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Bridging the gap: Using design based activities to develop problem-solving skills in Qatari high school students

Hanaa Loutfy[1], Yossra Osman[1], Abdullah Najjar[1], Meera Abu Soufah[1], Abdul Salam Abd[1], Siba Moussa[1], Moustafa Selim[1], Maream Daey[1], George Haleem[1], Tricia Kerr[2], Ghada Salama[1], Beena Ahmed[1]

[1]Texas A&M University at Qatar, Doha, Qatar
[2]Department of Education, Qatar University, Doha, Qatar

ABSTRACT

A substantial number of secondary school students are accepted into engineering schools without adequate exposure to key engineering based skills, such as analytical thinking, problem solving, critical thinking and design. Unfamiliarity with the practical skills needed in engineering leaves students unprepared, leading to poor academic performance and demotivating them about engineering. It is critical that students be able to apply learnt scientific concepts to solve real life problems. In this paper, we will present a set of design-based learning activities created to help develop the analytical thinking and problem solving skills of students in local Qatari secondary schools. We will discuss implementation details of these design-based learning activities along with results, comments from participating students and teachers as well as data analysis.

Keywords: design-based learning, engineering, Qatari secondary schools, analytical skills, critical thinking

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1. INTRODUCTION

Despite the significant role that technology and science play in our daily lives, secondary schools often do not provide their students with sufficient exposure to scientific skills such as critical thinking and problem solving. Although students at Texas A&M University at Qatar have strong science and math skills, they are incapable of applying them in real world situations due to their under developed problem solving skills. Results from a previous study we performed at Qatari secondary schools[1] showed that skills such as analytical thinking, problem solving and design were not incorporated into their Science, Technology, Engineering and Mathematics (STEM) courses leaving students unprepared for careers in engineering and science.

Qatar is not the only country that faces the issue of deficiency in preparing secondary school students for engineering. A lack of exposure to these skills has been identified as a leading cause for students' withdrawing from engineering in the United States;[2] almost 50% of the students that pursue engineering are unsuccessful in obtaining their engineering degrees.[3] Lately, a number of initiatives have been introduced to better prepare students for engineering by incorporating engineering based activities in primary and secondary schools.[4] Project Lead the Way (PLTW), a method used in the United States to stimulate the interest of students in engineering, introduces projects to school courses and curricula in which the students were able to discover engineering and expand their knowledge of the field.[5] The increased exposure achieved through PLTW has proven to improve the students' preparation for university level engineering courses in contrast to traditional methods.[3]

In Section 2 of this paper we present several design-based activities developed for use in Qatari STEM curricula to build students' problem solving skills. As active learning is not common in Qatari schools, we tested these activities in a select group of secondary schools and collected feedback from students and teachers about the design-based learning approach, which is summarized in Section 3. The paper concludes with a discussion and directions for future work.

2. METHODS

We developed a set of activities based upon the design-based learning cycle shown in Figure 1. Design-based learning is a form of active learning, where learning is attained via a design project; students solve problems in teams with their peers. This encourages the application of the students' knowledge of the subjects to create a solution while developing their problem solving and critical thinking skills. It also promotes visual learning through the implementation and construction of their solution.

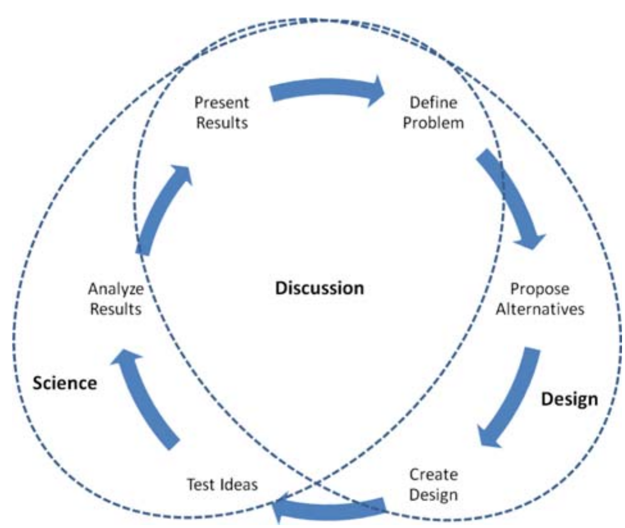

Figure 1. Design-based learning cycle.

Our activities commenced with a problem definition stage after which students are asked to propose alternatives to the given problem. In the design and test phase of our activities, the students were encouraged to propose and test several designs, discuss with their peers while allowing for factors such as cost and time efficiency. The hands-on experience attained through these activities stimulated the students' creativity and showed the importance of trial and error methods as initial designs often do not succeed. To motivate the students and introduce a ‘fun’ element to the activity, the students tested their designs in a competition. Students then participated in group discussions, where they discussed questions such how they came up with their designs, the scientific concepts they used in their design, changes they would make, reasons for their design success/failure and possible improvements after seeing their test results.

A. Design-based Activities

All the design-based learning experiences were chosen to align with the Qatari secondary schools’ science curriculum. The projects were developed around the real-life scenario of problems faced by residents at a remote island devastated by a recent tsunami as listed below. The students applied scientific concepts to design, implement and test a practical solution for a specific problem on the island using materials readily available from a stationery store. Limitations on the materials available, time and budget were introduced to mimic real-life engineering problems.

1) Airborne Delivery (Figure 2)

To understand the concept of air resistance, the students in this project were asked to design a flying device to move medical supplies from the mainland to injured victims on a remote island.

Figure 2. Airborne delivery design.

2) Fantastic Elastic (Figure 3)

The objective here was to design a car powered by an alternative energy source for the islanders due to the destruction of all the petrol stations. Energy conservation concepts such as potential and kinetic energy conversion were used in the car design.

Figure 3. Elastic car under construction.

3) Purification (Figure 4)

The students were asked to build a water purification system for the islanders. The students used the concepts of density and solubility to purify a bottle of polluted water.

Figure 4. Purification system being tested.

4) Bridges to tommorrow (Figure 5)

In this activity, students built a replacement for a destroyed bridge on the island. Students had to apply concepts from physics (torque and force) and geometry to build the bridge.

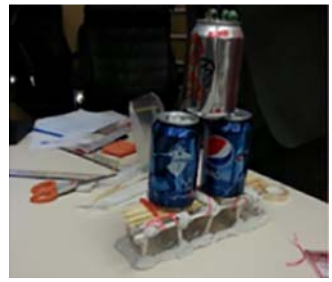

Figure 5. Bridge being tested.

5) Electromagnet (Figure 6)

Here students had to design an electromagnet to remove huge metallic debris, which was hindering the cleaning and rebuilding process on the island after the tsunami.

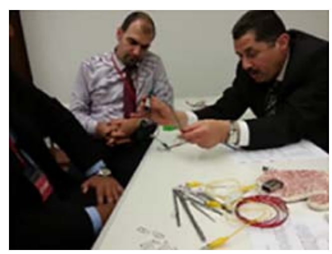

Figure 6. Materials in electromagnet.

B. Surveys

We tested these activities during a workshop conducted in two Qatari secondary schools. At the end of the workshop, both students and teachers were asked to provide their feedback through surveys on the activities. A Likert scale was used to respond to the statements in Table 1 and Table 2. In classroom observations conducted during the activities, the investigation team ranked the statements in Table 3 as either consistently, frequently, sometimes or never observed.

Table 1. Questions in students survey.

Q1. Before this activity, I knew that engineering involved design
Q2. This activity helped me understand the steps in engineering design
Q3. This activity helped me understand that there can be several different solutions to a problem
Q4. This activity helped me improve how I analyze problems
Q5. This activity helped me know how to make technical decisions
Q6. The problem solving in the activity helped me learn the scientific concept involved
Q7. I enjoyed working in a team to complete the activity
Q8. This activity is a more interesting way to learn traditional lecture
Q9. I would like my teachers to use this method in their classes
Q10. I am considering going into one of the fields of engineering

3. RESULTS

Eight classroom observations were recorded from the conducted student workshops with surveys collected from 117 students and 4 teachers. The survey responses on the design activities are summarized in Table 4. As seen, the students gained a positive experience from the activities as 92% of the students mentioned they had enjoyed teamwork in Q7. 80% of the students thought these activities helped them understand that engineering involves problem solving and designing skills. Also 60% of the students reported that they were able to understand the scientific concepts involved in each activity through problem solving skills. However only 59% of the students felt that their technical

Table 2. Questions in teachers survey.

Q1. Before this activity, my students knew that engineering involve design
Q2. This activity helped my students how they analyze problems
Q3. The problem solving activity helped my students learn the scientific content involved in it.
Q4. This activity helped my students in identifying alternative solutions
Q5. This activity helped my students understand that engineering involves design
Q6. This activity helped my students understand how to make technical decisions
Q7. This activity helped my students understand the steps involved in engineering design
Q8. Working in teams was a positive experience for the students
Q9. The students were more engaged in this activity than the traditional lecture
Q10. I will implement some of the ideas I learned from the activity

Table 3. Questions in classroom observations.

Q1. Students understood the problem.
Q2. Students discussed ideas with each other.
Q3. Students understood the constraints in the design problem.
Q4. Students were able to come up with different solutions/designs to solve the problem.
Q5. Students were able to make good design decisions.
Q6. Students were able to complete the design activity.
Q7. Students worked well together.
Q8. Students understood the presented scientific concept.
Q9. Students worked with interest on the activity.

Table 4. Student survey results.

	Response (117 Students)			
Question	*Strongly Agree*	*Slightly Agree*	*Slightly Disagree*	*Strongly Disagree*
1	76 (65%)	35 (30%)	5 (4%)	1 (1%)
2	63 (54%)	37 (31%)	15 (13%)	2 (2%)
3	88 (75%)	26 (22%)	2 (2%)	1 (1%)
4	70 (60%)	35 (30%)	8 (7%)	4 (3%)
5	59 (50%)	49 (42%)	8 (7%)	1 (1%)
6	66 (57%)	26 (22%)	18 (15%)	7 (6%)
7	92 (79%)	16 (14%)	5 (4%)	4 (3%)
8	88 (75%)	25 (21%)	3 (3%)	1 (1%)
9	88 (74%)	17 (15%)	9 (8%)	3 (3%)
10	65 (56%)	25 (21%)	12 (10%)	15 (13%)

decision-making skills were affected by these experiments (Q5). The overall results show that the students enjoyed and benefited from design-based learning.

The teachers' responses are represented through the values in Table 5. In Q1, one of the four teachers responded that the students did not know engineering involved the use of design. All the teachers agreed that the activities helped the students in identifying alternative solutions to the problems (Q4), which was a main objective of the design-based learning process. Other than Q1, all the teachers agreed with the statements in the survey.

Table 5. Teacher survey results.

	Response			
Question	*Strongly Agree*	*Slightly Agree*	*Slightly Disagree*	*Strongly Disagree*
1	1	2	0	1
2	3	1	0	0
3	3	1	0	0
4	4	0	0	0
5	2	2	0	0
6	3	1	0	0
7	3	1	0	0
8	3	1	0	0
9	3	1	0	0
10	3	1	0	0

Classroom observations made during the students' workshops are given in Table 6. The researchers noted that the students did not fully understand all of the problem statements and constraints (Q1 and Q3). They also observed that the students were not able to come up with solutions independently (Q4) and would often ask their peers or the teacher for hints. The students were seen to have worked well together (Q7), with enthusiasm (Q9) and frequently finish the designing of the project (Q6).

Table 6. Classroom observation results.

	Response			
Question	***Consistently***	***Frequently***	***Sometimes***	***Never***
1	2	4	2	0
2	3	4	1	0
3	0	5	3	0
4	0	2	5	1
5	1	4	3	0
6	2	5	1	0
7	4	2	2	0
8	1	4	3	0
9	6	2	0	0

4. DISCUSSION

The collected survey results indicated that 85% of the students favored design-based learning over regular lecturing due to the engaging nature of the activity. The students were able to propose different methods to solve the problems indicated in each activity. Through testing, most of the students were able to identify errors in their initial designs and were able to redesign them accordingly. The classroom environment was observed to be more active than that of a traditional classroom. Students suggested ideas to each other and identified the activity goals. When the students were split into groups and asked to perform a scientific curriculum-based activity, students were involved in discussions among themselves, asked questions, and provided feedback.

The students displayed a positive attitude towards the activities and produced unexpected, very impressive results when they were challenged to find solutions, given limited materials, under time and budgetary constraints. A number of groups asked their teachers whether their approach was applicable before they started building their design. We also noted that in most groups only one or two members in each group did most of the hands-on work, while the others watched, discussed, criticized and gave some input. The discussion sessions showed that the students understood the scientific concepts behind the activities and they were able to present them along with their designs. The results also show that design based learning activities are effective in attracting students to engineering; 77% of students stated they were considering a career in engineering after participating in the workshop (Q10).

The teachers also showed great enthusiasm toward these activities; 85% were willing to incorporate such ideas in the classes they teach. They unanimously agreed that such activities are needed for students to gain a better understanding of engineering. However, it was noticed that the teachers helped the students by giving out several clues as they performed the activities. They explained the required task, and gave more information than required, which at times diminished the imagination of the students in creating more unique, creative designs. This indicated that the teachers needed to be properly trained in how to conduct these activities to maximize benefit to the students.

5. CONCLUSIONS

This study evaluated the learning effectiveness and motivational appeal of design based learning in Qatari secondary schools. The classroom observations, along with the feedback collected from teachers, school administration and students indicated that these activities were received positively, while being a novel idea to most of the students and teachers. The success of these activities indicates that they can effectively aid the students in understanding scientific concepts and solving problems using critical thinking skills.

Our study shows that design-based learning can be an effective component of science education at the secondary school level and thus should be incorporated into the curricula of Qatari secondary schools. Teachers in Qatari high schools should be encouraged to incorporate design-based learning experiences in their classrooms several times in the semester to ensure that the students can gain from these hands-on activities. These activities can assist in developing the critical and analytical thinking skills of the students as well as introduce them to the concept of teamwork and increase the retention of the scientific concepts around which the projects are based. Further work is needed to study if design-based learning is effective in enhancing retention of material and improving student performance.

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