The Impact of Inverting the Cognitive Domain of Bloom's Taxonomy Using STEM Methodology on the Nine Graders Achievement and Attitude in QSTSS

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January 14, 2019

Introduction

Searching the open literature has revealed an increasing interest in STEM education among the educational communities. Worldwide different schools apply STEM approach differently. Most schools apply STEM through conducting culminating comprehensive projects by the end of each chapter or semester. In Qatar Science and Technology Secondary School “QSTSS”, STEM is taught as a separate subject with its themes and strands. However, there is a lack in the studies that objectively evaluate the accumulating different experiences in the implementation of STEM education. Therefore, the current research attempts to fill a gap in the assessment and evaluation of STEM education.

The rationale for conducting the current research is to objectively evaluate the adopted STEM approach and methodology by QSTSS from the students’ point of view considering the students attitude towards sciences, their performance, and their dispositions towards future career selection.

Research Significance

The current research is important for the educational policy makers in the ministry of Education, the schools’ principals, and the teachers. In addition, the research is highly significant for the members of the whole educational community interested in implementing STEM education or any of its features such as PBL, critical and creative thinking, active learning, and 21st century skills.

The research analyzes the application of STEM approach in QSTSS from the students’ point of view, measures its outputs, and objectively evaluates them. In doing so, the strengths and weakness of applying STEM education will be pinpointed and discussed.

Therefore, the current research would be a useful tool for policy makers to make overall judgement about the STEM approach and for teachers to apply the best practices in STEM and to figure out why it might in some cases fail.

The research is also important for educators as it explains the best order of the six levels of the cognitive domain of Bloom's taxonomy.

Objectives

The main objectives of the current research are to evaluate the adopted STEM approach and methodology by QSTSS from the students' point of view considering the students attitude towards sciences, their performance, and their dispositions towards future career selection. Based on the above the following procedural objectives protruded:

1- To investigate the impact of implementing STEM approach on nine graders' attitudes towards learning STEM in QSTSS.
2- To investigate the impact of STEM approach on nine graders' performance in QSTSS.
3- To investigate the impact of STEM approach on nine graders' dispositions towards the selection of future careers in QSTSS.
4- To investigate the impact of inverting the levels of the cognitive domain of Bloom's taxonomy using STEM methodology on the nine graders' attitude towards STEM learning.
5- To compare the efficiency of applying STEM approach as a separate curriculum to that as culminating end of term projects.

Research Problem

Problem Identification and Reflection on the problem

It has been noticed a high degree of reluctant among Qatari students from joining the Engineering faculties in universities after finishing the secondary education in schools. The Qatari male students are also unwilling to join medical colleges and almost none of them has continued his education in any of the abstract scientific specialties in university. Moreover, tracking the students in different schools from month to month and following them up during successive academic years has revealed that many of them have weak 21^{st} century skills. Only a small proportion of them had to a certain degree the necessary life skill. The lack of the necessary scientific knowledge and skills and the 21^{st} skills would make failure unavoidable result.

This made the educational policy makers in Qatar reevaluate the needs of the Qatari students in a changing world. They decided that among the most essential skills that the students need are scientific enquiry, problem and project-based learning and applying data in critical thinking.

A partial solution to the above problem could be provided by the practical lab work of the curriculum. Yet, this is an easy but plausible solution to the above problem. In fact, practical work and activities are considered an essential part of learning and teaching sciences. However, the efficiency of these practical sessions is questionable. From the accumulating expertise of the Qatari Ministry of Education and interviewing many science teachers have revealed a general disappointment from the practical part. Reviewing the literature has revealed a similar negative disposition among many science teachers who claimed that in many cases the practical work does not fulfill its assigned goals (Millar, 2009).

In 2016 the educational policy makers in Qatar came to a conclusion and decided to establish the first STEM school in Qatar under the name Qatar Science and Technology Secondary School for Boys (QSTSS). The main objectives of the school are to provide the learners with the opportunity to learn in an environment equipped with some of the most advanced educational facilities and to enable them to join the engineering and the medical faculties in the most recognized universities.

Problem formulation

There is a general reluctant among Qatari male students from continuing their university education in the fields of engineering, medical, or abstract sciences. They also suffer from weak 21st century skills. Therefore, to revert that trend and to motivate the students to join the engineering, medical and scientific faculties, STEM approach was adopted and applied in QSTSS. Hopingly this would enhance students' performance and improve their attitudes towards science learning and provide them with the necessary 21st century skills.

Dimensional analysis of the problem

There are many reasons that cause the male Qatari students to refuse to join, engineering, medical, and sciences faculties. The first reason might be the presence of many other options that would leave them financially secure such as joining the military forces or the economy faculty. The second reason is that the students believe that they would not have the necessary requirements to graduate from those faculties due to weakness in their scientific background. The third reason studying medicine takes a long time, few extra years are needed to become a specialized doctor. Moreover, the students are not aware enough about the importance of engineers and doctors to the society. The continuity of the unwilling trend would with time have dramatic effects on the whole society as the state cannot always depend on expatriates to fill these vacancies.

Problem Documentation: Evidences for the problem existence

According to the ministry of Ministry of Development planning and Statistics (https://www.mdps.gov.qa/ar/statistics1/pages/default.aspx) there are 31 engineering specialties in Qatar and that there are 47600 engineers in Qatar out of them is only 2900 Qatari engineers. Considering the total number of Qatari population which is 2,634,000 according to the consensus of September, 2017, the proportion of engineers to the whole population would be about 1.8%. the percentage is comparable of that to Japan. However, if considering the Qatari engineers only, the percentage would drop to 0.11%. In the academic year 2016/2017, the number of Qatari graduates from public universities ad colleges from engineering faculties was 18 males to 85 females, pharmacy 0 males to 3 females, medicine 0 for both genders. However, the number of graduates from Administration and Economics faculty was 116 males and 463 females.

The above numbers clearly show that there is a general trend among Qatari male students not to join medical, engineering, and science faculties.

Research hypotheses and Questions

Based on the research objectives, the following research hypotheses were formulated:

1- There are statistically significant differences ($\alpha \leq 0.05$) in the attitudes of nine graders towards STEM learning due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology.
2- There are statistically significant differences ($\alpha \leq 0.05$) in the nine graders achievement in pretest and posttest due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology.
3- There are statistically significant differences ($\alpha \leq 0.05$) in the nine graders' dispositions towards future career due to the STEM approach.
4- There are statistically significant differences ($\alpha \leq 0.05$) in the nine graders' attitude towards learning STEM due to applying STEM approach as a separate curriculum rather than culminating end of term projects.

From the above hypotheses, the following research questions were derived:

1- Are there statistically significant differences ($\alpha \leq 0.05$) in the attitudes of nine graders towards STEM learning due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology?
2- Are there statistically significant differences ($\alpha \leq 0.05$) in the nine graders achievement in the pretest and posttest due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology?

3- Are There statistically significant differences ($\alpha \leq 0.05$) in the nine graders' dispositions towards future career due to the STEM approach?

4- Are there statistically significant differences ($\alpha \leq 0.05$) in the nine graders' attitude towards learning STEM due to applying STEM approach as a separate curriculum rather than as culminating end of term projects?

Procedural Definitions of Concepts and Terms

Bloom's Taxonomy:

A system of classifying the learning objectives into three subsets called domains (cognitive, affective, and sensory). Each subset comprises groups of action verbs arranged hierarchically in order of increasing their complexity (Bloom, et al., 1956).

STEM Education (academically):

The acronym stands for Science, Technology, Engineering, and Math. STEM is a teaching approach and methodology in which the learners apply engineering principles and technological tools to explain and understand scientific concepts. Teaching through STEM is learner centered and often involves implementing projects and solving problems (Morgan et al., 2016).

STEM Education (Procedural):

One of the subjects taught in QSTSS (for course description, see the research methods).

Achievement (academically):

The total competencies, knowledge, and skills that the student gains and reflects the range of achieving the learning objectives in all school subjects. It represents the objective judgment on the student's performance in the contiguous assessment and school's standardized tests (Stoker and Ward, 1996, P).

Achievement (Procedural):

the overall student's mark in the midterm and final standardized tests prepared by the researched and acknowledged by the school's academic deputy in the Ministry of Education and Higher Education / Qatar.

Attitude:

The overall students mark in the attitudes questionnaire.

The Theoretical Frame

The theoretical rationale for implementing the current research comes from the interdependence between motivation, achievement, and instructional strategies. In this research, STEM approach will be used as an overall frame containing different active learning strategies that are students based including project-based earning, problem-based learning, critical and creative thinking. These strategies will be powered by some of the most advanced tools and equipment.

The theoretical frame of the current research comprises establishing the relationship between STEM education and students' achievement in standardized tests, their attitudes towards learning sciences, and their dispositions towards their future careers. In this research it is assumed that applying STEM education would enhance students' achievement and improve their 21st century skills (Durencls, 2010). The research also questions and challenges the hierarchical structure of the six levels of the cognitive domain in Bloom's taxonomy by applying STEM methodology.

To answer the research question about the achievement, pretest and posttest were set. A questionnaire was specifically designed to measure the students' attitude towards STEM learning. Moreover, in this research STEM was applied in two ways: First, through culminating, end of chapter projects. Second, as a separate curriculum weighing two hours weekly.

The research investigates the relationship between STEM education future career selection. It assumes that teaching STEM or through STEM would change the students' dispositions towards career selection. No one can question the importance of engineers and doctors in the modern community. Unfortunately, there are some engineering and medical specialties with no Qatari citizens majoring in them. If this problem persists, there will be no more Qatari doctors or engineers.

Literature Review

Bloom's taxonomy is a system for hierarchical classification of the learning objectives in order of increasing complexity. The system comprises three domains: cognitive, affective, and sensory (Krathwohl, 2002). The cognitive domain contains a list of verbs used to formulate SMART objectives. The acronym SMART stands for specific, measurable, assignable, relevant, and time-based. Because of its critical contribution to teaching and learning, Bloom's taxonomy has been a central reference issue in curriculums design and implementation. Bloom's taxonomy is used not only in formulating the objectives, but also in setting the assessment plan and choosing the proper teaching methodologies and strategies and consequently the lesson activities (Fadul, 2009).

The revised version of Bloom's taxonomy published in 2001 comprises six verbs in the cognitive domain arranged in order of complexity. Below is a brief discussion about the levels of the cognitive domain in reference to the STEM education i.e. how they are implemented in STEM curriculum.

1- Remember: this level aims providing and assessing the students at the basic knowledge. No explanation, analyzing, or any deep thinking is required here. The students at this level are only required to memorize and remember the information and the facts directly given to them by the teacher, textbook, or any other resource.

2- Understand: this level is usually used in lesson plans when the teacher's intention is to provide the students with the comprehension and to let the students demonstrate their understanding of given ideas and facts by. At this level the learners usually compare and contrast, organize, describe and interpret.

3- Apply: the students at this level are required to use the knowledge they gained at previous levels to solve problems in new contexts and situations.

4- Analyze: at this level the students deeply investigate ideas and concepts to identify the elements of each and to find out any hidden connections between them.

5- Evaluate: doing evaluations is an integral part of any educational process as it fulfills the humanitarian nature of the students to do judgments. It is very necessary to develop and enhance this skill among the learners as they will always need to assess, check, validate, and verify the type of information provided to them or they might encounter in the contexts of their learning. In doing so, the students need to learn how to develop their own rubrics to enable them to be objective and always evidence-based.

6- Create: while analysis is going for the whole to the parts, synthesize or create would require the students to gather the parts into one unit, forming the whole. Creating goes beyond simple synthesis as the learners are producing their own products and this would usually require then to go through the design cycle.

Since its publication in 1956, the six levels of the cognitive domain of the Bloom's taxonomy of the thinking skills was subjected to several critiques, revised and modified by many educators. For instance, Vygotsky has published his "Constructivism Theory" (Vygotsky, 1973), Gardner in 1993 (Gardner, 1993) has published his theory about the multiple intelligences and Marzano has published in 2000 his new taxonomy of educational objectives (Mazarano, 2000).

Even though these critiques recognize the presence of the Bloom's six levels in the cognitive domain, they doubt the existence of the sequential arrangement of the levels in order of their complexity due to the unclear links of hierarchy (Paul, 1993). Some educators consider these levels as separate discontinuous categories. Other educators among whom who recognize the hierarchy of levels in Bloom's cognitive domain often underestimate the low levels (remember, understand, and apply) and consider them unworthy to teach. However, teaching and learning the lower levels is essential and an integrated part of the whole educational process as it enables of establishing for the skills needed for the higher categories. There are many themes in different subjects based on students' ability to observe, identify, and classify. These skills are all in the first or lower levels of hierarchy. Keene et al. (2010) claims that the levels of the cognitive domain are not discrete units but rather they are continuous and have connection lines between them. They based on the "Constructivism Theory" of the Russian educator Vygotsky assume that the low-level skills provide support and scaffold for the high-level skills.

Since the publication of the revised version of the cognitive domain taxonomy in 2001 (Lorin et al., 2001), big breakthroughs in technology influenced every single part of our life including education have occurred. For a child born and living in a cyber, electronic world that shapes his mentality and thinking, teaching him using traditional and classical methods would not be so effective. Fortunately, the huge advances in technology has also reshaped the teaching resources. For instance, searching the open literature has revealed huge number of virtual reality (VR) and augmented reality (AR) teaching resources. STEM education is used by many educational institutions as it takes advantage of the new learning opportunities created by technology through the integration of technology and engineering in teaching sciences and math.

In the learning and teaching contexts, STEM can be used as a methodology creating new learning, motivating environment and as a curriculum creating the context in which the students learn. STEM approach goes beyond ordinary practical laboratory activities, project or problem-based learning. It succeeds in areas where lab works usually fail to fulfill the educational objectives (Millar, 2009).

STEM is a multidisciplinary curriculum operates on four pillars Science, technology, Engineering, and Math. In STEM education the students are required to apply technology and engineering in learning sciences and mathematical. This way of integration and incorporation puts the four pillars of STEM concepts in their natural context. In STEM based - education the students are engaged in different activities and projects where they can find and express themselves and develop their scientific as well as their 21st skills.

The theme of STEM suggests that Science and Technology are best taught and interpreted through Engineering and they are all based in Mathematical elements (SoonBeom et al., 2011).

In a study done by Chung (2014), secondary school students joined robotics projects in which they were asked to apply engineering skills, scientific knowledge, and available sensors technology in their designs. Working on the projects has fostered the students' interest and engaged them in STEM success. The students creatively applied STEM subjects into their projects. Surveying the students by the end of their projects showed that adding design to robotics was effective, as it has brought beauty, joy and creativity to the work. Project-Based Learning and Problem-Based Learning despite the differences between them serve one major goal that is critical thinking and research (baker, 2011). PBL as an instructional method is student centered. It allows the instructor to go beyond the traditional teaching methods and promotes new learning practices and habits.

Instead of using a rigid lesson plan that directs a learner down a specific path of learning outcomes or objectives, PBL allows in-depth investigation of a topic (Harris & Katz, 2001 cited by Faris A., 2008). Integrating PBL would increase the students' attitudes and improve their achievement in sciences (Faris, 2008). Among the 21st century skills, that STEM approach promote through PBL are collaborative learning and group work. Group work plays an important role in building a homogeneous community of learners and enhancing the cooperation between them. This consequently would positively affect the achievement and the attitudes of students.

Collaborative learning is defined as an educational approach to teaching and learning that involves groups of learners working together to solve a problem, complete a task, or create a product (Faris, 2009). In collaborative learning the students talk among themselves and socialize naturally and through these talks learning occurs, and their communication skills develop (Srinivas, 2009).

Reflection on the Literature Review:

There is a debate among educators about the hierarchical structure and the contiguous nature of the six levels in the cognitive domain of Bloom's taxonomy.

I can classify the educators into three groups:

1- **Denying Group:** educators in this group deny the existence of any hierarchical system in the six levels of the cognitive domain. However, they at least admit the presence of these levels.

2- **Partly Admitting:** the educators in this group admit the presence of hierarchical structure only among the first three levels. However, they consider the highest three levels parallel to each other.

3- **Admitting group:** educators in this group recognize the presence of connecting lines among the six levels. For this group of educators, teaching should be sequential and move from the lowest level to the highest level.

Each of the above groups has their own evidences and arguments. For me, I personally think that we are living in a changing world that always require us to revise our understanding and comprehension of the educational process. In this context, the rapid advances in technology require us to prepare the students to the possible problems they might encounter in the future and that are hard to predict in the presence time. Hence, problem Based learning (PBL) would be the most effective teaching strategy. Problem based Learning and parallel to it Project Based Learning that start by giving the learners the ability to apply before the introduction of the concepts would create a positive, motivating learning environment that enable the learners to comprehensively understand and analyze the problem.

Considering the nature of any cognitive activity or task as a continuous process of learning through unknowing, doing mistakes, recognizing and identifying the unknown, and finally knowing would clearly establish the connecting lines among the six levels of the cognitive domain. However, viewing the cognitive domain from this angle would impose big questions about what levels should come first and what should come last.

In summary, the six levels of the cognitive domain can be arranged in different possible teaching orders. Using STEM methodology in teaching allows us to invert and/or to disperse the levels of the cognitive domain in Bloom's taxonomy starting with create and evaluate followed by analyze, understand and apply and finally remember. The impact of STEM education on Bloom's taxonomy is dispersive and create different possible arrangements. Educators can use the six levels of the cognitive domain in any order to teach sciences. STEM education imposes and enables inverting the hierarchy. This suggestion gives a strong teaching order for the six levels within almost each STEM lesson or project. However, other orders are still possible and acceptable.

Action plan related to research actions

Determining the adopted actions

A detailed action plan for implanting the research and testing its assumptions was set. In order to implement the research in the best way, the adopted actions were divided into three sections (before, during, and after) the implementation (table 1). Then I set a plan for the actions taken in this research and connected to the research problem (table 2).

The Action and Evaluation Plan		
Adopted Actions		
Before the start of the projects	**During the implementation**	**After the implementation**
1- Choose the topic of the project. 2- Determine the project objectives. 3- Determine how the students will present their findings. 4- Determine the evaluation strategy: ask questions to measure how deep the pupils understand and comprehend the lesson. 5- Set a rubric to evaluate the students' projects. 6- Inform the lab supervisor to prepare the necessary materials and equipment. 7- Get the necessary approvals and appointments for field trips and visits. 8- Prepare the questionnaire about the pupils' attitude.	1- Divide the students into heterogeneous groups by achievement 2- Introduce the topic in an attractive way to motivate the pupils. Ask uncommon questions to make the students think to make them want to learn more. Ask simple questions to motivate the students to focus. 3- Redistribute the groups into homogeneous by achievement ones, assign a leader for each group. 4- Start the project with a practical activity to make all the students work and to break the ice. 5- The students start collecting the data using the internet and the tablets. 6- The groups start taking measurements and doing calculations. 7- The groups start analyzing their findings and results. 8- Follow up the groups, observe their work, and give advice. 9- Each group presents and discusses their work and results with the whole class and listen to the given feedback. 10- Motivate the students to participate and to present their work in the school's science fair and competitions.	1- The students will take an End of Chapter Test to measure their achievement in fulfilling and comprehending the learning objectives. 2- Analyze the students' projects using the projects evaluation rubric.

Table 1. Determining the actions taken before, after, and during the implementation.

After identifying the actions to be taken and in preparation for implementing the research projects, I set the following schedule showing the time needed for accomplishing the research activities (table 2). The research was carried in coordination with the school's administration in October – January, in the first semester of the academic year 22018 / 2019.

Date	WEEKS	LESSONS NO.	LESSON AND PROJECT TOPICS
2/9 -6/9	Week 1	1-5 (5)	Design an insulator
9/9 -13/9	Week 2	6-10 (5)	Our sense of hearing project
16/9 -20/9	Week 3	11-15 (5)	A chemistry experiment
23/9 -27/9	Week 4	16 – 20 (5)	Average and instantaneous velocity Project
30/9 -4/10	Week 5	21 – 25	Acceleration project
7/10 -11/10	Week 6	26 – 30	Forces in Equilibrium
14/10- 18/10	Week 7	31 - 35	Bridge Construction: measuring tension and compression
21/10 -25/10	Week 8	36 - 40	Spaghetti bridge competition
28/10 -1/11	**Week 9**	**41 - 45**	***Pretest: Mid Term Exams (28 Oct - 6 Nov 2018). "Review for mid-terms".***
4/11– 8/11	Week 10	46 - 50	Moments in equilibrium investigation
11/11-15/11	Week 11	51-55 (5)	Strength of members investigation
18/11/-22/11	Week 12	56-60 (5)	Investigating Biomechanical Properties of plant materials
25/11-29/11	Week 13	61-65 (5)	Finding Young's Modulus and Flexural Modulus for metals and polymers
2/12-6/12	Week 14	66 – 70 (5)	Solar Tower Construction project
9/12-13/12	**Week 15**	**71 – 75 (5)**	**Posttest: End-of-Term 1 Exams (9 Dec 2018) / Questionnaire**

Table 2. Action plan for implementing the project.

The projects, activities, and generally the STEM lessons followed a "Do -then - Explain' Model. In which the students were first engaged, in activities, producing their products and checking if it works or not and why. It was not necessary to explain anything such as the scientific concepts or mathematical formulae except the procedure. While doing the activity, the questions posed by the students would drive their understanding and comprehending of the lesson's key concepts and ideas. So, the implementation of the activity didn't follow the general model of learning that starts with low skills levels such as remember and understand, it rather started with creating and evaluating; i.e, the activities started from the top of the Bloom's taxonomy to the bottom.

Research Methodology

The Semi-experimental approach was used in this research as this approach is appropriate for using with this kind of researches. Pretest and posttest were done to investigate the impact of the STEM methodology on improving the students' attitude towards science learning and enhancing their academic performance.

Research variables

The STEM teaching methodology represents the independent variable while the students' academic performance and their attitude towards learning STEM and sciences in addition to their dispositions towards future career represent the independent variable.

All other variables such as the quality of the students and the teacher were remained fixed.

Worth mentioning that in this research STEM used in two ways: a- as a separate teaching curriculum and b- as culminating activities carried out at the end of each chapter.

Sample Selection

The research sample consists of 25 nine graders (9B + 9D) from Qatar Science and Technology Secondary School for Boys (QSTSS), that is the same school where the researcher works.

The chosen students to participate in the sample were know achievers compared to their colleagues as were shown by their results in the pretest. The candidate students were first interviewed to investigate their dispositions towards future career. The chosen students to participate in the study were unwilling to continue their university education in one of the engineering, medical, or science fields.

The Limits of the Study

The current study was restricted to the following limits:

- The study sample was limited to the nine graders studying in QSTSS (Doha/Qatar) during the first semester of the academic year 2018 / 2019. However, the research community might extend to include all secondary schools' male students studying in Doha / Qatar.
- In the study, a summative test for measuring the achievement prepared by the researcher himself was used and authenticated by the school administration and the Evaluation Institute in the Qatari Ministry of Education and Higher Education. To measure the students' attitudes towards learning STEM, the study used a questionnaire originally set by (White et al, 1997), and modified by (Osborne et al, 2003). The questionnaire was further modified where necessary to make it appropriate for the study objectives. Therefore, the results of the study will be restricted and limited by the distinctive features and characteristics of the measuring tools, i.e., the pretest, the posttest and the questionnaire. All tests and questionnaires have their limitations as they cannot ever cover all the aspects and topics.
- The results of the study will be limited only to the nine-grade, the STEM class that participated in the study. Consequently, the results of the study are limited by the class / grade and the taught subject.

Mechanism of research implementation

STEM lessons are delivered in the morning sessions as the students are more active and willing to participate at that time. In some periods, a colleague teacher was invited to help in distributing the tools and organizing the work. At the beginning of each lesson I explained the topic and the task to the students, introduced the objectives and the expectations and how they will be evaluated by the end of each activity.

The projects, activities, and generally the STEM lessons followed a "Do -then - Explain' Model. In which the students were first engaged, in activities, producing their products and checking if it works or not and why. It was not necessary to explain anything such as the scientific concepts or mathematical formulae except the procedure. While doing the activity, the questions posed by the students would drive their understanding and comprehending of the lesson's key concepts and ideas. So, the implementation of the activity didn't follow the general model of learning that starts with low skills levels such as remember and understand, it rather started with creating and evaluating; i.e, the activities started from the top of the Bloom's taxonomy to the bottom.

Difficulties and alternative solutions

During the implementation of the project, I was faced by some obstacles and difficulties that I made my best to overcome them. The majority of these problems were:

1- The long time needed for the preparation for the projects: to overcome this problem, a help was asked from colleague teachers and I was forced to work outside the school hours for a late time.
2- The use of new technology: extensive training was given to the students prior to the start of the projects on the use of the new devices and sensors.
3- Unwilling to participate: some students expressed their willing not to participate; I motivated them by giving extra marks and thanking letters to the participating students.
4- Frustration and loss of motivation: the students were disappointed by their performance in the pretest (mid-term exam). To overcome this problem, the academic deputy was invited to talk and to explain to them that they still have a good chance to compensate and there is a big opportunity for them to score high.

5- Following up the students during the course of the research: a help was asked from a colleague teacher to organize the work.

Data Collection Tools: Description and Utilization

Research tools:

1- The pretest and the posttest

Table 3 shows the specifications of the pretest. The pretest (Appendix 1) consists of 10 multiple choice statements and 5 constructive response (essay) questions.

Serial	Unit	Hours	Relative Weight	Total Points	Description of Test Questions			
					SR (Multiple Choice)		CR (Essay)	
					Number	points	Number	Points
1	Science, Technology, Engineering and Mathematics	12	15	4	4	4	0	0
2	Measurements, Quantities and Notation	12	15	4	0	0	1	4
3	Position, Velocity and Acceleration	14	17	5	1	1	1	4
4	Forces and Equilibrium	14	18	6	2	2	1	4
5	The Strength of Materials	14	18	6	2	2	1	4
7	Work, Energy, Power	14	17	5	1	1	1	4
	Total	80	100%	30	10	10	5	20
DOK	Questions	DOK 2 = 30%				DOK 3 = 20%		
	SR	3				2		
	CR	1				1		

Table 3. Pretest specification table.

The pretest was standardized and authenticated by the school's academic deputy and the assessment specialists in the Ministry of Education and Higher Education. The pretest was submitted to scheduled to students on October 28, 2018. Table 5 shows the specification table for the posttest (final exam). The posttest consisted of 10 multiple choice questions and 9 constructive response questions. The questions in both tests were varied in their degree of knowledge (DOK). The posttest contained some repeated questions from the pretest (anchor questions) to track the students' progress in achievement.

Serial	Unit	Hours	Relative Weight	Total Points	Description of Test Questions			
					SR (Multiple Choice)		CR (Essay)	
					Number	points	Number	Points
1	Work, Energy, Power	14	20	10	2	2	2	5 + 3 = 8
2	Machines	12	17	8	3	3	1	5
3	Electricity and Circuits	14	21	11	1	1	2	5 + 5 = 10
4	Electric Power	14	21	11	2	2	2	5 + 4 = 9
5	Waves and Sound	14	21	10	2	2	2	4 + 4 = 8
	Total	68	100%	50	10	10	9	40
DOK	Questions	DOK 2 = 30%				DOK 3 = 20%		
	SR	3				2		
	CR	3				1		

Table 4. Posttest specification table.

The posttest was standardized and validated by the academic deputy and a group of STEM teachers. The posttest was submitted to students on Dec 9, 2018.

2- The Questionnaire:

A questionnaire (Appendix 2) was developed to measure the pupils' attitudes towards STEM learning, collaborative learning through group work, problem-based learning and project-based learning. The questionnaire was distributed by the end of the first semester in the academic year 2018 / 2019 after the students have fulfilled all the requirements of the STEM course and carried out the required projects.

The used questionnaire (Cronbach α = 0.76) was originally set by (White et al, 1997), and modified by (Osborne et al, 2003). The questionnaire was further modified where necessary to make it appropriate for the study objectives and presented for a group of teachers in the school for amendment and validation.

The questionnaire contains four sections (A, B, C, & D); the first section comrises 27 statements and is directed to measure the overall attitude of students towards STEM learning, the second section comprises 4 statements and is directed to measure the students' attitudes towards collaborative learning through group work in STEM. The third section contains four statements and is directed to measure the students' attitudes towards problem solving. The last section comprises seven statements directed to measure the overall attitude of students towards projects integration and implementation in STEM.

The questionnaire statements were rated on a 4-point Likert scale in an ascending order as follows:

- Strongly disagree - 1 point
- Disagree - 2 points
- Agree - 3 points
- Strongly agree - 4 points

For the purposes of statistical analysis, the first two responses (strongly disagree and disagree) were pooled together and the same was done for the last two responses (agree and strongly agree).

Twenty-five copies of the questionnaire were distributed to the students, returned, and considered valid for analysis. The maximum result was 168 distributed as follows: 108 for A section, 16 for B & D sections, and 28 points for D section. When analyzing the questionnaire, the marks of the negative statements were reversed and added.

3- The Personal Interview

Personal interviews are considered an important tool for obtaining information from its direct human resources. In its simplest form, the interview consists of a group of questions or statements set by the researcher and posed to the subject students (Creswell, 2012). Th researcher then records the data. There are different types of interviews including one-on-one, focus group, telephone, e-mail, guided, and open-ended questions.

In this research, the interview was used as a tool to collect qualitative data about the students' dispositions for future career. In the interview, the participant students were asked open ended questions about the factors that affect and determine their career choices and their attitudes towards university education. The interview investigated the parents' and society impact on the personal choices of the students. The students' responses were recoded and transcribed for further analysis.

Actions taken and implementation mechanism

1- Reviewing the related open literature published in Arabic, English, and Russian.
2- Preparing the projects and the semester plan for the STEM course.
3- Choosing the sample.
4- Doing the pretest.
5- Applying the STEM approach (see the attached video: https://youtu.be/vcpUaG_vbHc).
6- Doing the posttest, distributing the questionnaire, analyzing the results, and writing the research report.

Results presentation and Discussion considering the Hypotheses

I. The results of Questionnaire

The STEM lessons were performed following the "Do-Then-Explain" model in which the students start the activities creating products, evaluating and analyzing them rather than remembering and understanding. This way of delivering the content inverses Bloom's taxonomy as it starts from the high skill levels of the cognitive domain to the lower ones.

To test the first hypothesis from which the first research question was derived "Are there statistically significant differences ($\alpha \leq 0.05$) in the attitudes of nine graders towards STEM learning due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology?", I distributed 25 questionnaires over 25 students present in the class before implementing the STEM approach. All the questionnaires were returned and considered valid for analysis. Then I redistributed 25 copies of the questionnaire after the experimental part of the study was accomplished. All the copies were returned and considered valid for analysis. The means and the standard deviations for the students' responses in the questionnaires were calculated table (5). The questionnaire (Appendix 2) comprises 42 statements with the highest mark 168. When analyzing the questionnaire, the negative statements were reversed then added.

Table 5 shows that the value of the t-calculated (t=1.98, α=0.05) is higher than the value of the t-tabulated (t=1.68, α=0.05, D.F. = 48) therefore the hypothesis stating that there are statistically significant differences in students' attitude towards STEM learning due to STEM approach was accepted.

Objective	The tool: Questionnaire	Number	Mean of responses sums	Standard deviation	T-value	Significance (α-value)
Measuring the students' attitude towards STEM	**Pre**	**25**	**72.5**	**10.82**	**1.98**	**0.05**
	Post	**25**	**151.4**	**12.67**		

Table 5. means, standard deviations, and the results of the t test in the attitudes questionnaire.

II. The results of the pretest and posttest

To test the validity of the second hypothesis from which the second research question was derived: **"**Are there statistically significant differences (α ≤ 0.05) in the nine graders achievement in the pretest and posttest due to inverting the cognitive domain levels of Bloom's taxonomy using the STEM methodology?", the number of the students who passed and who failed were counted. The success and performance percentages, the students' average and the standard deviation were calculated. Table 6 summarizes the results of the students in the pretest and the posttest. T-test ($\alpha \leq 0.05$) was done to compare the averages of the students in both tests (table 7).

	Pretest	*Posttest*
Mean	13.84	24.64
Standard Error	1.16	0.91
Median	14	26
Mode	17	29
Standard Deviation	5.81	4.57
Sample Variance	33.8	20.90
Minimum	3	16
Maximum	24	30
Count	25	25
Succeeded	10	25
Failed	15	0
Success %	40%	100%
Achievement %	46.1%	82.1%
Number of students who got the full mark	0	3
The highest mark	24	30

Table 6. Descriptive statistics for the pretest and posttest results.

Objective	The tool: Test	Number	Mean	Standard deviation	T-value	Significance (α-value)
Measuring the improvement in the students' performance	**Pretest**	**25**	**13.84**	**5.81**	**2.01**	**0.05**
	Posttest	**25**	**24.64**	**4.57**		

Table 7. means, standard deviations, and t-test results for the students' performance in the pretest and posttest.

Since the value of the calculated t test (t=2.01) is higher than the value of the tabulated one (t=1.68), we accept the hypothesis that states that there are statistically significant differences in the students' achievement due to the STEM education.

III. The results of the interview

To test the third hypothesis from which the third research question was derived "Are There statistically significant differences ($\alpha \leq 0.05$) in the nine graders' dispositions towards future career due to the STEM approach?", the students were interviewed in focus groups of 5 students. Trend analysis (fig. 1) of the students' responses in the interviews has revealed that joining a STEM program or studying in a STEM school has the greatest effect on the students' choices in the selection of future careers. Out of the interviewed 25 students, 18 students have expressed their willing to study in one of the engineering specialties in the future, 5 five them show their desire to join a medical college, while the last two students still unsure and show some hesitation about their future choices.

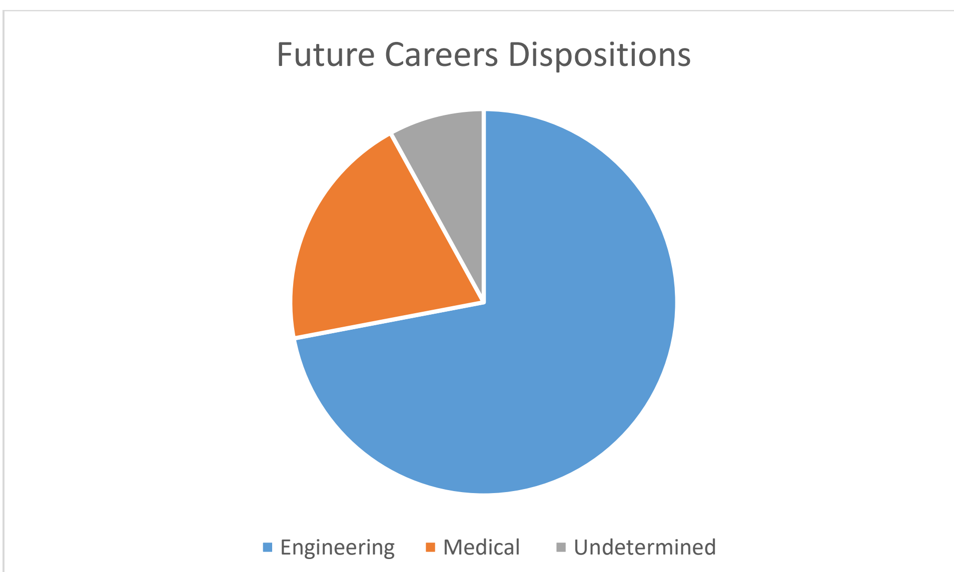

Fig. 1. A pie chart showing the proportion of students willing to work in the engineering and medical fields.

Below are some of the students' reflections towards STEM education and its impact on the personal choices:

- Group work adds too much fun to the investigations.
- I feel happy and satisfied that I can use advanced technology such as the ones used in the FAB lab.
- Working with robotics made me want to study more about the microprocessors and their engineering.
- I wish in the future I can use robotics in treating serious diseases and carry out surgical operations.
- Now, it's easy for me to plan and implement a scientific investigation.
- I learned much from the spaghetti bridge project and the insulator project more than the ordinary textbook could teach me.

To test the fourth hypothesis from which the fourth research question was derived: "Are there statistically significant differences ($\alpha \leq 0.05$) in the nine graders' attitude towards learning STEM due to applying STEM approach as a separate curriculum rather than as culminating end of term projects?", the questionnaire was analyzed considering its 4 dimensions:

1- Dimension A: comprises statements [A1 – A27] and measures the students' overall attitude towards STEM learning as a separate subject.
2- Dimension B: comprises statements [B1 – B4] and is directed to measure the students' attitudes towards collaborative learning (CL) through group work in STEM projects.
3- Dimension C: comprises statements [C1 – C4] and its objective is to measure the Students' Attitudes towards problem solving (PBL) in STEM.
4- Dimension D: comprises statements [D1 – D7] and measures the overall attitude of students towards projects in STEM.

Table 7 shows the average responses for each student for the four dimensions of the questionnaire.

	Average (A)	Average (B)	Average (C)	Average (D)
St.1	3.93	4.00	4.00	4.00
St.2	3.19	3.50	3.75	3.83
St.3	3.41	3.50	3.75	3.67
St.4	3.67	3.25	3.25	3.67
St.5	3.52	3.00	3.75	3.83
St.6	3.52	3.25	3.75	3.67
St.7	3.67	3.50	3.75	4.00
St.8	3.59	4.00	3.75	3.67
St.9	3.37	3.75	3.25	3.67
St.10	3.52	3.50	3.50	3.83
St.11	3.63	3.75	3.75	3.67
St.12	3.89	3.75	3.50	3.67
St.13	3.37	3.25	4.00	3.67
St.14	3.63	3.25	3.50	3.50
St.15	3.15	3.50	4.00	3.83
St.16	3.48	3.50	2.75	2.67
St.17	3.19	3.50	3.75	4.00
St.18	3.33	3.75	2.75	3.83
St.19	3.41	2.75	3.75	4.00
St.20	3.07	3.75	3.50	2.83
St.21	3.26	3.25	3.25	3.17
St.22	3.41	3.50	3.25	3.33
St.23	3.30	2.75	3.00	3.50
St.24	3.41	3.25	3.25	3.50
St.25	3.04	3.25	3.50	3.17
Average	3.44	3.44	3.52	3.61
St. Dev.	0.228	0.325	0.353	0.346

Table 7. the average responses, and the standard deviations for each participant student in the questionnaire.

Table 8 summarizes the results of the questionnaire considering the four (A, B, C, and D) dimensions of the questionnaire.

	St. overall attitude towards STEM as a separate subject [A1 – A27]	St. attitudes towards CL through group work in STEM. [B1 – B4]	Students' Attitudes towards problem solving in STEM. [C1 – C4]	Overall attitude of students towards projects in STEM. [D1 – D7]
Average (A, B, C, & D)	3.43	3.44	3.52	3.61
Standard Deviation	0.228	0.325	0.353	0.346

Table 8. Averages and standard deviations of the students' responses in the 4 sections of the questionnaire.

To investigate if there are any differences in the students' average responses across the four dimensions (A-D) of the questionnaire, Single Factor ANOVA test (table 9) was done using Microsoft Excel software (2018).

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups (A, b, C, & D)	0.483467078	3	0.161156	1.602748	0.193819	2.699393
Within Groups (A, b, C, & D)	9.65276406	96	0.10055			
Total	10.13623114	99				

Table 9. Single Factor ANOVA test for the four dimensions (A-D) of the questionnaire.

The results of the ANOVA test show that P-value is 0.193, which is much greater than the significance level (0.05). therefore, we can accept the null hypothesis, the hypothesis of no difference stating that the mean of the responses for the 4 different dimensions are equal. So, we can conclude that there are no differences in the impact of teaching STEM as a separate subject or as integrated projects with the curriculum.

Discussion and Interpretation of the Results

The research, based on previous studies, initially assumed that applying STEM education would have positive, statistically significant effects on the students' attitudes towards learning sciences, collaborative learning and PBL. It also assumed that STEM education would affect the students' dispositions towards future careers and in this sense, STEM would direct them towards studying medicine, engineering, or related subjects. The research also assumed that STEM education will enhance and improve the students' performance in standardized tests.

The STEM lessons were constructed in a way to follow the general model of "Do-Then-Explain'. In this model the students are immediately engaged in activities that require them to create and evaluate products. It was not necessary to explain anything except the procedure. As the students proceed with their activities, they ask questions that will drive their understanding of the lesson's key ideas and concepts. The advanced techniques and facilities in QSTSS allowed the development of such lessons where the students can synthesize their product first using the augmented reality or virtual reality, they can assemble bridges and measure the stress and strain in the members under compression and tension. The collapse of the bridge raises questions in the students' minds about the allowed loads that different bridge members can sustain. This way of driving the lesson, (create, evaluate, then explain, apply, understand and remember) enhances students learning, improves their achievement, and increases their positive attitudes towards sciences.

To test the validity of the above assumptions a pretest was given to the students and the attitudes' measuring questionnaire was distributed then STEM program was applied. After the accomplishment of the STEM program, the students took the posttest and the questionnaire was redistributed. Moreover, the participating students were interviewed to collect their responses about their dispositions towards future careers.

Analyzing the questionnaire considering its dimensions has clearly revealed a strongly positive attitude towards learning sciences due to STEM education (table 6 & figure 2) and that there wis significant improvement in the students' achievement in the standardized tests (table 8 & figure 3). These results were verified using t-test (α ≤ 0.05).

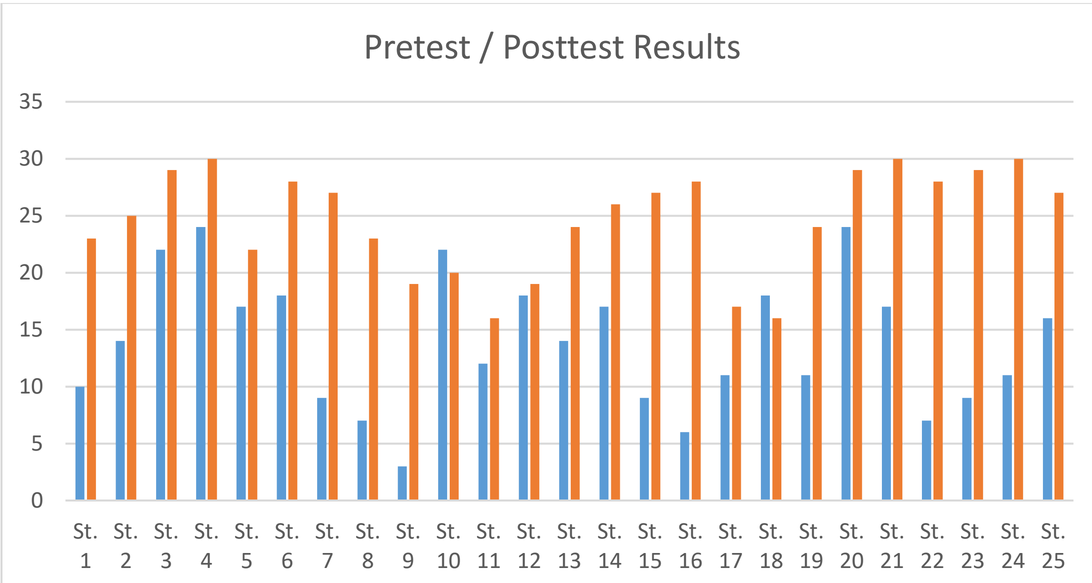

Fig. 2. A clustered Column Chart represents the students results in the pretest and posttest. The blue columns are pretests while the orange ones refer to the posttest.

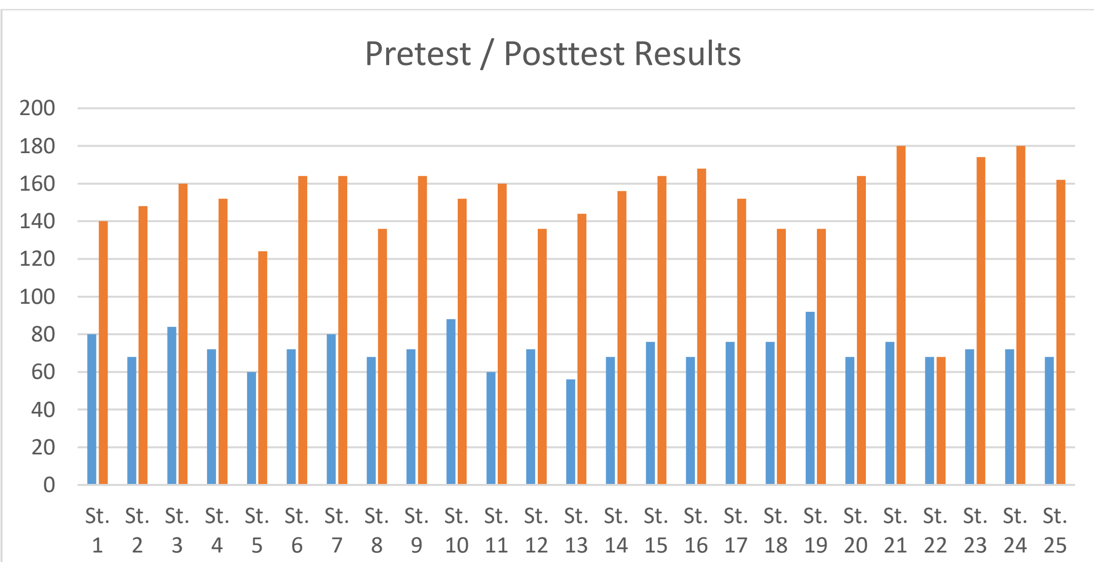

Fig. 3. A clustered Column Chart represents the students results in the questionnaires before and after the application and accomplishment of the STEM program.

The results of the study showed that the students who participated in STEM education have a strong positive attitude towards continuing their education in the future in one of the engineering or medical fields.

The above results could be explained considering the nature of the STEM program and analyzing its activities and projects. Inverting the six levels of the cognitive domain of Bloom’s taxonomy as explained before had a positive effect on the students’ learning. It creates a medium where the students first create, evaluate, and analyze then they apply, understand and remember.

In QSTSS STEM is an introductory course for AP courses in Biology, Chemistry, Physics and Math. STEM focuses on basic science concepts and their connections to everyday life through different engineering designs and applications. Connections to everyday life and society include energy conservation, pollution, health, the origin of the universe, pseudoscience, and the search for life in extreme conditions. While advanced mathematics is not required for this course, basic math with simple algebra and some trigonometry is extensively utilized. Problem solving, reasoning, data analysis, and graphing skills are emphasized throughout the course. The overall goals of the STEM course include students' gaining an appreciation for the physical, chemical and biological world, improved students’ critical thinking and reasoning skills, and improved scientific literacy to enhance the 21st century skills. The major topics covered in the STEM course are Newtonian mechanics, fluids, heat, vibrations, electricity and magnetism, light and sound, atomic structure, nature of chemical reactions, basic chemistry of life, ecosystems, Earth and cosmology. STEM teaching is by its nature student’s centered that relies heavily on active learning using project-based learning and problem-based learning. However, STEM education takes advantage of the well-equipped laboratories available in the school including the fabrication lab, energy lab, and robotics lab. Moreover, the VR and AR activities are used to strengthen the students’ knowledge or to introduce a new topic. In summary, STEM develops research skills, critical and creative thinking.

To implement the STEM course activities and projects, the students were divided into small groups of 3. The discussions and talks among them formed the context in which the students were learning. In many times, theses discussions were so significant and critical for teaching and learning.

The students to fulfill the requirements of their projects were asked to design models and prototypes such as the insulator cup and the spaghetti bridge that met certain engineering and safety criteria. In presenting their projects, the students show deep understanding of the used scientific principles. Working on the projects facilitates the engagement of all the students in the teaching and learning cycle. In all the projects, the students were asked to use advanced technology such as sensors and data loggers for data collection, interpret the results mathematically and give engineering explanation for their results. While working on the projects the students were not only exploring science but also discovering their potentials, abilities, attitudes, and dispositions. STEM education gave the students the ability to rediscover themselves and reshape their personalities.

Post-Research Reflection and Evaluation of the Results

The study sample comprised 25 nine grade students who participated in the STEM educational course held by QSTSS in the first semester of the academic year 2018 / 2019. Before the start of the STEM program, there was a general trend among the Qatari students, (study community), not to join medical or engineering faculties. Where the traditional educational programs delivered in different state schools failed to revert the students' dispositions and to motivate them to join scientific faculties, the policy makers in the Qatari Ministry of Education decided to establish a scientific school equipped with the most advanced technology, labs, and techniques. The school started with 60 students in grade 9 distributed over 4 sections. In QSTSS, STEM is taught as a separate subject weighing 10 hours weekly.

The current study proves that STEM education is essential and pivotal for Qatari students. According to the study results, STEM education has succeeded in providing the students with a strong scientific background, improved their achievement in the standardized tests. Moreover, it was proven that STEM education has affected the personality of the students, and it has positive impacts on the students' attitudes towards learning sciences. The study showed that students who participated in STEM program became willing to continue their university education in one of the medical or engineering specialties.

The study showed also that STEM education is necessary for the students as it provides them problem solving skills, critical thinking, creative thinking, and other 21st century skills.

Overall, the results of the study show that students react positively with STEM education and increases their motivation towards learning.

However, I would like to strengthen the STEM program at QSTSS with more long-term projects that investigate real life problems including health issues, environmental pollution, gas production, and industry. In the future, I would give the students more space and opportunity to work independently and to encourage them to be self-learners.

Conclusions and Generalizations

The results of the present study showed clearly the effectiveness of STEM education in improving the academic outputs of the nine graders. The statistical analysis showed that there are statistically significant differences in results of the students in the pretest and posttest as well as in the attitudes questionnaire before and after the implementation of the STEM program. These differences were due to and in favor of the STEM educational program. Considering the study results, the STEM educational program should be generalized to cover all students at all levels from Kindergarten to grade 12.

The Follow-up Plan and the Amending Actions Related to the Research Problem

To foster the positive effects of the research on the achievement and attitudes of the students who participated in the STEM Educational Program, a plan for evaluating the program and assessing the students was set (table 10) based on which I would introduce some necessary amendments. The amendment plan was applied starting January 2018.

Action	Purpose	Duration	Targeted students
Holding the End of Term exam	To Measure the achievement of the learning objectives	120 min	The students participating in the study (the sample)
Analyzing the students' projects considering the rubric	To recognize what was accomplished and what wasn't accomplished and why	180 minutes	
Students present their work	Evaluating the students' progress and celebrating their efforts	240 minutes	
Organizing a whole class objective discussion about the pros and cons of STEM program	Taking feedback from the students and utilize them in future planning	60 minutes	
Motivating the students by presenting their works in the class and school fairs	Celebrating the students works, enhancing self-esteem, and improve motivation towards engineering and medicine	60 minutes	

Table 10. Follow up, Amendment, and Evaluation Plan.

Recommendations and Suggestions

There was a strong, positive effects for the projects and activities of the STEM program on the students' achievement and attitude. Based on the study results, it is highly recommended that:

- Providing the STEM educational program with more projects and activities that foster active learning and creative thinking.
- Measuring the impact of STEM education on the students' creative thinking.
- Identifying the students' preferences at the beginning of the academic year and use that in choosing the topics for the projects.
- Extending the STEM Educational Program to cover more schools and more students from both genders and at all levels.

Most educational programs classify the learners into three major categories (high achievers, low achievers, and intermediate achievers). The differences among the three student groups are usually covered using additional worksheet, assigning more time, or giving individual tuition. However, it is thought that because of its nature STEM programs would not work well with the low achievers. Here I would say that from my experience, any traditional amendment program targeting low achiever students tries to simplify the subject, tailor the education to match the students' abilities. I think this approach would not have positive permanent effects on the students even though it might help the low achievers to pass the exams. However, STEM works differently. It creates a new challenging and motivating environment. It provides the medium and the context for all students to learn leaving nobody behind. STEM works through elevating the students' potential for learning but not lowering the level of the curriculum. STEM keeps our expectations from all students high.

Finally, this study is a call for educational policy makers to establish more STEM schools to reach all the students.

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Appendices: Appendix 1: Pretest

First Selective Response Question

1.1 **Which of the following statements best describes a scientific theory?**

- A Tentative
- B Wrong when first proposed
- C Well – established
- D Supported by a limited number of evidences

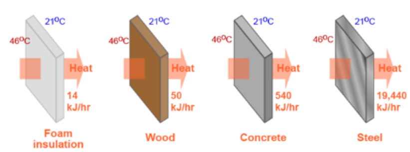
1.2 **Sound waves are characterized by pitch, frequency and amplitude. What is the relationship between pitch, frequency, and amplitude?**

- A Low-pitched sounds have low frequencies.
- B Low-pitched sounds have high frequencies.
- C High-pitched sounds have low amplitudes.
- D High-pitched sounds have high amplitudes.

1.3 **Which of the following phenomena is a chemical change?**

- A Mixing sand with water
- B Condensation of water
- C Molten iron solidifies
- D Burning Natural gas

1.4 **The below figure shows heat flow through different materials. In terms of insulation, which of the materials would be a best choice to build a house in the desert?**



- A Steel
- B Concrete
- C Foam
- D Wood

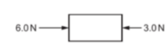
1.5 **Which of the following statements describe displacement?**

- A A football player kicked a ball 40 meters away.
- B A hiker walked 6 km through the wilderness
- C A student sits 3 m in front of the teacher's desk.
- D A man drove his car a 1 km north of the train station.

1.6 **Which of the following forces acting on a bridge are reaction forces?**

- A The force created by the weight of the bridge.
- B The force created by a person walking on the bridge.
- C The force created by the pillars of the bridge.
- D The force of the wind blowing on the bridge.

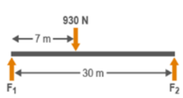
1.7 **The diagram shows an object being acted upon by two forces.**



What is the size of the resultant force?

- A 2.0 N
- B 3.0 N

A 930 N student walks across a bridge held up by pillars spaced 30 meters apart. How much force is each pillar supporting when the student is 7 meters from the left pillar? Show your work.

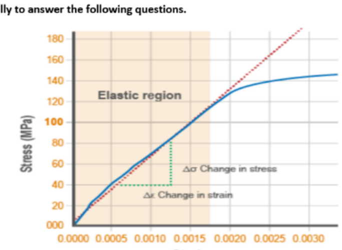


Answer:

____

Fifth Question	L8.1 – L8.4	4

The graph below shows the relationship between stress and strain for a given material. Study it carefully to answer the following questions.



1- Draw an arrow on the graph to show the ultimate tensile strength.

2- What are the units of the strain?

____

3- What is the region of elasticity for the above material?

____

4- Calculate Young's Modulus (Modulus of elasticity) for the above material?

Appendix 2: Questionnaire on the Impact of PBL towards STEM Learning among Nine Graders in QSTSS

This questionnaire comprises 4 parts. Read each statement and then mark (√) the square that best shows how you feel (4 is the highest and 1 is the lowest).

A. Overall attitude of students toward STEM

	Strongly Disagree	Disagree	Agree	Strongly agree
	1	2	3	4
1. I enjoy STEM at School				
2. I look forward to STEM lesson				
3. I feel good about my progress in STEM				
4. To me, technology and engineering are exciting				
5. I think that learning STEM is important				
6. I enjoy the activities we do in STEM				
7. STEM is one of the most interesting school subjects				
8. I want to find out more about the applications of engineering and technology				
9. To me, science and math are fascinating				
10. Finding out how things work is important				
11. I think that STEM teachers help me to learn				

12. I like talking to my friends and relatives about what we do in STEM lessons				
13. I can think and share my ideas in STEM				
14. We should have more STEM lessons each week				
15. I am learning how to carry out STEM investigations				
16. I am learning lots of useful skills such as taking measuring, data recording and plotting graphs				
17. I use computers and technology in STEM to help me to learn				
18. STEM teachers help me to learn and use new scientific words and their meanings				
19. I can use my math skills in STEM to solve engineering problems and draw graphs				
20. Assigning a specific role to me in the STEM projects is useful and helps me to understand				
21. I am learning about big ideas such as forces and energy, particles, pollution, health problems				
22. The activities in my projects are fun and interesting				
23. At the end of each project, we share and discuss our findings				
24. The STEM in school is not important to my everyday life				

25. Doing then understanding is more important than understanding then doing				
26. STEM is too difficult for most students to comprehend				
27. I would like to have a career in technology or engineering				
B. Student attitude towards group work in STEM projects				
1. I feel happy working in groups				
2. Group work is essential for learning STEM				
3. Learning scientific concepts through memorizing helps me learning STEM				
4. Learning scientific concepts through projects helps me learning STEM				
C. Student attitude towards problem solving in STEM				
1. As a result of participating in STEM projects, my ability to define and solve a problem has improved				
2. I feel that I can apply STEM skills and principles to "real life" problems				
3. I am confident that I can analyze a STEM problem				
4. Application of STEM principles to other subjects is essential				
D. Overall attitude towards projects in STEM				
1. I would like to participate in other STEM projects				

2. Overall, I would rate this STEM project				
3. Compared to other courses at the school, projects helped me learn more than usual				
4. Sharing the results and artifacts created by me in science fairs and competitions is very important to me				
5. Receiving feedbacks on my work has enriched my work				
6. Talking with other students and teachers about my projects highly motivates me				
7. I feel satisfied after participating in STEM projects.				

Appendix 3: Lesson Plan 1.3: A chemistry experiment

This is a warm-up lesson designed to engage students and do some simple, fun chemistry while also introducing the idea of experiments and experiment design. The actual chemistry is complex, but that is not the point of the activity.

Learning objectives

The student will be able to:

- Conduct a simple experiment and record data in a table
- Recognize the qualities of a good experiment design
- Critique a poor experiment design

Prior knowledge

None

Teaching tools

- 1_3_AChemistryExperimentSlides.pptx
- 1_3_AChemistryExperimentAssignment.docx
- 1_3_AChemistryExperimentAssignmentAnswers.docx

Materials

Assignment/Investigation

- One box of four-color food dyes
- Four cuvettes
- An eyedropper
- Sodium hypochlorite bleach in a dropper bottle
- A 10 mL graduated cylinder

Electronic resources

- None

Lesson Plan Segments

Setup

This is a do-then-explain activity. It is not necessary to explain anything except the procedure. Student's questions will drive the understanding of the key ideas of the lesson.

Experiment outline

1. Set up cuvettes with colored water. This gives practice being careful, and using cuvettes and eyedroppers.
2. Students count how many drops of bleach it takes to make each cuvette turn clear. Some of the colors are "stronger" than others and take less bleach.

Slide presentation content

- Setting up the experiment?
- Recording your observations and data
- Making conclusions
- Good and bad experiment design

Student work

- Complete the activity and record the data
- Answer questions from the assignment

Assessment Questions: What are some characteristics of a good experiment design compared to a poor experiment design?