacher preparation. Sorby, Oppliger and Boersma[4] discuss several engineering courses developed for non-majors within the documentation of their unique engineering course intended for future K-12 educators. Hargrove-Leak[5] provides another example of an engineering course embedded in a liberal arts curriculum.

Course structure

At California Polytechnic State University, San Luis Obispo teacher preparation candidates may major in a variety of different subjects including Liberal Studies, Math, Physics, etc. Following completion of their undergraduate degree they enter into either the Multiple Subject or Single Subject Teacher Education Preparation Program in the School of Education. All students majoring in Liberal Studies will pursue a teacher credential post-graduation thus this new course was developed within the curriculum of the Liberal Studies major.

The first offering of the course was titled Subject Matter Apprenticeship and was a two unit course designed to facilitate structured application of a specific content area in schools and informal educational settings - in this case engineering design.

Drawing on the department resources and its connections to other majors the student makeup was composed of five liberal studies majors and two math majors who have a concentration on secondary teaching. All seven students were seniors. Liberal Studies students are destined for careers in elementary education, and have a mathematics background that includes four courses in developing mathematical understandings. While they were, mathematically, not at the same preparation level as the two math majors, their preparatory coursework was complementary.

The course objectives were for students to be able to: (1) Apply the engineering design process to create a product or process, (2) Approach design challenges by working together in an efficient team setting, and (3) Become more reflective and skilled with providing actionable feedback in team settings. As implied by the objectives, the course consisted of two team design

challenges – the first introductory in nature to orient the students to the engineering design process and the PBL approach. If PBL is new to the student s/he may feel somewhat at a loss in the beginning, finding that learning is to be self-motivated rather than directed by the instructor. The second design challenge built upon principles of the first challenge, extending these in technological complexity and duration. Students presented their solutions to faculty and peers at the end of the quarter.

Design Challenge I (shown below and in Figures 2-4) was planned to span approximately three weeks, and asked students to design a wheelchair ramp for a home on a very restricted lot, requiring difficult geometric constraints. Each student team was presented with a different residence configuration in relation to its vehicle driveway, and asked to design a ramp so that a resident who was in a wheelchair could safely enter the home (Figures 3 and 4). The launch of the design challenge included a discussion of the engineering design process, time for students to ask what information was needed to design the ramp for their particular site, and a group brainstorm about important geometric constraints. Students then explored campus on a "field trip," in wheelchairs, to personally identify constraints of ramps and wheelchair accessibility on [our campus] facilities (Figures 5 and 6). The students used this experience to determine how they could safely and feasibly construct their ramps, and supplemented their experience with additional research on Americans with Disabilities Act (ADA) requirements. Students were also encouraged to be mindful of Engineering Design Process, but were given no additional instructions.

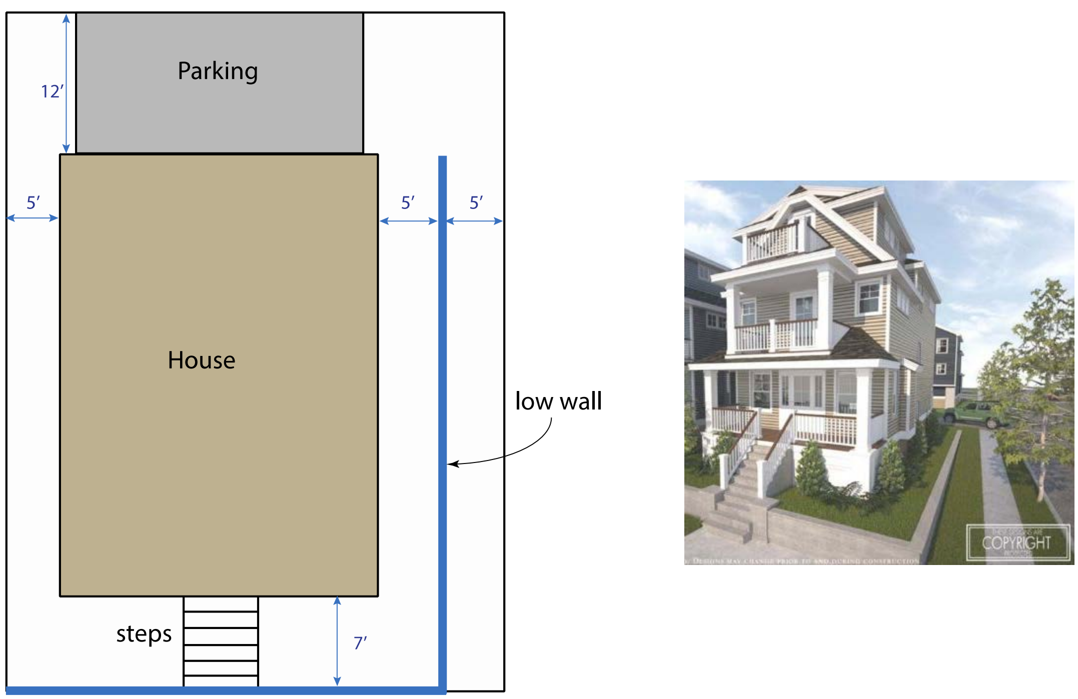


Figure 3. Sample lot and residence for Design Challenge I.

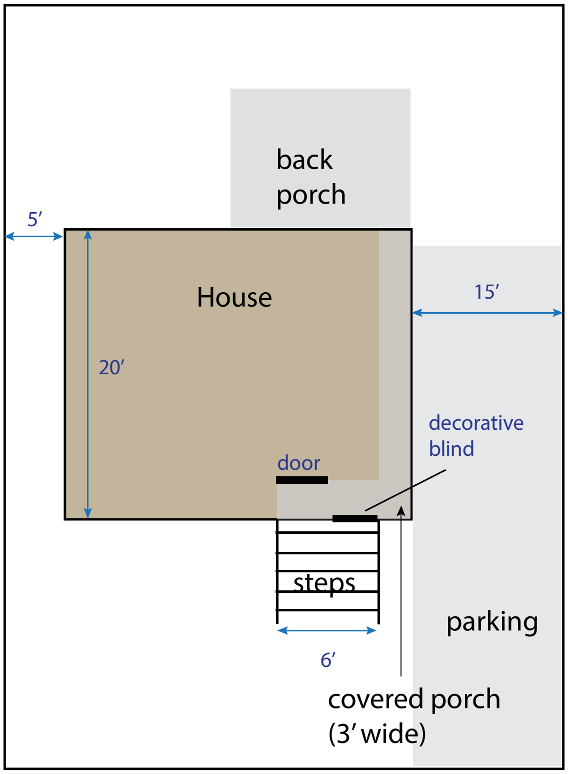


Figure 4. Sample lot and residence for Design Challenge I.

The campus “field trip” to use wheelchairs and explore ramp configurations, combined with initial brainstorm sessions, took approximately 3 class sessions. The remaining three class sessions were reserved for the students to construct a scale model of their ramp on their lot. For this final product, in which the students used foamcore, basswood, string, and other smaller scale building materials, students were permitted to construct their model to any scale that they deemed appropriate.

Figure 5. Using wheelchairs to explore accessibility

Figure 6. Exploring ramp configurations

During this three-week design challenge, instructors provided materials and served as a sounding-board for students' ideas, but did not weigh in on any particulars of students' design ideas, unless asked. Students were entirely self-directed, uncovering unexpected constraints in their designs, and adapting them accordingly – all independently. For example, one pair of students had designed a long continuous ramp, but had to change their design upon discovering that there is a maximum length of ramp, after which a level platform is required (by ADA guidelines). Another group had designed a ramp but later realized that it was 2 feet longer than their lot, and had to adjust. Finally, all groups had to grapple with how to make big enough platforms where the ramps change direction. Students, who also did all of the troubleshooting of how to correct them, identified all of these design problems themselves. Often, before instructors were even aware of potential problems with students' designs, other groups would aid one another, creating both inter- and intra-group collaboration. Photos of the students working to identify wheelchair constraints and construct their ramps and, Figures 8 and 9 below, demonstrate how they had to manage their team dynamic to collaborate on a single final product.

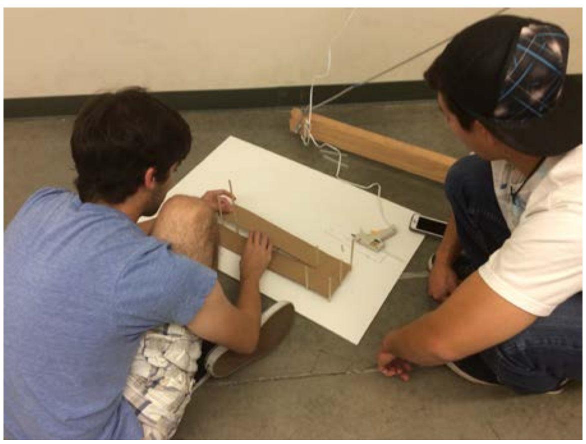


Figure 7. Ramp model construction

Figure 8. Ramp model construction

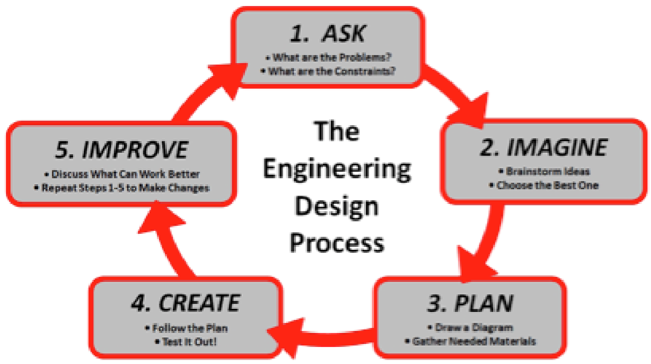
At the conclusion of Design Challenge I, all three teams of students participated in a "checkpoint" to help assess their team's progress, and their own contributions to their team. Additionally, students weighed in on their final designs, and anything they wish they had done differently. All students also elected to stay on the same teams for Design Challenge II, the primary design challenge.

The second design challenge also examined an accessibility problem. Student teams were to design a device to help a person who uses a wheelchair safely enter and exit a specific vehicle. The device was to be relatively portable, sufficient to safely allow the person to get into and out of the vehicle, allow multiple uses, comply with any ADA safety standards that pertain to lifts and take into account other important considerations for people with accessibility issues. The final deliverables of the design was a complete design sketch of the device from several angles as well as a 1:5 scale model of the device. Figure 9 shows the design challenge, as presented to the students. Note the emphasis for the students to be mindful of their use of the engineering design

process as they complete this project. To support construction of the model students were given access to engineering laboratories and equipment for fabricating the models.

Your next mission is to design a device to help a person who uses a wheelchair safely enter and exit his/her new vehicle (seen below; assume it is already outfitted to allow this person to drive the vehicle). This device should be relatively portable, sufficient to safely allow the person to get into and out of this vehicle (tall enough, stable enough, etc…), allow for multiple uses (i.e. could be used to lift the chair in other settings, not just into the vehicle), comply with any ADA safety standards that pertain to lifts, and take into account other important considerations for people with accessibility issues.

This device can be motorized, hydraulic, hand-operated, etc… there are no restrictions on the type of device you design, as long as it suits the requirements listed above. To help you, we will provide opportunities to explore and use the engineering labs and equipment, a question/answer session with a teacher from a local PBL school who has some experience with accessibility challenges, and opportunities to explore existing devices.



As you are designing your device, please be mindful of the Engineering Design Process, as discussed at the outset of the quarter. Document all of your work and all iterations of your idea, and both for us and for yourselves, also document the reasons you are continuing to pursue *or* deciding to scrap a particular idea. Be sure to include physical and/or mathematical bases for your decisions, and take care to use precise language! You will likely have more trials/iterations with this Design Challenge, compared to our first one!

Figure 9. Instructions to students for the second design challenge.

The specific vehicle that was chosen for this project was a Ford F-350 pickup truck. Since some owners of vehicles that are not specifically designed for wheelchair access choose to modify these vehicles and make them accessible, we also gave the student teams the freedom to explore possible modifications. Some examples of these include dropping of the floor of the car so that a wheelchair can be used as the driver's seat or modifying the driver-side door to open more widely for wheelchair access.

Fabricating the physical models was a major challenge given the time constraints of the course and the students' limited abilities to use a typical machine shop's equipment. To overcome this, we chose to focus the students on using a laser cutting machine as the main fabrication tool and acrylic sheets as the main material. This choice necessitated teaching the students to use a basic computer drawing tool to create two-dimensional drawings of parts, which are then sent to the laser cutter to create the parts. Even with no prior experience in using the commercial software,

students required less than one hour of hands-on instruction before becoming sufficiently proficient to create the drawings independently. Figures 10-12 show the work of one team during their planning phase, the cardboard prototype, and the final model.

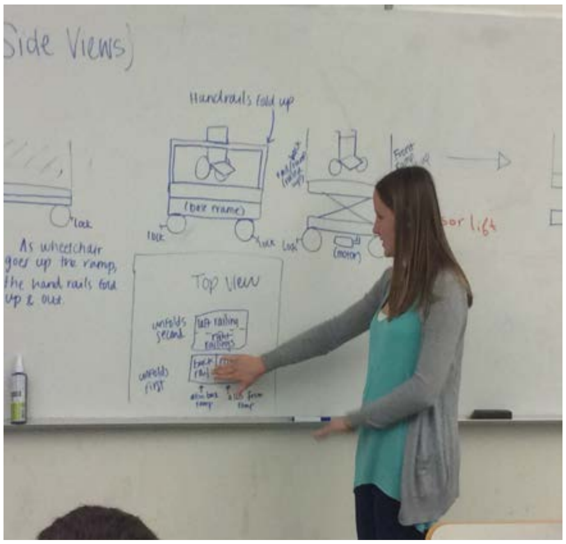


Figure 10. Planning the lift

Figure 11. Developing a preliminary lift model

Figure 12. One team's design for Design Challenge II.

In keeping with the project based learning approach faculty served as coaches – asking questions, prompting inquiry and providing expertise on subjects as student needs arose.

Course Evaluation

The course objectives were for students to be able to: (1) Apply the engineering design process to create a product or process, (2) Approach design challenges by working together in an efficient team setting, and (3) Become more reflective and skilled with providing actionable feedback in team settings. At each design challenge checkpoint students were asked to summarize their work, to discuss their progress from the prior checkpoint, to rate themselves as a team member, to reflect on what aspect of their personal work they would like to improve and to provide feedback to their teammates.

In relation to reflections and team feedback, all students were able to be reflective regarding their management of time and effort and to resolve to work toward improvements in their performance. They were also able to be examine the effectiveness of their communication within the team, be supportive of their team members and suggest how they could better work together. One student expressed it in this way "The feedback motivated me to think outside of the box, collaborate, and constantly think of ways to improve the prototype."

Student understanding of the engineering design process improved between the first and second design challenge. All students developed a more hands-on approach to design and learned new skills with new tools to execute their designs. "I've tried to be more hands on with the construction of our prototype." Having completed the first design challenge and approaching the second design challenge one student commented "Since the last checkpoint, I have been working on continuously thinking critically about aspects to improve our model to make it the best it can be. With the last design challenge, our group decided on what ramp we wanted to do and we simply completed the design, but with this design challenge I have pushed myself to always look for improvements that can be made. This has been very successful because it allowed me to challenge my mind and be a better contributing team member." Another described their process - "For DC2, our group began by brainstorming ideas. During our next class meeting, we combined our ideas to start drafting a prototype. After hours of drawing plans to the correct (1:5) scale, we started building the prototype. Using cardboard, tape, and push pins, the group assembled a model of a wheelchair lift. Once we were satisfied with the model, we used AI [Adobe Illustrator] to design the plans for the actual model. The laser cutter printed all of our pieces on plastic. After assembling the parts and making adjustments, we constructed the model using glue and hinges." Students discovered the necessity of iterating a design - "I have built things that might fail, but I used more trial and error for this challenge." Additionally, students identified processes to aid their engineering design "I began keeping all of our diagrams in one sketchbook. Using the sketchbook for measurements, notes, and sketches is an excellent reference tool." Students could see the value of the problem solving technique "This course taught me how to design engineering projects for my future classroom, introduce the engineering design cycle to my class, and how to use this process in real life situations when problem solving! :)"

The introduction to project-based learning took some students by surprise and their discomfort was expressed "The course was not what I expected. I thought we would focus more on the education of project based learning but instead we simply worked on projects using project based learning. I would not have taken the course had I known this is what it would be."

Through the course evaluations students expressed the value of the course in stimulating ideas on incorporating engineering in their future teaching. "Before the design challenges I never thought that I could design and build things. Now I have so much more confidence in myself to apply all of these skills and techniques in the classroom." "… the course taught me multiple ways of introducing and teaching the engineering design cycle…" Students also spoke of improved self-efficacy - "I feel as though I learned a lot about what goes into the engineering design process. More importantly, I feel more comfortable and excited to bring what I have learned into my future classroom for my students. I also learned a lot about the importance of teamwork and collaboration." "One lesson I learned from this experience is that not every detail will work out as expected. There is always room for error as well as improvement, and in order to be an effective problem solver you need to be prepared for both. This will without a doubt lead me to success because I will be prepared for whatever is thrown at me and I will know what steps to take in order to tackle the situation."

Conclusions

The course represents the first iteration of a liberal studies offering focused on the engineering design process that was developed for undergraduate students intending to pursue a teaching credential pre-service K-12. Two design challenges introduced students to both project-based learning and the engineering design process.

This course will again be offered in the spring term to a similar student body. Efforts are currently underway to advertise the focus of the course design challenges in Liberal Studies, Math, Physics, Liberal Arts and Engineering Studies departments. We hope to grow the class size to 24 students from these different majors. The class will again be team taught, this time by and engineering faculty member and instructor from a New Tech Network high school using PBL as the principal instructional method. A pre- and post-survey focused no assessing student awareness of PBL, co-teaching, and universal design for learning in relation to Common Core Standards and Next Generation Science Standards will be administered. Additionally data will be gathered through student interviews, and videos of student meetings. Students will be tasked with maintaining an engineering design notebooks. This data will be coded to evaluate the degree to which students applied the engineering design process in their work, and the effectiveness of PBL and engineering design to support and demonstrate the student's math and science content knowledge.

This work represents one aspect of an ongoing collaboration between education and engineering faculty and a local school district toward improving teacher preparation for K-12 education. We gratefully acknowledge support for this work under the grant "Transforming Teacher Preparation through Project-Based Learning Curriculum" awarded to [this] University from the S. D. Bechtel, Jr. Foundation via the CSU Chancellor's Office.

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