Rainbow Sculpture: Analysis of a Hands-on Case Study for an Introductory Engineering Course

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Abstract

The Rainbow Sculpture is a man-made achievement that exemplifies how engineering and art can function concertedly. This sculpture, which now stands in Stockholm Harbor, is a visual icon that required the work of experts in many fields to complete. This paper discusses how this piece of art was utilized to teach freshmen engineers about engineering problem solving; in addition to functionality, it was emphasized that aesthetics, creativity, and imagination are important parts of design. Surveys taken at the completion of the course indicated that student interest in this project was very high. In the interest of providing long-term retention of fundamental skills, several inductive learning techniques were employed. By maintaining student interest, we hope that the skills they learn from this experience will stay with them throughout their engineering careers.

Introduction

This project, entitled the “Rainbow Sculpture: Artistic Engineering”, adapted from Clifford Matthews’ *Case Studies in Engineering Design* 1, is a case-based learning study that extends into hybrid problem/project based learning. “Rainbow Sculpture” borrows bits and pieces from many different techniques to reach and impress upon a broad array of audiences. Students that learn best by getting their hands dirty get the opportunity to do so. Students that learn best by studying examples get a detailed history lesson on the actual design and construction of the real Rainbow Sculpture. Students that learn best by discovery learning are able to use basic math and science skills that they already have to create models in a new and exciting way. All in all, most students should be able to connect to this project in some way, attributing to the fact that interest in “Rainbow Sculpture” was by far the highest of all the projects for the course in which this was implemented.

The Rainbow Sculpture currently stands in the entrance to Stockholm Harbor in Sweden. It serves as a welcoming sight for the harbor’s many frequenters. The structure itself is half of a parabolic arch that is situated at water’s edge. A high-power pump forces the harbor-water through the sculpture’s steel framework to expel it horizontally at the sculpture’s apex. The water falls back into the harbor in a parabolic path, thus “completing” the arch. The design and construction was a collaboration of engineers, artists, city-planners, and others.

“Rainbow Sculpture” was utilized as a case-based learning project in an introductory engineering course entitled “Engineering Solutions.” The course includes several different case studies designed to cover a wide array of engineering problems. Our qualitative and quantitative findings concerning this project will be compared with the other projects to estimate its relative success. The main objectives of this course are to introduce students to each of the fields of engineering, establish peer networks that students can use for support in future courses, and develop teamwork skills. As such, “Rainbow Sculpture” was tailored to meet these objectives. The course consists of around 400 students separated into 4 lecture sections and 17 lab sections. For this task, they worked in teams of 3-5 people. Teams were randomly chosen, so most teams consisted of
members from various disciplines and diverse backgrounds. The students were then given the following task: to design and construct a small scale model of their own Rainbow Sculpture. By this we mean that they must adhere to the general guidelines of making an arch that is half man-made and half water. However, they have the freedom to build it out of whatever materials they choose and to alter its appearance in creative ways. The general structure of this project is as follows:

1) Research- The students learn about the science, engineering, and art behind the Rainbow Sculpture as well as the social, environmental, and economic implications it has for Stockholm Harbor.

2) Constrained problem solving- The students are introduced to the constraints involved in accomplishing the task. Just as the real Rainbow Sculpture had various constraints, so does this project. They are provided with a small scale model of a harbor and must design a structure that will fit in this harbor and achieve the desired results.

3) Calculations- The students must perform calculations based on given information to determine the path of the water as it exits the structure.

4) Design- The students must design the structure by mathematically modeling the arch to symmetrically match the path of the water.

5) Construction- The students must physically construct a model of the sculpture for testing. The testing is done in class so the students can observe the work of their peers. Each team places a target where they calculate the water ejecting from the sculpture will land. They then vote on the most creative, most aesthetically pleasing, and most realistic sculptures for bonus points.

Method

Shortly after experiencing a presentation in which the students were introduced to the actual Rainbow Sculpture, they were given their task: to construct their own (small-scale) Rainbow Sculpture. To accomplish this task, they had to go through many engineering processes including problem definition, research, brainstorming, design, modeling, calculation, budgeting, finding and obtaining materials, construction, testing, and diagnosis. The students were given the following information and constraints on which to base their designs:

1) The sculpture and the water it ejects should form a parabolic shape and must be fully contained within the small-scale harbor. Figure 1 shows a schematic representation of the harbor with its dimensions. It is constructed from ¼” plexiglass and is open at the top. A 1’x2’ piece of pegboard can be positioned as desired on top of the basin. The holes in the pegboard are ¼” in diameter and are spaced 1” apart. The pegboard is used for mounting the sculpture (the sculpture cannot be simply held in place by one of the group members).

2) A commercial aquarium pump is used to provide the force to propel the water through the sculpture. The total pumping power of the pump (given in units of L/min) is provided to the students.

3) A rubber tube is connected to the pump. This tube is used to carry the water through the sculpture. The end of the tube should be placed at the exit of the sculpture such that the water leaves the confinement of the tube at the apex of the structure. The inside diameter of the tube is provided to the students.

4) The shape of the structure should be as symmetric as possible with the path of the water as it exits the sculpture and falls back into the harbor, thus “completing” the arch. See figure 2 for an example structure.
With this information, each group must design their own water sculpture. Because the solution is rather open-ended, it is not simply a matter of plugging in the given numbers and calculating a solution. They must choose the value of certain parameters (for example, the height of their structure) and then calculate for the other variables. If their solution does not meet the constraints in some way (i.e. the total length of the arch would be larger than the harbor) they must adjust the choices they made and recalculate. This introduces them to the concept of engineering design. Once they have tuned all of the variables so that all of the constraints are met, they can model the sculpture mathematically and then begin construction and testing.

Approach

This project was purposefully designed to appeal to a large array of learning styles by employing a variety of teaching techniques. The Rainbow Sculpture project can most accurately be categorized as a case-based learning study that extends into hybrid problem/project based learning. The foundation lies in the analysis of a real-world structure (case-based learning). In problem-based learning, students are forced to formulate their own solutions with little previous knowledge on how to do so. In project based learning, students are concerned with producing a finished product given a set of constraints. This project involves the analysis of an existing
system and the utilization of knowledge, some previously obtained and some not, to produce a finished product. These techniques were used because studies have shown that inductive learning techniques increase conceptual understanding and retention of material. In addition, this project involves a large amount of active learning, which has also been shown to increase understanding. A more detailed assessment of how each of these types of learning fits into the project follows.

**Case-based Learning** - The inception of the Rainbow Sculpture project originated as a case study of an existing structure. By analyzing the process involved in designing and constructing, the students could get an idea of what the engineers working on the project experienced. Why did they decide to build a sculpture in Stockholm Harbor? How did they come up with the design? What types of people were involved? What constraints did the designers have to meet? How did they go about meeting these constraints while still achieving their original objective? These are all questions that can be answered by studying an example that clearly demonstrates the engineering process and how it fits in real-world applications. There is a lot to learn by studying the Rainbow Sculpture. However, we also want to appeal to those students who learn best by discovering the answers themselves.

**Problem-based Learning** - Some students learn best by being shown the end goal and given the opportunity to discover their own path to get there. Because of this, problem-based learning techniques were employed in the design of “Rainbow Sculpture.” In the case-based learning part of the project, the students were exposed to the techniques that the engineers used to come up with a solution. They were not, however, given details as to how the engineers performed the calculations to come up with their design. This is where problem-based learning comes in. The students were given information concerning the size of the harbor, the strength of the pump, and the diameter of the tube connected to the pump. They were intentionally not given the equations they would need to determine the path of the water as it exits their structure. The method to do this is something they had to discover themselves. Arriving at a solution would require predominantly levels 3-5 of Bloom’s Taxonomy. Levels 3 and 4, application and analysis, must be used to recognize the need to use dimensional analysis and high-school ballistics equations. Synthesis (level 5) must be used to integrate all of the information in such a way as to arrive at a possible solution. It should be noted that, to prevent too much student frustration, the necessary calculations were not exceedingly difficult. This was done because it is not their ability to do calculations that we were interested in. It was their ability to discover a path that leads to a possible solution that is important. This is a skill that becomes much more important as they progress through their engineering education (and unfortunately is not emphasized enough using traditional teaching techniques). Also, inductive learning techniques such as this have been shown to increase long term information retention. Thus, by providing the opportunity for the students to discover their own path to a possible solution, they are developing a crucial engineering skill.

**Project-based Learning** - Some students feel they learn best by actually creating a finished product. Seeing how design and calculations can come together to create something is often very satisfying. And to entice the students to work even harder on the physical construction of the sculptures, a slightly competitive incentive was built into the project. The public display of their creations and the bonus points that were offered (for most creative, most aesthetically pleasing, and most realistic) encouraged the students to put 110% into the design and construction of their sculptures. Not surprisingly, especially considering the tools and resources available to the average dorm-dwelling
college student, many of the results were quite creative. But this is precisely one of the skills we would like them to develop: constrained problem solving. Figure 3 shows some examples of the structures that were created. So, with an incentive to build something creative while adhering to engineering constraints, the students were able to see how all the work on paper could come to a realization that they could see and experience themselves.

Figure 3. Examples of model Rainbow Sculptures

Conclusions

Qualitative and quantitative analyses of this project were performed. One of the questions that was asked on a survey after the completion of the project was “How interesting was the case study?” The possible answers to this question were “High”, “Medium”, and “Low”. “Rainbow Sculpture” by far received the best rating for interest with 46% of the students responding with “High”. Figure 4 summarizes the results in comparison to the other case studies that were offered in that semester.

One reason that the interest may have been so high is because of the hands-on component of the project. However, because problem-based learning (discovery learning) was built into the project, 22% of the students responded that the task was not clear. This is not surprising as the students are used to rigidly structured projects where the methods of obtaining the goal are, for the most part, given to them rather explicitly. Figure 5 shows how clear the students thought “Rainbow Sculpture” was in comparison to the other case studies in the course.
Figure 4. Student responses to question regarding interest of projects.

Figure 5. Student responses to question regarding clarity of projects.
Overall, we feel that the responses show that the project was successful in teaching crucial engineering skills while maintaining the interest of the students. Multiple learning styles, including case-based learning, problem-based learning, and project-based learning were utilized to appeal to the widest array of students possible. The project incorporated a large number of engineering skills including problem definition, research, brainstorming, design, modeling, calculation, budgeting, finding and obtaining materials, construction, testing, and diagnosis. By engaging a wide variety of students in a project that utilizes a large number of engineering skills to create a finished product, it is hoped that all of the students leave the course with a feeling of accomplishment and satisfaction. They have had their first exposure to real engineering.

Bibliography


Biographies

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Adam Halstead is a Ph.D student at the University at Buffalo. He received his B.S. in 2005 and his M.S. in 2007, both from the University at Buffalo. His research interests lie in multifactor stress aging of electrical systems and partial discharge analysis. He is also very interested in the investigation and analysis of novel teaching techniques in the engineering field. Adam has been actively involved in the course Engineering Solutions as a teaching assistant for 3 years and as a student assistant for an additional 3 years.

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Jennifer Zirnheld received her Ph.D in 2004 and is a Research Assistant Professor in the Department of Electrical Engineering at the University at Buffalo and the Deputy Director of the Energy Systems Institute. Dr. Zirnheld teaches two senior technical electives in the fields of power engineering and electrical devices. She is also the coordinator of and teaches a section of EAS 140, which is the introduction to engineering for freshman in the School of Engineering and Applied Sciences at UB. Dr. Zirnheld’s technical expertise is in the areas of, but is not limited to, dielectric phenomena, Power and Energy Management, Generation and Distribution, multifactor stress aging, partial discharge analysis and systems of systems integration. Dr. Zirnheld has been an instructor for, and the course coordinator of, the Engineering Solutions course for the past several years.