Learning Project Management Skills in Senior Design Courses

James M. Conrad[1] and Yesim Sireli[2]
University of North Carolina at Charlotte, College of Engineering, 9201 University City Blvd, Charlotte, NC 28223

Abstract - **US university engineering programs include a "senior design" course in their curricula. These courses are a student's last opportunity to use design skills learned in school. Student teams work to solve a problem while demonstrating their design and technical skills. A survey of one university department's program showed that few student groups complete the full functionality promised at the outset, and many groups did not even complete working systems, only working subsystems. If the students possessed project management skills, they could be more successful. Pedagogy of project management concepts is suggested, based on the Project Management Institute's "Project Management Body of Knowledge". An evaluation plan is also suggested for assessing the value of this new framework.**

Index Terms – Capstone, project management, scope, senior design, work breakdown structure.

INTRODUCTION

In today's competitive business environment, engineers cannot afford to be pure engineers. In the last decade, many companies have reduced the numbers and levels of management positions and have given more decision-making authority to teams at lower levels. Therefore, engineers need to have project management (PM) skills to manage various aspects of a project-driven technological organization combining engineering problems, human factors, and financial issues. Consequently, to be successful in this work environment, it is crucial for engineers to have some level of project management knowledge BEFORE they join the workforce.

US university engineering programs have been mandated by accreditation organizations to add a "senior design" course to their curricula. These courses, also called "capstone" courses, are a student's last opportunity to use design skills learned in school on a substantial effort. Student teams identify a problem to solve and spend one or two semesters completing their work. The ultimate goal is for students to demonstrate their skills by completing a project on time and with full functionality. Unfortunately, some student groups do not complete the full functionality promised at the outset. If the students possessed PM skills, they could be more successful. While many universities teach some PM concepts, guidelines for faculty to follow are sparse. Often, time available for instructing students is limited, and many faculties lack the PM knowledge and skills to effectively teach or mentor senior design groups.

The main goal of this study is to investigate and quantify the need for appropriate project management knowledge to achieve higher quality results in senior design projects at an engineering department via a survey of instructors. The results of this survey will be used as the basis for further study, framework of which is also discussed in upcoming sections. Therefore, this paper includes survey details of the Senior Design Course of the Electrical and Computer Engineering Department at the University of North Carolina at Charlotte. It then describes an appropriate pedagogy for introducing PM topics into a senior design course, with a method for evaluating the success of this pedagogy. It will also define the methodology for instruction that best utilizes a typical university engineering department's skills. This model has been defined by university engineering faculties who have also served as project managers in industry and have PM certifications.

THE IMPORTANCE OF PROJECT MANAGEMENT

A number of studies concluded that implementing effective PM adds significant value to organizations. The Standish Group found that a large portion of the $250 billion spent each year on IT application development is lost as a result of ineffective PM [1]. Many organizations in the information systems industry either abandon their efforts after allocating substantial resources or fail to achieve the anticipated outcomes from their investments due to ineffective PM practices [2]. The Center for Business Practices (CBP) has conducted industry-wide studies using a group of measures that document the value of PM to organizations. A recent survey included more than 100 senior-level PM practitioners and 97% of the respondents said PM adds value to their organizations [3]. These studies and alike prove that PM implementation provides considerable gains to an organization when it is done properly. However, they lack the cause and effect relationships between an organization's PM goals and the steps it has to take to implement related PM practices.

Many engineers are now either faced with management responsibilities at their current positions, or promoted to higher positions [4]. Therefore, they need to have PM skills to

[1] Department of Electrical and Computer Engineering, jmconrad@uncc.edu
[2] Engineering Management Program, ysireli@uncc.edu

manage various aspects of a project-driven technological organization combining engineering problems, human factors, and financial issues and to work in a cross-functional team either as a manager or as a member of the team. Consequently, to be successful in this work environment, it is crucial for engineers to have some level of PM knowledge and experience BEFORE they join the workforce. Similarly, it is critical for companies to consider their employees' PM skills as they are hired, to be competitive. For this reason, this research aims to quantify the value of PM knowledge in engineering college seniors as discussed in the following sections.

SENIOR DESIGN AND PROJECT MANAGEMENT

In a senior design course, students create teams of two to four participants, identify a problem to solve or product to create, and spend one or two semesters completing their work. Students attempt to demonstrate their technical and design skills by completing a project on time and with full functionality. Unfortunately, some students do not complete the full functionality promised in their original requirements documents or "project contract". Some do not even complete working systems, only working subsystems.

While many universities include PM concepts in their curriculum [5], guidelines for faculty to follow are sparse. Often, time available for instructing students is limited, and many faculties lack the PM knowledge and skills to effectively teach or mentor senior design groups. Further, there is no data available to demonstrate the improvement senior design groups could realize if they implement PM practices.

Previously, the author conducted an elective course that included activities that they could use during the senior design course [6]:

- Project identification: Students identified the project they wished to complete and submitted a one-page proposal to the instructor. The project was either approved or rejected. Rejected projects could be resubmitted. Several projects were rejected for being either too simple or too complex. These situations were shared with the class (with names removed) so that all students could learn project scope.
- Project design: Students wrote a detailed design document describing the technical aspects of the project. The entire class reviewed these design documents. This taught students the importance of an accurate and complete design.
- Project planning: Students submitted a project schedule with specific milestones. This taught students how to identify amounts of work and create small deadlines, instead of one big one at the end.
- Lab notebook: Students were required to keep a notebook with all of their lab observations included. The instructor checked their books each lab session. Project notebooks are required for their capstone project, and this class activity taught them to embrace this habit early.

The anecdotal results of this class were that all teams were able to construct a device that matched their design requirements as written, and nearly all performed the required tasks on time. Those that did not perform had minor problems that were typically solved within one week of the deadline.

FACULTY ASSESSMENT OF SENIOR DESIGN SUCCESS

A survey was conducted of Electrical and Computer Engineering (ECE) Faculty at UNC Charlotte on senior design project performance. The goal of this survey was to document the level of PM skills of the ECE students, by gathering inputs from educators who guide and grade senior design projects. The survey is intended to document students' PM abilities by investigating the following [7]:

- Technical skills to measure students' ability of implementing basic PM tools and techniques through a project life cycle.
- Socio-cultural skills such as teamwork and communication to manage real-world problems.

The questions are listed in Table 1, below. Questions 14 to 18 are related to students' socio-cultural skills while the rest measures technical skills. For questions 1 to 18, a 1 – 5 scale was used as follows, indicating student ability increasing from 1 to 5.

1. Non-existent
2. Poor
3. Moderate
4. Good
5. Excellent

In addition, a N/A option was also presented to the participants.

Questions 19-20 are yes or no questions and question 21 asks the instructor to enter a percentage for the completeness of student projects. The survey was sent to 16 senior design project instructors and Table 1 contains all 21 questions as well as the number of inputs received for each question. It also tabulates the statistical results of the survey including the mean, standard deviation, 95% confidence interval (CI) with t-distribution, and upper and lower limits for the results of questions 1 – 18 and 21, and total percentages for questions 19 and 20.

Table 1 shows the mean values as well as the confidence intervals for the inputs of questions 1 to 18 since they are based on the same 1-5 scale.

According to Table 1, the following conclusions are drawn for questions 1 – 18 (based on the same 1-5 scale):

The lowest mean values belong to questions 6 and 7 (2.75 and 2.50 respectively), which aim to measure students' ability to foresee potential risks involved in the project and create contingency plans. Instructors evaluate these skills between "poor" and "moderate." On the other hand, it should be noted that question 7's confidence interval (CI) is among the widest (±0.51) due to relatively high variation of the responses to this question.

TABLE I
SURVEY RESULTS OF ECE FACULTY'S ASSESSMENT OF SENIOR DESIGN GROUP PERFORMANCE

Question	# Inputs	Mean	Standard Deviation	95% Confidence Interval (t-dist)	Lower Limit	Upper Limit
1) Please rate your students' ability of setting clear goals for their projects.	15	3.20	0.68	±0.37	2.83	3.57
2) Please rate your students' ability of identifying clear tasks to achieve their goals.	16	3.19	0.83	±0.44	2.74	3.63
3) Please rate your students' ability of setting schedules for their tasks.	16	3.19	1.05	±0.56	2.63	3.75
4) Please rate your students' ability of constructing the budget for their projects.	15	3.40	0.83	±0.46	2.94	3.86
5) Please rate your students' ability of identifying the resources needed to accomplish their projects.	16	3.38	0.89	±0.47	2.90	3.85
6) Please rate your students' ability of foreseeing potential risks involved in their projects.	16	2.75	0.68	±0.36	2.39	3.11
7) Please rate your students' ability of creating contingency plans.	16	2.50	0.97	±0.51	1.99	3.01
8) Please rate your students' ability of setting and attending regularly scheduled meetings.	15	3.80	0.77	±0.43	3.37	4.23
9) Do your students provide their status reports on time?	12	3.67	0.49	±0.31	3.35	3.98
10) Rate the quality of these status reports.	13	3.46	0.78	±0.47	2.99	3.93
11) Do your students provide their final reports on time?	16	4.06	0.68	±0.36	3.70	4.42
12) Please rate the quality of their final reports.	16	3.81	0.66	±0.35	3.46	4.16
13) Rate your satisfaction with the final products of senior design projects (e.g., prototypes).	16	3.56	0.96	±0.51	3.05	4.08
14) Please rate your students' leadership skills.	15	3.47	0.74	±0.41	3.06	3.88
15) Please rate your students' problem-solving skills.	16	3.44	0.51	±0.27	3.16	3.71
16) Please rate your students' teamwork skills.	15	3.87	0.64	±0.35	3.51	4.22
17) Please rate your students' negotiation skills when a disagreement occurs during the course of the project.	15	3.67	0.62	±0.34	3.32	4.01
18) In general, please rate your students' performance in meeting your / their customers' expectations.	16	3.44	0.81	±0.43	3.00	3.87
19) Do your students make mid-term changes during the execution process of their projects? YES or NO	16	YES: 75% / NO or N/A: 25%	N/A	N/A	N/A	N/A
20) Do your students use any project management tools (e.g., Gantt charts, work breakdown structure, project network diagrams such as CPM and PERT, etc.)? YES or NO	16	YES: 6% / NO or N/A: 94%	N/A	N/A	N/A	N/A
21) In general, how much complete are these projects when it is time for grading? Percentage: ______	16	76%	16.7%	±9.3%	66.7%	85.3%

Question 11, which measures the timeliness of students' final reports has the highest mean value (4.06); somewhat higher than "good." This indicates that survey participants are quite satisfied with this skill.

Responses to questions 1-6, 8-10, 12-18 present similar mean and variation values (mean: 3.19 to 3.87, CI: ±0.27 to± 0.47), indicating that the instructors' evaluation for the rest of the skills are between "moderate" and "good." However some skills are closer to "moderate" and others are to "good" as follows:

- Evaluations for questions 1-5, 10, 14-15, and 18 are closer to the "moderate" level. Therefore, students' ability of identifying clear goals, tasks, schedules, budget, and resources is between "moderate" and "good," but closer to "moderate." In addition, the quality of their status reports, leadership and problem-solving skills, and their overall performance in meeting expectations are also rated in this category.
- Evaluations for questions 8-9, 12-13, and 16-17, are closer to the "good" level. Therefore, students' ability of organizing regular meetings, providing timely status reports, and quality final reports are evaluated between "moderate" and "good," but closer to "good." Also in this category are their teamwork and negotiation skills.
- In addition, based on the responses to question 19, 75% of the participants agree that their students make mid-term

changes during the execution period. On the other hand, 94% of the instructors say that they do not use any PM tools (question 20). According to question 21, the average completeness of senior design projects is 76% with a 95% CI of ±9.3%.

Final Survey Analysis

The analysis of this initial survey reveals that the timeliness of final report submittals is evaluated as the most satisfactory skill of UNC Charlotte's ECE senior design students. They organize regular meetings and provide timely status reports at a level between "moderate" and "good," but closer to "good." The quality of final reports, and teamwork and negotiation skills are rated at this level as well. However, there are a number of skills that must be improved to achieve the highest level of student performance possible. The overall performance of the students in meeting expectations is rated between "moderate" and "good," but closer to "moderate." Their project planning abilities (setting clear goals, tasks, schedules, budget, and resources) are also rated in this category. Socio-cultural skills such as leadership and problem solving are additional candidates for improvement. Students are not able to foresee risks and prepare contingency plans accordingly since these skills are rated between "poor" and "moderate."

ADDING PROJECT MANAGEMENT TO A SENIOR DESIGN COURSE

The Project Management Institute, the professional organization for project mangers, has identified a "Body of Knowledge" [8,9] useful for managing small and large projects. Those who have served as a project manager and have displayed a mastery of this body of knowledge can earn the "Project Management Professional" (PMP) certification. Although this body of knowledge and certification is valuable in industry, it is too extensive to cover completely in a university curriculum centered on technical skills. It is, however, an excellent basis which educators can draw from and incorporate into existing courses.

Projects are merely processes that are organized and executed to bring about a result. The Project Management Institute has identified five groups of processes that incorporate one or more similar processes [8]:

- Initiating - authorizing/starting the project.
- Planning - defining and refining objectives and courses of actions, and creating a project plan.
- Executing - carrying out the project plan.
- Controlling - monitoring progress to ensure project objectives are met.
- Closing - bringing the project to an orderly end.

These groups are linked with arrows that show flow of information, as shown in Figure 1. This pedagogy includes only the planning, controlling, and executing processes.

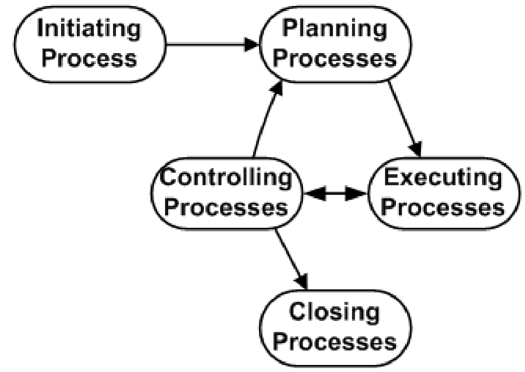

FIGURE 1
PROCESS GROUPS AND LINKS BETWEEN GROUPS [8]

In the Project Management Body of Knowledge, there are nine knowledge areas that contain processes that span two to four of these groups. These knowledge areas are [8]:

- **Project Integration Management (1)**
- **Project Scope Management (4)**
- **Project Time Management (4)**
- Project Cost Management
- Project Quality Management
- Project Human Resource Management
- **Project Communications Management (1)**
- **Project Risk Management (4)**
- Project Procurement Management

The bolded knowledge areas above represent those that should be addressed in detail in a senior design course. Further, the numbers in the lines represent the number of processes in that knowledge area that should be specifically taught in the course. These processes have been identified as important to PM by the author, a certified PMP, and are also consistent with the survey results. The survey revealed that students have problems with project planning (setting clear goals, schedule and resources), communication, numerous midcourse changes, and risk management. Appropriate project integration, scope, time, communications, and risk management knowledge will teach them how to deal with these problems to achieve much better outcomes in their senior design projects, as well as in the workforce.

Project Management Modules

These fourteen processes can be grouped into three distinct pedagogical modules and taught over the course of a minimum of three weeks, with at least three hours of classroom instruction for each module. It would be expected that each module would include lecture with hands-on, in-class exercises and well as assigned and graded homework. The senior design students could learn from these exercises and apply the knowledge to their own projects.

Project Scope and Work Breakdown Structure Identification: Often a senior design project has an industry or academic sponsor. In this module the students will learn how to identify the scope (expected deliverables and functionality) of their project and develop a scope statement that satisfies their sponsor. Students will also learn how to verify and control changes of the scope. Another important concept taught in this module is creating a work breakdown structure (WBS). A WBS is a deliverable-oriented grouping of project components that organizes and defines the total scope of the project [8,9]. A WBS is considered one of the most important documents of project planning - it is the used in most of the other project processes. Students will practice creating a WBS all the way down to the work package level.

Project Time and Integration Management: Once the project scope and WBS is developed, project activities are planned. In this module students will learn how to convert their WBS to specific identifiable tasks, and then sequence these task to create a project plan that can be followed during project execution. This module will also include an introduction to PM tools like GANNT charts and the application MS Project.

Project Risk Management and Reporting: Risk management is a concept that receives little attention in the academic world, but is an important component of large project implementations. Students are not prepared to address problems that arise in their own senior design projects, and thus are rarely able to respond to risks in their first employment position. This important topic is taught in the third module, and includes planning, identifying, controlling, and mitigating risks in a project. Students will also learn risk assessment and progress reporting during project execution.

These modules will be created in the summer of 2005 for implementation during the 2005-2006 school year in the UNC Charlotte ECE Department Senior Design Course.

EVALUATION PLAN OF A NEW CURRICULUM

Potential participants of this new senior design course are students of the Electrical Engineering (EE), Mechanical Engineering (ME), Civil Engineering (CE), and Engineering Technology (ET) departments of The University of North Carolina at Charlotte. Primary and secondary objectives of this research are as follows:

- Primary Objective: Quantify the value of PM implementation by determining project performance level with and without PM skills in terms of an organization's PM needs. This will be achieved by measuring the performance of the senior design students with and without PM knowledge as discussed in the next section.
- Secondary Objective: Develop PM instructional materials for COE senior design students.

Evaluation Strategy

Senior design students from all engineering majors (EE, ME, CE, and ET) at the COE, UNC Charlotte will be participants of a survey developed for the purposes of this research. All engineering disciplines are included in this study to cover a multi-industrial base. Half of these students will be taught complementary PM skills (Group A), and the remaining half will not (Group B). Then, each group's performance will be measured based on the survey and compared to determine the value of implementing PM in their projects.

This evaluation attempts to quantify the value of PM implementation by using selected independent and dependent variables. An independent variable is defined as the skills that a student should gain from PM knowledge and a dependent variable as the rewards that accrue to the industry depending on the level of the independent variables. Examples of independent variables are systems thinking, ability to establish methodology, and ability to define clear objectives. Among the potential dependent variables are level of complexity of the project, resource allocation / timing, and customer satisfaction. The goal is to measure the effects of the independent variables on the dependent variables by means of a Quality Function Deployment (QFD)-based matrix (Figure 2). Quantitative results will provide the level of satisfaction that a company will likely achieve by hiring engineers with PM skills, and/or the dissatisfaction it will suffer from hiring engineers without PM skills. To determine the levels of the independent variables, survey questions will be phrased to acquire clear understanding of the levels of the students' PM skills. Same questions will be asked to each group with the same rating scale. For example, the survey will ask the students who do not receive PM training (Group B) to rate their methodology development skills. Then, it will ask the same question to the other group who is taught PM skills (Group A). Therefore, two different independent variable ratings will be gathered from the groups.

The researchers will identify the dependent variables (an organization's PM needs) and with additional help from the senior design course instructors, they will determine the effects of the independent variables on the dependent variables (c_{ij}). Then, all this data will be entered into a QFD-based matrix as shown in Figure 2. Once the relationship matrix is complete, the level of satisfaction for each dependent variable is calculated as in Equation (1).

$$D_i = \sum_{j=1}^{n} c_{ij} I_j \qquad (1)$$

D_i : The level of satisfaction achieved for each dependent variable

c_{ij} : The influence of each independent variable on each dependent variable

I_j : The rating given by students for each independent variable

(mean value of all project scores in each project type category)

Independent Variables (I_j)

Dependent Variables (D_i)		Systems thinking (I_1)	Definition of objectives (I_2)	Establishment of methodology (I_3)	…	…
Level of complexity of the project (D_1)		c11	c12	c13	…	…
Resource allocation / timing (D_2)		c21	c22	c23	…	…
Customer satisfaction (D_3)		c31	c32	c33	…	…
…		…	…	…	…	…
…		…	…	…	…	…
…		…	…	…	…	…

FIGURE 2
QFD MATRIX: INDEPENDENT – DEPENDENT VARIABLE RELATIONSHIP

Satisfaction level for each dependent variable (D_i) is computed for each group and the results are compared to document the effect of PM knowledge on senior engineering student performance. This will indicate a student's performance level with and without PM skills in terms of an organization's PM needs. For example, effective resource allocation and timing is an important PM goal for an organization. If the level of satisfaction achieved for this dependent variable (D_2 in Figure 2) is 60% based on the data collected from Group B, and it is 75% according to the data from Group A, this increase can be explained by Group A's higher performance due to their PM knowledge. Therefore, the value of PM implementation is quantified.

CONCLUSIONS AND FUTURE WORK

It is well documented that the effective implementation of project management tools and techniques provides both technical and socio-cultural improvements in starting, executing and finalizing projects in any organization [7]. It is among the responsibilities of an academic institution to equip individuals with tools and techniques as well as social skills for the real world, and project management knowledge is essential for students to effectively work in a project-driven environment involving teamwork and timelines and budgets to meet. The objective of this study was conducting a survey of instructors at the Department of Electrical and Computer Engineering (ECE) at UNC Charlotte, to investigate the need for project management knowledge for students at the senior design level. The results indicated that the students have problems in project planning, communication, midcourse changes, and risk management., and a typical senior design team only completes about 76% of their intended functionality. These results will be used as the basis for further study on adding more project management skills in senior design, the framework of which is also included in this paper.

Future work for this effort is to develop the detailed class materials and evaluate them with a control and a test group of senior design students. The results of the materials development and evaluation of these methods will be the subject of future articles.

REFERENCES

[1] Hebert, B., "Tracking Progress," New Zealand Management, vol. 49, no. 1, pp. 24-28, February 2002.

[2] Jiang, J. J. and G. Klein, "Information System Success as Impacted by Risks and Development Strategies," IEEE Transactions on Engineering Management, vol. 48, no. 1, pp. 46-54, February 2001.

[3] DMReview.com Web Editorial Staff, "Center for Business Practices: The Value of Project Management, DM Review Direct Special Report, February 18, 2003.

[4] Babcock, D.L. and L.C. Morse, *Managing Engineering and Technology*, 3rd Edition, Prentice Hall, 2002.

[5] Middleton, N.T. and L.R. Burch, "Experimental Engineering Management in Collaborative Graduate-Undergraduate Projects," *Proceedings of the 1997 Frontiers in Education Conference*, Salt Lake City, UT, November 1996.

[6] Conrad, J.M., "Stuffing More Learning into the Computer Engineering Curriculum Bag: Capstone Course Preparation," *Proceedings of the 2002 Frontiers in Education Conference*, Boston, MA, pp F3D-20 to 23, November 2002.

[7] Gray, C.F. and E.W. Larson, *Project Management: The Managerial Process*, 2nd Edition, Mc-Graw Hill, 2003.

[8] Project Management Institute, *A Guide to the Project Management Body of Knowledge, 2000 Edition,* 2000.

[9] Project Management Institute, *A Guide to the Project Management Body of Knowledge, Third Edition,* 2004.