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Integrating Interdisciplinary Project-Based Design Streams into Upper-Level Electrical Engineering Courses: A Methodology toward Implementing Applications-Oriented, Associative Project Streams into Electrical Engineering Courses

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Abstract

Semester-long design projects associated with capstone Senior Design courses are nothing new to engineering education.[1] And, occasionally, incorporating those semester-long design projects into specific, design-based courses has also been well-documented.[2] But, integrating semester-long design projects into all of the students' "design-based" and "non-design-based" engineering courses throughout their entire engineering curriculum represents a new "authentic-learning" approach toward teaching engineering to students. Medical Schools and Law Schools predominantly use authentic learning, or experiential learning, techniques to teach our future doctors and lawyers.[3] Engineering education has been slow to follow their lead in this regard, basing almost all instruction on lecture-based and laboratory-based teaching methodologies, rather than authentic learning methodologies. However, in the Spring semester of 2010, an educational initiative was begun to determine the value of integrating semester-long, Project-Based Design Streams (PBDSs) into the entire electrical engineering curriculum. Due to the exceptional response by the students[4], not two years later, there were seven engineering courses that had incorporated semester-long project design streams into their curricula. This paper examines the primary initiative for the inclusion of semester-long design projects into a majority of electrical engineering courses. The paper also examines the manner in which those semester-long design projects were incorporated into the various students' "design-based" and "non-design-based" engineering courses distributed throughout the various degree programs offered within the department.

Project-based Learning Methodologies

Authentic learning is an educational methodology through which students are immersed in activities that replicate "real life" situations in which the students may find themselves after they graduate, and as they begin their careers. Authentic learning methodologies are used extensively to instruct medical students and law students.[3] Engineering education also employs some authentic learning techniques by requiring students to complete internships or cooperative educational placements in industry. Project-based learning is a subset of authentic learning as it applies to engineering education. A significant amount of engineering education is involved in teaching students the fundamentals of problem solving skills. These problem solving skills are now predominantly taught through lecture-based instruction and laboratory instruction. Unfortunately, these two methods of teaching problem solving skills are oriented more toward teaching students solutions to very small-scale problems, rather than the complex projects that the students will be working on when they graduate. A much better way to teach those complex problem-solving skills that the students will need in their careers is to start with complex projects that permeate their instruction at the undergraduate level. Project-based learning fills that role by honing the students' problem-solving skills through large project design requirements. Authentic learning, as it applies to engineering education, is Project-based learning. Projects are challenging, and present complex questions and problems to the students. The students need that level of complexity to fully develop their problem-solving and decision-making skills. Project-based learning is a “constructivist” approach to education, and also includes authentic assessment, team-based cooperative learning and presentation skills.

Introduction and Implementation

It has been readily shown that when students are given semester-long projects on which to work that they spend a much greater amount of time on that course, and the project in particular, then they would have spent if the course's assessment had only been based on homework, laboratories and examinations.[5] However, it was also desired to determine the minimum overall grade weighting that the PBDS needed to have in order to still motivate the students toward maximum effort in their semester-long project. If the overall grade weighting of the semester-long project had little, or nothing, to do with the amount of time that the students spent on their project, then the PBDS could much more easily be integrated into both the “design-based” and “non-design-based” courses within the curriculum. For that reason, from the outset, the PBDS overall grade weighting has always been kept relatively low, at only 15% of the students' final grade.

There were also questions about the optimum structure of the semester-long PBDS. Some of those fundamental questions are listed below:

1. What phases of design development should be included in the PBDS?
2. Should the students all be working on the same project, or should each student group be working on a different project?
3. What size should the student groups be for optimal teamwork and communication skills to be developed?
4. Should the students be able to choose the members of their project group, or should they be assigned by the instructor?
5. How many reports or presentations should be required of the students throughout the semester?

Those were but a few of the questions that had to be answered prior to the initial design of the structure of the PBDS.

In the Spring semester of 2010, the first step in this educational experiment was begun through the integration of a semester-long, Project-Based Design Stream (PBDS) into the introductory first-year Electronic Design course. In addition to the first-year students' weekly labs and lectures, the students were also required to undertake a semester-long design project, similar to the major requirement of a capstone Senior Design course. This first PBDS experiment was originally designed to slowly expand on this first offering by systematically creating PBDSs in other “design-based” courses. However, during the integration of that first PBDS into Electronic Design, it was quickly realized, through positive student responses in their Course Evaluations, that the semester-long design project had exceptionally piqued the students’ interest and curiosity.[4] It had also caused them to spend a much greater amount of time on the course in general, and more specifically on the design of their semester-long project.[5,6] With such positive feedback from their Course Evaluations and team interviews, it was decided to fast-track the educational initiative. Rather than waiting a full year, until the following Spring semester, to extend the implementation of the PBDSs into a second electrical engineering design course, it was instead decided to incorporate a PBDS into an upper-level electrical engineering course, Analog Circuit Design, in the following Fall semester.

That course also received a 95% positive feedback from the students concerning the incorporation of the PBDS into the course's curriculum.[7] The positive feedback from the upper-level students only reinforced the positive feedback that had already been received from the first-year students. The increased interest, effort and appreciation shown by all of the students in both the first-year and upper-level design courses promulgated the expansion of the PBDS into other "non-design-based" upper-level electrical engineering courses. To date, the PBDS has subsequently been incorporated into five upper-level electrical engineering courses, in addition to the first-year Electronic Design course. The upper-level electrical engineering courses that have had a PBDS integrated into their curricula are the Analog Circuit Design course, the Advanced Sensors and Interfacing Systems course, the Data Communications course, the Computer Systems Architecture course and the Motors and Control course. In all of the upper-level electrical engineering courses in which the PBDS has been incorporated, the students have spent significantly more time in Project-based learning and authentic learning practices, due to their semester-long design project. The educational benefits that the integration of the semester-long PBDS offers students, relative to other electrical engineering courses that use only homework, laboratories and examinations as their primary assessment tools, are substantial. The PBDS also enhances other important "non-academic" skills that are necessary for electrical engineers to master prior to entering the workforce. These skills include leadership techniques, project costing and scheduling, teamwork building, production drawing and communication skills.

During that same Fall semester in 2010, the Data Communications course was the first upper-level "non-design-based" electrical engineering course to have a PBDS incorporated into its curriculum. During the Spring semester of 2011, no additional courses had a PBDS integrated into their curricula. It had been decided to analyze the effect of integration of the PBDSs into the four courses that already contained the PBDSs. This methodical approach was taken in an attempt to use the student course evaluation feedback to tailor the semester-long PBDSs to the individual courses in which the PBDSs had already been incorporated.

During the Summer semester of 2011, two more semester-long PBDSs were incorporated into two other "non-design-based" electrical engineering courses. One of those courses was Advanced Sensors and Interfacing Systems, and the other course was Computer Systems Architecture. During the following Fall semester, after the successful implementation of those two respective semester-long PBDSs, another semester-long PBDS was integrated into another "non-design-based" electrical engineering course, Motors and Controls. The incorporation of the PBDS into the Motor and Controls course marked the end of new PBDSs being incorporated into new upper-level electrical engineering courses.

In the Summer semester of 2012, the semester-long PBDSs that had been previously integrated into the courses of Advanced Sensors and Interfacing Systems and Computer Systems Architecture were further refined. This was done with a view toward implementing reforms into the semester-long PBDS structure that would allow better coordination of the design projects by the instructors, as well as to allow better integration of the PBDSs into the overall composition of the respective courses.

The Evolution and Design of the Project-based Design Stream (PBDS) Structure

Project-based learning methodologies, experiential learning practices and authentic learning techniques are not new to electrical engineering education.[8,9] Applications-oriented laboratories have always been a part of electrical engineering education. Course-associated laboratories have long emphasized and demonstrated the salient points of the concurrent lecture-based instruction that the students are receiving. Laboratories have always been an important and inherent part of most electrical engineering courses throughout the history of electrical engineering education.[10] As well, semester-long, capstone design courses, which are usually required during the final year of an electrical engineering student's course curriculum are also the norm, rather than the exception.

The differences between the traditional course-based laboratories and the senior-level capstone design courses are many and varied. Laboratories tend to reinforce the current lecture topic, without necessarily providing continuity between the laboratories throughout the duration of the course. On the other hand, capstone design courses usually emphasize the symbiosis of all the skills that the engineering student has acquired throughout their four years of instruction. The large differences between these two Project-based learning techniques leaves ample opportunity for other Project-based instructional methodologies to be employed in semester-long, design projects. This continuity of Project-based learning is the difference between a semester-long PBDS and common course-based laboratories. The semester-long PBDS allows the students to incorporate all of the new knowledge that they are receiving throughout the semester, as well as their previously gained technical knowledge, into the eventual culmination of their semester-long design project. In this way, the students realize an authentic learning experience, giving them skills in costing and estimating, engineering graphics, engineering economics and oral and written communications. In the final analysis, the students learn from constructing their own primary design, analyzing the electrical engineering constraints that are incumbent in that design, producing the engineering drawings and schematics, creating a prototype of that design, and analyzing the economic feasibility of their design.

As was mentioned earlier, one of the primary objectives of incorporating the PBDS into the electrical engineering course curriculum was that the overall grade weighting of the PBDS should be low, but still significant enough to motivate the students. The assessment of the semester-long PBDS has always been only 15% of the students' overall grade for the course, thereby making it a relatively small percentage of their overall grade, but still a large enough percentage to be a non-insignificant portion of their final grade. The project overall grade weighting is comparable to the grade weighting for the mid-semester examination. In actuality, the amount of effort that the students put forth in completing four major reports, an end of semester final presentation, and a prototype far outweighs the meager 15% of the students overall grade that they receive for the PBDS. However, not surprisingly, it has been found that generally the students actually allocate approximately 30% to 50% of the total time that they spend on the course toward working specifically on their semester-long design project.[11]

In the first rendition of the PBDS that was given to the first-year Electronic Design students, the students were able to choose the members of their own group. The project groups were limited in size to 2-3 students, with no allowance for student groups of four students or individual student groups. Each of the student groups were required to write a Development Proposal for their semester-long design project for any electronic, electro-mechanical or interdisciplinary project that they desired to put forward. However, they were also given a list of 25 candidate interdisciplinary design projects from which they could choose. Each of the groups was also required to submit four separate reports throughout the course of the semester, with a final oral presentation being required at the end of the semester. The four reports coincided with the four PBDSs phases, as outlined in the table below.

Development Proposal Phase	After investigating numerous different candidate projects, the students submit a 10-15 page Development Proposal to receive funding for their project.
Background History	The students detail all of the background history surrounding the electronic project on which they plan to work.
Costing and Scheduling	The students provide a detailed development plan that lists all of the costs involved in developing the project, as well as deadlines throughout the projects development.
Project Development*	The "Project Development" section is common to all of the four phases included in the PBDS.
Engineering Calculations Phase	After being qualified for funding for the project, the students complete all the required engineering calculations, schematics and drawings necessary to complete the project.
Engineering Drawings and Schematics	The students must provide all of the AutoCAD and Electronic Schematics necessary for the design of the project
Engineering Calculations	The students must provide a rigorous engineering analysis of the scientific fundamentals involved in the project
Project Development*	The "Project Development" section is common to all of the four phases included in the PBDS.
Prototype Manufacturing Phase	After having all of their engineering calculations examined and certified, the students then start to build their prototype and design their production methods.
Prototype	The culmination of the prototype Manufacturing phase is the presentation of a working prototype.
Production Design	The students also must provide a detailed description of the production process both for the prototype, as well as for larger production runs.
Project Development*	The "Project Development" section is common to all of the four phases included in the PBDS.
Economic Production Analysis Phase	After having created their prototype and detailing the production processes, the students then analyze the economics of establishing a small business to make 10,000 products.
Engineering Economics	The students must analyze the materials costs, the labor costs, the facilities and equipment rental costs, utility costs and miscellaneous costs that go into the overall cost of production.
Facilities Management	The students also design what facilities and equipment will be necessary for the most optimal production of the 10,000 products, and how those facilities should be laid out and organized.

Project Development*	The "Project Development" section is common to all of the four phases included in the PBDS.

*The Project Development section of each of the four phases of the PBDS is used to assess how well the student group has progressed through the development of the project. The question asked at each of the developmental phases is whether the student design group is ahead of schedule and below budget. They're great for that section of the phase is dependent on how they answer that question.

As mentioned earlier, during the Fall semester of 2010, Analog Circuit Design, was the first upper-level design course to have a semester-long PBDS included in its course curriculum. At the time of its introduction, there were questions as to whether it would be more effective to have one single common design project for all of the student design groups in the course, or to have student groups determine their own projects. Or, on the other hand, should the project criteria be based on a broader design description, which would entail simply requiring the final project to include sensors, actuators and microprocessors, rather than dictating the final project's criteria more specifically. Throughout the development of the PBDS for the earlier Electronic Design course, it had become apparent that there was less competition between the individual groups than had been anticipated. For that reason, it was desired that the project criteria for the Analog Circuit Design course should become more standardized, but still give the individual student groups maximum flexibility in their design projects. In this way, there would be more competition between the individual groups, while still keeping the projects dissimilar enough to prevent the possibility of one student group copying one another. This small reform to the original structure has remained as the PBDSs have been integrated into the other electrical engineering courses.

The instruction given to the students at the beginning of the semester was to build a design project over the course of the semester that would use an electro-mechanical analog sensor, irrespective of whether that analog sensor was current-based, voltage-based, capacitance-based or based on some other electrical characteristic. The sensor could measure any physical property, whether that was pressure, temperature, fluid flow or any other physical property. Then, the analog signal needed to be digitized and analyzed in a microprocessor to determine critical decision boundary parameters. And, then, finally, the microprocessor must output a digital output that would trigger an actuator or illuminate a warning indicator LED. The students were required to submit the same four 10-15 page reports throughout the semester that the students in the first-year Electronic Design course were required to submit during the prior semester. The assessment and grade weighting of the PBDS on the students' final grade were the same as for the Electronic Design course.

In addition to the four reports, there was also a final oral and video presentation. During the first semester that the PBDS was offered, the final presentations were given only as the traditional oral presentations. However, since then, every final presentation has been required to be a 10-15 minute video presentation, which they present to the class as a whole. This not only enhances the students' oral communication skills, but also assists them in their public speaking and video presentation skills. During the first week of instruction in the course, the students were given an outline of the project requirements, a schedule of the deadlines for each of the four reports that were required, and a detailed discussion of their responsibilities concerning their project's development.

Conclusions

The integration of the PBDSs into the six electrical engineering courses within the curriculum has increased the interest of the students in the semester-long design projects, and the individual courses in general. It has also shown the students the main applications of the topics that they are studying within those courses. And, through competition between groups, has motivated them to put more time into the courses, and to enjoy the courses more fully. They are also using authentic learning methodologies to learn the topics within the courses more fully, and learn how to apply those skills more capably.

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