

ON TEACHING SIGNALS & SYSTEMS IN A PROJECT-BASED LEARNING ENVIRONMENT

Robert Sleezer, Eleanor Leung, Rebecca Bates

Minnesota State University, Mankato
Department of Integrated Engineering
Mankato, Virginia and Bloomington, MN USA

ABSTRACT

Project-based learning is a form of active learning where large-scale projects provide context for technical learning. Along with background information, this paper examines teaching and learning of signals and systems in the context of two ABET accredited project-based learning programs. Examples of projects, deep learning activities and classroom activities are provided.

Index Terms— Signal processing education, project-based learning

1. INTRODUCTION

Project-based engineering programs, where technical learning is contextualized with design projects, provide an alternative to traditional engineering programs. In project-based learning (PBL), students become familiar with approaching design projects from an engineering perspective and conducting projects in a professional manner as they acquire problem-solving skills and take ownership of the learning process. Student learning is guided by values of autonomy, self-directed learning, and connectedness, which have been shown to improve retention of knowledge. This paper provides an overview of the teaching and learning experiences of students in two engineering programs that offer the same degree at two extended campus locations. Students enter the upper-division program after completing lower-division pre-engineering coursework, typically taken at a community college. Students are placed on a vertically integrated team each semester and assigned a design project. Technical content, including a required core, is delivered in one credit modules which, in addition to providing a high-level overview of a topic through learning conversations, include a deep learning activity (DLA). This paper focuses on the signals and systems core credit, by describing some of the innovative active learning practices used during learning conversations and the range of DLAs used.

Selected by students with faculty guidance, DLAs provide an opportunity to apply key principles in a meaningful way. Each DLA represents approximately fifteen hours of work and ideally connects course content to a student's design

project, often becoming a design project deliverable. Types of DLAs include: designing, conducting, and analyzing an experiment; designing a system, component, or process; and developing a mathematical model of a system. Examples of projects and DLAs are provided, along with suggestions for adaptation to more traditional learning contexts. Challenges, opportunities and student learning outcomes and their metrics are discussed. Results related to the quality of student learning and student perception of learning are presented.

2. BACKGROUND

Project-based learning (PBL) has been implemented and studied in many forms (e.g., [1, 2, 3, 4, 5]). It differs from problem-based learning and other forms of active learning where close-ended or very constrained problems are used to motivate learning, typically in the context of a lecture-type course [6]. Although both are forms of active learning, PBL can be considered an extreme form because of the use of real world projects and student autonomy in finding creative solutions. Engineering undergraduate programs typically culminate with a design project experience that ties together multiple engineering courses to support synthesis of engineering technical knowledge. For some students, this is their first experience with an engineering design process. In contrast, PBL programs Iron Range Engineering (IRE) and Twin Cities Engineering (TCE) [7] where the authors teach use four upper-division projects to motivate technical learning. The senior capstone design experiences tie together not just technical learning, but professional and design learning from prior semesters [7]. These two programs offer an ABET accredited Bachelor of Science in Engineering where students can earn a focus in electrical engineering by taking 14 of 16 elective credits in electrical topics and by completing two of four semester-long projects focused on electrical systems.

2.1. Theoretical Foundations & Related Work

Motivated by ABET EC2000 [8, 9], the founders of these programs brought together information about engineering learning (e.g., [10, 11]), learning in general (e.g., [12]), and reflection (e.g., [13, 14, 15]) to create a program that results in

students meeting ABET-defined outcomes ([8] Criterion 3). Meeting the outcomes that reflect professional skills such as communication, teamwork, lifelong learning, and ethical implementation of technical knowledge requires learning these skills in an engineering context. A project-based context meets both the constraints and standards identified by engineering education researchers and accreditation stakeholders. IRE and TCE received the 2017 ABET Innovation Award.

There are many examples of using other active learning approaches in traditional signals and systems classes to benefit student learning, including use of gamification and Maker activities [16], virtual lab environments [17] and applying a teamwork learning approach [18].

2.2. Project-Based Context

When students join Iron Range Engineering or Twin Cities Engineering as juniors, they are placed on a vertically integrated design team, which may include students in any of the four terms in the program, and assigned a project. This project is of the scope and scale associated with capstone design projects in other programs (or larger). Students earn three credits of Design and three credits of Professionalism for working on the project. The three Design credits are associated with the actual design of the project while the three Professionalism credits are associated with work that is not the actual design (e.g., communication, project management, teamwork, etc.). Topics related to Design and Professionalism are discussed in a one hour Seminar students take each semester. In addition to Design, Professionalism, and Seminar students also must earn technical credits. These credits are delivered in one credit hour modules. There are sixteen core credits and sixteen electives each student is required to take. Signals and systems is one of the required core. Students focusing in electrical engineering often take additional signals and systems credits.

Students learn technical topics through formal learning conversations as well as independent study with advising from faculty, affiliated instructors and peers. Early in the semester they focus on new knowledge needed to complete their projects, and later in the semester they shift to advanced knowledge that relates to project execution.

3. ACTIVE APPROACHES IN COURSES

Learning conversations, DLAs, and semester-long projects all provide opportunities for actively engaging with content.

3.1. Learning Conversations

For each one credit technical module, students meet with an instructor for one hour learning conversations twice a week for eight weeks. Class size ranges from 5-15. Students are expected to be prepared for the conversation and the meetings

are active. Learning conversations may be similar to a flipped classroom [19]. Faculty take advantage of course software to post short content videos, suggest readings, and link to external content (e.g., The Massachusetts Institute of Technology Open Course Ware [20]) in order to enhance peer learning. These approaches are easily translated to a traditional course.

One faculty member has students state a simplified interpretation of the big picture for the course every day. After learning some of the context, students will respond to a question asking about the purpose of Signals and Systems with “tearing signals apart, putting them through a system piece by piece, and putting them back together”. All new material is then connected to one of the steps in this mantra. Examples include convolution, which explicitly goes through this process in the time domain, and system properties, which are connected to the mantra as a way to see how different systems affect signals in different ways. This framing could be used by any instructor, however, getting students to chant a daily mantra will depend on the instructor’s personality.

There can be an emotional factor to success. Faculty work to ensure students are frustrated enough with the problems they are working on that they must rely on each other but not so frustrated that they lose hope. This may require letting students take the wrong path, until they are stalled or stuck in a loop when a small hint will get them on the correct path. Sitting with this frustration and not providing an answer before a student has had a chance to discover it requires patience.

Connecting students to the rest of the world is beneficial as well. A successful intervention was called “4S” day, not a transform, but “Sunny Sidewalk Signals & Systems”. The conversation went outside where everyone used sidewalk chalk to work through the consequences of time shifting, frequency shifting, multiplication, and differentiation on the Fourier series of a signal. Public display of content knowledge resulted in a sense of pride, along with the delight of being in the sun. While this may be difficult with a larger class, shifting the perspective in a class by focusing on solving a shared problem, or asking students to have a conversation at lunch about signal properties can achieve similar connections.

Another method to further enhance the active and collaborative learning environment is through gamification, the use of game-based elements in non-gaming environments. Using three different game-based interactive online platforms [21, 22, 23] allowed for instant feedback on students’ level of technical understanding. These tools were used to review concepts. Since the gaming platforms provided real-time assessment, if the majority of the students chose the incorrect answer the instructor stopped to discuss the reasoning behind the correct answer. One student reflected that “it adds fun to a class that could be stressful and is also another learning tool that uses adrenaline to remember items/concepts.” Another student remarked that it was “very valuable as we only had enough time to answer multiple choice based off our conceptual learning with no repercussions for getting it wrong.”

3.2. Contextualization with Projects and DLAs

A project tied directly to Signals and Systems involved a lift platform for a production line painting booth. Students needed to examine different solutions for measuring the height of the platform and determine the most appropriate device for their application. By applying the fundamental principles of Signals and Systems to the chosen device, an ultrasonic range finder, the students were able to describe why the device's performance limitations were what they were.

Another project team developed and implemented a vacuum monitoring system within the tubing network for a local maple syrup company in northern Minnesota. A sensor was placed at the end of each mainline to read the vacuum in that specific mainline and relay raw vacuum readings to the sugar house approximately 2km away. The data received was converted into readable information for the company's workers.

The team researched different methods, both wired and wireless, of sending the vacuum reading signal and decided to use radio frequency. This project also resulted in DLAs. Two students did extensive research into wired and wireless communication. This learning aided in their decision to use wireless communication, specifically radio frequency, as the method to send the vacuum sensor signals back to the sugar house. The final design's wireless communication abilities were tested extensively on campus and on-site. The wireless transceiver chip used was a line-of-sight communication channel, so the team had realistic concerns about transmission through the maple trees. Adding a right angle SMA antenna had better than expected results. The client was very pleased with the work of the student design team and expressed a desire for future work, providing an opportunity for students to extend the project solution to include wireless transceivers and a permanent receiver antenna.

Projects also provide strong contextualization for later formal learning. Two examples are "Shut Up" and "A-Ware". Shut Up was an active noise cancellation project with the goal of canceling vibrations on surfaces to reduce ambient noise. A-Ware was an electroencephalogram (EEG) driven intervention technology designed to help users increase their concentration. Even though students took Signals and Systems in later terms, they learned about relevant applications that provided motivation for the content. The students who participated in these projects came into the class having already thought about many of the early building blocks and were ready to begin building on their knowledge. They could also revisit the project to provide context for DLAs.

The use of entrepreneurial mindset [24] to solve an open-ended problem was part of one semester's DLA. All the students were given the same open-ended problem: to propose whether infrared or radio frequency should be used for the design of interactive Mickey Mouse hats at Disney. Students worked in pairs to do research and apply the technical knowledge from the course to solve the problem. In their final so-

lution, students considered how to create value for the client and the end user of the product which highlights their use of entrepreneurial thinking, a program outcome. Initial student feedback from this process was mixed as some students did not like the topic chosen while other enjoyed applying signals and systems property to an application they had not considered before.

4. EVALUATION

4.1. Numeric Metrics

Grading at these programs use a 0 to 5 scale, related to the words Deficient, Weak, Acceptable, Desired, and Exemplary. These are then mapped to letter grades. The average Signals and Systems grade for these programs in the last five offerings was slightly less than a B+ or "Desired". This translates to 3.23 on a 4.0 scale with local averages of 3.26 (IRE) and 3.20 (TCE). Of the 37 students in these classes, 10 had an electrical focus, 20 had a mechanical focus and 7 focused in other areas. The average for EE focused students is slightly higher than others (3.33 vs. 3.20). By comparison, on campus students in a traditional program at the same university have a grade average of 2.79 for a 3 credit class required for electrical and computer engineering majors.

The PBL faculty are strict graders within the system. Grades show that students are generally mastering the material, while being able to use it in a project context. The higher grades suggest that these approaches provide more opportunity for mastery and engagement, not just for electrical engineers, but for all in the program.

Along with faculty evaluation, students evaluated their experience using anonymous feedback at the end of the course. Instructors included 5-point Likert-scale questions and open-ended responses. The questions targeted different areas of the module from the technical content delivered to professional behavior. Results in Table 1 show that the responses were generally positive (slightly to very). One question asked if the facilitator followed the 1/x rule. This question reinforces a value common to both programs where 1/x means for x participants in a discussion each person should be speaking 1/x of the time so everyone contributes and no one dominates the conversation. 66% agreed with this statement. Fewer students agreed the material was potentially useful, but the majority were not EE focused. Common themes emerging from the open-ended questions are that students learned a lot and would keep the same workload. Suggested improvements were to increase the number of assigned readings so that students can better prepare for learning conversations and to allow more discussion on potential applications.

4.2. Faculty Reflection

Another form of evaluation is formal faculty reflection. The two faculty members who have taught the module wrote ex-

Table 1. Student Feedback ($N = 12$)

Question	% Positive Feedback
Students were engaged in the learning conversation.	66
Instructor followed the 1/x rule.	66
The learning environment was safe (i.e, ask questions, make errors, and learn from mistakes without negative repercussions).	83
I learned a lot from this module.	50
I believe my grade will reflect my capabilities in this area.	80
The professional expectations were adhered to.	100
Assignments were helpful, appropriate in scope, & relevant.	66
The information learned was valuable to my future.	50

tensively on how they taught, what they taught, and how students learned. This approach fits into the continuous improvement model of the programs, where faculty meet together each semester to discuss implementation plans for improvement. An external analysis and discussion resulted in identification of comment themes, recommendations for changes, and ideas for replicating approaches across the two programs and into more traditional programs.

Faculty regularly tried new approaches in their teaching, with the goal to have interactions truly be conversations rather than lectures. One example included focusing on key principles rather than concepts that may also be covered in other courses. Another was adding problem solving games and fast feedback to better engage non-EE students. The “daily mantra” was a result of reflection on the disconnection in understanding both the math and why it was needed. This high level map helps students stay connected to the signals and systems context, helping the math have meaning.

With the end goal of students being able to solve problems and apply signals and systems, spending time with faculty (or guest industry experts) to focus on key areas of difficulty with concepts and solutions, rather than introducing all new material, means contact time is useful and meaningful. Students come to class knowing where pain points are because they have wrestled with the material before class.

As self-directed as most of the students are, the majority of them need some scaffolding in order to complete assignments in a timely manner. This was most evident in the DLAs as students would usually not start working on them until one week before they are due. Students prefer when a DLA can be tied directly to their design project but when it is not it becomes hard to get them interested. This was addressed by assigning the DLA topic on interactive hats (described above)

at the beginning of the module. Although this was met with mixed reviews, assigning specific DLA deliverables, such as client scoping questions and midpoint summary, throughout the module encouraged students to move forward with their DLA solution and report documentation. Students turned in their final DLA report within three days after the end of the eight week block which is earlier than seen in other modules.

It was observed that because students use DLAs and projects to contextualize the course content with real world problems, the sometimes abstract concepts in the course become tied to concrete case studies. Even when a particular concept does not connect to a project or DLA, there is typically enough of a relation to convince students of the utility of the material. If this is not the case for a specific student, the collaborative nature of the program coupled with the diversity of projects allows all students to ground their knowledge in a real world context. Supporting student collaboration and interaction in larger traditional classes can address this.

When students work on real-world or industry-motivated projects, they see the value of course content. When they have choice in the type of project, they are personally motivated to solve it. When students struggle to identify a project or DLA, faculty guidance following an appreciative advising approach (e.g., asking students about themselves, what their long-term goals are, and why they care about this) [25] can mean students are better able to identify their own interests and how that might relate to the course content.

The process of faculty reflection and willingness to keep learning better approaches puts faculty members in the same learning state as the students. It does not negate their expertise in course content; instead, it provides an opportunity for better learning and more student engagement.

5. CONCLUSIONS

Although we encourage students to continue learning about signals and systems, providing a one credit experience for all focus areas in our program has motivated innovative practices to engage students. This has resulted in positive experiences and contextualized learning for all students as well as a strong foundation that electrical-focused students build on with additional study. Real-world projects that use topics from signals and systems, active learning approaches, and student-motivated deep learning activities all contribute to successful learning. Planned future work includes building a concept inventory to better compare learning across terms and to traditional programs and longitudinal testing of concept retention.

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