Athens Institute for Education and Research
ATINER

ATINER's Conference Paper Series
ELE2017-2313

A Novel Method of Teaching a Capstone Final-year Design Course in Electronic Engineering over a Two-Semester Interval

Scott Grenquist
Associate Professor
Wentworth Institute of Technology
USA

An Introduction to ATINER's Conference Paper Series

ATINER started to publish this conference papers series in 2012. It includes only the papers submitted for publication after they were presented at one of the conferences organized by our Institute every year. This paper has been peer reviewed by at least two academic members of ATINER.

Dr. Gregory T. Papanikos
President
Athens Institute for Education and Research

This paper should be cited as follows:

Grenquist S. (2017). **"A Novel Method of Teaching a Capstone Final-year Design Course in Electronic Engineering over a Two-Semester Interval",** Athens: ATINER'S Conference Paper Series, No: **ELE2017-2313.**

Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
URL Conference Papers Series: www.atiner.gr/papers.htm

ISSN: 2241-2891
17/11/2017

A Novel Method of Teaching a Capstone Final-year Design Course in Electronic Engineering over a Two-Semester Interval

Scott Grenquist

Abstract

A capstone final-year design course is common to most engineering degree programs at institutions of higher education throughout the United States. The curriculum and learning outcomes for the standard capstone design course has, over the past couple decades, become standardized between the engineering institutions across the United States. A novel alternative approach to the final-year capstone design course was undertaken at our institution, which modified the two-semester capstone design course in order to include more topics concerned with intellectual property development and business entrepreneurship, topics deemed valuable for our graduates. The first semester of the capstone design course includes many topics from the recognized core curriculum of the accepted standard, final-year capstone design course, such as: 1) An initial Project Development Proposal Stage, including a background history of the intended design project, an estimated cost breakdown of the design project, and a detailed outline of the project's scheduling of goals and deadlines, 2) An Engineering Design and Analysis Stage, including an engineering-based analysis of the original design project, as well as detailed engineering drawings of the intended design project, and 3) A Prototype Development Stage, including a completed prototype assessment, as well as manufacturing construction drawings and instructions for manufacture. However, the second semester of the capstone design course curriculum includes newer and more innovative topical areas, which have historically not been integrated into a final-year capstone design course. Similar to the structure of the first semester, the second semester of the capstone design course is also separated into three stages. However, these three stages are concerned with teaching the students about entrepreneurship, business planning, engineering economics, patent prior art search techniques, and intellectual property rights. All of the subject matter considered in the second semester of the capstone design course are topics concerned with these subject areas. Overall, the expanded instruction in the second semester assists in strengthening and broadening the students' experience throughout the student design process. The addition of the second semester has been extremely well-received by the students, as demonstrated by the high student satisfaction surveys for this new approach to the curriculum of the course.

Keywords: Capstone Design Project, Constructivism, Patents education, Project-Based Learning.

Introduction

Final-year, capstone design courses are an invaluable learning tool that students can use to incorporate all of the various and disparate engineering knowledge that they have attained throughout their engineering degree program into creating a novel and useful project. The capstone design projects aspire to bring all of the knowledge, skill and effort that the students have acquired throughout their engineering degree programs to bear on a complex and broad problem, which is based on project design. Capstone design projects have become the rule, rather than the exception, throughout engineering degree programs in the United States, being offered at over 90% of all engineering institutions of higher education (Todd et al., 1995). However, half of the engineering capstone design courses that are offered at engineering institutions throughout the United States are designed as single semester courses, teaching an ever more standardized core curriculum throughout that single semester (McKenzie et al., 2004). And, at the engineering institutions that have extended the capstone design project to a multi-semester course sequence, the course still mainly contains the same standardized core curriculum that the single semester course incorporates-only over two semesters, rather than one. For example, the listing of topics in the two-semester capstone design course at Florida State University is shown below (Shih and Gupta, 2017). What is apparent from the list of topics and learning outcomes presented below is that these topics and learning outcomes are synonymous with the topics that are presented in a single semester capstone design course.

Team organization and motivation
Interpersonal skills applied within the design team and with the 'customer'
Technical writing (specifications, proposals, reports, online documents, etc.)
Engineering drawings
Presentation skills
Professionalism and ethics
Scheduling and budgeting
Personal time management
Project planning, work breakdown structure, and design record-keeping
Preparing a project scope
Identifying customer needs and needs assessment
Product synthesis based on customer needs
Concept generation and selection
Preparing an engineering specification
Preparing a design criteria document
Identifying system architecture
Problem formulation and application of engineering disciplines to design components
Ability to pursue design under conditions of shifting requirements
Interface identification and tracking
Consistency of purpose and project management skills

In contrast to simply expanding the overall time that is dedicated to the various standardized core curriculum topics, it was our intention to dedicate the second semester of the capstone design course to introducing new and innovative subject areas that would best assist our students in entrepreneurship and intellectual property development. Therefore, during the first semester of the two-semester capstone design course, it was decided to include most of the topics that are usually found in single-semester capstone design course. This allowed all of our students to participate in the traditional, standardized capstone design course that is taught at most of the engineering institutions throughout the United States.

However, in the second semester, we decided to introduce new subject areas that would be better directed toward the attributes of our graduate population. Our institution has been very fortunate by traditionally having a very high percentage of alumni that are entrepreneurs, and who eventually start their own businesses. Therefore, it was decided that the second semester should incorporate topics that could assist the graduates in their future endeavors of entrepreneurship, invention and business. In that regard, it seemed appropriate to include topics pertaining to patent prior art searches, the patent application process, intellectual property development, business planning techniques and engineering economics. The second semester curriculum of the capstone design course primarily includes these subject areas, but still also evaluates the students for their teamwork, their presentation skills, their project management skills, and many other project-based learning skills.

Project-based Learning Methodologies

A major component of final-year capstone design courses is the concept of authentic or experiential learning (Lloyd et al., 2001). Authentic learning is an educational methodology through which students are immersed in activities that replicate "real life" career situations, in which the students may find themselves working after they graduate. Authentic learning methodologies are used extensively to instruct medical students and law students (Schuwirth et al., 2003). One instance in which engineering degree programs incorporate authentic learning techniques is when those programs require students to complete internships or to complete cooperative educational placements. Another manner in which authentic learning can be incorporated into the curriculum is through requiring a final-year capstone design project. Project-based learning is a subset of authentic learning as it applies to engineering education (Frank and Kordova, 2009). A significant amount of an engineering student's education is involved in acquiring fundamental problem solving skills. Although these problem-solving skills are taught predominantly through lecture-based courses and laboratory instruction, an essential cumulative authentic learning experience is when the student finally applies all of the knowledge and skills that he has attained toward their final-year capstone design project.

Usually, a standard engineering course instructs the students in a very specific subject area of engineering. For instance, courses in thermodynamics, data communications or electromagnetic field theory are very specific to the core topic being covered. In contrast to this, the final-year capstone design course broadens the students' outlook, and requires them to use knowledge from many different subject areas to solve complex problems. This type of problem-based learning attempts to integrate all of the various knowledge and skills that the students have learned prior to that point to solve a systems engineering problem, manifested in their design project. This broadening of their curriculum not only incorporates problem-based education, but also manifests this problem-based education in a project-based framework. It also is strongly authentic and experiential learning.

A final-year capstone design project is an excellent way to teach students the problem-solving skills that they will need to succeed throughout their professional careers. Project-based learning fills this role by enhancing the students' problem-solving skills by forcing the students to constantly respond to the numerous and various problems occurring throughout their project development. The students need that level of problem complexity to fully develop their problem-solving and decision-making skills, which will be essential if they are eventually going to become successful in their engineering careers. Project-based learning is a "constructivist" approach to education, which also includes authentic learning, team-based cooperative learning, and lifelong learning (Carew-Leader et al., 2009).

The Curriculum Design of the Two-semester Capstone Design Course

The final-year capstone design course in electronic engineering has always had a multi-semester course structure. However, similar to many other engineering institutions, the two-semester course sequence at our institution traditionally used the additional time to simply expand the first semester course's standardized core curriculum into the second semester. No matter which curriculum the two-semester capstone design course employed, the composition of the student project groups has always been limited to 2-3 students per group, with the students choosing their own team members to comprise their project group. Students also have always been able to choose to work individually on their own distinct capstone project. In addition to having the choice to pursue design projects of their own choosing, the students are also given a list of 25 candidate interdisciplinary design projects from which they can also choose. Once the student project groups are decided, each of the student groups is required to write a Development Proposal as the first stage of their capstone design course. The Development Proposal submission is to include a discussion on the background history of the project's major technical points, as well as a projected schedule, outlining the deadlines for major development goals. The Development Proposal submission also must evaluate overall costs that are estimated for the completion of the design project.

Each of the project groups are also required to submit two more reports throughout the progression of the first semester of the course sequence. The first of these two other reports concentrates on the Engineering Analysis stage of the design project's development. It is a well-known fact that project-based learning methodologies, experiential learning practices and authentic learning techniques are not new to electrical engineering education (Böhne et al., 2002; Michaud et al., 2000). 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 receive throughout that respective course. Laboratories have also always been an integral and inherent part of most electrical engineering courses throughout the history of electrical engineering education (Dixon et al., 2002). Final-year capstone design courses not only incorporate all of the attributes associated with laboratory experiential learning methodologies, but also broaden those attributes by having the students draw on all of their acquired knowledge and skills to successfully accomplish the project.

However, the differences between the traditional course-based laboratories and the senior-level capstone design courses are many and multifaceted. Laboratories tend to reinforce the current explicit lecture topics, without necessarily providing continuity between the multiple laboratories offered over the duration of the course. Not to mention that laboratories do not extend across course boundaries. Laboratories that emphasize in network theory, usually do not include topics that would be useful in signal processing. On the other hand, capstone design courses many times emphasize topical areas that extend across many different previous courses, and across multiple years of instruction. This broader symbiosis of continuity inherent in the capstone design courses is the major difference between the authentic learning attributes offered by course-based laboratories and those offered by final-year capstone design courses. In addition to utilizing the knowledge and skills that students have learned in previous courses, the capstone design course also gives students experience in costing and estimating, engineering graphics, engineering economics and oral and written communications. The curriculum design of the first semester of the capstone design course sequence is illustrated in the table below (Grenquist, 2013).

Table 1. *First Semester Final-year Capstone Design Course Curriculum*

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 six 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 six 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 six phases included in the PBDS.

*The Project Development section of each of the six phases of the capstone design project 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 their development schedule and whether the group is below their projected budget. Their grade for the Project Development section of that respective phase is dependent on their assessment in those two areas.

In contrast to the standardized core instructional areas that are taught in the first semester of the course sequence, the second semester of the capstone design course sequence provides students with experience in patent prior art search techniques, patent application methodologies, engineering economics and business planning practices. In the first semester, the students learn from constructing their own primary design, analyzing the engineering constraints that are incumbent in that design, producing the engineering drawings and schematics required for that design and creating a prototype of that design. In the second semester of the course sequence, the students shift to analyzing the engineering economics, business planning and patent feasibility of that original design. The curriculum design of the second semester of the capstone design course sequence is illustrated in the table below (Grenquist, 2013).

Table 2. *Second Semester Capstone Design Project Course Curriculum*

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 six phases included in the PBDS.
Patent Prior Art Search Phase	After analyzing the business planning and economic analysis of a viable manufacturing business, the students examine whether their project would be a strong candidate for the issuance of the patent.
Prior Art Search Similarities to Their Project	The students are assessed on how close the prior art search centered on areas and classifications in which their project would exist. How is the prior art associated with their project.
Prior Art Search Information Clarity	This section of the phase is assessed contingent upon how the students respond to the prior art “claims”. How effectively do the students determine whether the claims existent in the prior art obviate any chance for a successful patent application.
Project Development*	The "Project Development" section is common to all of the six phases included in the PBDS.
Patent Application Phase	After extensively searching prior art to determine whether their project would qualify for the issuance of a patent, the students develop a full Non-Provisional Patent application, including the creation of a series of claims, and a full set of patent drawings.
Patent Application	The students are assessed on the complexity, appropriateness and breadth of the claims that they make concerning their project’s patent application.
Patent Application Drawings	In this subsection, the students are assessed on how well their patent application drawings correspond to the requirements for patent drawings by the US Patent and Trademark Office.
Project Development*	The "Project Development" section is common to all of the six phases included in the PBDS.

In addition to the six reports over the two-semester course sequence, there is also a final video presentation. Rather than have a final oral presentation, in which the students simply describe their project development over the two-semester course sequence, the students are instead required to create a 15-minute video presentation. This video presentation must describe the project evolution, and also be used as a marketing promotion for the product. In this way, the video not only enhances the students’ overall communication skills, but also assists them in creating multimedia presentations, which are naturally going to be an ever more important presentation skill for the future.

Conclusions

Currently, although there are several final-year capstone design courses that incorporate engineering economics into the course curriculum (Tickles et al., 2013), there are no capstone design courses that include intellectual property topics as a major part of the capstone design course's curriculum. And, yet, intellectual property development is a significant aspect in most engineering and science careers (Mok et al., 2010). Business planning, engineering economics, patent prior art search techniques and patent application procedures are all a necessary part of any engineering education. The best and most effective place to include these subject areas in an engineering student's education is in their final-year, capstone design course. In this way, these most important topics will be still salient to engineering graduates as they begin their new careers in their engineering fields.

References

Böhne, A., Faltin, N. and Wagner, B. (2002) Self-directed learning and tutorial assistance in a remote laboratory. *Interactive Computer Aided Learning …*, 1-13. Retrieved from http://bit.ly/2A639sO.

Carew-Leader, A., Therese, S. and Currie, M. (2009) CG623 Teaching & assessment of meta-attributes in Engineering: identifying, developing and disseminating good practice (EMAP), 1-95. Retrieved from http://bit.ly/2AMUAiC.

Dixon, W. E. W., Dawson, D. D. M., Costic, B. T. and De Queiroz, M. S. (2002) A MATLAB-based control systems laboratory experience for undergraduate students: toward standardization and shared resources. *... IEEE Transactions on*, *45*(3), 218-226. Retrieved from http://bit.ly/2j2FRJj.

Frank, M. and Kordova, S. (2009) The capacity for engineering systems thinking (CEST) of senior engineering management students: Learning in a project-based learning (PBL) environment. *... Annual Conference on Systems Engineering …*, *2009*(April). Retrieved from http://bit.ly/2AVfKMf.

Grenquist, S. (2013) 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. Presented at 12th ASEE Annual Conference and Exposition, American Society for Engineering Education.

Lloyd, B., Rice, M., Ferguson, C. and Palmer, S. (2001) *Engineering the future: Preparing professional engineers for the 21st century*. *International Journal of Applied Engineering Education*. Melbourne, VIC, Australia. Retrieved from http://dro.deakin.edu.au/view/DU:30010101

McKenzie, L. J., Trevisan, M. S., Davis, D. C. and Beyerlein, S. W. (2004) Capstone Design Courses and Assessment: A National Study. In *American Society for Engineering Education*. Retrieved from file:///C:/Users/User/AppData/Local/Temp/capstone-design-courses-and-assessment-a-national-study.pdf

Michaud, F., Clavet, A., Lachiver, G. and Lucas, M. (2000) Designing toy robots to help autistic children-an open design project for electrical and computer engineering education. *... for Engineering ...*. Retrieved from http://bit.ly/2yOVmet.

Mok, M. S., Sohn, S. Y. and Ju, Y. H. (2010) Conjoint analysis for intellectual property education. *World Patent Information*, *32*(2), 129-134. http://doi.org/10.1016/j.wpi.2009.07.004.

Schuwirth, L. W. T., van der Vleuten, C. P. M., Schuwirth, W. T., Van Der Vleuten, P. M., Schuwirth, L. W. T. and van der Vleuten, C. P. M. (2003). The use of clinical simulations in assessment. *Medical Education*, *37 Suppl 1*, 65-71. http://doi.org/10.1046/j.1365-2923.37.s1.8.x.

Shih, Chiang and Gupta, N. (2017) Florida State University Senior Design Project :: Class Overview. Retrieved June 11, 2017, from http://fla.st/2z9EVh2.

Tickles, V. C., Li, Y. and Walters, W. L. (2013) Integrating Cost Engineering and Project Management in a junior engineering economics course and a senior Capstone project design course. *College Student Journal*, *47*(2), 244-263. Retrieved from http://bit.ly/2zIMk6j.

Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R. and Anthony, D. K. (1995) A Survey of Capstone Engineering Courses in North America. *Journal of Engineering Education*, *84*(2), 165-174. http://doi.org/10.1002/j.2168-9830.1995.tb00163.x.