Using DMAIC in Designing Capstone Courses to Enhance Essential Skills in Undergraduate Students.

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Abstract— **The role of the university is to provide society with holistic professionals: not only with domain of technical areas, but also with essential skills to support their performance at the organizations. This paper describes the use of DMAIC as the backbone of the senior design course at Escuela Superior Politecnica del Litoral (ESPOL) in Guayaquil, Ecuador. Senior design projects are developed in real companies with multidisciplinary teams following the different stages of DMAIC. In this document, we explain the faculty guided process, from the project selection and its definition to the solution and control plan. Also, we analyze the evolution of student outcomes -related to essential skills- as a consequence of improvements in the capstone process. We measured the changes in: written communication skills in native language, verbal communication in English -as a second language-, ability to function on multidisciplinary teams and awareness of the impact of the engineering profession. The results show significant improvements in each student outcome through the DMAIC stages. We conclude that senior design course; successfully supports the university in the emphasis of essential skills in engineering students. At the same time, this scheme enables students to effectively solve the problem of the firms.**

Keywords—DMAIC; capstone course design; essential skills

I. INTRODUCTION

Dutson, A. J., Todd, R. H., Magleby, S. P. and Sorensen, C. D. in [1] express: "The typical theoretical science and mathematics-based curricula encourage the analytical approach to problem solving, while system design, integration, and syntheses are what industry needs." With this purpose in mind, the engineering school of Escuela Superior Politecnica del Litoral (ESPOL) in Guayaquil, Ecuador established the senior design course to emphasize the engineering design abilities and the essential skills of its students through the solution of problems within real companies.

Active learning is generally defined as any instructional method that engages students in the learning process [3]. In short, active learning requires students to do meaningful learning activities and think about what they are doing [1]. Reference [2] shows that that active learning has a greater impact on student mastery of higher- versus lower-level cognitive skills. Also, [2] indicates: (i) active learning increases in achievement hold across all of the STEM disciplines and occur in all class sizes, course types, and course levels; and (ii) active learning is particularly beneficial in small classes and at increasing performance on concept inventories.

Problem-based learning (PBL) is an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. This method is always active and usually collaborative or cooperative [2].

Senior capstone design courses typically contain many examples of student centered learning. The focus of most of these courses is on the design project, which includes collaborative, cooperative, project-based, and PBL. Students working in capstone design project teams are doing the real thing. According Edgar´s Dale cone of learning, students will learn and remember the problem solving process from a real company environment; instead of simply reading the material from a book or listening to a lecture [4].

This paper describes the use of DMAIC as the backbone of the senior design course and the evolution of the following student outcomes (SOs): 1) written communication skills in Spanish, 2) verbal communication in English -as a second language-, 3) ability to function on multidisciplinary teams and 4) awareness of the impact of the engineering profession through the capstone design course process.

This document is structured in sections: section II, presents a literature review of problem-based learning, capstone courses, Six Sigma and DMAIC. Next, in section III we explain the launching process. Section IV details DMAIC as the backbone of the senior design course. Afterwards, section V refers to the methodology used to asses the aforementioned SOs. Section VI presents the results and finally section VII shows the conclusions of the study.

II. Literature Review

Engineering educators are facing demands from various sectors to produce graduates who can be effective in today's borderless k-economy. To accommodate these demands and adapt to changes in the 21st century, problem-based learning is proposed as an alternative to traditional lectures in supporting engineering graduates to acquire the desired attributes [5].

PBL focuses in experiential learning, organized around the investigation, explanation, and resolution of meaningful problems. In PBL, students work in small collaborative groups and learn what they need to know in order to solve a problem. The teacher acts as a facilitator to guide student learning through the learning cycle [6]. PBL reports both positive and negative effects. Among the positive effects [6] lists: 1) construct an extensive and flexible knowledge base; 2) develop effective problem-solving skills; 3) develop self-directed, lifelong learning skills; 4) become effective collaborators; and 5) become intrinsically motivated to learn.

On the other side, [3] states three negative effect size of PBL: 1) PBL with non-expert tutors, 2) Self -paced and 3) Self-directed learning. The first finding is consistent with some of the literature on helping students make the transition from novice to expert problem solvers. Research comparing experts to novices in a given field has demonstrated that becoming an expert is not just a matter of "good thinking" [7]. Instead, research has demonstrated the necessity for experts to have both a deep and broad foundation of factual knowledge in their fields. The same appears to be true for tutors in PBL. Therefore, faculty might be advised to be cautious about the amount of self-direction required by students in PBL, at least with regard to promoting academic achievement as measured by traditional exams [3].

In many schools, senior-level capstone courses have been developed recently in an effort to bring the practical side of engineering design back into the engineering curriculum. Such courses provide an experiential learning activity in which the analytical knowledge gained from previous courses is joined with the practice of engineering in a final, hands-on project. The development of capstone design courses has been influenced by many sources, including the Accreditation Board for Engineering and Technology (ABET), numerous industrial companies, and engineering educators [1].

Reference [1] categorizes experiential learning activities into two areas: those that have "simulations" and those that have "authentic involvement." Reference [1] describes and contrasts the areas as follows: "Simulations" consist of contrived situations that are carefully designed to meet selected learning objectives and are under close faculty control. The Authentic involvement activities expose the student to real situations with totally open-ended projects, although the faculty may influence the selection of the situations and set performance criteria to assure that positive learning objectives are met." Authentic involvements use outside clients while simulations use experimental laboratories, guided design, or case studies.

Reference [8] accentuates the development of soft skills in the case of software engineers during capstone design courses and PBL. According to [8], imitating industrial processes can contribute to addressing the challenge of maturing soft skills, mainly because they show students the need for applying such skills.

Practice is crucial for mastering skills such as problem solving. However, greater gains are realized through explicit instruction of problem solving skills. However, traditional engineering courses do not generally teach problem solving skills explicitly [3].

Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates. This comprehensive methodology takes the complex task of process improvement and breaks it down into elementary components, which in turn reduces task complexity [9].

The improvement procedure of Six Sigma is generally known under the acronym DMAIC, standing for Define, Measure, Analyze, Improve and Control. DMAIC procedure helps a user to find a strategy for analyzing and solving a problem, and thus structure the problem at hand [10].

The Industrial Engineering program at ESPOL prepares their students in several problem solving approaches in its continuous improvement area. Due to its structured activity scheme and focus on customer need, faculty chose DMAIC to emphasize student design abilities and at the same time fulfill the companies' objectives through the capstone design course.

III. Lauching the Process

Designing a capstone course for an 18-week semester is quite a challenge. In [9] the authors state that the duration of a capstone course has a great effect on course structure. Therefore, the industrial engineering program at ESPOL uses DMAIC structured scheme with clear timely deliverables per stage. The latter allows to emphasize: system design, integration, and syntheses; as well as essential skills in the students.

A. The Starting Point: Selecting the Projects

Each undergraduate engineering program at ESPOL counts with a capstone course coordinator. The role of the coordinator is to assure projects with active involvement of the students and real design experience in a company environment. Sources of projects include: contacts from faculty (65%), companies that previously had a capstone group (25%) and proposed projects from the students (10%). Students propose projects from companies where they did internships or are currently working. At the first round, in the first semester of 2015, all the capstone projects were obtained through contacts of faculty with the industry.

Capstone course coordinator visits the potential client. There, together come up with a problem general statement, expected benefits for the client and potential deliverables. The DMAIC methodology eases the approach to the firms. Even though, some companies have not used the methodology before, they understand it and are willing to have the experience of its implementation. It is made clear for the client, that the students are responsible of the project. However, 100% of clients states that having a faculty member as a coach is auspicious for the project.

During the visit, the capstone course coordinator also evaluates if the company has a feasible environment to implement the DMAIC methodology. For example, industries that had recent massive layoffs are not suitable for the capstone course process.

The quality assurance committee of the industrial engineering program evaluates projects to assure the real design experience required by ABET. Once the committee approves the projects, they are ready to be shared with students.

B. Kick off Meeting and Project Selection Process

The main purpose of the kick off session is to share project information with the students, review the DMAIC process and its expected deliverables and explain the grading system. Capstone course coordinator presents projects, clients and coaches. Coaches are assigned to projects based on their industry experience and interests.

Students work in group of two. Each group has a coaching session per week. The pair of students select two potential options of projects. Capstone coordinator receives the information by e-mail and assigns projects based on FIFO (first group interested, first project assigned). In this way, if option number 1 is not available, the group is assigned option number 2. The assignment is done during registration days.

IV. DMAIC AS THE BACKBONE OF THE SENIOR DESIGN COURSE

The project starts the first day of the semester with the presentation of the students to the process sponsor, process owner and the focal point of the company. Fig. 1 shows the DMAIC stages and time allocation per phase applied to the capstone design course at ESPOL.

In this way, the Define, Measure and Analyze phases total 9 weeks -middle of the semester-. Improve chapter is divided in two parts: a) proposal and b) implementation of solutions or prototypes. Faculty decided to allocate 4 weeks to the proposal of improvements and/or prototypes. It is critical to capstone design students to assure proper solutions generation, prioritization and planning. The implementation of solutions and/or prototypes and the generation of control plans take 5

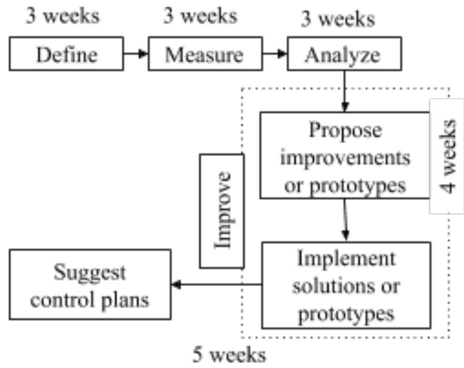

Fig. 1 DMAIC process in capstone design course

weeks of the semester. During the capstone design semester, students are invited to attend to 5 talks of 1 hour each. The topics cover: DMAIC methodology, storytelling and creating presentations with impact. The DMAIC is cover in detail in some of the courses of the industrial engineering program,

In order to close each DMAIC stage, students are required to make a graded executive presentation in English (their second language) to an experienced faculty member. The professor takes the role of a supervisor. During this presentation, questions, answers and communication in general are in English.

A. Deliverables

Following DMAIC, there are minimum deliverables to assure that the students reach the desired results in each stage (see Table I for details) and finally attain the project objective. From the Define phase, the students have to internalize the problem statement, the response variable/attribute baseline and macro-process. With the support of the project sponsor and liaison engineer, students assemble the project support team.

TABLE I. MINIMUM REQUIRED DELIVERABLES PER DMAIC STAGE

Stage	**Minimum required deliverables**
Define	Problem statement. SIPOC. Time series analysis. SMART objective. Critical to quality (CTQ) tree. Team. Project charter
Measure	Data collection plan. Process mapping. Analysis of data reliability. Capability analysis. Focus problem statement.
Analyze	Brainstorming of potential causes. Fishbone of the causes. Cause weighting matrix. Cause verification plan. Verification of causes. Five whys analysis. Root causes.
Improve	Brainstorming of solutions. Solution prioritization matrix. Implementation plan. Evidence of implementations. Results.
Control	Control plan

The involvement of a liaison engineer has an effect on the results of the project. Reference [1] found that projects that were funded by industry and then turned completely over to the students were invariably less successful than those that had an interested liaison engineer involved with the project.

The Measure phase mainly consists of developing a suitable process mapping, data collection plan, capability analysis and focused problem statements. Analyze consists of using brainstorming sessions with the team to generate causes affecting the main problem statement. The phase continues with the construction of Ishikawa, weighting cause matrix and cause validation plan. Analysis finishes with cause verifications and the application of 5-whys' technique to reach root causes.

Improve stage is divided in two parts: 1) proposal of improvements or prototypes and 2) implementation. The first one, includes solutions brainstorming session for each root cause with the team, solutions prioritization matrix and implementation plan. The final part must evidence the implementations in the company or the prototypes. Also, the students must verify the results and show the before and after indicators. Validations of the CTQ tree after the implementation is required as well.

Due to semester time constrains, in the Control stage the students are required only to propose a control plan. This phase differs from a non-academic DMAIC process. In the non-academic case, project leaders will have to present the evidence of: training, development of visual controls, indicators, operational meetings and a reaction plan. All these deliverables assure control of the root causes.

V. ASSESMENT METHODOLOGY

The Industrial Engineering program started measuring SOs in 2015. The academic year has two semesters. Even though, faculty form SOs in their classes every semester; they report their evaluation once a year. This scheme allows to balance evidence collection and measurements efforts.

In order to asses the evolution of the attainment of SOs: 1) written communication skills in Spanish, 2) verbal communication in English -as a second language-, 3) ability to function on multidisciplinary teams and 4) awareness of the impact of the engineering profession along the capstone design course process, we took significant samples in some of the DMAIC stages during a specific semester (see Table II for details). This study comprises measurements from 2015 to 2017.

Faculty from the Industrial Engineering Department developed evaluation rubrics for each SOs. Levels of accomplishment of the SO are: Unsatisfactory (0,00 - 2,499 points), Developing (2,50 – 4,99 points), Satisfactory (5,0 – 7,499 points) and Exemplary (7,50 – 10,00 points).

In the case of written communication skills in Spanish, authors measured took samples twice the semester. The first sample evaluates the attainment of the SO in the "Analyze" stage and the following measures the student SO in the "Control" phase. This sample scheme reflects the real process, since students prepare a partial written report with their work from Define, Measure and Analyze. The final report comprises all the DMAIC stages.

Hypothesis testing for the difference with correlated samples, evaluates significant differences between the attainment of the SO between the partial and final report.

In the case of verbal communication in English -as a second language-, the first semester of this study will show just one sample at the end of the DMAIC stage. This is due to the fact that students only videotaped and oral presentation in English at the end of the capstone design process then.

The next year, in order to improve the results of the SO, a graded executive presentation in English was required to close each DMAIC stage. This study shows significant random samples of the results of the SO in Define, Analyze and Control.

In this case, an analysis of variance (ANOVA) will support the analysis of significant differences of the achievement of the SO among the stages. Also, a Dunnett simultaneous test with Define phase as a control will check significant evolution on the fulfillment of the SO versus the initial state.

The SOs: ability to function on multidisciplinary teams and awareness of the impact of the engineering profession present samples in Define, Analyze and Control in order to asses their evolution.

VI. RESULTS

This section shows the tabulations of the statistics detail in the previous section for each SO.

A. Written communication skills in Spanish

The test for correlated *samples (T-Test of mean difference = 0 (vs > 0))* shows significant differences in the accomplishment of this SO between Control and Analyze phases in the three-year period of analysis (p = 0,03 in year 1, p = 0,001 in year 2 and p = 0,001 in year 3). The results imply that there are significant improvements in terms of the quality of contents, coherence, writing style in Spanish and the use of graphs between an initial and final stage.

In the partial evaluation at Analyze stage, faculty acting as coaches write down and explain feedback to the students. Fig. 2 shows the evolution of the differences among three years of the written communication skills in Spanish. Although, the graph depicts a reduction on the variation of the differences of the SO versus the first year of the capstone design course, there is not evidence of significant improvement among the years (p = 0,88).

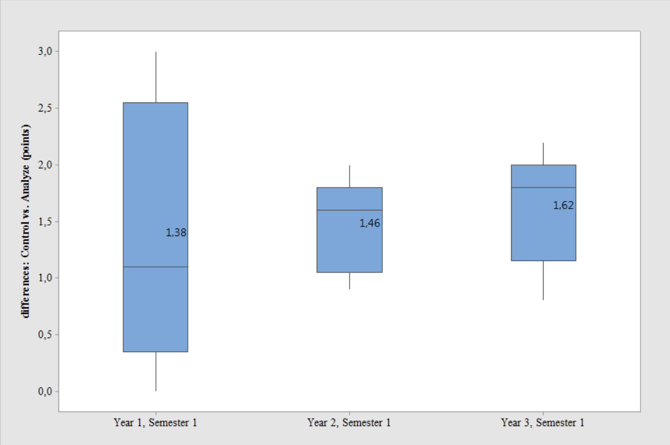

Fig. 2 Evolution of the differences in written communication skills in Spanish: Control vs. Analyze phases

B. *Verbal communication in English -as a second language-*

It is a challenge to emphasize verbal communication skills in English as a second language. The first year the results of the SO reached a “satisfactory” level (7,35/10 points, with significant variation below the second quartile). In that opportunity, students prepared a 7-minute video explaining their capstone design project. Videos showed a lot of room of improvement in terms of: transmission of the message according to the audience, message structure and argumentation. Besides that, it was evident that the students had difficulties structuring a 7-minute presentation of the whole project.

To increase the opportunities for students, faculty decided to have five executive presentations (7-minute) per DMAIC stage. The new system included faculty feedback in terms of the content and the presentations techniques. Fig 3. Displays the results of the statistical analysis. The graph shows significant improvement of the SO from the “one-shot” presentation versus the five executive presentation format (see results on Control phase). In the second year, there is a significant improvement from the Control versus Define stage (p = 0,012). During the the third year, process there are no significant differences among the means of the SO in Define, Analyze and Control.

C. *Ability to function on multidisciplinary teams*

This student outcome is regarded as critical for engineering students [8]. The industrial engineering external advisory committee always highlights the need to achieve the highest results in this SO. The rubric of this SO evaluates if the student:

- Completes assigned tasks according to their role within the work team.
- Assumes the result of collective work as his/hers.
- Communicates assertively and actively with team members and clients.

Fig. 4 portraits the development of this outcome along a three-year period.

Dunnett statistical test evidences significant differences between Control and Define periods of the capstone design project in year 1 and year 2, consider p = 0,047 and p = 0,041; respectively. The test does not support significant differences in the SO while comparing the Analyze and Define phases (p = 0,253 in year 1, p = 0,234 in year 1 and p = 0,315 in year 3).

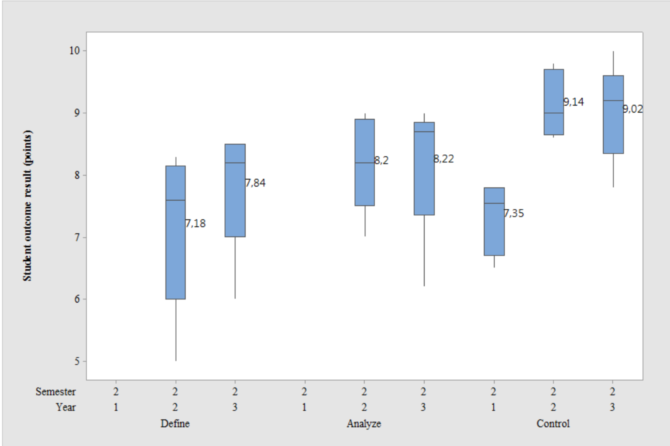

Fig. 3 Evolution of verbal communication in English –as a second language-, through Define, Analyze and Control phases

During executive presentations, faculty critically revises the roles and expected contributions of each member of the team according to the Definition deliverables. Also, during the presentation of the Analyze stage, faculty revises the the participation of team members in cause generation and validation. During the last executive presentation students are expected to explain the participation of the team in the generation of solutions and the proposal of suitable controls (see Table I for details on deliverables).

D. *Awareness of the impact of the engineering profession*

Dunnett test evidences an increase on this SO realization between the Control and the Define phase ($p < 0$). Faculty hypothesize that this SO sums up the experience of the industrial engineering capstone design process.

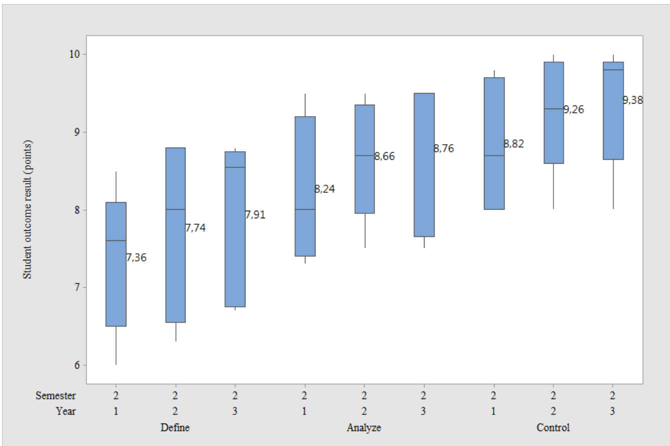

Fig. 4 Evolution of ability to function on multidisciplinary teams, through Define, Analyze and Control phases

VII. CONCLUSIONS

- The improvement procedure of Six Sigma is generally known under the acronym DMAIC, standing for Define, Measure, Analyze, Improve and Control. DMAIC procedure helps a user to find a strategy for analyzing and solving a problem, and thus structure the problem at hand [10].
- The test for correlated *samples (T-Test of mean difference = 0 (vs > 0))* showed significant differences in the accomplishment of written communication skills in Spanish between Control and Analyze phases in the three-year period of analysis (p = 0,03 in year 1, p = 0,001 in year 2 and p = 0,001 in year 3). The results imply the existence of significant improvements in terms of the quality of contents, coherence, writing style in Spanish and the use of graphs between Control and Analysis phases.
- Fig 2. shows significant improvement of verbal communication in English –as a second language- from a "one-shot" 7-minute presentation at the end of the semester, versus a scheme of five executive presentations. With the last system each 7-minute presentation closes its DMAIC stage and students receive feedback from the deliverables and the presentation itself.
- The ability to function on multidisciplinary teams is regarded as critical for engineering students [8].
- Dunnett statistical test evidences significant differences between Control and Define periods, while evaluating the ability to function on multidisciplinary teams in year 1 and year 2, consider p = 0,047 and p = 0,041; respectively.
- Faculty hypothesize that the results of the outcome: Awareness of the impact of the engineering profession sums up the experience of the industrial engineering capstone design process. There is significant difference between the final (Control) and the beginning stage (Define).

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