



Building the Design Competence in Industrial Engineering Junior Students through realistic constraints of the Operations and Logistics Laboratory

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Abstract

This paper provides a laboratory development experience through a product design project with junior students of the Industrial Engineering (IE) program in Universidad del Norte, Barranquilla, Colombia. In the course “Productive Systems Design” (PSD) the students had the opportunity to develop their final project according to the needs of the Operations and Logistics lab, which serves around 6 courses of the IE department. Students were introduced to a challenge: to design a product with its manufacturing process that will be used in the assembly line provided by the lab, and to evaluate its potential impact into the upcoming lab experiences across the curriculum. The experience allowed the students to design a product that could be assembled in a lab which emulates a real environment. The projects complied with realistic constraints of capacity, time, inventory, cost, dimensions, number of work stations, line balance, and environmental, social, and safety constraints. The experience also involved the faculty members that teach different IE labs courses who played the role as clients and evaluators of the projects.

The initial results from the experience with the students are promising. Despite the fact that the students faced a big challenge to accomplish the requirements, the results showed that the students performed better in providing a design solution by using the engineering design method. It was possible to satisfy the needs of the potential clients and to validate the requirements. In addition, involving junior students in the development of their own future lab experiences, improved their engagement with the program, motivation to their future professional development, and enabled the development of ABET professional skills such as “ability to design a system, component, or process...” and “ability to function on multidisciplinary teams”.

Introduction

All engineering students must be prepared to have the ability to design a system, component, or process to meet desired needs within realistic constraints. This is a requirement for all ABET accredited programs within the Engineering Accreditation Commission (EAC¹). The IE department from Universidad del Norte is committed to produce highly skilled competent engineers to the society and considers that the design competence is essential for the students to be employable upon graduation. To develop this competence, the IE program has developed learning strategies in different courses across the curriculum that culminates with the major design experience in Capstone Design. The Productive System Design (PSD) course, is the first course at the junior level that allows students to develop a complex design experience that requires: 1) to design a product and

its production process; 2) to determine the best location for facilities; 3) to design a facility layout; 4) to carry out an analysis of capacity.

The use of a structured Cooperative Learning (CL) strategy suggests a positive environment for the students to help each other to develop the design competence in the Engineering curricula. In the past years, the assessment process in the program has allowed to identify new opportunities to improve the design competence and to close the gap between the freshman and senior design experiences. For the PSD course, the new lab facilities and the commitment of the lab instructors from the upcoming courses allow the junior design experience to be enriched and very beneficial for the IE students.

The focus of this work threefold: firstly to show the impact of the implemented CL strategies in the PSD course and its outcomes; secondly, to analyze the impact of the involvement of potential clients and their needs and the realistic constraints for design projects at the junior level; and thirdly, to show the impact of motivation strategies to engage students in their future laboratory activities.

Motivation

Early design experiences in the curriculum are developed in the Introduction to Industrial Engineering course. At the sophomore level, even though there is another design experience, students do not have all the skills and knowledge to deal with more complex problems. Given the gap between freshman-sophomore and junior design experiences, the PSD course at the junior level (sixth semester) is chosen to be the appropriate environment to enhance the students' performance regarding the design competence. In previous terms, the instructors requested the students to design a product for a specific client (e.g. toys for babies from 6 to 24 months, home gym equipment for adults, safer utensils for housewives, among others), to design the manufacturing process, and to provide a plant layout. Based on those experiences, the instructors perceived a low student motivation and engagement with their assignments, and consequently, the grades and final assessments were not as expected. Final assessment of the course evidenced: 1) the problem and the clients' needs were not aligned to the student expectations and knowledge; 2) it was difficult for the students to design a production process with the appropriate location and facilities and layout for a product they were not familiarized; and 3) it was difficult to assess the performance of each student within the group.

Some discussions about changing the course project began during the 2013. The course instructors started to review potential initiatives that were related to lab practices from the upcoming courses. Lab instructors were involved in the process and CL strategies and learning styles and their benefits were evaluated to enhance the junior design project experience and the ability to work in teams.

Background

Previous work has shown that not just industrial engineering students but all Science, Technology, Engineering and Mathematics (STEM) students are predominantly active, visual, and sensing learner types². However, it is evident that most undergraduate engineering courses are generally taught toward reflective, verbal, and intuitive learner types³. This is in fact the exact opposite of the suggestions made from multiple learning style studies⁴. Engineering teaching is more focused on theory and mathematical proofs over practical, “real world” applications and experimentation favored by sensing learners⁴.

As is suggested by Felder⁵, in order to meet Student Outcome C (SOc) from ABET (SOc: Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability), there are some activities that the students can do from freshmen to senior. A more self-directed and self-determined approach is needed, in which students reflect on what is learned and how to learn, and in which educators teach students how to learn for themselves^{6,7}.

A suitable learning environment facilitates the development of skills in the students and their ability to learn^{8,9}. The role played by the laboratory practices is vital to the training of engineering professionals and the development of their professional skills. The implementation of new laboratory practices and pedagogical approaches in engineering programs is imperative to take advantage of technological resources and create environments that enable the development of autonomy and self-direction of students. Likewise, it is important to innovate in more interesting scientific experiences to keep students motivated¹⁰.

Felder suggests some instructional methods that address the SOc, and one is to use structured CL if designs are to be done by teams⁵.

One goal of the CL is to enhance students' learning and to develop students' social skills like decision making, conflict management, and communication. To achieve these goals, it is necessary to form small groups of students working together in a structured process to solve an academic task¹¹.

According to Chiang et al, interactions through small working groups promote knowledge sharing, discussion, active listening and constructive feedback from students¹². Thus it is possible to achieve self-directed learning helping students to assume responsibility for achieving their own knowledge. In small groups, students are motivated and able to play an active role in the exploration and development of new knowledge cooperating with the general learning abilities of the group¹³.

In order to enhance the learning experience in the junior design experience, the PSD project has integrated distinct elements that experts have identified in the literature. New tools that assess team work are expected to improve CL, and consequently, the ability to design the

product, process and location, and to improve social skills. Likewise, new technological resources from supportive facilities were expected to improve students' motivation to deliver better projects solutions. In the same manner, new product design requirements were presented to students to enhance engagement in the process. The methodological aspects to develop the new learning experience were integrated and they are showed in the following sections.

Curricular Context

The course "Productive Systems Design" (PSD) of the IE program at Universidad del Norte typically has enrollments each semester of about 80 students. It is a 16 weeks course and usually, there are two instructors to meet the demand. In the IE program, the production/operations teaching area is supported by six full time faculty members and four graduate assistants. The course covers the following topics: 1) Operations Management; 2) Services vs. Manufacturing; 3) Product Design and selection of the production process; 4) Facilities: location and design; 5) Assembly Line Balancing; and 6) Production Capacity Analysis.

Supporting Facilities

The IE department has among its facilities the operations and logistics laboratory. This is a teaching-learning facility, foster manufacturing and warehousing operations in a reduced scale. It has an average capacity of 35 students. The laboratory is intended to provide on a smaller scale, the productive and logistics representatives processes real infrastructure. The place simulates a production facility along with a distribution center. The laboratory is equipped with an assembly line for semi-manual processing of final products and shelves with RFID technology that simulates a distribution center.

Implementation

The final course project

During the second week of the academic semester, the instructor asks the students to group in teams of 4 members. The students can choose their team members, and they commit to a minimum of two hours meeting per week to document their work in preparation of the final report.

During the second semester of 2014 the course met 3 hours per week for class. The course enrollment was 76 students and there were 19 groups. The new requirements for 2014 were to design a product to be used by the students at the university; the assembly process has to be done in the facilities of the Operations and Logistics lab and must be economically sustainable.

The following evaluation criteria were provided to the students at the beginning of the semester. These criteria should be considered for product design, manufacturing process, location and distribution plant layout based on the SOc. The rubric designed was based on the relevance and completeness of the following objectives (For more information, see Appendix 1: Rubric SOc)

- Identify user needs and the associated technical requirements.
- Identify (technical, economic and / or environmental) restrictions on product, process and location.
- Generate and select a design solution by analyzing different alternatives (ie. analysis methodology and appropriate selection).
- Designing the detailed solution (i.e. relevance between design and requirements, use of appropriate standards).

The following evaluation criteria were considered to assess the student's ability to work in teams (For more information, see Appendix 2: Rubric SOd: **An ability to function on multidisciplinary teams.**)

- Distribution of the roles in the team (Clarity, fair and consistent distribution of roles).
- Interaction inside the team (Listen other members opinions, comments based on facts and proper justification).
- Contribute to the team functioning (effectiveness of the working method, detailed description of tasks).

During the semester, there were three sessions, of one hour each one, with some of the stakeholders of the project: the IE chairman, the graduate assistants in charge of the laboratory experiences, and the lab coordinator. The instructor and graduate students met with the groups once every two weeks for a minimum of one hour to follow up the advancement of their projects.

The IE chairman provided a motivation speech about the impact of the project: it is possible to create a new product that will be used by the students of the IE program. The winning project will have the opportunity to be granted by the IE Department in order to have the product parts available for the lab experiences of the second term of 2015.

The graduate assistants provided a detailed explanation of all the different lab experiences covered in IE professional courses: Work Study, Quality Management and Control, Industrial Safety and Environmental Management, Logistics and Simulation. It is important to notice that students taking PSD course have only taken the prerequisite (Work study course), so they have not done all laboratory experiences.

The lab coordinator provided a detailed explanation of the laboratory configuration: there are seven working stations, geometry of the tables, and one worker per station. It is suggested that last station is kept to quality verifications

The students had a voluntary midterm presentation to follow up the advances of the project. At this point, the students had to show the initial product ideas, how the product would solve the students' needs, and to describe the process from the first idea to the last stage of the progress done.

The final presentation was a formal presentation where the stakeholders of the project played an investor's role. Students must handle a visual support presentation (power point, Prezi, etc), a written report, and the physical prototype.

Based on the Engineering Design Method, the final report must have:

- A detailed description of all stages of the product design. It should include all assumptions the design is based on.
- A documented evolution of the product design. If several alternatives were considered, the process had to be described. The process by the final product was selected or modified.
- A description of the quality standards that were considered for the product, plant layout and manufacturing process.
- A physical prototype like mock-ups (clay, wood or other), fabrication, or rapid prototyping. The type of prototype chosen should fit the specific needs of the product especially since there was a significant cost involved.
- A virtual demonstration of the product and its functionality (video or design drawings).
- A detailed description of the manufacturing process of the product.
- A description of the product assembly process.
- A technical analysis of materials (raw material and possible suppliers); equipment (machines and infrastructure); human resources (direct labor and production overheads).
- Market analysis (i.e. description of the market, competitors, competitors pricing, selling price of the product).
- An analysis of the budget and break even for the first year of operation (there should be an estimation of the product price according to the market).
- A plant layout and the distribution graph, with all the elements considered (i.e. offices and warehouses). There should be a list of assumptions the design is based on.
- The amount of the initial investment.

It was crucial for IE students to learn how to not only apply the design methodology but also to take this one step further to be able to solve a specific problem according to client's needs.

Project evaluation

The final grade was calculated based on the following criteria. There were four evaluators assessing the final presentation and the course instructor evaluates the written report. The criteria was focused on: 1) how do the group identify the client's needs; 2) if there were used any methodology like surveys or QFD¹; 3) the product attributes and how innovative is; the identification of the restrictions and how they were surpassed; 4) the ability to identify cost consideration and the estimation of the investment required; and 5) the plan layout and the location of the plant. The weight of each criteria is showed in the Table 1: Evaluation criteria.

Table 1: Evaluation criteria

Element	Questions	Weight
Product Design	How does the group identify the client's needs and the used methodology? Is the product attributes relevant for the problem? How innovative is the product? How does the group identify the restrictions and How they were surpassed? How the product has changed during the semester?	30%
Service of the product	How does the product could be used in the Operations and Logistics lab?	10%
Cost	How does the group addressed the cost considerations? Which were the considerations of the estimation of the investment required?	20%
Location	How does the group identify the location needs? How does the group identify the location restrictions and how they were surpassed? Does the group use different methodologies to find the best location?	20%
Plant Layout	How does the group identify the plant layout needs? How does the group identify the plant layout restrictions and how they were surpassed? How the plant layout has changed during the semester?	20%

Complementary, this activity provides an opportunity to assess the ability to function in a multidisciplinary team (Student Outcome d (SOd) for ABET). As most of the time the students are working out of the classroom, it is not easy for the instructor to judge this

¹ Quality function deployment

outcome. In order to solve this situation, after the final presentation each student had the opportunity to evaluate his teammates using a rubric. Besides, to evaluate the role played by each student within the group, each one was given a symbolic amount of \$75 in order to be distributed among peers based upon the individual performance. Then, for each student was added the total compensation received. This method provided an idea of the real contribution that each student had contributed in his group.

Results

The results showed that the impact of the activity is highly positive. 13 groups out of 19 meet with the instructor at the midterm point. The average grade of the groups with the check point session at the final project was 4,33 out of 5.0. For those groups which did not participate in this activity the average grade was 3,04 out of 5.0.

The final project grades had an average of 4,01 out of 5.0 (SD=0.57). See Table 2 for more detailed information. Comparing with reports from previous semesters, the results were better in terms of quality. This reflected a greater commitment with the activity.

Table 2: Evaluation results

Element	Average	SD
Product Design	1,2 out of 1,5	0,22
Service of the product	0,4 out of 0,5	0,16
Cost	0,77 out of 1.0	0,12
Location	0,86 out of 1.0	0,11
Plant Layout	0,78 out of 1.0	0,15

These are some of the products the groups showed. Illustration 1: Hanging Gardens was a decorative product for interior decoration. Illustration 2: Ecological seat was a household item that can be used for different purpose such as an organizer of magazines, champagne bottles, or side table, among others. It is made entirely of cardboard double flute.

Illustration 3: Stuffholder was a product to be used in the work or study place which functionality is to store glasses, beverage bottles, pens, memos, snacks, clips, among other things.

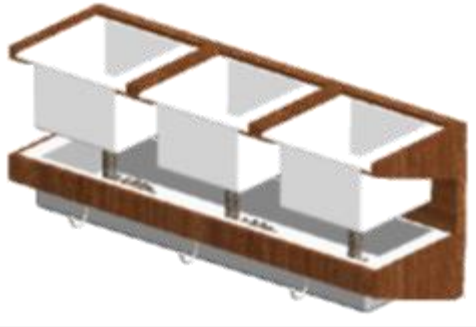


Illustration 1: Hanging Gardens



Illustration 2: Ecological seat



Illustration 3: Stuffholder

The ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability was measured using a rubric. Figure 1 shows that more than 80% of the students receives a satisfactory evaluation in the following criteria: 1) Identify user needs and restrictions on product, process and location and 2) Generate and select a design solution by analyzing different alternatives. Besides more than 70% of the students receives a satisfactory evaluation in the following criteria: 3) Design the detailed design solution.

The ability to function in a multidisciplinary team was measured using a rubric and a compensation model. Figure 2 shows that more than the 80% of the students received a satisfactory evaluation in the following criteria: 1) Distribution of the roles in the team; 2) Interaction inside the team; and 3) Contribution to the team functioning. Figure 3 shows that 91% of the students received between \$ 55.5 and \$ 69.5 as a symbolic reward for the work done in the project. The maximum reward received by one student was \$75 and the minimum was \$28.

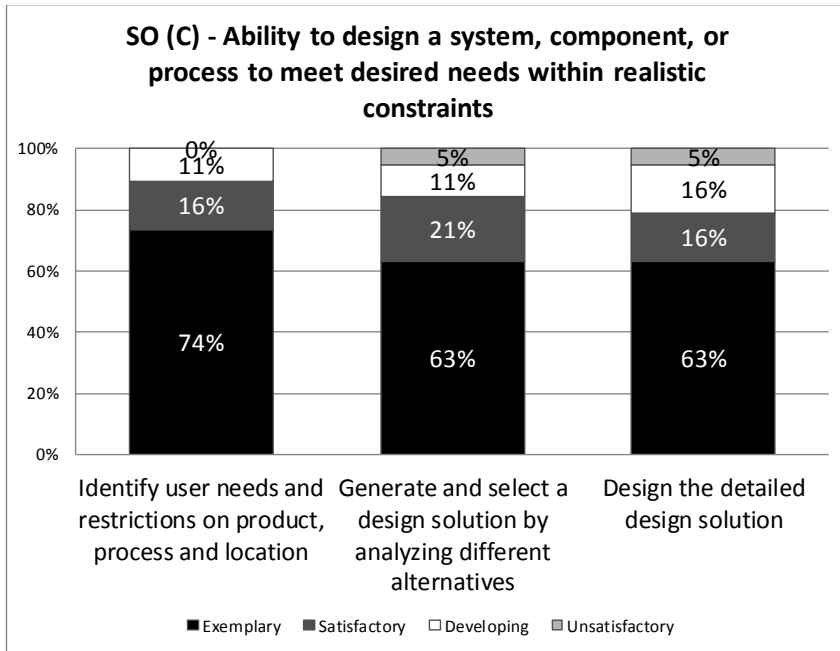


Figure 1: Stacked bar chart for the assessment of the ability to design a system, component or process to meet desired needs within realistic constraints.

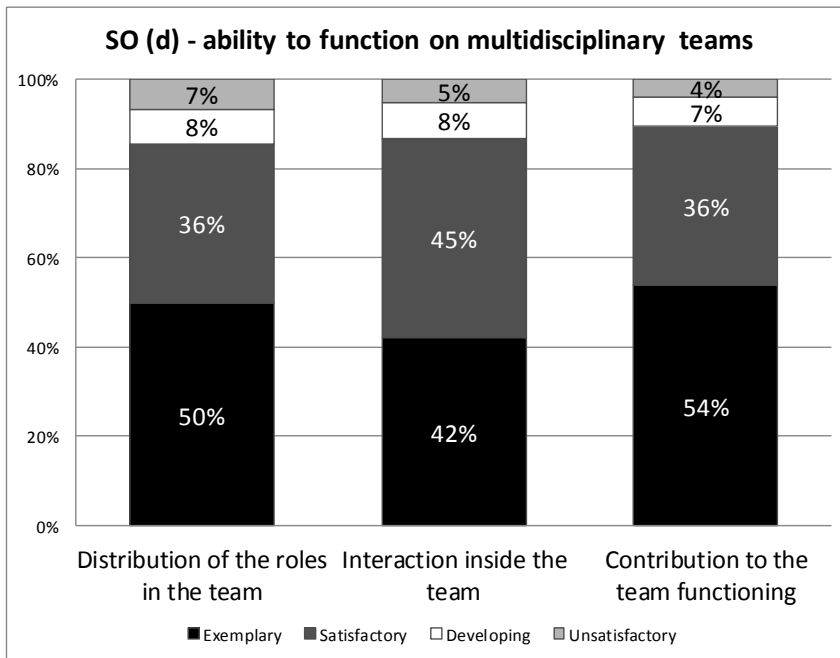


Figure 2: Stacked bar chart for the assessment of the ability to function on multidisciplinary teams

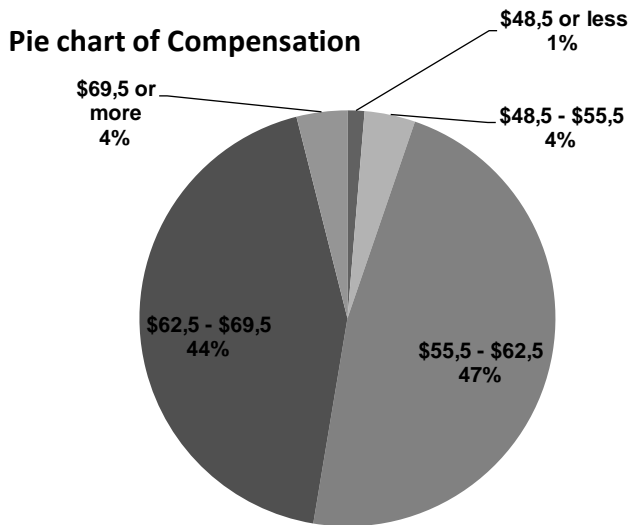


Figure 3: Pie chart of the students performance reward.

Discussion and Conclusion

This work has provided valuable insight into building engineering competence in IE students, specially the design and work in teams. Even when lectures were active learning dialogues between the instructor and the students in the classroom, it is important to provide a realistic environment so the students could be identified.

In the evaluation of the results various objectives of the activity were reviewed, obtaining in all cases a positive balance by the students and their satisfaction because of their participation and accomplishment. It is visible in the different stages of the experience the inclusion and apprehension of theoretical knowledge taught in the lecture. Thanks to the simulation of a real learning environment, students were able to recognize the role that design competence plays in their professional work, taking advantage of the situational motivation generated in active learning activities.

According to the performing results of the final project grades, for the next semesters, the midterm check point will be mandatory for all the teams. The recommendations provided by the instructor in the early stages of the design process increase the performance outcomes.

For future semesters, it would be complementary to have information about the motivation the students have with the activity, not only by the perception of the instructor, but of the results of a survey.

The qualities of the results are better when CL strategies are implemented. Besides, students perform better when they are involved in a real world environment and when they recognize the contribution to future laboratory activities.

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Appendix 1: Rubric SOc: Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.

Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
1. Identify user needs and restrictions on product, process and location.	Does not identify the minimum needs or relevant product, process and location constraints.	Identify the minimum needs or relevant product, process and location constraints.	Identify the needs or relevant product, process and location constraints. Or both are identified and at least one does not have appropriate value.	Identify the needs and relevant product, process and location constraints. All these elements have appropriate values.
2. Generate and select a design solution by analyzing different alternatives	Does not show any alternative solution. Or the showed one not suitable for the problem. Or there is a lack of a methodology to analyze different alternative solutions.	Shows an alternative solution. Or the showed ones are not suitable for the problem. Or the solution chosen is unsuitable with major mistakes in the methodology to analyze different alternative solutions.	Shows different alternative solutions suitable for the problem. Or there are minor mistakes in the methodology to analyze different alternative solutions.	Shows different alternative solutions suitable for the problem, and selects the better one. There is evidence of an appropriate and relevant methodology to analyze different alternative solutions.
3. Design the detailed design solution.	Most elements of the design are not relevant to the client's needs. No standards are used or the used are not appropriate.	Some elements of the design are not relevant to the client's needs. Some appropriate standards are used.	Most elements of the design are relevant to the client's needs. Most appropriate standards are used.	All elements of the design are relevant to the client's needs. All appropriate standards are used.

Appendix 2: Rubric SOD: An ability to function on multidisciplinary teams.

Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
1. Distribution of the roles in the team	Rarely the roles assigned are met in order to the good performance of the team	Sometimes the roles assigned are met in order to the good performance of the team	Mostly the roles assigned are met in order to the good performance of the team	Always the roles assigned are met in order to the good performance of the team
2. Contribution to the team functioning	There is not participation within the team.	Sometimes there is active participation within the team.	Usually there is effective active participation within the team.	Always there is effective active participation within the team.
3. Interaction inside the team	Is always talking and does not listen to his teammates or does not allow others to talk.	Sometimes does listen to his teammates or allow others to talk.	Mostly does listen to his teammates or allow others to talk.	Always does listen to his teammates and allow others to talk.