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Abstract

This paper describes how a Capstone Course in the area of Systems Engineering and Engineering Management resulted in a very positive and productive learning experience for the students enrolled in a particular Engineering baccalaureate program. Research shows that practical capstone courses are linked to high levels of student engagement resulting in improved levels of persistence and learning (Noble, 1998[7]), and this particular university initiative proved those findings right.

Introduction

Students today should master and be able to apply an appropriate mix of general and technical learning that lets them function in the general social and professional environment and in their particular discipline. Educating and forming students so they are able to use acquired learning successfully is an important challenge (Balmori and Schmelkes, 2011[2]). Many institutions have overcome the notion that a collection of general education and theoretic discipline courses provide considerable learning but little practical focus by using teaching methods with a high level of practice and application, such as capstone courses, internships and practical courses (Provitera, 2007[8]). This paper describes a case in which a well designed and successfully integrated Capstone Course can serve as an amalgam of theory and practice and provide benefits like reinforcing learning, developing skills, and improving congruence with the discipline.

Background of the Institution

La Universidad de Monterrey (UDEM) is a private, non profit institution founded in 1969 in the city of Monterrey in northeastern Mexico. UDEM offers 35 undergraduate degree programs in fields such as business, medicine, architecture, engineering, education and law. It serves 3,000 preparatory, 8,000 undergraduate and 1,000 graduate students.

Its undergraduate degree program in Industrial and Systems Engineering is focused on forming engineers ready to work in productive organizations and improve their administrative and production systems. The program offers courses focused on manufacturing, operations, systems engineering, logistics, industrial security, quality administration and other fields related to industrial engineering. UDEM aims to graduate industrial engineers able to function as agents of change and improvement in all kinds of organizations.

The rationale for a Systems Engineering Capstone Course

From its inception in the 1970s, the Industrial and Systems Engineering program has offered courses with high practical content. A lot of the work, nevertheless, involved short exercises very limited in scope, in theoretical courses. In a typical course—say Tools for Improving Quality—the instructor invested most of a student's time in a study of various methodologies, foci and tools in the field available to improve quality in organizations. At the end of a course, a final project usually consisted in applying some tool taught in the course to an actual situation.

That method seemed to work well enough, though careful analysis revealed the practical work to be quite superficial, almost automatic, and not effective as a focused learning environment (Checkland, 1981[3]) in which students applied methodologies, learned from experience, then repeated the exercise to improve familiarity with it and skill in applying it as a change agent. Students had to produce an integrating final project in one semester (around 18 weeks), and both students and instructors pointed out that, at the end of the whole degree program, students were not ready to undertake a high caliber project which incorporated much learning, skills, and professional attitudes.

Responding to that problem, the university introduced a Capstone Course in systems engineering in the mid 1980s. It came in the next to last semester of the program, just before the student thesis and graduation. Lasting 17 weeks, the course required students to develop an intervention for improvement in an administrative system, aimed at integrating and applying methods and skills learned along the way. Thus students used acquired systems engineering methods in fundamental ways instead of making nick of time adjustments of little consequence.

The Systems Engineering Capstone Course has been part of the degree plan since the mid 1980s, and at the beginning of 2000, it was redesigned as part of a curricular change to be even more profitable for students. The following paragraphs describe the redesign criteria, the course is it is presently, and some of its impact on student learning.

Capstone Courses Advantages

Higher education has used Capstone Courses for a long time, but they have come to the fore in recent years. The reasons are many: many institutions have found that students today are more focused on practical activities, *doing things* (Keller, 2004[6]); recent research as revealed as well that Capstone Courses are good tools for integrating learning and skills and for increasing students' sense of identity and belonging within the discipline (Flores, 2005[4]); on another hand, Capstone Courses offer benefits such as solidarity among teachers, linkage with the professional sector, a focus for institutional fund raising, external exposure for faculty, a source of materials for study and academic presentations, and one more way to determine levels of student acquisition of learning.

Course Redesign

The Systems Engineering Capstone Course was redesigned in 2000. The redesign aimed to improve the level at which students could work in coordination to improve the performance of processes in key areas of organizations by applying systems methods and concepts.

Three focus group sessions identified the purposes of the redesign (also useful in judging the redesign's effectiveness): one of faculty involved in the course, another with students and graduates who had taken the course and a third of professionals from organizations in which students had carried out an intervention.

Among the purposes/objectives of the redesign were:

- Maintain and improve the course's characteristics as a systems engineering course.
- Develop students' skills as consultants and change agents.
- Use intervention and problem solving methods relevant to the discipline and aligned with its practices.
- Apply student learning acquired in required courses before the Capstone Course.
- Position the course in the semester just before the Final Project and graduation.
- Integrate basic learning in systems engineering and other knowledge and skills relative to the discipline: statistics, problem solving, finance, management, industrial engineering, process analysis and improvement, innovation, reengineering, and diagnosis and resolution of problematic situations.
- Develop professional skills, such as composition, public speaking, personal interactions, group work, and work under pressure.
- Prepare students for the professional world. At this level, many students lack high level professional experience. The course can function as an internship to introduce students to the professional world and make their integration into it more orderly and natural.
- Provide a guided practicum in systems engineering, not just a work experience. Faculty involved in the redesign spoke of "avoiding students doing routine or clerical work but rather exposing them to the very real and complex problems of modern organizations."

The course redesign took into account courses that are requirement for taking the Engineering Capstone Course, such as:

- Systems Theory
- Systems: Concepts, methodologies and applications
- Statistics
- Analysis and improvement of processes
- Industrial engineering
- General management
- Quality tools
- Project management
- Systems simulations
- Total quality management

Students are expected to apply skills learned in those courses when they undertake their own intervention.

Input for the redesign

Various inputs went into the redesign:

- The design's goals/objectives, defined by faculty, alumni and clients (see above)
- Specific faculty suggestions for improvement
- Suggestions arising from the literature
- Good practices in other institutions (see below)

Analysis of good practices

Learning what other institutions were doing helped identify good practices appropriate for the purposes of the degree plan.

In 2000 a study of 15 Mexican universities that offer degrees in Industrial and Systems Engineering revealed that eight asked students to undertake a non supervised internship, which seven required a supervised intervention.

The first eight asked students to carry out some activity related to his major in a large organization, then report his experience to an instructor—basically a job. Many of those institutions lacked resources to supervise high level interventions.

The seven institutions requiring a supervised, formal systems intervention worked from a set of elements identified as good practices. The number of practices used varied among them. Some had very highly articulated courses, while others, though they claimed to offer formal capstone courses, used only a few elements. Table 1 lists some of those good practices and the usage percentage amount the seven institutions.

TABLE 1 – CHARACTERISTICS PRESENT IN CAPSTONE COURSES IN DIFFERENT INSTITUTIONS

CAPSTONE COURSE CHARACTERISTICS	% of seven institutions Present
A (consulting) team is created	86
An intervention proposal is documented	43
A defined methodological focus for the intervention is developed	29
A formal faculty assessor (advisor) is assigned	71
Project carried out in a robust organization	86
An appointed representative from the client organization participates	14
Frequent, regular meetings with the supervising instructor	57
Weekly progress reports and evaluations	71
Formal presentation(s) of progress	29
A final session with the client	57
A final closing presentation to faculty	57
Faculty in earlier courses evaluate	43
Student self-evaluation	43

The Systems Engineering Capstone Course Redesigned

The course was redesigned as described and positioned in the curriculum and has been used for the last ten years. Some of its key elements follow.

General description. The Systems Engineering Capstone Course is an integrating course taken in the next to last semester of the degree plan. Students carry out an intervention in a functioning organization, applying the focus and methodologies of systems engineering to improve the performance of specific processes and indicators. The intervention is carried out with teams of from four to six students (consultants).

Planning the course. About 8 weeks before the course starts, all the eligible students are notified to register and invited to attend a meeting where the scope and expectations of the course are presented. At the meeting, they get a general description of the course and learn that for the first day of class they must form a working team and present an intervention proposal, including the name of the client organization. The logic of that is that students need to start working on the project from the first day of class instead of investing a lot of time organizing teams and finding clients. In the past, the first three weeks of the course were spent organizing teams and finding customers and defining projects, therefore leaving less time to the actual intervention. Student groups of four to six members form independently, beginning at the information session (their primary job between then and the first days of class is to formally become a team and to identify a client and the problem area the group will tend to).

Students visit various organizations to choose a client and a project, and they identify the needs that might arise during a systems intervention. Students use pre-diagnostic models in the interviews to uncover a problem area. (Note that a problematic situation, not just a problem, is their goal. The first is unstructured; students must be challenged to identify the problem, not carry out an intervention around a known problem, as often happens with technical problems.) At this point, faculty may have clients/projects already identified, but more often the student team just find it, both a challenge and a learning opportunity.

Intervention Proposal. Four weeks before classes start, students must present an intervention proposal in a formal document which describes the intervention to be carried out using systems methods for 17 weeks in an actual organization. The proposal must describe the client, the background of the problem, the <u>unstructured</u> problem they will solve, the objective, indicators for evaluation, the desired goals, the methodological focus for the intervention (ordinarily designed by the students), activities to undertake, the resources needed and contact people within the organization. Also included is a brief description of two other potential clients considered but not chosen and the reasons for the choice.

Generally, the kind of projects sought are found in Human Activity Systems, in which there are either technical systems or administrative activities with a strong human component. Examples are: simplifying procedures in an insurance company; improving the response levels in a hospital's urgent services; creation of a system of recognition and motivation for personnel in a government public service agency; improving the labor climate in a large industrial outfit; and analysis and redesign of tutoring processes in a public university.

Evaluating the Intervention Proposal. When the proposals are submitted, the Systems Engineering faculty meet to evaluate them and decide which ones they approve, which they approve preliminarily (and the changes they require), and which they reject. For approval, a project must meet the following requirements, among others:

- must be in a non industrial area (must deal with management or some other human activity, not merely an industrial engineering exercise)
- must be sufficiently challenging for the team and the 17 week period; projects either too small or too large are rejected
- must involve a serious client
- must deal with a considerable problem area whose causes are not clear (to assure the need for a diagnostic exercise)
- must deal with a situation clearly susceptible to systems methodologies

Results are sent to the students; when projects are accepted with conditions or rejected, the team must submit a corrected project (if conditioned) or a new project (if rejected) 10 days before class begins. The faculty review the revised projects and make a final judgment: approved, approved with conditions (which must be dealt with before class begins), or rejected (whose proposers cannot take the course in the current semester, rare but not unknown) In the planning stage, students must act as consultants, propose the project to the client rather than just learning what the client wants. Many clients know what they want, though they often ignore the *real* problems.

Assigning an Advisor. A member of the faculty is assigned to advise each project. The advisor is familiar with the methods used by the students or the client organization. An advisor regularly assists with from two to four projects.

Formalizing the Team as a Consulting Group. Teams whose projects were accepted must be completely organized during the first days of the course. Each team develops its own philosophy, structure, principal roles, working rules, and modus operandi, as well as brochures and other documentation to describe its work. On Friday of the first week of class, the team makes a formal presentation of all the above to its advisor.

Project Stages. Projects are divided into three principal stages: analysis, design, and implementation. The first step takes 8 weeks, the second 5, and the third 4. As is natural with systems engineering projects, the diagnostic exercise is key and requires a lot of work, since the problem areas are usually not well structured (Ackoff, 1971[1]; Checkland, 1981[3]) and subsequently require lengthy analysis.

Methodologies. One of the course's greatest strengths is that students must act as consultants. They must be able, therefore, to use systems engineering tools, methodologies, processes and systems engineering techniques, such as intervention methodologies in soft systems (Checkland, for example), diagnostic tools, quality tools, orderly change processes (Argyris, for example), process analysis and design (mostly managerial), benchmarking, lean office, quality function deployment and balanced score cards. Throughout the project, students must be able to identify the right method or focus to analyze a situation (Jackson and Flood, 1991[5]) and then become thoroughly familiarly with those methods and foci and their creators.

Executing the Project. Each student will invest roughly 15 hours a week to execute the project, studying materials related to the project, visiting the client organization, working in the office (discussions, writing), and following up with their advisors.

Weekly Advisement Sessions. The working group meets weekly for 1.5 hours with the adviser to review progress and compare it to the plan. The advisor leads off a discussion which lets the team grasp how well it is moving forward and which way to go from there. At the end of every meeting, without exception, the team generates a report including matters agreed upon, the team's commitments in the next week, the time each member dedicated to the project during the week, and a consensus judgment whether the project is running late, on time or running ahead. Another report discusses the quality of the results (and counts as an exam).

Presentations. Throughout the course and aside from the presentation to the faculty of the working team and the proposal (week 1 of 17), the team makes additional formal presentations on the results of their analysis (week 8), the results of the design phase week

13), and the final results (week 17), once to the client and once to the faculty in all cases. The presentations should be professional and are evaluated as much for presentation skills as for the results along the way. Finally, the team presents a written executive progress report at each stage.

Evaluation. Each student's final course grade includes various components: the quality and energy of the effort, the results achieved, the quality of written reports and presentations, the client's evaluation, personal self-evaluation, and the opinion of the academic panels.

Student Learning

The course's student learning outcomes are related to familiarity and practice with systems methodologies and development of professional skills. At the end of the course, each student receives a personalized evaluation including the components of his team and of the student as a person. Minimum passing grade is 7 on a 0-10 scale. The average results of seven teams/projects carried out in Fall 2011 by 29 students follow. No student failed that semester. The rubric in Table 2 is simplified for purposes of this report, but each student sees his specific required results at each point along the scale.

Results provide feedback to students in the class and help inform faculty in earlier courses whether or no their students are achieving their leaning objectives. A sustained effort in that direction for the last 10 years has generated many actions to raise the level of their courses and of student learning. Students also report increased satisfaction in terms of their clients and their projects.

TABLE 2 – STUDENT LEARNING OUTCOMES
Results; Term: Fall 2011; Teams: 7; Students: 29

	Score (scale: 0-10)
A. SYSTEMS ENGINEERING COMPETENCES the student:	Present
1. Can decide after a short prediagnostic exercise, whether a particular situation can sustain an intervention for improvement.	9.3
2. Can develop and document the basic elements of a systems intervention (an intervention proposal).	9.1
3. Can select the methodological focus required for a particular problem situation (Jackson & Flood Model).	9.5
4. Can develop an analytical method for diagnosing problematic situations (based on well known methodologies).	8.8
5. Uses systems methods and tools to learn about a problematic situation (rich pictures, systems mapping, etc).	9.0
6. Can use methodological tools to identify symptoms in a particular situation (focus groups, interviews, analysis of processes).	9.5
7. Can identify a problem area's symptoms successfully (with objectivity, impartiality and a systemic vision).	8.9
8. Can articulate the symptoms of a problem area adequately.	9.0
9. Can use tools to identify problems' root causes, such as 5Ws, Current Reality Tree or Affinity Diagrams.	9.2
10. Can identify the root causes of a problem area successfully (with objectivity, impartiality and a systemic vision).	8.9
11. Can manage systems design methodologies successfully to improve a situation (eg: Checkland, BPR, VSM).	8.8
12. Identifies solutions creatively.	9.0
13. Identifies solution proposals using relevant criteria and distinguishing between exclusive and complementary alternatives.	9.0
14. Uses appropriate design steps to develop improvement proposals (expectations, concepts, in detail).	8.4
15. Uses benchmarking effectively to generate new ideas when appropriate.	9.2
16. Develops a plan for implementing solutions appropriate to the situation (designs procedures, training, publication, etc.).	9.3
AVERAGE:	**9.1**
B. PROFESSIONAL SKILLS Elements to evaluate:	
1. Quality of documents produced (focus, style, spelling, etc.).	8.9
2. Public presentations (effectiveness, professionalism).	9.0
3. Team work (integration, definition of roles, collaboration).	9.4
4. Work under pressure (order, effectiveness).	8.9
5. Focus on the client (helpfulness, fulfillment of expectations).	8.7
6. Organization (meets deadlines, commitments, use of gantt charts).	9.0
7. Personal communication (effective, to the point, formal).	9.1
8. Influence on others.	8.7
9. Leadership.	9.0
AVERAGE:	**9.0**

Students' and Beneficiaries' Opinions

Upon graduation, students answer a questionnaire: "Which was the most enriching academic experience of your degree plan?" Among 25 experiences within the curriculum, roughly 70% have chosen "my capstone engineering course" since the course was redesigned.

In a university poll covering 50 elements that reinforce student engagement, many graduating seniors named the capstone courses as the most engaging, leading social service, professional work, certification courses, formal research, and method and case courses based on problem solving.

Students evaluate faculty involvement and teaching excellence at 4.82/5.00 (average), very good compared to 4.41/5.00 in regular engineering courses.

Beyond that, evaluations from clients (in general, engineering managers, purchasing, human resources in various companies) rate students at 4.65/5.00 (average) on an 11 question form dealing with results achieved, the team's professionalism, student's methodological skills, the quality of presentations and services delivered, the amount of energy invested, and the originality of solutions.

Among client comments:

- "At first I didn't know what to expect, but later I wondered if I were hearing right. I thought they were undergraduates, but the quality of their work looked more like what I'd expect from graduate students!"
- "What surprised me was the ease with which they found the root of our problem, their creativity at finding solutions, and the energetic way they implemented them. Real consultants!"
- "I recommend you keep this up, because other universities just send you students 'who do what you tell them to.' Far from that, your students get here asking 'What problem can we solve for you?'"
- "Professional, enthusiastic, very committed."

From students at the end of the course:

- "The best course I took in my whole time here. It helped me understand the whole curriculum, how to put together what I learned, even gut courses like culture and statistics."
- "I never worked so hard in any other course. It was a lot of work. The faculty might ask for a little less, but in the long run, it was worth it. I even got a job thanks to that project."
- "For three years I took course after course in methods, tools, innovators. Yuk. But when I took the Systems Internship, I finally learned to use all those methods. So many things the faculty told us about how complex companies are—how difficult they are to analyze, how complicated teamwork is, how important it is know how to write and do good presentations."
- "I was pretty tentative about my future, but now I have a lot of confidence. I'm sure I'm going to succeed as an engineer, because I worked with professionals in a big company, and they said I did a great job."

The course has produced other results. Various regional and corporate plans have grown out of the student interventions. The course has as well been a tremendous tool for connecting faculty and students with all sorts and sizes of companies. The Final Project faculty say there is a visible difference between students who take the capstone course and those who didn't, since they have other majors.

Future Actions

Much about the course can be improved. Just as each semester finds some things done well, participants also look for ideas from students, faculty and clients about what can be done better. Most recent improvements have aimed at maintaining the course's quality instead of redesigning it. Some adjustments we are considering now are: assuring that new faculty who teach the course (one of two in a given semester out of a total of six to eight faculty teaching the course) know the whole system well; that students choose truly challenging projects (since some shoot low); and mostly assuring that the final results entirely pleased the client. Clients' most frequent complaint is that "students design solutions and start implementing them—and then leave us holding the bag when they graduate." (Such comments might reflect on the level of client involvement.)

Conclusion

The qualitative and quantitative results presented here reveal that the Systems Engineering Capstone Course makes a difference in engineering students who take it. The all-round purpose of a capstone course is to integrate learning, skills, and attitudes; and to catapult students on to the next level. As a result of the dedication and effort of the faculty and the quality of the students, those goals have been met.

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