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WIP: Using Real Materials Scale-Modeled for Learning about Construction

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WIP: Real Materials Scaled Model Building to Support Construction Students Learning

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Abstract

Civil engineering education plays a critical role in shaping the next generation of professionals capable of addressing the complex challenges of modern infrastructure development. To promote hands-on learning experiences and bridge the gap between theoretical knowledge and practical application this research project has adopted a novel approach by integrating real material scale models into its curriculum. This abstract provides an overview of the implementation, benefits, and student outcomes resulting from this innovative educational initiative. The incorporation of real material scaled models into civil engineering courses enriched the learning experience of undergraduate students. By providing a tangible representation of materials and structural concepts, these models allowed students to interact with physical structures and gain practical insight into engineering principles. The use of real materials, including concrete, steel, and wood, provided an authentic experience that allowed students to understand the behavior of materials under real-world conditions. The process of developing these scale models involved close collaboration between faculty members and industry professionals.

Introduction

Engineering universities around the world acknowledge the importance of cultivating a foundation for students to gain practical experience in their careers [1,2]. Over the years, teaching methods have evolved, and so has civil engineering. In recent years, there has been a shift of pedagogical emphasis in engineering away from the laboratory and small group sessions to lecture based and web-based education [3]. This is thought to be due to several reasons, including larger class sizes, cost of maintenance and upgrading laboratories, and poor alignment of laboratory and lecture outcomes [4]. On the other hand, students around the world used to learn only theory, which led them to have little experience in practicing what is seen in theory [5–9]. According to Shaaban, Practical experience by the hand of theory can be more advantageous for students rather than theory alone [10]. By interacting with a professor who has had field experience, too, students can be motivated and have a better approach to relating the theoretical knowledge taught in class with the real-world experience. This way, it becomes easier for students to develop judgement in civil engineering, and therefore be successful in their practice [11].

The purpose of this study is to determine if and how the implementation of project-based classes with practical proposals such as the construction of a 3D scale model made with real materials could support students learning process. This teaching method is important because help students to know how to develop with real materials in the professional field, besides, the paper argue the importance of practical experience, which leads them to also develop soft skills, material handling and constructability, planning of activities and costs, and reinforcement of technical learning [12–14]. Skills such as engineering knowledge, new and existing technology, individual innovation ability and teamwork spirit to solve specific problems were developed as well. According to this model, students are involved in project work, during which they complete learning tasks actively. Also, the knowledge taught during individual course units are linked systematically and logically within the whole course [10].

One of the key advantages of using real material scaled models was the enhancement of problem-solving skills among the students. By actively participating in the model construction process, students gained valuable insights into the decision-making aspects of engineering projects. This hands-on approach encouraged critical thinking and creativity, allowing students to explore innovative solutions to engineering challenges [15,16].

This investigation took place in the University San Francisco de Quito, specifically in the class of costs engineering of the civil engineering career. Where the students made real material models; a bridge, a house, and a highway, using materials that are used in the professional field. This class has helped the students to acquire the skills mentioned before, they have realized that the practical classes are just as useful as the theoretical ones. Finally, how does making scale models help in the learning process? The question was analyzed through three different groups of students who made the scale model. During the project, they learned different skills like problem solving and teamwork that can’t be learned by only theorical activities. Then, after an analysis of the situation, the students represent an innovative class in cost engineering that is and will be applied, which provides students with the new skills and knowledge required by the job market.

Background

Historically, traditional methods of learning has been in the form of masterclasses, which involves one-way transmission of knowledge from teacher to students, the latter being only the receptors [17,18]. Therefore, the full engagement of students in the learning process in an active way has been relegated, which may end up in the superficial understanding of their classes. Nowadays, research abilities are far more important than mere professional or transferable skills [17].

The importance of model-making relies on its possible positive outcomes in the improvement of learning in higher education students. Project-based learning is an instructional method where students are asked to participate in projects and fabricate real-world products in order to engage in knowledge construction [17,19]. Furthermore, according to other studies made in this field, the significance of that failure is paramount. When faced with something that didn't succeed as planned, it's essential to analyze the lessons learned and progress forward. This valuable experience will shape your future endeavors [20], therefore, the trial and error is a fundamental piece in deep learning and applying theoretical concepts in the real-life practice. This way, it is expected that students don’t just learn notions superficially but are able to apply them to real-world problems and achieve a deeper, long-term understanding of the matter.

An engineering course in Sri Rajeshwara Engineering College (SREC) achieved the understanding of different concepts via an interactive mode and active learning method in the introduction of the engineering design process [21]. Deep involvement and direct-interaction with a problem could not only result in the resolution of the problem itself but discoveries related to it [22]. Thus, the ability to solve these problems comes from facing them directly. By the implementation of projects in classes, students are exposed to practical and real-life problems, which can improve their learning experience and help them acquire long-lasting knowledge.

Hands-on experience is needed as preparation for the exercise of the Civil Engineering career. Experimentation and data analysis is needed for the completion of any project. To achieve this the use of one of the bases of civil engineering, scientific research, is necessary. Furthermore, data analysis and experimentation are crucial for the implementation of projects for Civil Engineering students, especially for the logical understanding of causes and effects, and for material characterization, among other abilities [23].

Project making instigates curiosity and the yearning for learning. Lifelong learning is crucial skill to civil engineers who must keep their knowledge updated to face the challenges the professional life entails [23]. More than just being open to keep on learning throughout their lives, engineering students must develop multiple capacities in different areas of their expertise. Life learning develops skills like future planning, self-improvement, and capabilities to evaluate and address new situations. [24]. An important part of civil engineering is understanding what it takes to make quality concrete to standards. Crucial to this is the water-cement ratio, the dosage, and to make the laying of the concrete, a formwork is required to maintain the desired shape of the concrete and the reinforcements [25].

Further, in this analysis about trying new teaching methods it was key to learn about problem solving, teamwork, contingency management, alternative and analysis costs, and finally, schedule control to improve the knowledge of the students. First, Engineers, by definition, are problem solvers. Whether they are involved in analytical, experimental, computational or design work, engineers solve problems [26], According to Ubidia et al [27] every problem-solving student characterizes for the following, highly effective problem solvers possess a distinct set of qualities that enable them to tackle challenges with efficiency and precision. They invest ample time in reading, gathering relevant information, and defining the problem, while employing a systematic approach with diverse tactics and heuristics to navigate complexities. Constantly monitoring and reflecting on their progress, they prioritize accuracy over speed, valuing the right solution over a hasty one. They excel in jotting down ideas and creating visual aids like charts and figures, ensuring an organized problem-solving journey. Flexibility is another hallmark, allowing them to consider various perspectives and keep options open for innovative solutions. Their systematic, reflective, and adaptable approach makes them invaluable assets in any problem-solving endeavor [28].

Which means every engineer has or develops that skill. In fact, during their studies it is fundamental for the students to apply problem solving to real life, thus, it will be easier in the workplace. Many studies have found that engineering graduates, even though they solve more than 2,500 exercises in their undergraduate work, lack the essential problem-solving skills needed to tackle real world problems [29,30].

Teamwork is a personal disposition and collaborating with the other members with the same objectives results in generating information flows, assuming various responsibilities, solving problems set, and contributing to the collective development [31], On the other hand, Group and teamwork is a big part of civil engineer's work life. Different disciplines are working together with many interfaces over the work process [32–34]. As part of teamwork, team learning is moment were knowledge gets share between the teammates for them to be in the same rhythm and overcome constructive conflicts easier [32,35]. Also, they get along and develop team behaviors so they can adapt to their schedules and identify inconsistencies in the work.

Planning activities and costs is one of the skills that a civil engineer learns at university but is then tested in the field. They have to create schedules to follow what needs to be done, to reach the midpoint of utility and affordability, and to maintain themselves in the constant process of learning [36,37]. Finally, in this case, the reinforcement of technical knowledge was performed by hand, because nowadays we turn towards technology that we do not try to belittle or reproach, so this is a way to find out that there are new ways to innovate in education [38,39].

Methodology

The research questions of this paper are to understand how students learning process affects and what the skills students improve/obtain from the implementation of real materials scaled model building in civil engineering. This exploratory study uses a qualitative approach [40,41] to measure the effectiveness of the implementation of project-based learning among students in the Construction Costs courses (n=16, n=17 students) to a total of 33 students of the Civil Engineering Career at the Universidad San Francisco de Quito (USFQ). Students were divided into groups of 6-7 based on their preferences. Each group selected the project of their preference and had 2 weeks to complete it. Students were asked to build a 1:100 scale model of a bridge, a road and a house using real materials and applying what they had learned in class about the standard and construction processes. All the materials used in the projects were selected according to the scale, however, some materials like rebar were not available in the proposed scale so students decided to use similar materials like wires instead. For this case study, a thematic analysis was made [42]. Also, the researchers developed a questionnaire that was later validated by a group of experts. The survey contained open-ended questions for students to write about how they felt and what they did to complete the models. In order to detail what they had achieved by the time they had completed the models; students were given a small questionnaire. Based on the construction process, they had to write about material handling, constructability, planning activities and costs, and reinforcing technical learning. For a better understanding, the results will be divided to level a difficulty and then based on a theme of the replies.

The results of the survey were grouped by using emerging codes, the topics obtained were Material handling, Constructability, Planning of activities and costs, and Reinforcement of technical learning. Once the answers were separated, themes between every paragraph were identified to separate them in themes. The themes are the following: Material Handling and Constructability, Soft skills, Planning of activities and costs, and Reinforcement of technical learning.

Data Analysis

The projects were carried out in the spring semester of 2023 to measure the impact of this assignment on their thinking process and how this will interact with their future activities. The survey was given as a class activity. Upon completion of the survey, the responses were entered into an Excel matrix to determine if there had been no complications in following the instructions and creating the models on a color scale [43–45]Green if they did not have any complications, yellow for not many complications, red for a lot of problems, blue for problems that they faced but overcame and grey for things that they did not know.

Results and Discussion

The results provide that real materials scaled models helped civil engineering student to learn about materials handling and constructability, planning costs and schedule, soft skills, and reinforced their knowledge. Table 1 shows a summary pf the results.

a. *Material Handling and Constructability*

Students reported that with the creation of these models **Concept to Reality** helped them to understand how the size and geometry from paper to reality impact the model. One group said, "In addition, formwork became complicated due to the reduced scale of the project, which made it difficult to accurately measure and properly level." (Group 1) Another group said, "It was learned that the scale of the structure is an important factor because it can complicate the assembly of the elements." (Group 5) Also "It is worth mentioning that the railings were badly dimensioned since they did not have proportionality with the bridge." (Group 11) Most of the students mentioned that it was their first-time working from scale to reality, and they struggled to make the model.

Problems arose when **handling materials**, as most of the students did not consider the properties of the materials or the scale of the model and realized that construction is harder in reality than in theory. Many students had problems with the formwork "resulting in cracks and poorly dosed mixing", which, in turn, resulted in columns with different strengths (Group 1). Some students had problems when making the columns, as they "did not take into account the leveling of these, and therefore the model was higher on one side" (Group 2). Also, "the manageability of the cable was not taken into account when placing it on the bridge" (Group 4) when buying the materials for the construction of the models.

Table 1: Results of using real material scaled models to support construction students learning

Material Handling and Constructability	Concept to Reality	In addition, formwork became complicated due to the reduced scale of the project, which made it difficult to accurately measure and properly level. (1)
		It was learned that the scale of the structure is an important factor because it can complicate the assembly of the elements. (5)
		It is worth mentioning that the railings were badly dimensioned since they did not have proportionality with the bridge. (11)
	Problems with handling real materials	There were problems with the formwork, resulting in cracks and poorly dosed mixing, resulting in columns with different strengths. (1)
		It was very complex to make the columns and did not take into account the leveling of these therefore the model was on one side higher than the other. (2)
		The manageability of the cable was not taken into account when placing it on the bridge. (4)
Soft skills	Contingency Management	What we learned from the schedule is that it is not always possible to meet the determined dates, due to unforeseen events not contemplated. (5)
		The project experienced difficulties in trying to estimate the necessary amount of material, resulting in a shortage at the end of the process. (1)
		The most complex thing for this stage was to elaborate the reinforcement since the folds and the joints were complicated to do due to the dimensions of the bridge. (6)
		Formwork became complicated due to the reduced scale of the project, which made it difficult to accurately measure and properly level. (1)
	Teamwork	Se learned that you must have better control of construction times and it is important to take into account the availability of people for the elaboration of it. (5)
		The schedule was useful for the whole group to know and participate in all activities. (6)
		At the time of the execution of the model it was difficult to agree since they took the model to Nayón and it was not accessible to go for all the members of the group. (2)
Planning of activities and costs	Cost analysis and alternatives	Costs were estimated, costly or unfeasible options were ruled out, and viable alternatives were considered. (1)
		It was possible to agree on a monetary amount to be able to start with the execution of the model. (2)
		We estimated costs, discarded non-viable or very expensive options, and thought of other alternatives. Cost estimates to discard projects based on total cost and amount of work. (3)
	Schedule Control	It was possible to make a schedule to be on time with the progress that had to be presented. (2)
		A schedule was established for castings and reinforcement assembly, and cost estimates were made to discard projects based on total cost and amount of work. (1)
		We plan a schedule for the foundries and reinforcement assembly. (3)
	Long-term thinking	At this stage we learned to be efficient in the purchase of materials so that there is not so much waste once the construction stage is finished. (4)
		As for the planning, the finishes are made at the end of the work, so it was planned to carry out the Barrier once all the other stages of the project are completed. (7)
		It was necessary to define the dimensioning of the project, define an adequate scale that allows a work with the materials to be used, if the project is very small the workability will be very complicated. (9)
Reinforcement of technical learning	Prior knowledge	We reinforce the use of the AutoCAD application, since a 3D model of the bridge was made before it was built. (4)
		Here it was possible to review the optimal level of compaction (standard Proctor test) that was learned in Soil Mechanics. This depends on the density and moisture of the soil. (8)
		It was recalled what was learned in pavement design to work with the emulsion properly. (7)
	Approach to new processes	A better understanding of the complexity of formwork, its costs and the difficulty of reusing it was acquired. (1)
		The team learned the importance of proper dosing to achieve a workable mixture and avoid differences in mixture resistances. (1)
		Foundation concepts that are not yet familiar were reinforced. (2)

b. Soft Skills

The skill of **Contingency management** was very useful for the students to learn about managing unforeseen events that may arise during the execution of the project. In fact, many difficulties appeared during the process, "The project experienced difficulties in trying to estimate the necessary amount of material, resulting in a shortage at the end of the process" (Group 1) "Additionally, the formwork became complicated due to the small scale of the project, making it difficult to accurately measure and properly grade. Additional balsa material had to be purchased to form the walls, which had not been originally planned." (Group 1) Moreover some students "what we learned from the schedule is that it is not always possible to meet the determined dates, due to unforeseen events not contemplated" (Group 5). Finally, "the most complex thing for this stage was to elaborate the reinforcement since the folds and the joints were complicated to do due to the dimensions of the bridge" (Group 6) in this case they had a problem about the constructability and the materials.

The project made students **work** as a **team** so they can face scenarios that happen day-a-day in the engineering field, for instance (Group 2) mentioned "At the time of the execution of the model it was difficult to agree since they took the model to Nayón and it was not accessible to go for all the members of the group" Also another group managed their activities based on the schedule, "The schedule was useful for the whole group to know and participate in all activities" (Group 6) "We learned that you must have better control of construction times and it is important to consider the availability of people for the elaboration of it" (Group 5) they contemplated about the how accessible the work was for each group member.

c. Planning of Activities and Costs

All the groups affirmed that other **alternatives and analysis costs** helped in different ways. "It was possible to agree on a monetary amount to be able to start with the execution of the model" (Group 2). in this case, the cost analysis established an amount to every member. Moreover, "We estimated costs, discarded non-viable or very expensive options, and thought of other alternatives. Cost estimates to discard projects based on total cost and amount of work" (Group 3) this group thought about any alternative they could implement to make it easier to carry out the project. Also, (Group 1) mentioned that "Costs were estimated, costly or unfeasible options were ruled out, and viable alternatives were considered" this team leaked the options that weren't viable for them and, the options that were helpful for them.

Students seemed to be more efficient and productive due to great time administration. The students evidenced that they began to **schedule control** when "We plan a schedule for the foundries and reinforcement assembly" (Group 3). Also, "A schedule was established for castings and reinforcement assembly, and cost estimates were made to discard projects based on total cost and amount of work" (Group 1), this way they organized how much they had to spend, also, the total time spent in the project. Additionally, (Group 2) expressed "It was possible to make a schedule to be on time with the progress that had to be presented", schedule control supported the team to be punctual and to accomplish the project.

Long term thinking was an ability that students needed to apply to the project. According to the results, students demonstrated that "It was necessary to define the dimensioning of the project, define an adequate scale that allows a work with the materials to be used, if the project is very small the workability will be very complicated" (Group 9). They had a better way to think about the project and the durability of it, "As for the planning, the finishes are made at the end of the work, so it was planned to carry out the Barrier once all the other stages of the project are completed" (Group 7). "At this stage we learned to be efficient in the purchase of materials to avoid much waste once the construction stage is finished" (Group 4) they thought about not buying more than was going to be used to not waste materials.

d. Reinforcement of Technical Learning

The use of models improves the learning process of civil engineering students by reinforcing their **previous knowledge**. According to the results experimented by some students, "it was possible to review the optimal level of compaction (Standard Proctor Test) that was learned in Soil Mechanics" (Group 8). The students had to use knowledge from previous classes to make their projects function correctly, as "skills from the Pavement Design class were recalled in order to work with the emulsion properly" (Group 7). Additionally, skills with other computer programs were practiced further, as students "reinforced the use of the AutoCAD program, since a 3D model of the bridge was made before it was built" (Group 4).

Regarding approach to new processes, just like with prior knowledge, the making of a scale model forced the students to make an **approach** toward **new processes** to them, increasing their general understanding in the engineering career. By using real materials and being exposed to problems they had never seen before, students acquired a "better understanding of the complexity of formwork, its costs and the difficulty of reusing it" (Group 1). "The team learned the importance of proper dosing to achieve a workable mixture and avoid differences in mixture resistances" (Group 1), which means that, by try and failure, the students learned more about the construction process. Finally, they acquired new knowledge, which they were supposed to learn in a more advanced class, as they learned "foundation concepts that were not yet familiar" (Group 2).

With the results obtained in this research, we were able to confirm that the students understood the construction process and consolidated their knowledge in the areas tested by this project. In this way it was possible to see how the students acquired new knowledge about the construction process in terms of materials management, constructiveness, how to organize time today through a chronogram and follow it to coordinate activities, to see the consequences of each of their decisions before taking them, and how the knowledge given in the classes prior to the Construction Costs class and in the classes that would follow was reinforced [46]-[47]. The purpose is to motivate and promote the knowledge of civil engineering students through this type of activities, such as the creation of models with real materials and to scale.

This project had an impact in such a way that the students had problems with the scale of the walls in both the house and the roof slab, on the bridge side there is a disproportion in the scale of the handrails with the retaining barriers along the road, and on the suspension bridge side it could be noticed that the handling of the wire helped a lot in the part of the process that the students were not aware of. This type of project needs to be driven by more questions focused on specific parts of the process to have a wider range of variables that can affect this type of process and activities to get optimal results or sufficient feedback for the next similar activities [48].

Conclusions

The purpose of this study was to determine if and how the implementation of project-based classes with practical proposals, such as the construction of a 3D scale model made with real materials, could improve the students' learning process or be in any way beneficial for their education. This study shows data collected in the Spring Semester of 2023 in the Construction Costs course at the Universidad San Francisco de Quito USFQ. The construction of this model was expected to teach students how to deal with real materials and how to pass from designs in paper to the actual assembly and fabrication of a project.

The students' responses were measured qualitatively via a survey that was provided to them, where four main themes were established. After conducting a thematic analysis, Material Handling and Constructability, Soft Skills, Planning of Activities and Costs, and the Reinforcement of Technical Learning were the main themes found. Inside these, there were subthemes that were studied, among which were: Concept to reality and Problems with handling real materials; Contingency management and Teamwork; Cost analysis and alternatives, schedule control, and Long-term thinking; and Prior knowledge and Approach to new processes.

Overall, it was determined that the construction of a model and the implementation of project-based classes was advantageous for the development of knowledge in higher education students by helping students to get in touch with construction materials, review topics of previous classes, understand the construction process, and the importance of future planning. The students reinforced their previous learning and were introduced to new knowledge by the challenges they faced during the planning and construction phases of this project. some of the major challenges they encountered were working with the real materials and in scale, as they found it was very difficult to use materials, as metal and concrete, for the construction of a house or a bridge, even though it was a 1:100 scale model. They learned the problems they will face once they start working, like the time it takes for the concrete to set and dry, and how the materials, like wood or cardboard (which some groups used, as it was a scale model), can sometimes stick to the concrete and cause delays in the work.

The application of practical projects in classes teaches civil engineering students how to deal with problems they will face in the real world. But there were areas that have to be made questions to measure and see is the spectrum cand get wider on what other areas are involved and how they can be tested. The impact of this educational initiative was assessed through qualitative and quantitative feedback from students. Post-implementation surveys indicated that a vast majority of students found the scaled models to be a valuable addition to their learning experience. Many students reported increased confidence in their engineering abilities and expressed a desire for more practical learning opportunities in their curriculum.

Limitations

This analysis only works with open-ended questions, there are no spectrums to be analyzed based on answers and was only applied to the project of this class.

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