AC 2012-4043: IMPLEMENTATION OF A MULTI-DISCIPLINARY SYSTEMS ENGINEERING CAPSTONE DESIGN COURSE AT THREE PUERTO RICAN UNIVERSITIES

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Implementation of a Multi-Disciplinary Systems Engineering Capstone Design Course at Three Puerto Rican Universities

Abstract

This project adapted and implemented a multi-disciplinary systems engineering course at three Puerto Rican universities that serves students in multiple programs (including mechanical, electrical, and industrial engineering students) at each university. The course, which was previously developed, accommodates multi-disciplinary projects and complex systems projects. Approximately 35 faculty members attended a series of three training workshops. In the first, faculty learned about the tools and methods of a structured design process for systems engineering projects. In the second, they developed syllabi for their new courses by selecting from a menu of modular content to construct courses appropriate for their respective universities. In the third workshop, faculty received training on assessment best practices and agreed on a common assessment process. The new courses were implemented in three programs in the 2010-11 academic year and implemented in additional programs in the 2011-12 academic year. The paper describes the lessons learned in adapting and implementing the systems engineering-based multi-disciplinary capstone design courses as well as assessment results for the first year of implementation.

Introduction

As engineering teams undertake more high-risk and complex multi-disciplinary projects, it is necessary to have a design process that is agile and accommodating of technology change. The tools and methods of a structured design process support such projects. In addition, most engineering curricula do not address systems engineering topics and systems integration issues. The goal of our project is to adapt and implement a multi-disciplinary systems engineering course at three Puerto Rican universities that serves students in multiple programs (including mechanical, electrical, and industrial engineering students) at each university. The course, which was previously developed, accommodates multi-disciplinary projects and complex systems projects.

Many of the graduates of the three universities go to work for US companies in Puerto Rico or on the mainland, and others go into US graduate programs. The capstone design experience plays an important role in developing their potential for a successful engineering career. The need for engineers trained in systems engineering design also becomes imperative for Puerto Rico with the establishment in recent years of aerospace design and manufacturing companies like InfoTech (Pratt & Whitney), Honeywell, and Hamilton Sundstrand.

Background on Participating Universities

The three Puerto Rican universities working on the project have relatively young engineering programs. The School of Engineering at the Universidad del Turabo, established in 1990, offers undergraduate programs in Mechanical, Electrical, Computer, and Industrial and Management Engineering. Approximately 70 students take capstone design courses each year. The School of Engineering at the Inter American University-Bayamon was established in 1995 and has four

engineering programs: Mechanical, Electrical, Computer, and Industrial. Approximately 60 students take the capstone design courses each year. The Polytechnic University of Puerto Rico offers eight engineering programs. Approximately 180 students take capstone design courses in the mechanical, electrical, and industrial engineering programs each year. All three universities have capstone courses in the fifth year of their curricula. At Turabo and Inter American, the courses are one semester long, while at Polytechnic the courses are two trimesters long. The main source of capstone projects at all three universities is the industry in Puerto Rico. Funding for constructing the projects is very limited. Sometimes the students perform fundraising activities; without funding, the design remains a paper design.

Overview of Design Course Module Content

Our project integrates Systems-Engineering based design into Capstone Design courses taken by mechanical, electrical, and industrial engineering students at the three universities. Currently, most of the capstone projects fall within a single area of specialization. However, a few interdisciplinary projects are being done, mostly by teams composed of electrical and mechanical engineering students.

One of the co-authors from a collaborating mainland university previously developed modular course content of this type. This systems engineering based multi-disciplinary course, depicted in Figure 1, incorporates best practices in content and structure.[1,2] It had not been tested in widespread implementation previously. The course was designed to be modular so that relevant modules could be selected, allowing programs to adapt the content to their course requirements. This flexibility accommodates the different course durations, project team sizes, and engineering disciplines. The course includes detailed instructional material for each project step shown in the figure. Course content can be found at: www.nasacapstonedesign.mtu.edu. For systems engineering based projects, seven functions are particularly important:

Design Objectives and Constraints
Weighted User Requirements
Functional Descriptions
Validation and Verification
Interfaces and Interface Control Documents (ICDs)
Milestone Reviews
Risk Management

Design Objectives and Constraints and Weighted User Requirements are established in the Design Problem Analysis phase. Functional descriptions are developed during the System Level Conceptual Design phase. Validation and Verification occur at multiple points in the design cycle ensuring that the design meets the objectives and requirements. Interfaces and ICDs document where and how system elements connect or communicate with each other. Milestone reviews occur between and during all phases and facilitate knowledge sharing and identification of challenges. Risk management is accomplished using tools such as FMEA (Failure Modes and Effects Analysis) and reliability analysis.

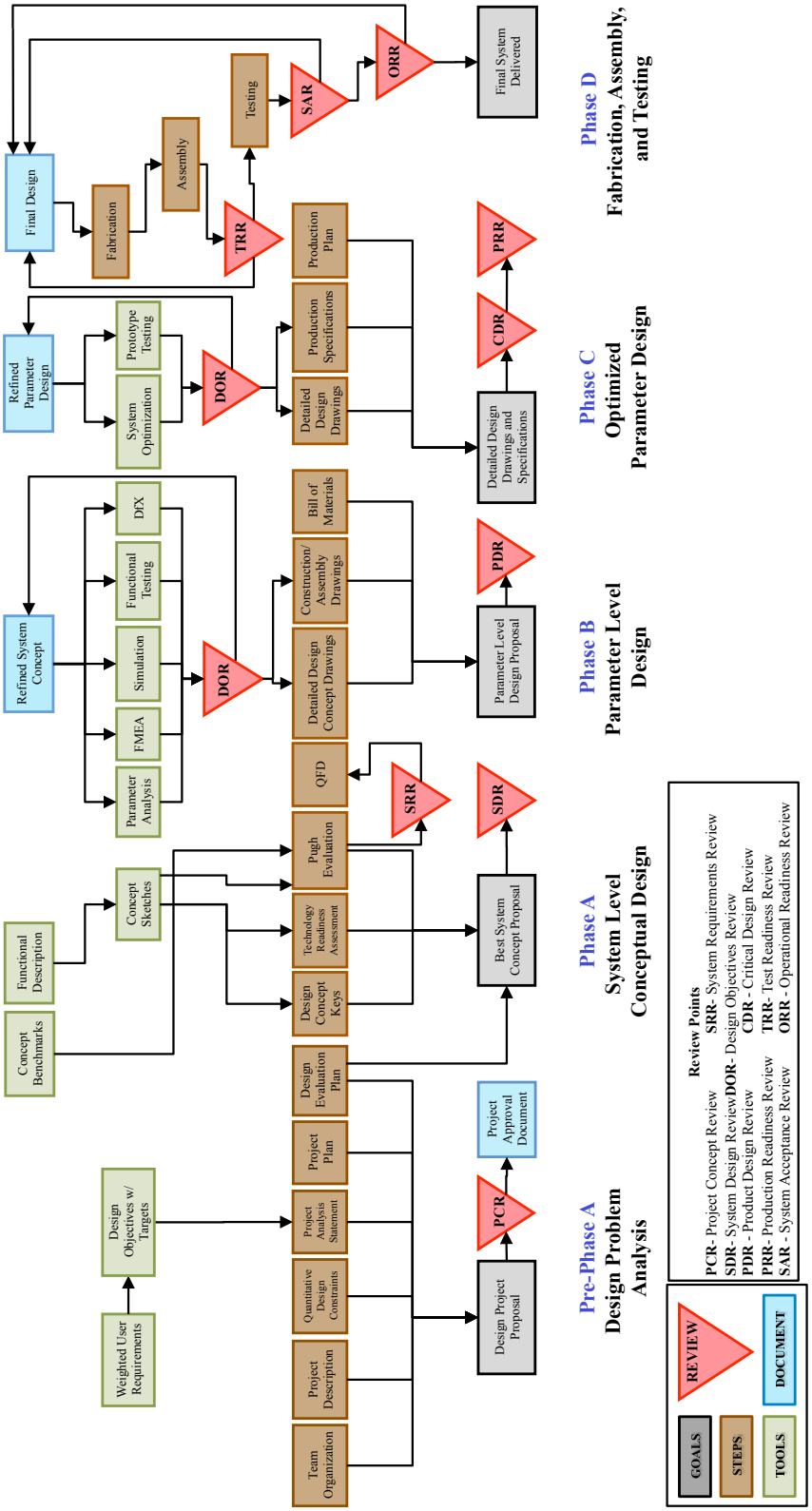

Figure 1: Design process for systems engineering based multi-disciplinary capstone projects

Faculty Workshops

Approximately 35 faculty members from the three participating universities attended a series of training workshops, facilitated by the mainland university collaborators. In the first workshop faculty learned about the tools and methods of a structured design process for systems engineering projects. In the second, they developed syllabi for their new courses. To do this, they selected from a menu of modular content to construct courses appropriate for their respective universities. In the third workshop, faculty received training on assessment best practices and agreed on a common assessment process (including a common set of attributes to assess).

Assessment Process

For the assessment process, we had several goals. First, we wanted to be able to quantify the impact of the new curricular materials on student learning (summative assessment). We also wanted data that would provide helpful feedback to course instructors for continuously improving their courses (formative assessment). Finally, we wanted a process that was common to all three universities and integrated with their existing ABET assessment processes.

Development of the process involved two major tasks: choosing what to measure and choosing the methods of measurement. In choosing what to measure, information was synthesized from multiple sources: best practices from the literature, a questionnaire of faculty at the three participating universities, and current assessment practices at the participating universities. Safoutin et al. proposed an attribute framework for design skills (outcome c).[3] They break design skills into fourteen components. They further divide each component into multiple sub-components. Besterfield et al. adopted a similar approach for all of the ABET outcomes (a-k).[4] Based on this attribute framework, a questionnaire listing 43 attributes spanning six of the ABET outcomes (c, d, f, g, h, i) was prepared. We asked fifteen faculty members at the participating universities to rate the importance of each attribute in their capstone course on a scale of 1-5 with 5 being most important. Twenty-seven of the 43 attributes had an average rating above 4. Table 1 shows how this data was used to reduce the number of attributes under consideration for each ABET outcome.

Table 1: First reduction in number of attributes to assess based on faculty questionnaire

ABET Student Outcome	Number of attributes rated	Number of attributes with rating > 4
(c): an ability to design a system, component, or process to meet desired needs	14	9
(d): an ability to function on multi-disciplinary teams	12	6
(f): an understanding of professional and ethical responsibility	4	3
(g): an ability to communicate effectively	4	4
(h): the broad education necessary to understand the impact of engineering solutions in a global and societal context	2	1
(i): a recognition of the need for, and an ability to engage in life-long learning	7	4

At an August 2010 assessment workshop, after considering other assessments in their programs, the faculty elected to focus on three ABET outcomes: design (c), teaming (d), and communication (g). Thus, the list of attributes was further reduced. After combining a few overlapping attributes, the final list has 16 items as follows:

Outcome (c): an ability to design a system, component, or process to meet desired needs

Need Recognition - Identify stated and unstated wants and needs that motivate the design effort; convert them into a needs statement

Problem Definition - Determine design objectives and functional requirements based on needs statement; identify constraints on the design problem; and establish criteria for acceptability and desirability of solutions

Planning - Develop a design strategy, including an overall plan of attack, decomposition of design problem into subtasks, prioritization of subtasks, establishment of timetables and milestones by which progress may be evaluated

Information Gathering - Gather information about the design problem, including the need for a solution, user needs and expectations, relevant engineering fundamentals and technology, and feedback from users.

Concept Generation - Transform functional objectives/requirements into candidate solutions

Modeling - Employ models of the physical world to provide information for design decisions

Evaluation and Selection - Objectively determine relative value of proposed solutions by using evaluation criteria; select most feasible and suitable concept among design alternatives

Implementation - Create an instance of physical products, processes, or simulations for purpose of testing

Outcome (d): an ability to function on multi-disciplinary teams

Participation - Understanding of and willingness to be fully involved in team efforts

Active Listening - Conveying understanding and using listening skills to move a conversation forward

Feedback - Giving and receiving constructive criticism

Judgment/Using facts - Reaching conclusions based upon clear analysis of facts and ideas

Outcome (g): an ability to communicate effectively

Written Communication - Produce written reports suitable for a variety of audiences

Oral Communication - Give formal oral presentations suitable for a variety of audiences

Graphical Communication - Use graphs, pictures, schematics to convey ideas

Informal Communication - Communicate by informal means such as meetings, email, and phone

We checked that the above would map to the design process shown in Figure 1. Figure 2 shows how the attributes map to the design process. Note that this ABET outcome based assessment process will provide information about most elements in the design process.

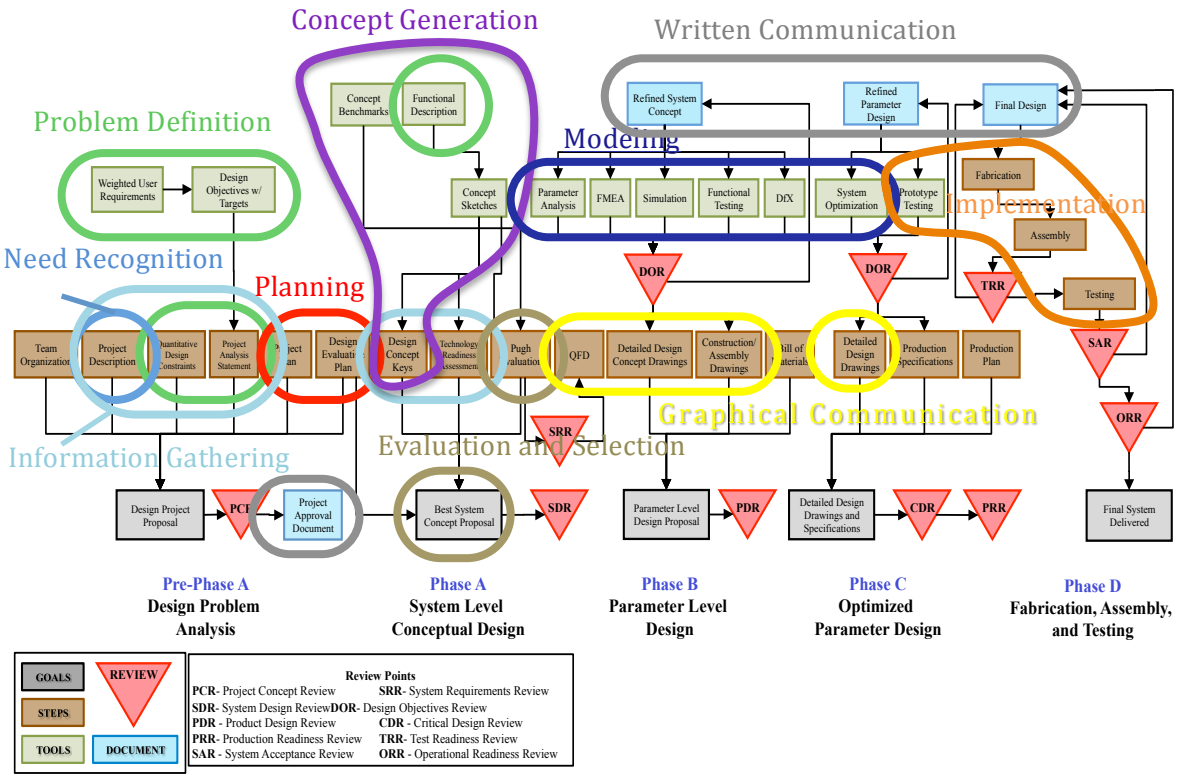

Figure 2: Mapping of design and communication attributes to systems-based design process

In addition to the above, we considered the seven key functions for systems engineering mentioned earlier. Most could be integrated into the assessment of the ABET outcome (c). For example, Design Objectives and Constraints, Weighted User Requirements, and Functional Descriptions would be assessed as part of Problem Definition. Milestone Reviews would be assessed as part of Planning. Validation and Verification would be assessed as part of Implementation. Two functions did not fit well with the attributes above: Interfaces and Interface Control Documents (ICDs) and Risk Management. These would be added as additional items in the assessment instruments.

Another part of the development process was selecting a way to characterize the level of student learning. We considered a rating scale from poor to excellent for each attribute. Following the example of Safoutin, et al.,[3] we also considered Bloom's taxonomy: knowledge, comprehension, application, analysis, synthesis, and evaluation. These authors add "Valuation" to that list. Because most the programs were comfortable using Bloom's taxonomy in their existing assessment processes, we settled on that one. The expected levels for each attribute varied. For example, for some attributes, a comprehension level is expected while for others a synthesis level is expected. None of the programs expected the highest level (evaluation) in the capstone courses. The assessment questionnaires and rubrics would reflect this variability in expected learning. Besterfield, et al. directs readers to a web site with example rubrics for evaluating the

attributes along this type of scale.[4]

Having decided on the attributes and levels of learning, the next step is to select and develop instruments that balance the need for good information and practicality. The TIDEE group did an extensive review of the design and education assessment literature and chose four types of assessment instruments - student written papers, team peer evaluations and questionnaires, design reports, and oral presentations.[5] Teams at the participating institutions prepare final written reports and give final oral presentations. Thus, an evaluation survey for each of these makes sense. Also, to assess teaming, we chose a student questionnaire. Finally, project sponsors have a valuable perspective as they interact with teams throughout the projects. They are in a good position to assess attributes such as informal communication skills that cannot be assessed in a report or oral presentation. Table 2 summarizes the four assessment instruments and the attributes that each assesses.

Table 2: Summary of assessment instruments for capstone projects

Instrument	**Completed by**	**Attributes Assessed**
Written Report Evaluation	Faculty Advisor and Other Readers	Design attributes System engineering functions Written and graphical communication
Oral Presentation Evaluation	Faculty Advisor and other audience members	Subset of design attributes Oral and graphical communication
Student Questionnaire	Students	Teaming Valuation of design process activities, types of communication, and systems engineering functions
Sponsor Questionnaire	Project Sponsor	Design attributes Written, oral, graphical and informal communication

Preliminary Assessment Results

The new courses were implemented in one program per school in the 2010-11 academic year and implemented in additional programs in the 2011-12 academic year. Final reports were assessed in spring 2011 for the first three programs (one at each of the three universities). Figure 3 shows the results of this first assessment. The two attributes specific to systems engineering functions—interface control and risk management—showed the lowest levels of learning, which was expected as these are new learning outcomes in these capstone design courses.

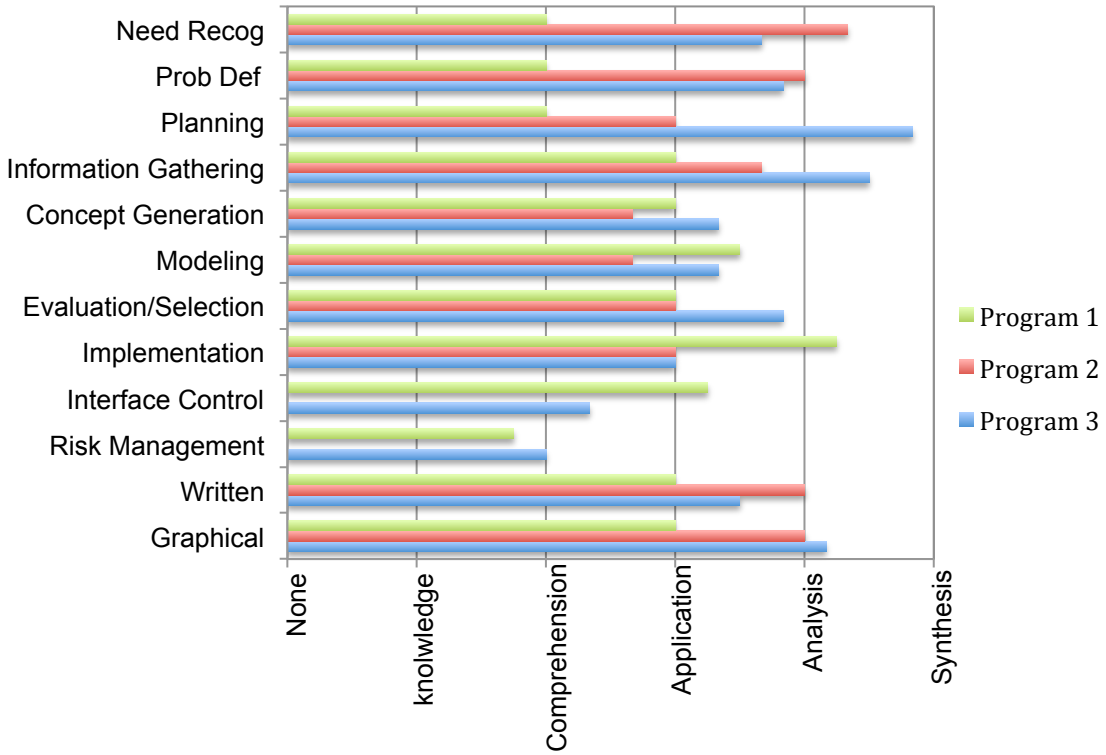

Figure 3: Written report assessment results for spring 2011 projects at the three participating universities

Conclusions and Future Work

This project has implemented a multi-disciplinary systems engineering course at three Puerto Rican universities that serves students in multiple programs (including mechanical, electrical, and industrial engineering students) at each university. Thus far, 35 faculty members coming from 13 different degree programs (and most with previous capstone design teaching experience) have been trained on the systems engineering-based design process. In the 2010-11 academic year, three programs and 95 students were impacted. The programs have adopted the design process modules that best meet the needs of their students and projects, which vary widely in topic and scope. Additional programs at the three universities are modifying their capstone courses in the 2011-12 academic year. Assessment data will be used to further improve on the capstone courses.

Acknowledgments

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