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Assessing the Impact of an Engineering Design Workshop on Colombian Engineering Undergraduate Students*

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Engineers iteratively apply their disciplinary knowledge to develop solutions to ill-defined problems considering varying and often competing criteria and constraints. Design is a process engineers use to solve ill-defined problems necessary to fulfill human needs. While worldwide institutions are increasingly introducing engineering design in undergraduate engineering education, the extent of integration of design into the curriculum ocurr at varying degrees. In this study we focus on a higher education institution in Colombia through a single case design. We specifically evaluated the effect of a workshop designed to introduce engineering design to engineering students in a context where there have been limited initiatives and resources to introduce engineering design. Two groups of students from different engineering programs in a public university in the Colombian Caribbean region participated in an eight-hour workshop. The workshop involved a design challenge of creating a net-zero energy house using a CAD tool. The two groups were comprised of 20 systems engineering students and 25 industrial engineering students. Pre- and post- instruments were collected and analyzed to assess the effect of the workshop on students' understanding about engineering, disciplinary knowledge, and effective practices of engineering design. The results suggest that the design workshops employing CAD simulations can support engineering education in three ways by: (1) broadening student knowledge about the engineering practice; (2) fostering the acquisition disciplinary content knowledge; and (3) increasing student proficiency regarding engineering design.

Keywords: engineering design; Colombia; CAD; Energy3D

1. Introduction

Worldwide nations acknowledge the critical role of scientists and engineers with the knowledge and skills to solve complex problems in a global society [1–3]. Despite the international call for engineers, many lack awareness of what engineering entails and have difficulty describing what engineers do. Students' attitudes towards engineering have been linked to retention of these students at critical points in their career [4]. It is not uncommon for engineering students to start their undergraduate engineering studies with limited knowledge about the field they are entering [5], and few students enter engineering from another major [6] in large part due to a lack of knowledge of engineering.

In Colombia, similar to other western countries [2, 3, 7], there is a lack of engineering professionals to supply the needs of the market [8]. Different factors may contribute to this shortage. For instance, many high school students do not know what an engineer does or how one can be useful [9]. Furthermore, although the enrollment numbers in Colombian engineering programs during the last ten years have been increasing (from 209,853 students enrolled in 2004 to 374,678 in 2014) [10], one of the largest drop-out rates in college level education in Colombia is found in these programs: ~56% [10, 11]. These high drop-out rates can be linked to personal, academic, socio-economic, and institutional reasons. Students do not feel motivated to continue their engineering studies, in part because they do not see the value of doing engineering work, or because the pedagogical strategies are poor.

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This study explores these two potential factors through the implementation an eight-hour engineering design workshop for engineering students in a public university in Colombia. Hence, the study examines student understanding of engineering profession, and the effect of introducing innovative engaging pedagogical practices such as learning by design [12]. The workshop comprised an energy efficiency design challenge using a CAD tool called Energy3D. The activities were divided into four sessions of two hours each. The research questions for this study are:

RQ1. What is the effect of an engineering design workshop on student understanding about the engineering practice?
RQ2. What is the effect of an engineering design workshop on student disciplinary knowledge about energy efficiency in a global context?
RQ3. What is the effect of an engineering design workshop on student understanding about the engineering design process and good practices of an informed designer?

2. Literature review

2.1 Engineering design

In the United States, design has been explicitly recognized as a crucial component of an engineering education through ABET accreditation criteria [13]. ABET states in Criterion 5 that "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs" [13, p. 4]. Thus, design is an essential component of an engineering education.

Engineering design is also an important element for engineering practice. Engineers solve complex problems that are usually unstructured and have multiple possible solutions. Informed designers iteratively refine their solutions by gathering information, identifying quality criteria and constraints, generating and testing ideas, making informed decisions, reflecting, and communicating [14]. Design is not only an activity, but is also a way of thinking [15] and represents "a mix of rational, analytics thinking and creativity" [15, p. 28].

Engineering design has also been highlighted as a useful pedagogical tool to teach engineering and science concepts. Engineering has been included in undergraduate curriculum traditionally as senior level course (i.e. capstone design) but is becoming more common throughout earlier years (i.e. cornerstone design) [16]. The National Academy of engineering recommends that "the essence of engineering—the iterative process of designing, predicting, performance, building, and testing—should be taught from the earliest stages of the curriculum, including the first year" [17, p. 53]. Authentic practices such as engineering design not only scaffold student learning about a disciplinary topic, but also develop skills such as teamwork, communication, ethics, and time management, among other professional skills [18]. Because of the importance of design in an engineering education, research has investigated the learning trajectory of design by studying experts [15, 19], and expert-novice differences at the university level [19, 20]. Such studies impact design education.

2.2 Engineering in Colombia

Engineering education in Colombia is guided by the "Asociación Colombiana de Facultades de Ingeniería—(ACOFI)." ACOFI was first created in 1975 and comprises 85% of the higher education institutions offering engineering programs in Colombia. ACOFI's strategic plan 2015–2025 includes the encouragement and improvement of the quality in teaching, research, innovation, technologic development, and social responsibility activities, developed by engineering schools and academic programs, towards an international visibility [21]. One of the strategic axes of this plan focuses on the quality of engineering schools, and involves the following actions: (1) encouraging continuous improvement in teaching and learning processes; (2) systematically improving the skills of engineering students with feedback to the curriculum; (3) supporting the instruction and the engineering practice with integrity criteria; and (4) promoting systemic and reflective thinking in engineering, focusing on technical, environmental and social criteria.

Some of these actions are aimed to address student drop-out. The drop-out rate in Colombian engineering programs is very high (~56%) [10–11]. Serna and Serna [9] asked second year college students from different institutions about their experience studying engineering at their university. Only 54% of the students were happy with their studies. The reasons they mentioned include but are not limited to: low quality teachers, lack of motivation, and poor pedagogical strategies. Similar results were found with fourth-year engineering students. Only 44% of the students were happy with their program. Moreover, when recently graduated engineers where asked whether they would recommend someone else to study engineering, 47% said no. From this group, only 53% mentioned being happy with their careers, and the rest of them cited the following concerns: (1) the industry does not have a clear engineering profile (15.6%); (2)

poor formation processes in colleges (14.8%); (3) low salaries (13.3%); (4) reality and college education are not aligned (12.6%); and others. Colombia students cite the following reasons in leaving a STEM program [7]: (1) lack of motivation on introductory courses; and (2) lack of support by the institutions with the required math.

Moreover, many high school students and college students do not know what engineering is, or how it can be useful. For instance, Serna and Serna [9] analyzed the context of engineering enrollment in Colombia using surveys for high-school students. They interviewed 1,542 high-school students and found that only 6.7% were interested on pursuing an engineering career. When they asked students from non-engineering majors why they did not choose engineering, a large portion of students (~50%) answered that there is no future in engineering or it is not clear what the engineering programs are about or what an engineer does, alluding to vague conceptions of engineering.

In 2006, ACOFI created the journal "Educación en Ingeniería" aiming at disseminating professional academic experiences in engineering education by Colombian and other Latin American universities. A review of the published papers during the last five journal issues shows the interest of Latin American researchers to explore student learning styles and preferred pedagogical strategies in engineering [22]. For instance, Ventura, Palou, Széliga, and Angelone [23] studied incoming engineering students in Argentina, and found that these students prefer learning experiences that involve active, sensory, visual, and sequential activities. Another study by Argüello [24] assesses the effect of introducing a CAD tool for a geometry course in engineering programs in a Colombian university. The authors suggest that the use of this CAD tool not only supported the student learning process and changed their perceptions about the course, but also the drop-out rate in the school of engineering decreased 14% during the first school year after this implementation.

Nevertheless, these five recent journal issues did not present any evidence of the use of the term "engineering design" or "learning by design" by Colombian or Latin American universities. Even though some studies may still be using certain forms of engineering design, it is startling that they are not explicitly talking about engineering design as learning outcome nor as a pedagogical strategy.

This study focuses on introducing the engineering design process into the Colombian engineering curriculum in the context of solar energy efficiency. Using learning by design [12] as a conceptual framework, we expect that students take advantage of a different pedagogical strategy (innovative in the Colombian context) to learn about the engineering design process, effective engineering practices, and solar science. Students will solve a design challenge while reflecting on their own processes. The challenge will be solved using an interactive educational CAD tool called Energy3D.

3. Theoretical & instructional frameworks

Design is a reflective process [25]. Reflection is especially critical when solving ill-defined problems that require learning and transfer to solve a given challenge. Encouraging student reflection is "one method for transforming students and helping them to become more open to taking challenges and integrating them into new applications" [26, p. 1]. Additionally, asking students to reflect in and on their experiences better prepares students to become effective engineers [27]. However, the pedagogical strategies that are customary in engineering education have led to students' lack of understanding the value of engineering. In this paper, we utilize Schön's [25] reflective practitioner theory to discuss students' understanding about the engineering practice, the engineering design process, and disciplinary knowledge regarding energy efficiency in the context of engineering students in Colombia.

Learning by design™ [12] is an engaging pedagogical strategy that integrates case-based reasoning and problem-based learning to introduce science concepts. Learning by design™ focuses on providing students with design challenges that makes them follow an iterative problem solving process, while reflecting and collaborating with instructors and peers to better understand the science concepts behind the challenge. Learning by design™ takes advantage of situating the learning process in authentic contexts, changing the role of the instructor to a facilitator, and promoting active learning. For the context of the workshop, we centered learning by design to an engineering design challenge using an educational CAD tool. Specific interactions among students and with the instructor, besides the reflection scenarios during the workshop are described below.

4. Methods

This paper presents a case study to evaluate the effect of an engineering design workshop on student understanding about: (1) engineering practice; (2) engineering design process; and (3) solar energy efficiency. A case study is a good approach for this context because it can "address research questions concerned with the specific application of initiatives or innovations to improve or enhance learning and teaching" [28, p. 191]. Fig. 1 summarizes the con-

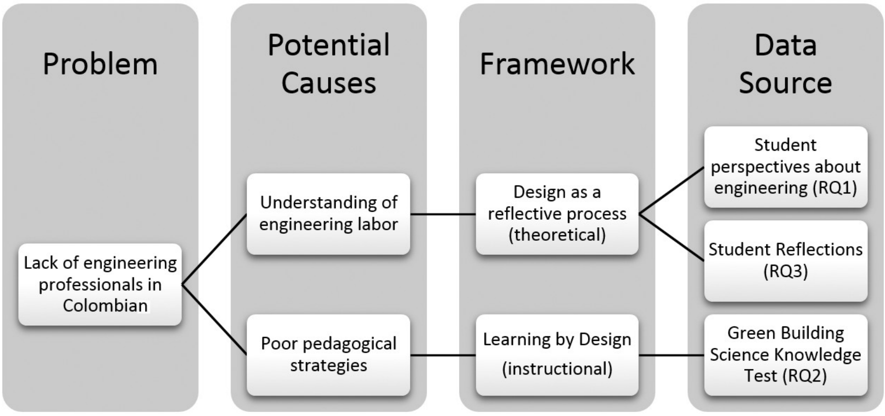

Fig. 1. Summary of the research rationale.

nections among the problem, some of the causes that may affect this problem, the theoretical and conceptual frameworks, the data sources, and the research questions.

4.1 Participants

Forty-six engineering students in a Colombian public university in the Caribbean region participated in this study. Twenty-one students (44.44%) were enrolled in a systems engineering program, while the remaining 25 students (55.56%) were enrolled in industrial engineering. The gender distribution was 32 males and 14 females, but the systems engineering group only had two of these female students.

The engineering program at this public university is a five-year program. Student academic level was distributed throughout the program with the majority of the students in 3rd or 4th year. The current academic level is described in Table 1.

As part of the pretest, the participants answered a question aiming at characterizing the sample based on the kind of job they would like to have as an engineer? From those who have some idea about their future careers, 13 students would like to work as software developers, nine students would like to be managers, nine students would like to create their own company, five students would like to either be software or product designers, three students would like to work in IT infrastructure, and two students would like to work as researchers.

Table 1. Number of students per academic year

Year	Number of Students
1st	1
2nd	6
3rd	15
4th	19
5th	5

4.2 The workshop

The workshop was composed of four two-hour sessions conducted with two groups of engineering students. The workshop included an engineering design challenge in the context of solar energy efficiency aiming at increasing student understanding about engineering practice, engineering design process, and solar energy efficiency strategies.

Energy3D was the tool used by the students to approach the design challenge. Energy3D is a free, open-source educational CAD tool that allows students to create 3D buildings. The students can install solar panels on their buildings to generate energy. These solar panels have different energy efficiency factors and different costs depending on the preferences of the designer. Other features of the software allow students to modify materials, orientation, and colors of the house, create different kinds of trees, and use different types of roofs. Energy3D also includes data collection simulators such as cost analysis, energy consumption, Heliodon, shadows, and orientation analysis, to inform designer decisions [29]. Fig. 2 depicts the user interface of Energy3D with the Heliodon and the shadows turned on.

The design challenge required students to create three designs for a net-zero energy house before making an informed decision using to select one of their designs as "best." The full design challenge description is presented in Appendix A.

During the first session, students had 30 minutes to become familiar with Energy3D. After this time, the design challenge was introduced to the group, and students started their designs. The second session started with existing real-world examples of net-zero energy houses. The instructor provided a set of real-world examples and asked students to reflect on energy efficiency strategies from the examples to incorporate on their designs. At the middle of the second session, several sketches of

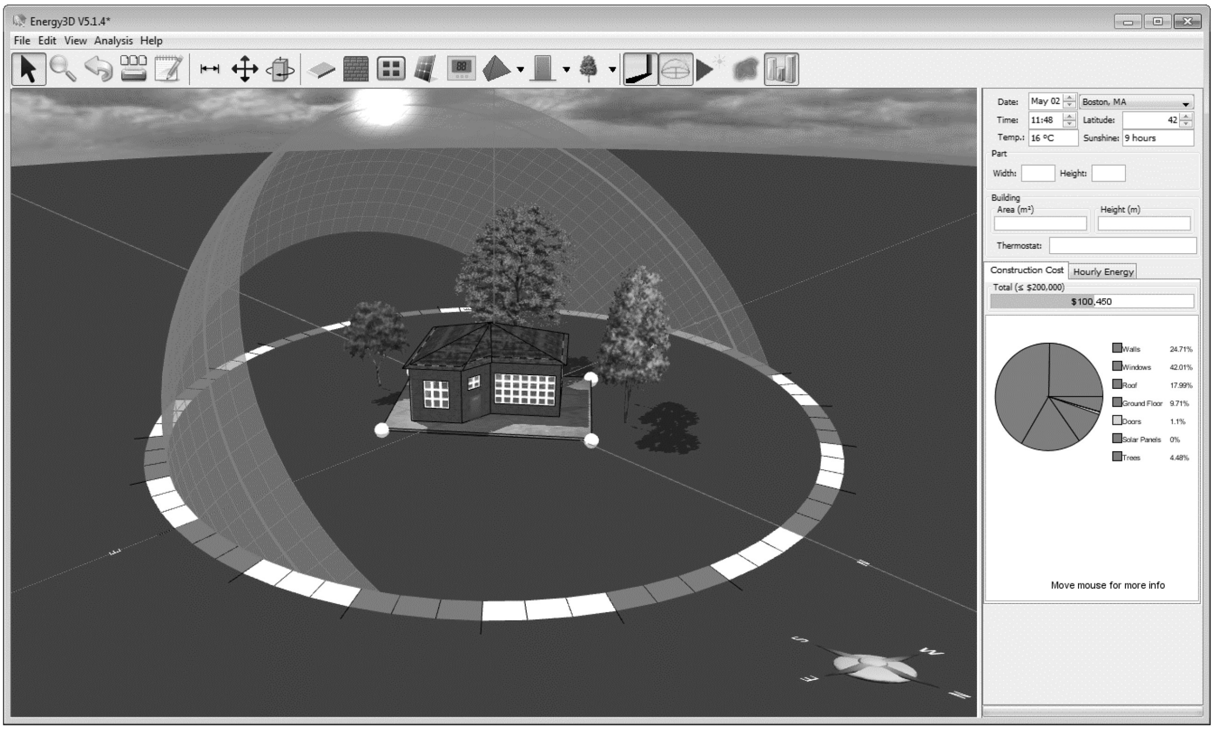

Fig. 2. Design of a house using Energy3D with the Heliodon and the shadows turned on.

possible design processes were presented to the participants, and they discussed similarities and differences among the sketches. Again, the participants were asked to reflect on their design process, sketch it, and share it with another student.

During the third session, the instructor initiated an open discussion with the group about students' strategies to reduce energy consumption or to maximize solar energy production. During the discussion, students were to explain the strategy that helped them to improve their designs. The last 30 minutes of this session, the participants worked on PowerPoint slides to present their three designs and the final solution they proposed. During the fourth session of the workshop, students gave a five-minute presentation detailing their designs with a reflection on their design process.

As described earlier, this workshop was implemented using learning by design [12] as pedagogical strategy. Students are presented with a global-context design challenge that they need to solve iteratively, supported by an instructor who acts as facilitator. Students continuously test their designs using Energy3D analysis tools. Furthermore, several instances of reflection and collaboration are promoted into the classroom activities, in which the instructor identifies and discusses student misconceptions, and encourages them to investigate the challenge to support their design process.

4.3 Data collection

Students completed pre- and post-survey instruments as part of the design workshop experience.

Student strategies for solar energy efficiency were prompted using questions from a test assessing science learning, the Green Building Science Knowledge Test, which are presented in Appendix B. This instrument is intended to assess disciplinary content knowledge on energy efficiency responding to the research question: *what is the effect of an engineering design workshop on student disciplinary knowledge about energy efficiency in a global context?*

Finally, in order to answer the third research question (i.e., *what is the effect of an engineering design workshop on student understanding about the engineering design process and good practices of an informed designer?)* we reviewed students' reflections on the workshop. Students were required to have a presentation of their final design. Students were provided with a template of seven PowerPoint slides that they should complete and present to the rest of the group. These seven slides were (1) title of the presentation including a name for the house; (2) an agenda or outline for the presentation; (3) a sketch of the design process they followed; (4) pictures and data of the three designs they created; (5) the decision matrix they employed to choose one of the designs; (6) the final design; and (7) a reflection on what they learned during the workshop.

Also, the post-survey included three questions related to this reflection process: (1) To what extent did this workshop empower you as an engineer?; (2) Please describe what are the most relevant aspects of this workshop; and (3) please describe ways in which this workshop could be improved. We consider students' reflections as a data source to explore their understanding about the engineering practice, the engineering design process, and disciplinary knowledge regarding energy efficiency after being exposed to this workshop.

4.4 Data analysis

The multiple choice questions from the Green Building Science Knowledge Test were analyzed by counting the number of students who answered the question correctly, both on the pretest and on the posttest. Similarly, the Likert scale questions were compared between pretest and posttest. For the Likert-scale data we employed paired t-tests in order to assess the effect of the workshop on student responses. An impact score between 1 and 3 was considered a 'low-impact', a score between 3 and 5 was considered an 'average-score', and a score larger than 5 was considered 'high-impact'.

The qualitative data (i.e., open-ended questions and student reflections) were analyzed using open-coding and axial-coding. Frequencies were counted for the categories in the pretest and in the posttest. The identified categories on the pretest responses were compared to those identified on the posttest responses to assess the effect of the activity on student responses. Two researchers separately analyzed 20% of the data and compared their categories. Whenever there was a disagreement, the researchers met to negotiate the categories. Once an agreement was reached, one of the researchers completed the data analysis with the categories that had been negotiated.

5. Results and discussion

5.1 RQ1. What is the effect of an engineering design workshop on student understanding about the engineering practice?

Three themes emerged from the 17 categories identified between pretest and posttest open-ended question "What does an engineer do?" Table 2 describes all the categories with sample quotes and the percentage of student responses for each category. Students mentioned *design strategies* such as planning or decision making both on the pretest (40.85%) and on the posttest (37.77%).

Similarly, *general tasks* such as optimization or problem solving were evenly mentioned on the pretest (56.34%) and on the posttest (50%). Interestingly, most of the categories within the theme *considerations of design* were not present on the pretest (only 2.82% of the responses) but emerged on the posttest (12.21%). Two additional categories that were not present on the pretest but were on the posttest are to generate ideas (2.22%), and to evaluate solutions (1.11%). Using creativity was present more often on the posttest (5.56%) while building was present more often on the pretest (2.82%).

On the pretest, students identified the engineering labor as an applied field that focuses on designing and building tools and objects by the means of applying science knowledge. They also saw themselves as problem solvers and optimizers. However, they did not seem to have a clear idea of the process and considerations an engineer should take into account. This result suggests that students were able to identify important aspects of engineering design process such as: (1) engineering designs are context-dependent; (2) there are multiple solutions to a problem; (3) the decisions should be made based on evidence, and (4) quality criteria and constraints are important considerations.

Nevertheless, after being exposed to the workshop, students started to highlight these considerations of design. The exploration of multiple solutions, considering the context, the quality criteria, and the constraints, as well as making evidence-based decisions were present on the posttest. Overall, this result suggests that students already came with the conceptual knowledge (i.e., knowing what) about the engineering labor but the workshop helped them to better understand the procedural and strategic knowledge (i.e., knowing how, and knowing when, where and how) [27].

5.2 RQ2. What is the effect of an engineering design workshop on student disciplinary knowledge about energy efficiency in a global context?

Student understanding about energy efficiency significantly increased from pretest to posttest. The distribution of student selection to the available choices for each question is presented in Table 3. The Green Building Science Knowledge Test comprises five multiple-choice questions with five options each (A, B, C, D, E). The correct responses for each question are bolded. Note that both options B, and C can be valid choices for question 4. Santa Marta is not exactly in the equator and therefore, the sun does not pass exactly on top of a house. As long as the student justifies her/his selection, both options are valid.

The percentage of students who chose the correct option increased as follow: 73.7% for question 1; 66% for question 2; 26.9% for question 3; 28.7% for question 4, and 23% for question five.

Note that at least 19% of the students had selected option E (i.e. "I am not sure") for every question on

Table 2. Categories for the question: What does an engineer do?

Theme	Category	Sample Quote*	Pretest (%)	Posttest (%)
Design Strategies	Applying Knowledge	*. . . give solutions to daily-life problems using tools based on sciences, such as math, physics, and chemistry*	15.49	11.11
	Innovate	*The engineering practice is basically the creation and innovation of tools.*	9.86	3.33
	Design	*An engineer's main responsibility is the design of things*	7.04	7.78
	Decision-Making	*The main factor for an engineer is to make decisions, but before that, the engineer must evaluate all the possibilities to address the final goal*	4.23	3.33
	Use creativity	*An engineer uses her/his inventiveness, knowledge, and creativity for applications in the daily-life*	2.82	5.56
	Planning	*An engineer is in charge of planning, executing, and decision-making for a specific problem*	1.41	3.33
	Generate ideas	*The engineering practice consists of generating ideas to solve a given problem.*	0.00	2.22
	Evaluate	*Evaluate, manage, improve, innovate, and create tools. . ..*	0.00	1.11
Design Considerations	Multiple solutions	*. . .providing different solutions for a given problem*	2.82	3.33
	Context Dependent	*Creating solutions for problems within a specific context based on evidences*	0.00	3.33
	Constraints	*Trying to provide solutions for a community considering a specific set of constraints*	0.00	3.33
	Evidence-based	*Creating solutions for problems within a specific context based on evidence*	0.00	1.11
	Quality Criteria	*Innovating, designing, and making decisions, using quality criteria and constraints given by the problem.*	0.00	1.11
General Tasks	Problem Solving	*Giving solution to the problems in an efficient and precise way . . .*	35.21	30.00
	Optimization	*Optimizing existent processes / optimizing resources . . .*	12.68	12.22
	Innovation	*An engineering is a professional in charge of innovation . . .*	7.04	6.67
	Analysis	*The engineer is the person in charge of understanding, analyzing and solving . . .*	1.41	1.11

* Translated from Spanish by authors.

the pretest; reaching 55.3% in the fifth one (i.e. roof type for a house in Chicago). Most of the questions on the posttest had zero to six percent of the students selecting that option. Only for the fifth question 36.4% of the students still chose option E on the posttest, which is almost 20% less than the pretest. Student explanations for these responses on the posttest suggested that they were unfamiliar with Chicago's location or weather.

We used learning by design [12] as the conceptual framework for this workshop. The purpose of this approach was to provide students with an active learning pedagogical strategy that would engage students as well as allow them to better understand science concepts. This pedagogical strategy was innovative compared to the traditional lectures students are exposed to in Colombian engineering classrooms. This approach is also aligned to the active learning strategies that have been suggested to be preferred and more effective in Latin-American universities [e.g., 23, 24].

The results from the Green Building Science Knowledge Test suggest that students learned about solar science after working on the design challenge to build a net-zero energy house. While a significant portion of the students (19%–55%) answered at least one the questions on the pretest the option *"I am not sure"*, the number of students choosing this option was less on the posttest (19% for all the questions). Questions one to four were correctly answered on the posttest for a significantly higher number of students compared to the pretest. Only question five remained with a small percentage of correct responses. We believe that students' lack

Table 3. Distribution of student responses for the multiple choice questions regarding energy efficiency strategies

Question #	Pretest (% of students selecting an option)					Posttest (% of students selecting an option)				
	Options					Options				
	A	B	C	D	E	A	B	C	D	E
1	48.9	12.8	8.5	**2.1**	27.7	9.1	3.0	6.1	**75.8**	6.1
2	17.0	8.5	**12.8**	17.0	44.7	6.1	3.0	**78.8**	9.1	3.0
3	29.8	2.1	**48.9**	0.0	19.1	6.1	15.2	**75.8**	0	0
4	15.9	**27.7**	**31.9**	0	25.5	9.1	**24.2**	**60.6**	3.0	3.0
5	**4.3**	21.3	17.0	2.1	55.3	**27.3**	24.2	12.1	0	36.4

of knowledge about the location of Chicago may have influenced this result.

5.3 RQ3. What is the effect of an engineering design workshop on student understanding about the engineering design process and good practices of an informed designer?

5.3.1 Student reflections

At the end of the final presentations, students were asked to reflect on what they learned from the workshop. Thirty-one students wrote their reflections as part of the final slides of their presentation. These reflections were qualitatively analyzed and we present the results from this content analysis. Fourteen students (45.16%) highlighted how important it is to follow a design process to solve complex problems. For example, one student said: *''it is essential in a design process to have a step-by-step guide that allows me to plan, create, analyze, optimize, and validate the design, so that I can get a solution for a particular problem''*. Nineteen students (61.29%) mentioned at least one of the design strategies. The most mentioned design strategies were: understanding the problem (42%), making decisions (31.58%), generating alternatives (26.32%), gathering information (21.05%), and identifying constraints (21.05%). Other responses included: considerations for energy efficiency (45.16%), resource optimization (19.35%), and using CAD tools to support complex problem solving (9.67%).

5.3.2 Student perceptions about the workshop

The average score in student responses for the question: "To what extent does this workshop contribute to the development of your engineering competencies?" was 89.9% with a standard deviation of 12.45%. Student responses to the last two

Table 4. Student responses to the most relevant aspects and potential improvements for the workshop

Question	Description	Representative Quote	% of Responses
Most relevant aspects	Having a design process to solve real-world problems	*This is a workshop that allows us to interact with the real world, strengthening our engineering competencies, increasing our logical thinking and the outcome analysis to create feasible solutions, in a given time. I have strengthened my skill to identify processes*	63.6
	Resource optimization	*Through this workshop I learned to optimize economic resources and a new way to contribute to have a positive impact on the environment.*	21.2
	Energy efficiency and renewable energies	*The design process to decrease the energy consumption, and considering solar energy as an alternative energy source.*	24.2
	Positive impact for instruction	*The workshop is very good. It is something that can be applicable in our context although it may take some time to be applicable in Colombia*	15.2
	Workshop organization and planning	*the teachers and their quality to carry out the workshop* *The organization of the workshop, the feedback and the communication with the teacher.*	6.1
Opportunities for improvement	Having more time	*The time for the workshop. If the workshop lasted for more time, we would learn more.*	90.9
	Including additional topics as part of the workshop	*. . . including theoretical concepts at the beginning, and then finally be able to focus on the house design*	12.2
	Improvements in the software	*The software. Although it has an excellent design, there are some details to be improved*	6.1

questions regarding most relevant aspects of the workshop, and potential improvements for the activity were organized on categories as presented in Table 4. Note that the representative quotes are translated from Spanish into English.

Overall, students' reflections both on the posttest and during their presentations were examined to identify what they had learned in terms of the engineering design process and practices of an informed designer. Similar to RQ1, after being exposed to the workshop, students started to identify key ideas of the process. Almost half of the students discussed the importance of having a design process, and understanding that this process is iterative and context dependent. Students also mentioned the relevance of different design strategies such as understanding the problem (42%), making decisions (31.58%), generating alternatives (26.32%), gathering information (21.05%), and identifying constraints (21.05%).

Reflecting on action engages the process of learning and encourages growth along the path of becoming a professional. This reflection engages meaningful learning, and new insights and information get continually assimilated into the engineering students' understanding of engineering as a profession [25]. Students in professional education programs such as engineering need to establish a sense of who they are becoming as a professional. In this sense, students need more than engineering skills and knowledge. They also need a chance to think about their experiences to understand their growth. In our study, the workshop and reflection prompts allowed students an opportunity to reflect on their understanding about their profession as well as what behaviors are exhibited by engineering designers.

6. Conclusion

Colombia, like many other western countries, has an insufficient engineering workforce to solve the complex problems of a global society. Several factors contribute to this issue including the lack of understanding about the profession of engineering as well as the large dropout rate in engineering programs. This study explored the impact of a workshop on student understanding about engineering practice, disciplinary knowledge, and engineering design process for Colombian engineering undergraduates. Using learning by design as the instructional framework, the research team explored the use of innovative pedagogical strategies that challenge students to solve a real-world problem using an educational CAD tool. During the workshop, students were encouraged to collaborate, and to reflect both on their design process and on their disciplinary understanding.

The results suggest that after solving an engineering design challenge, students increased their awareness of engineering as a field and the engineering practice, understood better the science behind their solution to the design challenge, and identified effective engineering design strategies. Students were also highly motivated during and after the activity, highlighting the opportunity of interacting with real-world problems and iteratively refining their solutions. Future work will include integration and evaluation of these types of design activities within the regular engineering curriculum in Colombia.

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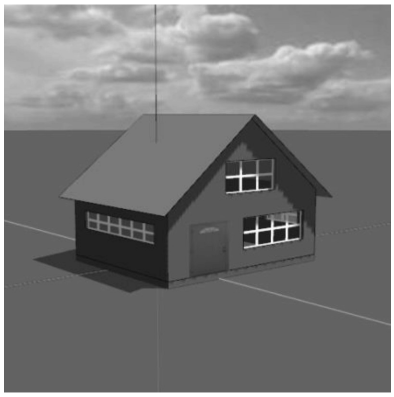
Appendix A—Design Challenge

Background

The client, a promising mid-size company, is committed to becoming a leader in the area of passive solar energy in residential buildings. According to the client, "all newly constructed buildings must consume nearly zero energy by the end of 2020." The key to solving this challenge is finding a way to take advantage of the free and unlimited energy from the sun without compromising the thermal comfort of the buildings for the occupants.



Design Challenge

The client has submitted a request for proposals for a zero-energy residential building. They are looking for a design that consumes no net energy over a year.

Statement of Work

The client wants all energy-cost simulations to be performed using the Energy3D platform. This software is available for download at http://energy.concord.org/energy3d/download.html

Criteria

A successful design must meet the following criteria:

Energy efficient: Consume no net energy over a year; the total amount of energy that the building uses annually should be equal to or less than the total amount of renewable energy that it generates.
Minimized materials cost
Easy to construct: Minimize the number of components needed to build the house while still meeting the other provided criteria.
Attractive exterior or "curb appeal": For example, the ratio of windows to walls or the number of trees.
Comfortably fit a four-person family: Approximate building area 100-200 m^2 and height 6-10 meters; default platform size is 12 m x 16 m.

Constraints

In addition, the following geometric and budget limitations exist:

- Each side of the house must have at least one window on each floor.
- Tree trunks must be at least two meters away from the house.
- Solar panels cannot hang over roof edges.
- Roof overhang must be less than 50 centimeters wide (the default is 25 cm).
- A house is defined as a space enclosed by one and only one set of connected walls.
  - **You can only build one house on the platform** (do not put multiple houses on the platform).
  - Do not add entry porches, dormers, chimneys, garages, or driveways.
  - Do not add additional buildings such as guest houses, dog houses, etc.

Appendix B—Energy Efficiency

1. You are designing a house for a client in Boston, Massachusetts. The client would like to have a large window on one side of the house. There are no trees or other buildings around this house. To maximize the energy efficiency of the house in the winter, on which side of the house would you choose to install the large window? Please explain your choice.
   (a) East side
   (b) West side
   (c) North side
   (d) South side
   (e) I am not sure
2. For a house located in Boston, Massachusetts, which side of it would be shaded most at noon regardless of the time of the year? Please explain your choice.
   (a) East side
   (b) West side
   (c) North side
   (d) South side
   (e) I am not sure
3. Which of the following colors would you choose for the roof of your house in order to improve its energy efficiency in the summer? Please explain your choice.
   (a) Black
   (b) Dark gray
   (c) Light gray
   (d) Color doesn't matter
   (e) I am not sure
4. For a house located in Santa Marta, Colombia, on which type of roof would solar panels be most efficient? Please explain your choice.
   (a) A steep roof
   (b) A slightly sloped roof
   (c) A flat roof
   (d) The angle of the roof does not matter
   (e) I am not sure
5. For a house located in Chicago, Illinois, on which type of roof would solar panels be most efficient? Please explain your choice.
   (a) A steep roof
   (b) A slightly sloped roof
   (c) A flat roof
   (d) The angle of the roof does not matter
   (e) I am not sure

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