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A Proposed Unit Based on the STEM Approach: Developing 21st-Century Skills Among Middle-School Students

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Abstract

This research aims to determine the effectiveness of a proposed instructional unit based on the integration of science and mathematics, following the STEM approach, to teach critical thinking and problem-solving as 21st-century skills. To achieve this goal, an experimental approach based on a quasi-experimental single-group design with a pre-test and post-test was used. The research sample consisted of 40 third-grade students in a middle school. A problem-solving skills test was developed, and the Watson Glaser Critical Thinking Skills Appraisal was used, the results showed statistically significant differences between the mean scores of the participant group in the pre-test and post-test measurements for both critical thinking and problem-solving skills. The research concluded that the proposed unit helped students develop 21st-century skills.

Keywords: *proposed unit, STEM, integration, science, mathematics, twenty-first-century skills, middle school*

1. Introduction

The present age is witnessing an information revolution and tremendous development in science and technology, which requires high-quality human skills to adapt and meet the demands of today's world. Science and mathematics play a prominent role in technical and knowledge progress and provide fertile ground for the development of thinking skills. They are characterized by regularity, self-control, and intellectual pleasure. These subjects have practical applications in all areas of life, helping to identify students' potential and abilities.

Many educational studies and theories have emphasized the importance of connecting science and mathematics. For example, the cognitive theory is one of the most prominent modern learning theories; it focuses on the mental processes that form the learner's cognitive structure, intending to achieve a deeper understanding of cognitive processes such as attention, perception, and problem-solving (Qatami, 2013). The cognitive theory confirms that integrating scientific experiences during learning encourages deep cognitive learning through the learner's interaction with integrated cognitive situations and the acquisition of scientific knowledge (Pang & Good, 2000). Likewise, the constructivist theory, from which the philosophy of sciences–mathematics integration derives, is one of the theories that states that knowledge is actively built by creating an environment for the learner to develop their knowledge by themselves (Zaytoun, 2007). The constructivist theory confirms that effective learning occurs as a result of the sensory experience of the world; learners respond to sensory experiences by developing cognitive structures and establishing links between previous and current knowledge in a way that enhances their understanding and knowledge-building (Berlin & Kyungpook, 2005).

According to Stohlmann et al. (2012), there are fundamental assumptions that connect science and mathematics from the perspective of the constructivist theory, namely:

1. The greater the complexity of scientific and mathematical knowledge, the greater the importance of deep explanations to learners.
2. The greater the impact of applying important mathematical and scientific knowledge to learners, the stronger the building of links between scientific and mathematical knowledge.
3. Scientific and mathematical knowledge is empirical knowledge.
4. Class interaction types increase the effectiveness of the change toward integration.
5. The approach should be based on the learners, and the classroom atmosphere should allow for knowledge exchange.

The integration approach of STEM is one of the most important educational approaches and modern trends dealing with developing and restructuring science, engineering, mathematics, and technology education. This approach is in line with global economic challenges and labor market needs, as well as learners' needs to acquire 21st-century skills that will help them cope with problems and challenges in their daily lives (Barcelona, 2014). Vasquez at el. (2013, p. 23) defined the STEM approach as "creating an educational system based on the integration of other specialized knowledge into one new and coherent unit, which helps learners to develop their skills and the ability to compete globally in the new economy market." Meanwhile, the National Research Council (2011) defined STEM as the "knowledge and understanding of scientific and mathematical concepts and processes required for personal decision-making and participation in the various cultural, productive, and economic fields of life."

The National Research Council (2012) emphasizes the integration of science, technology, engineering, and mathematics and highlights the culture of each discipline as follows:

1. Scientific culture, which comprises three dimensions: knowledge of basic facts, concepts, principles, laws, and theories related to other fields; the ability to link these ideas between disciplines, practices, and ways of thinking; and the use of science in solving problems.
2. Technological culture, which is the ability to use, manage, understand, and evaluate technology. It helps learners use scientific and mathematical tools and skills to solve problems and expand human capabilities.
3. Engineering culture, which is the ability to solve problems and achieve goals by applying engineering design processes and to reach the optimal solution to meet the needs of society.
4. Mathematical culture is the ability of individuals to formulate, employ, and interpret mathematical knowledge in various contexts, including the use of mathematical reasoning, concepts, procedures, and facts.

According to the above, we find that STEM emphasizes the integration of subjects by combining two or more disciplines to realize concept interdependence. It also establishes an important link with students' lives by applying new learning to daily life. By providing a variety of educational outcomes, STEM promotes 21st-century skills, such as problem-solving, critical thinking, communication, and cooperation. It also challenges students, so they do not feel bored and become more involved in the work due to the diversity of the educational context.

STEM has become a worldwide trend, garnering international attention since it is the primary driver of the global economy. Many countries, including the United States, the United Kingdom, and Australia, have focused on the quality of STEM education due to its essential role in building a knowledge-based economy and allowing students to acquire the necessary skills for the 21st century. Interest in STEM began in the Arab world in the second decade of the 20th century. The Kingdom of Saudi Arabia closely monitors modern trends in learning science and mathematics: Its Vision 2030 Document (2016) called for attention to the educational process and improving the educational environment to stimulate creativity and innovation, as well as new teaching methods that use developed curricula, innovative means, and the integration of knowledge. Many educational projects, programs, and initiatives have been launched to help students acquire scientific skills, develop teachers' capabilities and enable them to teach effectively, and establish virtual laboratories for science and mathematics, broaden the application of knowledge and skills. These projects also focus on global partnerships with leading international organizations and universities in science and mathematics education and establishing academic centers and digital content (King Abdullah Project for Education Development, 2014).

The literature has emphasized the importance of using STEM in teaching mathematics and science. For example, adopting an experimental design, Al-Saeed (2018) revealed the effectiveness of using the STEM integrative approach in developing mathematical excellence and 21st-century skills among middle school students. The study's findings revealed differences in the mean scores of the experimental and control groups in terms of their post-application of the 21st-century skills scale as a whole and each skill separately, with the experimental group scoring higher. Al-Zahrani (2019) used an experimental method to identify the effectiveness of teaching a STEM-based science unit for developing problem-solving skills and achievement motivation among sixth-grade female students. The study found the presence of statistically significant differences at ≥ α 0.05 between the mean scores of the experimental and control groups in the post-application of the problem-solving skills test as a whole and in each skill after the pre-control, with the experimental group scoring higher.

Iraqi and Al-Otaibi (2019), also using an experimental method, demonstrated the effectiveness of a proposed strategy based on the integration approach to teaching a conic section unit in developing achievement and critical thinking among third-grade secondary school students. The authors observed statistically significant differences at the 0.05 level between the mean scores of students in the experimental and control groups in an achievement test, the test of critical thinking skills, and the total scores post-application, with students in the experimental group scoring higher. In addition, Hilal (2021) aimed to identify the effectiveness of a unit developed within the STEM framework in developing higher mental skills (critical thinking and problem-solving skills) among primary school students. The experimental group outperformed the control group in the 21st-century skills as a whole and in each sub-skill, with statistically significant differences at the 0.01) level. The effect size of the unit in developing 21st-century skills was significant, with the experimental group scoring higher.

Hussein and Al-Saadawi (2021) followed a semi-experimental approach and concluded that a program based on STEM integration was effective in developing 21st-century skills among science major students at a faculty of education. The findings indicated statistically significant differences at the 0.01 level between the mean scores of the study group students in a 21st-century skills test post-application. In another experimental study, Al-Ahwal (2021) also found that a mathematics unit developed based on the STEM approach and Common Core State Standards for Math (CCSSM) was effective in improving the ability of middle school students to solve real-life mathematical problems. They found statistically significant differences at the 0.01 level between the mean scores of the experimental and control group students in the real-life mathematical problem-solving test, with the experimental group scoring higher. Ziadeh's (2019) experimental study demonstrated that a program based on the STEM approach was effective in developing critical thinking skills in mathematics among eleventh-grade female students in Gaza. The study showed statistically significant differences at the 0.01 level between the mean scores of the experimental and control groups in a critical thinking skill test, with the experimental group scoring higher, as well as a significant impact of teaching mathematics using STEM in developing students' critical thinking skills.

Previous studies have, thus, emphasized the development of 21st-century skills among learners using STEM. These skills are among the trends that have been embraced and advocated across disciplines by the Partnership for Twenty-first Century Skills (2015). The Partnership for Twenty-first Century Skills was established in the US through a partnership among a group of institutions and organizations and is concerned with clarifying how skills can be integrated into curricula. It has defined its framework through two initiatives: the Program for Identifying and Defining Skills and the Program for International Student Assessment (PISA). The first initiative provides the theoretical framework for the second. In this context, 21st-century skills have been divided into three basic skills: learning and creativity skills, digital culture skills, and career and life skills.

Critical thinking and problem-solving are among the learning and creativity skills that current research considers a new foundation for learning in the 21st century. Their application to content knowledge helps to increase motivation and improve learning outcomes, especially in science and mathematics. The results of international studies mentioned in the Education and Training Assessment Commission reports (2019 and 2018), such as the results of the PISA and the Trends in International Mathematics and Science Study (TIMSS), point to the low level of Saudi students in science and mathematics, their lack of basic knowledge, and their low ranking and below-average grades compared to students from other participating countries.

English (2016) highlighted the need for further studies on the significance of student learning, not just in terms of the various forms of STEM integration but also the specific disciplines that are integrated, from kindergarten through the end of secondary education (K-12). Unlike Al-Saeed (2018) and the current study, Al-Zahrani (2019), Hilal (2021), Iraqi and Al-Otaibi (2019), and Asqoul and Ziada (2022) dealt with the primary and secondary stages and did not cover the middle school stage, even though this is a crucial stage in learner's progression. In addition, some studies have been limited to critical thinking skills, while others were limited to solving problems. Some studies have dealt with various educational units in geometry, conic sections, and natural sciences; however, none have examined the integration of mathematics and science. This is the focus of the current research, which prepares a proposed unit based on the integration of science and mathematics according to the STEM approach to explore its effectiveness in developing 21st-century skills among female middle school third-grade students.

Arguably, STEM does not seek to simply integrate and merge the four fields, but rather to understand the real world holistically and comprehensively, instead of in fragments, with a focus on the function of knowledge and the importance of using knowledge and information to solve real-world problems and thinking critically about them (Al-Zahrani, 2020).

2. Research Problems and Questions

Based on the above, the present study responds to the reform movements in education, the importance of economic progress, and the recommendations of conferences on mathematics and science education and learning that have emphasized the importance of the integration approach in teaching and integration between disciplines. It is also a response to the poor results in international science and mathematics tests, the low level of students' thinking skills, and the call for educational research that applies the STEM approach in science and mathematics teaching and skills development in the 21st century. The study aimed to answer the following main question:

How effective is a proposed unit of instruction, based on integrating science and mathematics using the STEM approach in developing some 21st-century skills in middle school students?

The following sub-questions were derived from the main question:

1. What is the proposed unit of instruction for third-grade middle school students?
2. How effective is the proposed unit of instruction in developing 21st-century skills?

3. Research Hypotheses

In light of the study's objectives and research questions, the following research hypotheses were formulated:

1. There will be no statistically significant differences (significance level $\alpha \leq 0.05$) between the mean critical thinking skills scores of the experimental group in the pre-test and post-test.
2. There will be no statistically significant differences (significance level $\alpha \leq 0.05$) between the experimental group's mean critical thinking skills scores in the pre-test and post-test.

4. Research Terminology

4.1 STEM Approach

In this study, we defined STEM procedurally as a pedagogical approach that comprises science, technology, engineering, and mathematics. The STEM approach makes it possible to remove the traditional barriers between these subjects and present knowledge in an integrated and functional manner, connecting it to real life through the teaching of the proposed unit to third-grade middle school students.

4.2 Twenty-first Century Skills

The Partnership for 21st-century Skills (2015, p. 20) defines them as "the skills that learners need to succeed in school, work and life, including critical thinking and problem-solving skills, innovation and creativity, communication skills, collaboration skills, content learning skills, information literacy, media literacy, and life skills, such as leadership, productivity, adaptation, social responsibility, self-direction, and the ability to deal with others." In this study, we define them procedurally as a set of mental processes practiced by a third-grade middle school student that depend on critical thinking and problem-solving.

4.3 Critical Thinking

Mulnix (2010, p. 466) defines critical thinking as "the objective analysis of facts to formulate a judgment, make a decision, solve a problem, or evaluate evidence and facts." This study defines it procedurally as a way of thinking that focuses on making decisions about a problem and which requires the development of hypotheses, questions, and alternatives to analyze, interpret, and distinguish between correct and incorrect. It included three skills (interpretation, deduction, and evaluation of arguments) and was measured by the total score the third-grade middle school students achieved on the critical thinking test used in the study.

4.4 Problem-Solving Skills

The US National Council of Teachers of Mathematics (NCTM, 2000, p. 99) defines problem-solving as "engaging in a task for which the solution method is not known in advance, and which solution requires relying on learners' prior knowledge, which leads to the development of their understanding." This study defines it procedurally as a set of skills, namely sensing and identifying the problem, gathering information and data related to the problem, identifying alternatives to solving the problem, validating solutions, and generalizing results to solve the problem. Problem-solving skills were measured by the total score the third graders achieved on the problem-solving test used in this study.

5. Methods

This study adopted an experimental approach based on a quasi-experimental single-group design with a pre-test and post-test (Figure 1). Critical thinking and problem-solving pre-tests were applied to the study group, which consisted of a random sample of 40 female students from the third grade of the middle school at Rayha Girls Middle School in Taif. The selection of a sample size of 40 in the quasi-experimental design can be justified by considering the typical class size in the school, which ranges from 35 to 40 students. Therefore, choosing a sample size of 40 is proportionate to the class size and deemed appropriate for this quasi-experimental design. This ensures that the study group represents a typical classroom setting and enhances the generalizability of the study's findings to similar populations.

The Students were included in the sample after obtaining the approval of their parents and the school leader under the supervision of the Ministry of Education in the Kingdom of Saudi Arabia. The research was applied during the third semester of 2022. The sample was then taught the proposed unit, which was based on the integration of science and mathematics according to the STEM approach. After completing the proposed unit, the sample participated in post-tests on critical thinking and problem-solving. The effectiveness of the proposed unit of instruction in developing 21st-century skills in third-grade middle school students was determined by comparing the sample's scores on the pre-and post-tests.

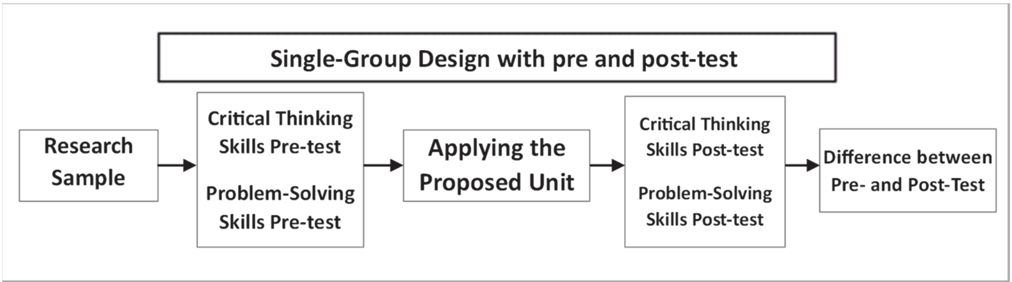


Figure 1: Research Design

6. Research Tools and Materials

The following research tools and materials were selected and built to answer the research questions and achieve the study's objectives. A teacher's guide was developed for the proposed unit and its teaching method, as well as student worksheets.

The proposed unit was designed based on the integration of science and mathematics according to the STEM approach, as follows:

- The first unit of the third semester in 2021 was chosen from the sciences, namely, motion, and mathematics, namely, quadratic functions. These units were selected due to their scientific and practical importance and realistic applications that help students develop 21st-century skills and the ability to solve real problems, the relevance of the topics to other curricula, and the possibility of teaching them in a framework that depends on the integrated approach of STEM.

The content of the two units was analyzed. We then combined them and reformulated the unit according to the STEM approach under the title "Motion & Functions." To do so, the topics were identified and named, and the procedural objectives for each topic, the topic components, and the ability level for each lesson were determined according to the TIMSS levels (knowledge level, application level, reasoning level), as shown in Table 1.

Table 1: Content of the proposed unit Third-Grade Middle School (Third Semester)

Unit	Topics	Procedural Objectives	Topic Components	Skill Level
Proposed Unit (Motion & Functions)	First Lesson: Motion & Graphical Representation of Quadratic Functions	1- The student learns about distance and velocity. 2- The student compares distance and displacement. 3- The student analyzes a graphical representation of the quadratic functions. 4- The student represents quadratic functions graphically. 5- The student infers the types of speed.	1- Defining distance, velocity, and displacement. 2- Comparison between distance and displacement. 3- Analysis of graphs of quadratic functions. 4- Representing quadratic functions graphically. 5- Average and instantaneous speed.	Cognitive
			1- Analysis of motion and graphic representations of quadratic functions in real-life problems. 2- Graphical representation of motion and quadratic functions in real-life problems.	Applied
			Solving 21st-century-skills problems.	Inferential
	Second Lesson: Acceleration and Solving Quadratic Equations Graphically	1- The student learns the concept of acceleration. 2- The student predicts the effect of acceleration on motion. 3- The student calculates the acceleration of the bodies. 4- The student solves quadratic equations graphically. 5- The student estimates the solution of equations from their graphical representation.	1- Defining the concept of acceleration. 2- Predicting the effect of acceleration on motion. 3- Calculating the acceleration of objects. 4-Solving quadratic equations graphically. 5- Estimating the solution of equations from their graphical representation.	Cognitive
			1- Acceleration and solving quadratic equations graphically in real-life problems. 2- Estimation of acceleration and solutions of equations from their graphical representation in real-life problems.	Applied
			Solving 21st-century-skills problems.	Inferential
	Third Lesson: Momentum and Solving Quadratic Equations by Completing the Square	1- The student learns about momentum (mass of motion). 2- The student explains why the momentum is not conserved, and why the momentum of collision is not conserved. 3- The student writes the square expression in the form of a perfect square. 4- The student solves quadratic equations by completing the square.	1- Defining momentum (mass of motion). 2- Explaining why the momentum of the collision is not conserved. 3-Writing the square expression as a perfect square. 4- Solving quadratic equations by completing the square.	Cognitive
			1- Modeling momentum and writing the square expression as a perfect square in real-life problems. 2- Solving quadratic equations by completing the square in real-life problems.	Applied
			Solving 21st-century-skills problems.	Inferential
	Fourth Lesson: Collisions and Solving Quadratic Equations Using the General Law	1- The student predicts the motion of objects using the law of conservation of momentum. 2- The student solves quadratic equations using the general law. 3- The student uses the discriminant to determine the number of solutions of a quadratic equation.	1- Predicting the motion of objects using the law of conservation of momentum. 2- Solving quadratic equations using the general law. 2- Using the discriminant to determine the number of solutions of a quadratic equation.	Cognitive
			1- Solving quadratic equations using the general law in real-life problems.	Applied
			Solving 21st-century-skills problems.	Inferential

The proposed unit, Motion & Functions, included four lessons to be taught over 12 classes, with each lesson divided into three classes following the merging process, as shown in Tables 2 and 3.

Table 2: Number of classes in the proposed unit

Number of classes for the mathematics unit topics	13 classes
Number of classes for the science unit topics	11 classes
Number of classes for the proposed unit after merging the science and mathematics units	(13+11)/2=12 classes

Table 3: Distribution of the classes for teaching the proposed unit (Motion & Functions)

	Lessons	**Lesson Topic**	**Number of Classes**
The proposed unit (Motion & Functions)	First Lesson	Motion & Graphical Representation of Quadratic Functions	3
	Second Lesson	Acceleration and Solving Quadratic Equations Graphically	3
	Third Lesson	Momentum and Solving Quadratic Equations by Completing the Square	3
	Fourth Lesson	Collisions and Solving Quadratic Equations Using the General Law	3
	Total		12

The lessons in the proposed unit each included a title, the time allotted for the lesson, the expected project for the lesson, the educational content, the role of the teacher and the role of the students, the activities and exercises, the assessment, the strategies used, the skills to be developed, the type of integration according to STEM, and the homework activities.

Table 4 includes an example outline of the first lesson of the proposed unit.

Table 4: Outline of the first lesson of the proposed Motion & Functions units

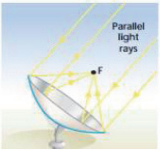
First Lesson	**Motion & Graphical Representation of Quadratic Functions**	**Number of Classes**	3
Performance Expectations	**At the end of the lesson, it is expected that the student will be able to:** Extrapolate the concept of distance and velocity. Compare distance and displacement. Represent motion graphically. Represent motion with quadratic functions graphically. Analyze the graphic representations of quadratic functions. Solve an open problem on motions and functions (project).		
Educational Content	**Teacher's Role**	**Students' Role**	
	Review quadratic equations and their properties. Form and build concepts with students and how to compare them. Present real-world experiences and problems on motion and quadratic functions through exercises and performance tasks. Project on motion and functions.	Review quadratic equations and address weaknesses through inquiry. Solve problems through inference and modeling to analyze motion and quadratic functions and represent them graphically. Exercise and practice solving exercises, tasks, and problems.	
Activities and Exercises	Worksheets in the form of activities to be solved in groups after each section of the lesson and link them with a stem.	**Assessment**	• Formative Assessment • Summative Assessment

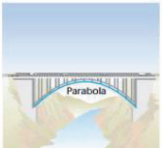
The worksheets of the proposed unit were designed so that each worksheet includes: the lesson title, worksheet number (each class has one worksheet), activity duration, activity type, and activity question. Examples are given in Table 5 for the worksheets of the first lesson of the proposed unit.

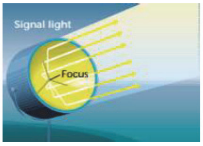
Table 5: First Class Worksheet

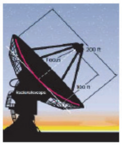
Lesson One	**Motion and Graphing Quadratic Functions**				
Worksheet	1	Duration of activity	5 minutes	Type of activity	Cooperative

Given the following forms:










Together with your group members, answer the following:

1- Name the shapes, and explain the function of each shape in everyday life.
2- Graphically edit the shapes. What do you notice?
3- Compare the shapes in terms of similarities and differences.
4- Relate the activity to other sciences (STEM).

The proposed unit was submitted to a group of math and science curriculum reviewers to assess the appropriateness of the lessons and activities according to the STEM integration approach. Its final form was modified based on the reviewers' comments.

The above answered the first research sub-question, "What is the form of the proposed unit for third-grade middle school students?"

To achieve the research objectives, the following research tools were developed.

1. Problem-Solving Skills Test

Referring to previous studies, a set of problem-solving skills was identified: identifying the problem, gathering information related to the problem, hypothesizing, validating hypotheses, and achieving the solution to the problem. A test was constructed with 20 items, 5 for each skill. It was a multiple-choice test in which the student received a score if their answer was correct for the task and zero points if their answer was incorrect, according to the answer key.

2. Critical Thinking Skills Test

The Watson and Glaser Critical Thinking Skills Test (Interpretation, Deduction, and Argument Evaluation) developed by Abdel Salam and Suleiman (1982) was used. The test consists of five subtests that measure critical thinking skills: recognizing assumptions, interpreting, evaluating discussions, deducing, and reasoning. Among these skills, three relevant to the present study were identified: interpretation, evaluation of discussion, and inference. The test consisted of 90 items, 30 for each skill, with the student receiving one point if their answer was correct and zero if their answer was incorrect, according to the answer key.

7. Validity and Reliability of the Research Tools

7.1 Validity

The validity of the research instrument was confirmed in two ways: before use with inter-rater validity and after use with internal consistency validity on an exploratory sample of 25 students from the research population (which was different from the research sample). A detailed description of this procedure is provided below.

7.2 Inter-rater Validity

After the critical thinking and problem-solving skills tests were completed, they were presented in their original form to a group of reviewers with expertise and experience in curriculum and teaching methods. A letter was sent to the reviewers stating the study's problem, objectives, and hypotheses and asking them to review the appropriateness of the questions, their clarity, their relevance to what they were measuring, and the soundness of the language as an assessment method and its suitability. Based on the reviewers' opinions about the appropriateness of the tests for the study's objectives and their comments and suggestions, the language of some questions was changed, and some additional questions were added. Others, however, were deleted so that the test became inter-rater valid.

7.3 Statistical Validity

The validity of the research instrument was statistically confirmed by internal consistency, applying the test to an exploratory sample of 25 students. The correlation coefficient was calculated between each question's score and the test's total score. The results are shown in Table 6.

Table 6: Correlation coefficients between each item score and total score of the critical thinking skills test

Interpretation Skill				Discussion Evaluation Skill				Deduction			
Sr.	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**
1	0.61	16	0.59	31	0.55	46	0.60	61	0.56	76	0.58
2	0.66	17	0.60	32	0.61	47	0.64	62	0.59	77	0.60
3	0.58	18	0.64	33	0.57	48	0.58	63	0.61	78	0.66
4	0.60	19	0.55	34	0.64	49	0.61	64	0.62	79	0.57
5	0.58	20	0.58	35	0.67	50	0.57	65	0.57	80	0.56
6	0.57	21	0.59	36	0.60	51	0.55	66	0.59	81	0.63
7	0.55	22	0.63	37	0.58	52	0.59	67	0.55	82	0.64
8	0.67	23	0.57	38	0.55	53	0.63	68	0.64	83	0.66
9	0.61	24	0.58	39	0.64	54	0.66	69	0.61	84	0.58
10	0.54	25	0.62	40	0.59	55	0.57	70	0.57	85	0.59
11	0.57	26	0.60	41	0.58	56	0.62	71	0.60	86	0.55
12	0.59	27	0.64	42	0.57	57	0.65	72	0.56	87	0.62
13	0.62	28	0.63	43	0.60	58	0.58	73	0.67	88	0.66
14	0.55	29	0.58	44	0.55	59	0.57	74	0.62	89	0.67
15	0.58	30	0.66	45	0.57	60	0.64	75	0.64	90	0.60

The correlation coefficients between each question's score and the test's total score ranged from 0.54 to 0.67. These values were positive, high, and statistically significant at a significance level of less than 0.05, indicating that the critical thinking test had a high degree of internal consistency validity. The correlation coefficients between each question's score and the test's total score, as shown in Table 7, ranged from 0.56 to 0.66. These values were positive, high, and statistically significant at a significance level of less than 0.05, indicating that the problem-solving test had high internal consistency validity.

Table 7: Correlation coefficients between each item score and total score of problem-solving skills test

Skills	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**	**Sr.**	**Coeff.**
Defining the problem	1	0.59	6	0.66	11	0.61	16	0.60
Gathering information	2	0.62	7	0.58	12	0.66	17	0.63

Skills	Sr.	Coeff.	Sr.	Coeff.	Sr.	Coeff.	Sr.	Coeff.
Making hypotheses	3	0.64	8	0.56	13	0.62	18	0.56
Validating hypotheses	4	0.67	9	0.63	14	0.59	19	0.61
Solving the problem	5	0.57	10	0.59	15	0.65	20	0.65

8. Reliability

Cronbach's alpha coefficient was used to confirm the reliability of the research instruments. The results are shown in Table 8.

Table 8: Cronbach's alpha coefficients of the research tools

Test	Cronbach's alpha coefficient
Critical Thinking Skills	0.95
Problem-Solving Skills	0.91

Cronbach's alpha coefficients ranged from 0.95 to 0.91 for the critical thinking and problem-solving skill tests, respectively, thus indicating that the research tools were reliable.

9. Statistical Methods

The appropriate statistical methods for data processing were identified as:

- Arithmetic means and standard deviations for the pre-and post-tests.
- T-test for two correlated samples to compare the research sample's mean scores in the pre- and post-tests.
- Eta-squared to estimate the effect size of the independent variable (the effectiveness of a proposed instructional) on the dependent variable (middle school students' 21st-century skills). Cohen indicated that the lower bound for a large effect is 0.14.

10. Research Procedures

We first reviewed educational, international, and Arabic literature on the research variables. We determined the proposed design of the unit for middle school students in light of the integration of science and mathematics according to the STEM approach.

We developed a teacher's guide and student activities for the proposed unit and presented them to a panel of specialized reviewers to check their suitability for the application and make any necessary changes. We elaborated a list of 21st-century skills that are appropriate for the middle-school level, as well as the nature of science and mathematics. Then, we conducted a pilot experiment to determine the research tool's reliability coefficient and application. The pilot survey sample included 30 students in the third grade of a middle school in Taif. The approval of the students' parents and of the school's leader was obtained under the supervision of The Kingdom of Saudi Arabia's Ministry of Education.

We taught the proposed unit to the research sample students and post-tested the research tool. We compiled the data, extracted the differences between the results of the pre-and post-test, determined the level of statistical significance for these differences, interpreted the results, and made recommendations and suggestions based on the research results.

11. Results and Discussion

The research hypotheses were validated through data analysis using appropriate statistical methods, which included a *t*-test for two interrelated groups (pre-post), calculating the effect (eta-squared).

The results obtained are presented below.

11.1 Testing and Discussing the First Hypothesis

The first hypothesis predicted that there would be no statistically significant differences significance level $\alpha \leq 0.05$) between the mean critical thinking skills scores of the experimental group in the pre-test and post-test. To test the validity of this hypothesis, the arithmetic means, and standard deviations of the scores before and after the critical thinking skills test were calculated. These arithmetic means were compared using the t-test for two related groups (pre-post). The results are shown in Table 9.

Table 9: T-test results comparing the mean scores of the pre- and post-tests of critical thinking skills

Test	Number	Arithmetic Means	Standard Deviation	*t*-value	Freedom Degree	Statistical Significance
Pre	40	46.48	5.30	16.11	39	0.01
Post	40	60.55	6.31			

Figure 2 shows that the arithmetic mean of critical thinking skills was 46.48 in the pre-test and 60.55 in the post-test, and the *t*-value was (16.11), indicating statistically significant differences at a significance level of less than 0.05, in favor of the post-test, with the post-test having the highest arithmetic mean (60.55).

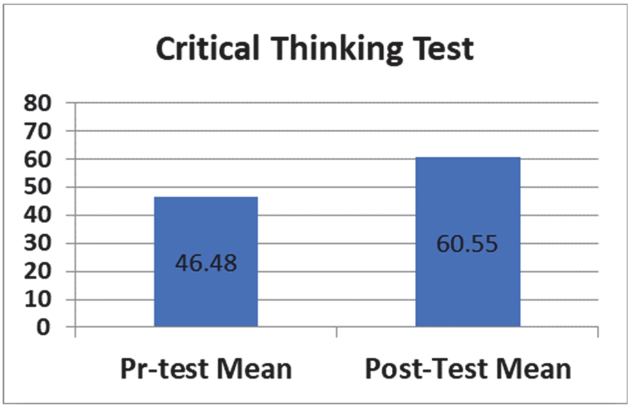


Figure 2: Arithmetic Means of Critical Thinking Skills in Pre and Post-Tests

The results indicate that the independent variable (the effectiveness of the proposed unit based on the integration of science and mathematics according to the approach STEM) influenced the dependent variable (the critical thinking skills of middle school students). To determine the effect size, eta-squared (η^2) was calculated as an indicator. The results are shown in Table 10.

Table 10: Size of the effect (eta-square) of the proposed unit on critical thinking skills

Independent Variable	Dependent Variable	t-value	Freedom Degrees	Eta-squares	Size Effect
Effectiveness of the proposed unit based on the integration of science and mathematics according to the STEM approach	Critical Thinking Skills	16.11	39	0.87	Large

The effect size was 0.87, which is a large value according to Cohen's criteria.

Based on the results, the null hypothesis was rejected, and the alternative directional hypothesis, "there are statistically significant differences at the 0.05 level between the mean scores of the experimental group in the pre- and post-tests of critical thinking skills," was accepted.

This finding is attributed to the effectiveness of the proposed unit, which helped students to acquire critical thinking skills through training in interpretation skills, discussion evaluation, and deduction; to link mathematics and science topics in one unit and achieve integration between STEM knowledge branches; and to communicate and cooperate in the performance of tasks and projects. This interpretation of the results is supported by those of Iraqi and Al-Otaibi (2018), Hassan and Al-Saadawi (2021) and Ziad (2019), who observed the effectiveness of the STEM approach in developing critical thinking skills. This finding is also consistent with those of Hilal (2021), who demonstrated the effectiveness of a STEM-based unit in developing 21st-century skills, including critical thinking. Our findings were distinguished from those of previous studies by the effectiveness of the proposed unit that combined science and mathematics with integration using STEM to develop critical thinking skills.

11.2 Testing and Discussing the Second Hypothesis

The second hypothesis predicted that there would be no statistically significant differences (significance level $\alpha \leq 0.05$) between the mean problem-solving skills scores of the experimental group pre-test and post-test. To test the validity of this hypothesis, the arithmetic means and standard deviations of the scores before and after the problem-solving skills test were calculated. These arithmetic means were compared using the t-test for two related groups (pre-post). The results are shown in Table 11.

Table 11: T-test results comparing the mean scores of the pre- and post- tests of problem-solving skills

Test	Number	Arithmetic Means	Standard Deviation	*t*-value	Freedom Degree	Statistical Significance
Pre	40	10.53	1.55	12.40	39	0.01
Post	40	15.45	1.96			

Figure 3 shows that the arithmetic mean of problem-solving skills was 10.53 on the pre-test and 15.45 on the post-test, and the t-value was (12.40), indicating that there were statistically significant differences at a significance level lower than 0.05 between the means of the pre- and post-tests of problem-solving skills, in favor of the post-test, with the post-test having the highest arithmetic mean (15.45).

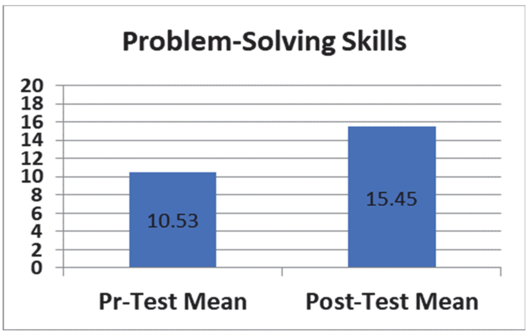


Figure 3: Arithmetic Means of Problem-Solving Skills in Pre- and Post-Tests

The results indicate that the independent variable (the effectiveness of the proposed unit based on the integration of science and mathematics according to the STEM approach) affected the dependent variable (problem-solving skills of middle school students). To determine the effect size, Eta-squared (η^2) was calculated as an indicator. The results are shown in Table 12.

Table 12: Size of the effect (eta-square) of the proposed unit on problem-solving skills

Independent Variable	Dependent Variable	t-value	Freedom Degrees	Eta-squares	Size Effect
Effectiveness of the proposed unit based on the integration of science and mathematics according to the STEM approach	Problem-Solving Skills	12.40	39	0.80	Large

The eta-square value was 0.80, which is a large value according to Cohen's criteria.

Based on the results, the null hypothesis was rejected, and the alternative hypothesis, "there are statistically significant differences at the 0.05 level between the mean scores of the experimental group in the pre-and post-tests of problem-solving skills," was accepted.

This finding is attributed to the effectiveness of the proposed unit, which helped students acquire problem-solving skills through training in problem identification, gathering information related to the problem, hypothesizing, verifying the hypotheses, and reaching a solution; the ability to link mathematics and science topics in one unit and achieve integration between STEM knowledge branches; and the ability to perform tasks and projects through appropriate activities and an appropriate environment to solve problems. The interpretation of this finding is supported by those of Al-Zahrani (2019), Hassan and Al-Saadawi (2021), and Al-Ahwal (2021), who showed the effectiveness of the STEM approach in developing problem-solving skills. This finding is also consistent with the results of Hilal (2021) and Al-Ahwal (2021), who emphasized the effectiveness of a STEM-based unit for developing 21st-century skills and problem-solving skills. Our finding was distinguished from previous studies' by the proposed unit's effectiveness that combined science and mathematics through the STEM integration approach to developing critical thinking skills.

The research results can be interpreted in light of the contents of the proposed unit (e.g., lessons, activities, and strategies), which helped develop 21st-century skills among third-grade middle school students through their interaction with the proposed unit and its applications in life, as follows.

12. Conclusions

The research findings can be interpreted in light of what was included in the proposed unit based on the integration between science and mathematics according to the STEM approach (lessons, activities, and strategies). The unit helped develop 21st-century skills among third-grade middle-school students through student participation in performing mathematical open-ended problem-solving tasks, solving realistic problems closely related to the situations and contexts of their daily lives, and interacting with mathematical tasks with high-level cognitive requirements in a way that prompted them to rely on themselves and think deeply about the situations and mathematical tasks of gradual difficulty presented to them. Students also participated in performing realistic investigative and exploratory activities or conducting laboratory experiments, scientific investigation processes that depended on their self-formulated questions and hypotheses, experimentally testing the validity of these hypotheses, and drawing logical conclusions, and projects that required them to perform engineering design activities and tasks for realistic situations, including employing the proposed unit's content in real life.

Further, the unit helped students design tangible educational materials such as modeling engineering design processes for realistic mathematical situations and problems and employing technology to discover and validate generalizations and mathematical ideas related to the proposed unit. The unit gave students the opportunity to test hypotheses, reach and generalize solutions, use a variety of methods and tools (e.g., models, illustrations, tables, graphs, tangible material, models) in representing real situations related to the proposed unit, use mathematical communication tools, and express the different experiences they gained during learning.

This research responds to modern trends in education and presents a unit based on the integration between science and mathematics according to the STEM approach. The educational field needs a new type of integration across curricula that benefit both learners by developing their 21st-century skills and teachers by allowing them to apply units that are integrated according to the STEM approach. This integration contributes to knowledge unity and remove barriers between the different fields of science. Officials in The Kingdom of Saudi Arabia's Ministry of Education and those responsible for building curricula can also benefit from this study's proposed unit when designing curricula that present STEM subjects more effectively. Finally, researchers can benefit from this study's findings and recommendations, which open new horizons for further scientific research in this field.

Officials in The Kingdom of Saudi Arabia's Ministry of Education and those responsible for building curricula can also benefit from this study's proposed unit when designing curricula that present STEM subjects more effectively. Finally, researchers can benefit from this study's findings and recommendations, which open new horizons for further scientific research in this field.

13. Limitation

The research was limited to the proposed unit based on the integration between Motion unit in science for the third grade of middle school in the third semester of 2022 and the Quadratic Functions unit in mathematics for the third grade of middle school in the third semester of 2022 according to the STEM approach. This study was also limited to testing only two of the 21st-century skills: critical ethinking (interpretation, deduction, and argument evaluation) and problem-solving skills (identifying the problem, gathering information related to the problem, hypothesizing, verifying the hypotheses, and reaching a solution).

The study's quasi-experimental design and the use of a single-group design were necessary due to the limited availability of only one classroom in the school where the study was conducted. Consequently, the generalizability of the study's findings to other age groups may be impacted.

13.1 ethical considerations

Ethical considerations were addressed and obtained approvals from the relevant authorities, including the Ministry of Education and the participating school. In addition, informed consent was obtained from the participants and their parents or guardians prior to the implementation of the study. The confidentiality of the participants was ensured, and measures were taken to protect their privacy. The potential risks and benefits of the study were carefully explained to the participants and their parents or guardians, and any concerns or questions they had were addressed. The data collected during the study was handled and stored securely, and the identities of the participants were kept confidential. Furthermore, the study adhered to established ethical standards, promoting fairness, integrity, and respect for the rights and well-being of all involved parties.

14. Recommendations

The results of the study can provide several recommendations:

- Teacher Training and Professional Development: Given the limitations of the study design, it is imperative to prioritize comprehensive teacher training and professional development programs. By equipping teachers with the necessary skills and knowledge in STEM education, they can effectively utilize the available classroom resources to enhance student learning experiences.

- Cross-disciplinary Integration within the Available Classroom: Despite the single-group design, educators can still promote cross-disciplinary integration within the classroom. By designing activities that connect different subjects, students can develop a holistic understanding of STEM concepts and their applications.
- Resource Optimization: Due to the limited availability of classrooms, resource optimization becomes crucial. Prioritize the acquisition and effective utilization of resources within the available classroom, such as scientific equipment and educational tools, to provide students with hands-on learning experiences.
- Collaboration and Partnerships: To overcome the limitations of the single-group design, foster collaboration with other schools, institutions, or organizations that have resources and expertise in STEM education. This collaboration can provide opportunities for students to engage in interdisciplinary projects and activities beyond the confines of the single classroom.
- Generalizability Considerations: Considering the limitations of the study's generalizability, it is essential to acknowledge the need for further research in diverse settings. Replicating the study in different contexts and age groups can help validate the findings and enhance the broader applicability of STEM education strategies.

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