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The Impact of STEM Approach to Developing Mathematical Thinking for Calculus Students among Sohar University

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ABSTRACT

This study aims to prepare an educational program based on integrating Science, Technology, Engineering and Mathematics (STEM) to develop students' mathematical thinking skills. It also aims to provide proposals that could have a major role in rebuilding some of the general features on which mathematics curricula can be built according to the STEM approach. The study used an experimental approach; the study sample consists of 121 students in a Calculus course. The participants were grouped purposefully into 50 control group and 71 experimental group. Results showed that the students in the experimental group who were exposed to the STEM approach surpassed the control group students who studied in the traditional way. Findings also indicated that the educational STEM approach activities had a positive role in the process of learning and searching for various sources of information. Besides, the STEM approach engages students in observation, discovery, interpretation, and discussion; activities that help them solve various issues. The study therefore recommends that students also perform educational STEM based activities in other mathematics courses.

Keywords: calculus, educational program, mathematical thinking, Sohar University, STEM

INTRODUCTION

The current century is witnessing continuous and rapid development in various aspects of daily life; such development requires paying attention to the educational process to develop different thinking skills among learners. It also requires training them how to prepare generations capable of facing such continuous development and overcoming the problems they face in their daily lives (Cai, 2000; Suherman et al., 2021). Many educational experts agree that thinking can be developed through learning content. Hence, for school curricula to contribute the development of thinking, the content should be designed and presented in a way that encourages the search for information and the exchange of learners' ideas, and motivates learners to think critically (Edwards et al., 2005).

The mathematics curriculum is considered a fertile field for the development of thinking skills because mathematics can be applied to various situations and problems. Solving these problems requires higher thinking processes and develops various thinking skills. Furthermore, these activities provide an opportunity to challenge learners' pre-existing ideas through investigation, exploration, observation and meditation on the natural phenomena that surround them (Miller, 2019).

This contributes to the development of the learners' ability to receive and absorb knowledge, integrate this into their mental structure, creates relationships between new knowledge with previous experiences, and transforms these experiences into meaningful concepts (Suherman et al., 2021; Obaid and Afana, 2003). The mastery of Aspects of Mathematical Thinking (henceforth AMT) invites learners to explore undefined horizons and unconventional paths. This helps them to come up with new and innovative ideas, especially when they are asked to provide an explanation or justification for a phenomenon. Mathematical thinking also helps students to provide new solutions to a specific problem in a unique and innovative way (Edwards et al., 2005). Some studies (English, 2023; Fannakhosrow et al., 2022; Edwards et al., 2005) focused on different teaching strategies in all educational stages in order to prepare a generation capable of facing current and future problems successfully, and capable to act and think in new and appropriate ways in diverse situations: this is meaningful learning (Maher, 2011).

Therefore, mathematic teaching should also be concerned with using different teaching strategies and approaches towards teaching mathematics. Many studies (Christensen et al., 2014; Gill and Billups, 1992; Tashtoush et al., 2020, 2022b) agreed on the necessity to reconsider mathematics curricula and methods of teaching and learning that still focus on memorization, and to reconsider closed educational environments that rely on the traditional textbook information as the only source of knowledge. Such an approach does not lead to increased mathematical thinking skills in all its forms. It weakens students' enthusiasm to use and acquire skills and their ability to persevere and exert more effort.

Developing mathematical thinking skills requires the use of modern teaching approaches and strategies, especially those that focus on integrating mathematics with other sciences. The approach also should encourage students to think, meditate and innovate rather than just memorize; to search for information rather than obtain it; and to open new areas for ideas and creativity. It should practice the mental operations that are necessary for improving mathematical thinking skills and motivate students to participate positively and effectively (Schielack et al., 2000). Developing students' mathematical thinking skills builds on their ability to show their understanding, knowledge, and mathematical skills. It constitutes a challenge to exhibit their thinking, justifications, and their multiple and different solutions, especially through students listening to each other's explanations, guesses, describing patterns, communicating their ideas to express the knowledge and procedures they use, monitoring their progress, and evaluating their solutions (English, 2023; Yasuhiro, 2002).

The NCTM Standards (2000) provide a comprehensive framework for developing mathematical thinking in students. NCTM emphasizes the need to develop mathematical thinking of all kinds among students, and to present mathematics to students as a thinking tool. This can be achieved by preparing students to use mathematical knowledge to solve mathematical problems with the ability to communicate and mathematical justification and guiding them to solve problems using different methods and strategies. The NCTM standards emphasize Content Standards, Process Standards, and Principles to Actions and are outlined in several key documents, including the "Principles and Standards for School Mathematics" (2000) and the more recent "Principles to Actions: Ensuring Mathematical Success for All" (2014). These "Principles to Actions" outline eight essential teaching practices for effective mathematics instruction:

1. Establish mathematics goals to focus learning.
2. Implement tasks that promote reasoning and problem solving.
3. Use and connect mathematical representations.
4. Facilitate meaningful mathematical discourse.
5. Pose purposeful questions.
6. Build procedural fluency from conceptual understanding.
7. Support productive struggle in learning mathematics.
8. Elicit and use evidence of student thinking.

These standards and practices are designed to ensure that all students develop a deep understanding of mathematical concepts and are able to apply them effectively in various contexts.

Understanding the AMT is an important basis for thinking. It originally depends on the method of discovery and discussion to reach a solution (Lutiffyya, 1998). The array of mathematical thinking patterns and their manifestations is very diverse, and this puts constraints on their development in education. These various patterns cannot easily be studied together, due to the characteristics that distinguish each pattern from another, so it is not feasible to develop one logical framework that includes them all.

One of the most prominent standards and in-depth ideas to be developed among students is inductive and deductive thinking, in addition to appreciating the power application of logical thinking in mathematics (Tashtoush et al., 2023a). Accordingly, it is important that students realize the increasing importance of thinking and proof in mathematics and make use of different patterns of thinking and methods of proof by having them investigate and work on solving real mathematical problems, to build a deep understanding in a way that centers the educational process around students (Cai, 2000).

In response to this, many global trends and international projects have emerged recently to reform and develop curricula and improve teaching and learning and to achieve unity and integration of knowledge to understand the real world surrounding the student. Important reform projects are the National Science Education Standards

(NSES), the STSE, the Entrance to Science, and the Next Generation Science Standards (NGSS), in order to build a creative generation capable of dealing with the rapid scientific and technological developments (Burrows et al., 2018; Elayyan and Al-Mazroi', 2020).

The STEM approach to cognitive integration of engineering, science, mathematics and technology is one of the most important modern approaches to improve teaching and learning in these different fields. The STEM approach is supported by many national educational institutions and international associations which aim to improve its human resources in various fields by encouraging creativity and contest. Therefore, America's National Governors Association (NGA) calls for the need to increase the competence of teachers in the field of STEM and increase the number of students who pursue advanced studies related to this approach (Elayyan and Al-Mazroi', 2020; Shirawia et al., 2023; Wardat et al., 2023).

The STEM approach appeared in USA at the beginning of the twenty-first century after the publication of the results of the Trends in International Mathematics and Science Study (TIMSS) that was administered in many countries, and the United States of America lagged behind its international competitors. The NGA highlighted that insufficient adherence to mathematics and science standards during general education limited integration of subjects with the real world and inadequate understanding of the interconnections between STEM fields are significant factors contributing to failure (Briney and Hill, 2013; Corlu et al., 2014).

The STEM approach stands as a crucial educational reform initiative and set of programs that aim to prepare a generation armed with scientific, technological, and engineering abilities. A generation who possesses knowledge and skills to face the challenges and problems in their daily lives and on the labor market (O'Neill et al., 2012). The STEM approach seeks to develop critical thinking among learners to help them find creative solutions to problems, and to distinguish themselves on the labor market (Hapidin et al., 2023). STEM aims to develop education, prepare students to deal with contemporary practical realities, and qualify and prepare them for future jobs (Al-Shirawia and Tashtoush, 2023). Most current jobs require applicants' competencies in scientific aspects and individuals should possess the ability to employ critical thinking skills and effectively collaborate in a group environment (Tambunan and Yang, 2022; Dugger, 2010).

Furthermore, STEM education integrates disciplinary knowledge in new fields or specializations, so the boundaries between the disciplines of the sciences, engineering, technology, and mathematics are crossed. Therefore, STEM education cannot only teach scientific subjects separately (Burrows et al., 2018; Holmquist, 2014). STEM seeks to prepare a scientifically and culturally enlightened generation in the field of science, technology, engineering, and mathematics, through the application of practical, investigative, scientific, hands-on, and heads-on activities. This enables the students to apply the acquired knowledge and practices to meet the challenges they face in their daily lives. It also contributes to the establishment of a human workforce capable of global competition, and the production and application of creative ideas in line with the requirements of the 21st century in the labor market (Eisenhart et al., 2015).

Scholars like Zheng et al. (2022), Gulhan and Sahin (2016), Gonzalez and Kuenzi (2012) indicated that there are five criteria for successful combination of the fields of STEM approach:

1. The greater the impact of the activities on the mathematical and scientific concepts that learners are interested in, the stronger the links that develop between scientific and mathematical knowledge.
2. Any scientific and mathematical explanations should be more in-depth when the complexity of the problem increases.
3. The STEM activities should be learner-centered.
4. The class structure should support the exchange of knowledge and facts between learners.
5. The impact on integration of science and mathematics depends on the effectiveness of the patterns and forms of classroom interaction.

The study of STEM programs and curricula provides the opportunity to better understand and comprehend the phenomena in which we live and to remove the artificial barriers between the four domains. STEM presents a learning model based on the interdependence, integration, and coherence between these domains (Lantz, 2009). The approach is directed at developing and spreading a scientific culture, with the aim of strengthening those links in the teaching and learning processes in the different stages of education (Rasheed and Tashtoush, 2023; Sanders and Wells, 2010).

In this context, educators have different opinions (Ye et al., 2023; Asunda, 2012; Carter, 2013; Finegold et al., 2011; Tsupros et al., 2009) regarding the principles and foundations that STEM programs are based on (**Figure 1**). However, there is agreement on the following general principles:

- **Communication:** STEM education aims to develop students' ability to communicate their ideas to others in a variety of ways including training them to learn and work in groups, and achieving interdependence of classroom, society, and labor market.
- **Integration of STEM:** This means providing students with activities that show and illustrate the integration between STEM disciplines. Create pathways and opportunities to provide students with high-quality

Figure 1. General principles and foundations of STEM

educational and professional experiences with disciplinary and interdisciplinary aspects as this qualifies them best for jobs in the future.

- **Employing Scientific Investigation:** This is done by shifting the center of focus from the teaching material to the learners and their needs, aptitudes, and interests. The contents of the course book is not just a set of facts, concepts, generalizations and principles that the teacher should transmit; the learner should also be provided with activities and practices that develop skills for investigation, to enable them to acquire new understandings and experiences elaborating on previous knowledge, experience and skills. Learners can employ and elaborate on these new insights when designing and making technological products that meet the needs and desires of people. This contributes to the development of skills for both inquiry and design and satisfies students' tendencies and needs.
- **Employing Engineering in Solving Problems:** Engineering focuses on developing mental images of technical problems and possible solutions and how to engineer these solutions through design, rather than learning the solutions themselves, with the aim of discovering, interpreting and solving problems. This provides the students with opportunities to discover the mutual relations between theory and practice, and between mathematics and science on the one hand and engineering and technology on the other, through problems situated in life contexts that help them develop critical thinking skills to be applied in various fields.
- **Encouraging Challenge:** The STEM approach challenges students for the sake of creativity and innovation. A STEM activity is an authentic problem based on scientific and theoretical foundations, principles and basic knowledge from which challenge and excitement stem without restrictions on how to achieve the desired goal, with students working in small groups that can encourage both collaboration and competition.

Summarizing, the STEM approach focuses on practical scenarios and fosters creative learning through problem-solving. It prioritizes active learning over memorization or traditional methods by integrating real-world problems and encouraging students to find solutions. Likewise, STEM learning aims to make students enjoy studying academic content in the fields of engineering, mathematics, science, and technology (Briney and Hill, 2013). Thus, it improves students' competence in these areas. In the STEM system, lesson planning involves presenting a problem to students. They are then tasked with gathering relevant information on the topic and conducting various experiments to test potential theories (Corlu et al., 2014; Tashtoush et al., 2023c; Tsupros et al., 2009).

The Effectiveness of the STEM Approach

Many studies (Zheng et al., 2022; Chondrogiannis et al., 2021; Pimthong and Williams, 2020; Bell et al. 2018; Christensen et al., 2014; O'Neill et al., 2012; Hartzler, 2010) reported on the impact of the STEM approach on studying and learning mathematics and science. Hartzler (2010) proved the impact of education programs based on STEM approach at all educational levels in general and the medium level at particular in developing students' achievements. Collaboration of teachers in strong professional learning communities within schools has been found to enhance the effectiveness of STEM teaching and improve student achievement (NCTAF, 2011).

Creative thinking and problem-solving amongst fifth, sixth, seventh and eighth grades students as well as the improvement of students' final examination results. Likewise, Carter (2013) identified the features of STEM approach which should be depended upon while teaching K-12 grades at Arkansas in the United States of America.

The study of Cotabish et al. (2013) reported the efficacy of STEM approach to developing learning and scientific concepts acquisition and knowledge content of mathematics and science amongst primary education students who participated in the treatments. The study reported the experimental group's outperformance of the control group who did not participate in STEM approach. Furthermore, Holmquist (2014) reported the importance of using STEM approach amongst primary stage students in developing students understanding and mastering of mathematical concepts in addition to positive attitudes that fourth grade students had towards STEM. Christensen et al. (2014) investigated the attitudes of (364) secondary school students at Taxes State, USA on the content of STEM education. The study reported that the attitudes of fresh students studying using STEM integration were like the attitudes of STEM experienced students and little bit different with the attitudes of students studying at high traditional schools. The study also reported that the isolated characteristics of STEM are affected by sex variable.

In the same vein, Rehmat (2015) indicated the importance of the STEM approach in developing higher thinking skills in mathematics and science for primary school students. The students of the experimental group who studied various activities and exercises based on the STEM approach in accordance with problem-based learning were better than the students of the control group who studied various activities and exercises based on the STEM approach using the traditional methods in their acquisition of cognitive content, critical thinking, and their attitudes towards STEM.

Kelley and Knowels (2015) aimed to find out the motivation which helps improve understanding of concepts related to mathematics, science, technology, and engineering using the STEM model. They found that using STEM helps students achieve high results in the assessment of mathematics, science, technology, and engineering. Results also showed that STEM based education provides the rationale for teaching mathematical and scientific concepts. Gulhan and Sahin (2016) showed that the use of STEM based activities contributes significantly to developing the perceptions and attitudes of fifth grade Turkish students towards the STEM education. Findings also showed that the experimental group was superior to the control group who studied using the activities mentioned in science and mathematics books.

In the context of secondary education in England and Wales, Bell et al. (2018) conducted a study to examine how teachers in design and technology education acquire new knowledge in STEM. The study aimed to understand how this knowledge is developed and integrated into their teaching practice, with the goal of fostering a diverse STEM-literate society. The study sought to identify the mechanisms through which knowledge acquisition takes place and explore potential implications for education and workplace learning.

Recently, Zheng et al. (2022) presented the common denominators in STEM practices in Chinese primary and secondary schools from the curricular perspective. Results showed the promotion of STEM approach in a comprehensive and integrated manner, especially through new technologies, and that education in China has an unbalanced geographical distribution. The study recommended the need to use STEM integration to develop students' creative abilities and skills. Likely, Pimthong and Williams (2020) conducted a study that highlighted the importance of implementing an educational program based on the STEM approach to enhance the understanding and readiness of pre-service math teachers to incorporate STEM principles. In their study, Chondrogiannis et al. (2021) focused on exploring the connection between Computational Thinking, the STEM approach, and agricultural education training within the Agriculture of Metamorphosis city. The aim was to examine how these elements intersect and influence each other in the context of agricultural education.

Existing literature and previous studies, however, seem to lack substantial exploration of the STEM approach at higher education levels. This study aims to extend the STEM approach from its predominant focus on K-12 education system to college and university-level students.

STEM in Oman

The limited numbers of studies which were conducted in the Omani context on STEM approach, stimulated Elayyan and Al-Mazroi' (2020) to probe the challenges that prevent teachers to apply STEM integration. Findings reported the presence of many problems pertaining to teachers, course content, and the learning environment. The study suggested developing new course content and preparing for STEM integration. The study also recommended the importance of preparing an education environment which suits the STEM approach.

The Ministry of Education in Oman pays great interest in the STEM approach and adopts a new system in education. The Ministry sets specific goals for teaching mathematics and science. The curricula included programs to develop students' knowledge and focus on the use of technology. 2018 marked the first phase of applying STEM Oman curriculum. It was launched in several public schools, under the supervision of the Omani Authority for Partnership for Development. The first teachers training center was established to apply the STEM approach. In the following year, the National Science, Technology, Mathematics and Engineering Week was launched in all public schools aligned with the Conference on the Fourth Industrial Revolution and its Impact on Education (Technologies without Borders), which was held in the state of Sohar. The conference highlighted the positive trends towards science, mathematics, innovation, and knowledge integration, and this confirms the keenness of the Sultanate of Oman and the attention that the Sultanate pays to STEM integration to consolidates such a basis among Omani students, in order to prepare a generation that contributes to development, is capable of creativity and innovation, and is qualified to compete in the labor market (Elayyan and Al-Mazroi', 2020; Wardat et al., 2024).

Problem Statement

Despite the increasing interest in the Sultanate of Oman in developing science and mathematics curricula, many education experts, teachers, and mathematics curricula developers reported that Omani students still face weaknesses in mathematics in general. Experts also face difficulties in helping students to acquire mathematical thinking skills. Such weakness is noticeable in the students' results which are still below the level of ambition in TIMSS. Besides, curricula experts believed that it is necessary to review mathematics curricula in the Sultanate and change the traditional class teaching. They confirm the implication for the fields of STEM to explain and interpret scientific phenomena and to search for teaching methods and strategies that give opportunity to emerge creativity and excellence in the fields of STEM approach. Relentless efforts were made by the various educational institutions to develop the quality of education and achieve the required global levels. The integration of the STEM fields has become a modern age necessity which requires collaboration to implement in education, in response to what many previous studies recommended (Al-Shirawia et al., 2023; Asunda, 2012; Finegold et al., 2011; Tashtoush et al., 2022b). Furthermore, traditional methods showed their inefficacy within the emerging modern teaching strategies, such as STEM. However, most of the teaching and learning strategies used in mathematics in Oman still are traditional. Furthermore, many mathematics teachers have limited modern teaching skills. Still, many researchers confirmed the importance of applying STEM education to developing mathematical thinking. Moreover, integration of mathematics in STEM education has not been investigated and assessed in many local contexts, such as in Oman. This study is in harmony with the global and Arab research priorities: the local research movement in the Sultanate of Oman aimed to improve the teaching of mathematics and to develop Aspects of Mathematical Thinking among students by integrating STEM into the teaching of mathematics.

Consequently, the current study has the following main research question: *What is the impact of using an educational program based on the STEM approach to develop students' mathematical thinking in a Calculus course in Sohar University?*

Study Significance

We expect that using an integrated approach for science, engineering, technology, and mathematics as a teaching strategy will have an effect on the learning outcomes for mathematics and enhance the learning process. Shedding light on the educational approach via its impact on students' mathematical thinking skills may convince specialists to adapt modern strategies when teaching mathematics and replace the use of traditional methods still applied by the majority of mathematical teachers. This study is one of the first of its kind to be conducted in the Arabian and Omani context; it shows the paucity of studies on the STEM approach. Besides, this study provides several STEM-based activities for teaching mathematics. This helps mathematical teachers to develop their teaching skills for teaching various mathematical topics. In the same vein, the findings of this study can be utilized for developing mathematical curricula; since up-to-date curricula will include integrated STEM activities meant to develop mathematical and innovative thinking skills in students.

Study Objectives

This study aims to prepare an educational program based on integrated STEM to develop aspects of mathematical thinking in students. In addition, it aims to provide suggestions for redesigning mathematics curricula and aligning them with the STEM approach for the future. It serves as a starting point and an invitation for researchers to consider and implement the STEM approach in college and university settings.

Procedural Definitions

- **STEM Approach:** a set of activities, educational practices, and interrelated scientific concepts that focus on the interaction and integration of science, engineering, technology, and mathematics around concepts and issues related to real life.
- **Educational Program Based on STEM Approach:** refers to a general, purposeful, and comprehensive scheme of structured content and sequential procedural steps represented in a set of strategies, methods, and purposefully planned activities to develop students' mathematical thinking skills in the light of the requirements of integrating the fields of science, engineering, technology, and mathematics.
- **Mathematical Thinking:** is a dynamic mental activity represented by the following manifestations: discovering the missing number in a series of numbers (sequences); extrapolation and generalization;

Table 1. Distribution of the study sample

Group	Demographic information		Frequency	Percentage
Control group	Gender	Female	44	61.9%
		Male	27	38.1%
		Total	**71**	**100%**
	Age	Level (1): 19 years	38	53.5%
		Level (2): 20 years	33	46.5%
		Total	**71**	**100%**
	Specialization	Mathematics education	46	64.7%
		Domain 2 teachers	25	35.3%
		Total	**71**	**100%**
Experimental group	Gender	Female	29	58.0%
		Male	21	42.0%
		Total	**50**	**100%**
	Age	Level (1): 19 years	31	62.0%
		Level (2): 20 years	19	38.0%
		Total	**50**	**100%**
	Specialization	Mathematics education	32	64.0%
		Domain 2 teachers	18	36.0%
		Total	**50**	**100%**

concluding; decision-making with justification; and coding. It is measured by the total mark that students obtain on the mathematical thinking test.

Characteristics and Limitations of the Study

This study has certain characteristics and limitations. Firstly, it focuses only on students who were enrolled in and actively studying the Calculus (1) course. Secondly, it was conducted once, during the first semester of the academic year 2022/2023. Thirdly, the study is conducted at Sohar University in the Sultanate of Oman. It focuses on exploring the importance of using the STEM approach in developing Mathematical Thinking. Lastly, the study applies instruments and psychometric measures of validity and stability that are deemed suitable for scientific research and aligned with the study's objectives.

METHODOLOGY

Research Design

A quasi-experimental design is utilized in this study. The experimental group was taught using an educational STEM based program whereas the control group was traditionally taught. A pre- and post-test along with a questionnaire were conducted. The current study is limited to students of the Calculus course. They registered to study during the first semester 2022/2023.

Participants

The participants consisted of Sohar University students in the Sultanate of Oman. Students who enrolled and regularly studied during the Calculus course of the Faculty of Education and Arts with the two specializations Mathematics Education and Domain 2 Teachers were taken as sample of the study. The study was conducted during the first semester of 2022/2023. Two divisions were chosen in a purposeful manner. The first constitutes the experimental group; they included 50 students taught according to an educational program based on the STEM approach. The second group is the control group and included 71 students; they were taught according to the traditional method. **Table 1** describes the demographic information for the study sample.

Instrument

After reviewing the literature on studies dealing with skills of mathematical thinking (Cai, 2000; Edwards et al., 2005; Holmquist, 2014; Makonye and Moodley, 2023; Tashtoush et al., 2023c; Schielack et al., 2000) a mathematical thinking test was developed that included five Aspects of Mathematical Thinking (Sequencers, induction and generalization, inference, decision-making and justification, and coding). The mathematical thinking test consisted of 23 items. Items were scored giving one mark for each correct answer and zero for each incorrect answer. As a result, the maximum attainable score for the test was 23, while the minimum score was 0 (see **Appendix A**). To verify the validity of the test, it was presented to a group of experts in this field. They commented to reduce the

Table 2. The result of the T-test for the independent samples

AMT	Group	Size	Mean	Standard deviation	T	Significance
Sequencers	Experimental group	50	4.52	1.626	0.340	0.661
	Control group	71	4.82	1.388		
Induction and generalization	Experimental group	50	3.34	0.960	0.233	0.895
	Control group	71	3.78	1.154		
Inference	Experimental group	50	5.26	2.994	0.205	0.755
	Control group	71	4.38	1.668		
Decision making and justification	Experimental group	50	3.26	0.984	0.140	0.720
	Control group	71	3.40	1.218		
Code	Experimental group	50	3.04	1.286	0.132	0.685
	Control group	71	2.88	1.154		
Total	Experimental group	50	19.40	6.512	0.379	0.550
	Control group	71	19.24	5.058		

Note. *Significance level ($\alpha = 0.05$)

number of test items, avoid multiple choice items, and rephrase some items. Difficulty coefficients and discrimination coefficients were calculated for each item, and the correlation coefficients for each item within its mathematical thinking aspect category and with the total test by applying it to a test group of 20 male and female students who were not part of the study sample. The difficulty coefficients for the items ranged from 0.42 to 0.77, indicating the level of difficulty for each item. The discrimination coefficients, which measure the ability of an item to differentiate between high and low performers, ranged from 0.38 to 0.72. Additionally, the correlation coefficients were calculated to assess the relationship between each item and the total score, as well as the correlation between each item and its respective category. These coefficients were 0.43-0.78 and 0.42-0.82, respectively. These findings confirm that the instrument is sufficiently valid to permit use for study purposes.

Ensuring the reliability, the test was verified using the test-retest method, with an interval of two weeks, on a pilot group out of the sample. Pearson correlation coefficient was calculated between the pilot group's performance on the two tests; the correlation reached 0.93. Reliability coefficient was also calculated using the internal consistency method according to the Kuder-Richardson Formula 20 which was 0.91. These values indicate that the instrument leads to stable outcomes, which aligns with the objectives of the research.

The mathematical thinking test was applied to the students of the experimental and control groups before the study was introduced. The mathematical mean scores and the standard deviations of the results of the students of the two groups were calculated on the five AMT (Sequencers, induction and generalization, inference, decision-making and justification, and coding) and on the test as a whole. A T-test for the independent samples was used to find out the differences between the mathematical averages. **Table 2** shows the results of (T-test) for the independent samples.

Table 2 shows that there are no statistically significant differences at the indication level ($\alpha = 0.05$) between the mean scours of students in the two experimental and control groups and the control of the five AMT (Sequencers, induction and generalization, inference, decision-making and justification, and coding) and the test as a whole. It means that there are no differences between the experimental and the control group with respect to the ability to perform on the test of mathematical thinking.

STEM-Based Educational Program

The teaching material comprises of a set of targeted strategies, methods and activities planned to develop and manifest students' mathematical thinking skills based on the integration of STEM fields. The materials also include a set of lectures, descriptions and detailed explanations supported by activities, class exercises and homework prepared according to the STEM approach, its advantages, foundations, and the topics that the program covers. The teaching material contains three main units (functions, sequences and series, geometry and number theory). These units are prescribed in the study plan for the Calculus course for students majoring in mathematics and teacher education program that require STEM. Teaching the subject took an entire semester of 13 weeks, with 39 lectures of 50 minutes each. A specification table has been created to ensure that the educational material aligns with the study plan for Calculus Course at Sohar University. This table includes information regarding the number of lectures assigned and the duration of each lecture, ensuring adherence to the prescribed time frame.

The content validity of the educational material was checked by displaying the content to a committee of experts in mathematics disciplines, mathematics curricula and teaching methods to determine the suitability for the objectives and the mathematical skills that the teaching material aims for. Amendments were made based on the juries' opinions.

Table 3. Students' performance on the mathematical thinking test and its aspects

AMT	Group	No	Pre-test		Post-test		Mean	Standard error
			Mean	SD	Mean	SD		
Sequencers	Experimental	50	4.52	1.626	7.04	1.018	7.138	0.160
	Control	71	4.82	1.388	4.96	1.286	4.862	0.160
	Total	**121**	**4.66**	**1.504**	**6.00**	**1.554**	**6.000**	**0.106**
Induction and generalization	Experimental	50	3.34	0.960	5.18	1.002	5.294	0.192
	Control	71	3.78	1.154	4.30	1.204	4.188	0.192
	Total	**121**	**3.56**	**1.076**	**4.74**	**1.184**	**4.740**	**0.128**
Inference	Experimental	50	5.26	2.994	9.12	3.298	8.780	0.314
	Control	71	4.38	1.668	4.82	1.494	5.146	0.314
	Total	**121**	**4.82**	**2.442**	**6.96**	**3.336**	**6.962**	**0.210**
Decision making and justification	Experimental	50	3.26	0.984	5.92	1.518	6.042	0.242
	Control	71	3.40	1.218	3.48	1.188	3.366	0.242
	Total	**121**	**3.34**	**1.098**	**4.70**	**1.828**	**4.704**	**0.162**
Code	Experimental	50	3.04	1.286	5.78	1.694	5.590	0.244
	Control	71	2.88	1.154	3.26	1.258	3.448	0.244
	Total	**121**	**2.96**	**1.212**	**4.52**	**1.950**	**4.518**	**0.164**
Total	Experimental	50	19.40	6.512	33.04	7.240	32.980	0.766
	Control	71	19.26	5.058	20.82	4.616	20.870	0.766
	Total	**121**	**19.34**	**5.776**	**19.34**	**8.616**	**26.930**	**0.542**

Summary of the Procedures

In order to accomplish the study objectives, several procedures were implemented, which included conducting a comprehensive review of relevant literature from previous studies. The researcher makes use of previous studies in utilizing and preparing the research instrument and educational material. In the same vein, the sample was determined by selecting two groups purposively. The first is an experimental group and the second is a control group. The instrument of the study was prepared in its initial form and presented to a committee of juries to validate it and check its reliability. Next, some items were modified based on the comments of the arbitrators' committee. The educational chapters were selected from the Calculus (1) course. They were redesigned and developed according to the STEM approach to be used in teaching the experimental group. The test was applied to the exploratory group that was chosen from the population outside the real sample. Finally, the coefficients of validity and reliability, and the difficulty and discrimination coefficients for the students' grades were calculated. At the beginning of the semester, both the experimental and control groups underwent the pre-test of their mathematical thinking skills, using the newly developed instrument. The experimental group received instruction with the newly designed educational material, while the control group was taught using traditional methods. At the end of the thirteenth week of the semester, the post-test was conducted for both groups by the researcher. The scores obtained from the mathematical thinking test were then assessed, monitored, and analyzed using SPSS version 23 to address the research question. The results were compared with those of previous studies and used to draw conclusions and provide recommendations.

Data Analysis

The data were entered into the computer for statistical processing procedures and analyzed using SPSS. The means and standard deviations of the students' scores were computed to reveal any noticeable differences in the arithmetic means. A MANCOVA test was employed to analyze the results of the mathematical thinking test in its entirety, as well as for each of its five aspects.

RESULTS

The main aim is to find the impact of the STEM approach on developing aspects of mathematical thinking. A second aim is to reveal if there are statistically significant differences ($\alpha = 0.05$) in students' performance on the mathematical thinking test. The results are presented in **Table 3**.

Table 3 shows the variation in the means, standard deviations, and adjusted averages of students' performance on the mathematical thinking test between the experimental and the control group. A MANCOVA test was performed to check whether the differences of the dependent variable (AMT) are significant and an ANCOVA was performed for the total score. The results are shown in **Table 4** and **Table 5**, respectively.

Table 4. MANCOVA analysis for students' performance on the math thinking test

Difference	Aspect of mathematical thinking	Sum of squares	df	Mean square	F	Significance	Effect size (η^2)
Pre-test	Sequencers	3.95	1	3.95	5.42	0.000	0.290
	Induction and generalization	2.05	1	2.05	2.00	0.000	0.130
	Inference	26.32	1	26.32	10.12	0.000	0.350
	Decision making and justification	1.26	1	1.26	0.80	0.025	0.020
	Coding	4.25	1	4.25	2.65	0.006	0.140
Post-test	Sequencers	20.65	1	20.65	28.68	0.000	0.660
	Induction and generalization	5.56	1	5.56	5.45	0.000	0.240
	Inference	48.32	1	48.32	18.58	0.000	0.560
	Decision making and justification	29.62	1	29.62	18.86	0.000	0.530
	Coding	18.32	1	18.32	11.45	0.000	0.420
Errors	Sequencers	85.95	118	0.72			
	Induction and generalization	121.52	118	1.02			
	Inference	306.98	118	2.60			
	Decision making and justification	186.09	118	1.57			
	Coding	189.36	118	1.60			
Total	Sequencers	32.000	120				
	Induction and generalization	18.593	120				
	Inference	147.481	120				
	Decision making and justification	44.315	120				
	Coding	50.370	120				

Table 5. ANCOVA analysis for the total score for the math thinking test and the effect size

Source of variance	Sum of squares	df	Mean square	F	Significance	Effect size (η^2)
Pre-test	312.980	1	312.98	76.15	0.000	0.54
Teaching method	513.420	1	513.42	124.91	0.000	0.68
Errors	485.770	118	4.11			
Total	983.426	120	312.98			

Table 4 shows that there are statistically significant differences ($\alpha = 0.05$) correlated with the teaching method on all AMT. The experimental group who was exposed to the STEM approach training program substantially better on the post-test on most aspects than the control group. In order to reveal the effectiveness of the STEM approach in developing AMT among students, the post-test effect sizes per aspect were calculated (see **Table 4**). Four effect sizes are moderate; one is small (induction and generalization). For example, the effect size for Sequencers is 0.66, this indicates that the training program based on the STEM approach explains about 66% of the variance in the development of this mathematical thinking aspect, while the rest of the variation is related to other influences. The researchers believe that these effects can be attributed partly to the fact that the STEM-based educational activities actively engage students in a range of tasks, where they assume various roles to address diverse issues. They go through processes such as observation, discovery, interpretation, and discussion, leading to generalization, decision-making, coding, and more. These activities aim to explore multiple approaches to test mathematical thinking thoroughly, enabling students to develop their ideas and cultivate various thinking patterns and expressions.

Table 5 shows that differences are significant ($\alpha = 0.05$), which can be attributed to the effect of the intervention. **Table 4** also shows the educational activities based on STEM approach influence students' performance in the total mathematical thinking test. The effect size when taking into account all aspects is 0.68, which is a moderate, almost large (0.8), effect.

DISCUSSION

Results of the study showed that the students in the experimental group who were exposed to the educational program based on the STEM approach have outperformed the students of the control group who studied in the traditional way. This result can be interpreted to the effective impact of the educational activities based on STEM approach. This educational program was prepared in a manner that challenges students' thinking, and in a way which is commensurate with the diversity of the students' mental levels. This provides equal opportunities for students to develop mathematical thinking in its various manifestations and considers the students' societal environment in which they interact with in a way that suits their tendencies and interests. The educational material deals with various life issues related to the daily reality of students and integrates the fields of mathematics, science, engineering and technology with each other. This approach requires the students to find solutions by themselves through interaction with their experiences and skills, which contributes to the development of mathematical thinking and its manifestations.

Reversely, the weak achievement of the control group can be attributed to the teaching practices in the classroom. They are dominated by teacher centeredness and their authority in all the teaching-learning situations. Students were hardly given an opportunity to think and engage in the learning processes. Students in traditional approaches are just perceived as recipient of knowledge from their teachers or the content of the curriculum. On the contrary, the educational activities based on the STEM approach have provided students with the opportunity to take more responsibility for their learning in an integrated manner in the fields of science, engineering, technology, and mathematics to build knowledge and reflect critically and constructively on their previous experiences. Besides, the STEM-based educational activities actively engage students in activities and has them play many roles while solving various issues, through observation, discovery, interpretation and discussion, generalizing, decision-making, justification, coding, etc., to reach all possible answers through mathematical thinking in several ways. This allows students to develop their ideas and different thinking patterns and manifestations. This finding is consistent with the findings of many studies (Cotabish et al., 2013; Gulhan and Sahin, 2016; Reppermund et al., 2017; Holmquist, 2014; O'Neill et al., 2012; Rehmat, 2015; Abri et al., 2023).

Furthermore, the educational STEM-based activities had a positive role in the process of learning and searching for various sources of information. This supports self-confidence and the ability to express opinions and think freely to suggest unconventional ideas, which made students feel that they are challenged, and they have to prove their capabilities and competence in the various ways available to them. This reflects positively on their thinking as confirmed by the literature (Margot and Kettler, 2019; Burrows et al., 2018; Eisenhart et al., 2015; Zheng et al., 2022; Salem et al., 2023; Tashtoush et al., 2023b). This finding is also in line with the Document of Principles and Standards for Mathematics Curricula (NCTM, 2000) which calls mathematics education to invest in students who think, search for knowledge, and learn mathematical concepts through different thinking skills, and transfer this to other situations in their reality.

No one can ignore the fundamental role that students-teacher and students-students interaction in integrated STEM plays to elicit argument, dissuasion and learning activities. All students in the experimental group were actively engaged in the learning situation, which contributes to reaching the correct answer and increases their ability for justification. This leads to the increase of students' performance in the experimental group in the mathematical thinking test in general.

The STEM approach also provided students with the opportunity to self-evaluate their performance through reflecting on, and discussing of, the activities offered. This is in alignment with the global trend to emphasize evaluation as a tool for learning (formative assessment) and not only for evaluating student performance (summative assessment).

CONCLUSION

This study concludes that learning activities based on STEM contribute to enhancing students' skills for aspects of mathematical thinking, which is consistent with the literature (Oppong-Gyebi et al., 2023; Tashtoush et al., 2023c; Goos et al., 2023; Carter, 2013; Garmire and Pearson, 2006; Sanders and Wells, 2010). Evaluating self-learning reflects positively students' achievements in solving various mathematical problems in different ways and helps them to think more clearly and overcome their mistakes and difficulties. Learning through the STEM approach leads to the acquisition of Calculus concepts and enables applications. The use of the STEM approach contributes to linking the subjects studied by students with previous knowledge and concepts. This improves retrieval, remembering, understanding, and application in other situations, and thus develops mathematical thinking.

Recommendations

The findings in this study lead us to recommend the following:

- We recommend having students in Calculus courses perform various activities based on the STEM approach. The implementation of this recommendation will have positive repercussions on engaging the students and centers the educational process around them, so that students can build their own knowledge partly from experience, which will accommodate them in the long term. STEM activities enhance students' mathematical thinking abilities.
- The study recommends redesigning mathematics curricula to comply with the global trend towards STEM approach and to offer training courses for mathematics teachers to teach them how to use the STEM approach.

- We recommend conducting further studies that demonstrate the importance of using the STEM approach for developing mono-disciplinary skills and knowledge in all STEM domains: mathematics, engineering subjects and the various natural sciences.

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APPENDIX A: MATHEMATICAL THINKING TEST

In questions (1-4), complete the series by writing the missing number.

1. 90, 900, 9000, ...

2. $\frac{1}{4}, \frac{1}{2}, \frac{3}{4}, \dots$

3. 2.5, 2, 1.75, …, 1.25

4. 3, 7, 15, …, 63

In questions (5-7), write the conclusion you can reach.

5. $a.\ 1 = 1$
$b.\ 2^2 = 3 + 1$
$c.\ 3^2 = 5 + 3 + 1$
$d.\ 4^2 = 7 + 5 + 3 + 1$
$e.\ n^2 = \cdots + 7 + 5 + 3 + 1$

6. $a.\ x^2 - 1 = (x - 1)(x + 1)$
$b.\ x^3 - 1 = (x - 1)(x^2 + x + 1)$
$c.\ x^4 - 1 = (x - 1)(x^3 + x^2 + x + 1)$
$d.\ x^n - 1 = (x - 1)(\cdots + x^3 + x^2 + x + 1)$

7. Write in words or symbols the generalization you infer from the following.
$a.\ \frac{2}{5} * \frac{5}{2} = 1$
$b.\ -\frac{3}{4} * \left(-\frac{4}{3}\right) = 1$
$c.\ \frac{1}{4} * 4 = 1$
$d.\ 7 * \frac{1}{7} = 1$

8. If the number of subsets for the set containing of two elements is (4) subsets, the number of subsets for the set containing of the set containing (3) elements is (8) subsets, the number of subsets for the set containing of the set containing (4) elements is (16) subsets.
What is the number of subsets for the set containing of (n) elements?

9. Find out the relationship between the numbers in the squares, and then complete the missing numbers.

4	7
6	5

16	49
	25

10. If the sum of the measures of the interior angles of a polygon whose number of sides n is equal to $(2n - 4)$ times right angle.
Then the polygon whose sum of the measures of its interior angles is 12-times right angles is a polygon …

11. If the addition operation is not distributed into the multiplication. Then $25 + (100 * 15)$ equals to:
$a.\ (25 + 100) * 15$
$b.\ (25 + 15) * 100$
$c.\ (25 + 100) * (25 + 15)$
$d.\ 25 + 1500$

12. In the following cards.

2	5	9	14	
4	8	13	19	26

What is the missing number in the last card?

13. The following cards are written by using the following rule: If a rational number appears in the upper half of the square, then its need to appears the additive multiplication of the same number. Which of the following cards agrees with the rule?

17	4/3-	3/2	7/5
1/17	3/4	3/2-	5/7

14. If the necessary condition for drawing any triangle is that the sum of the lengths of any two sides is greater than the length of the third side, which of the following lengths is suitable for drawing a triangle?

a. 6, 6, 12
b. 2, 3, 5
c. 5, 7, 13
d. 3, 6, 9

15. Every prime number is an odd number except 2, but not true every odd number is a prime number. Which of the following is prime number?

a. 21
b. 29
c. 81
d. 25

16. If you know that the cosines law for a triangle is: $a^2 = b^2 + c^2 - 2bc\cos a$. Malak wrote the cosines law in words as follows: “In any triangle, the square of any side is equal to the sum of the squares of the other two sides, plus twice the product of the two sides multiplied by the cosine of the angle between them.”
Do you agree with Malak? Justify your answer.

17. The following table shows the number of cows in two farms.

	Farm A	Farm B
Area in square kilometers	60	40
Number of cows	480	380

Mona says that farm A has a greater number of cows per square kilometers, while Safaa says that farm B has a greater number of cows per square kilometers. Which one is correct? Justify your answer.

18. In a cyclic quadrilateral, the sum of two opposite angles equals two right angles and vice versa. What do you conclude from the following two figures? Justify your answer.

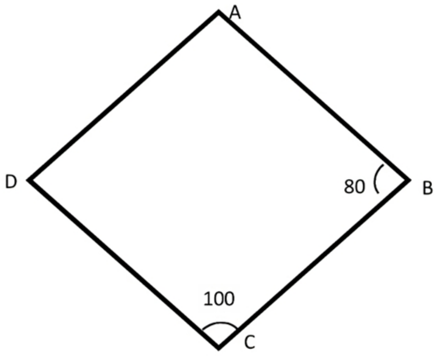

Fig. 1

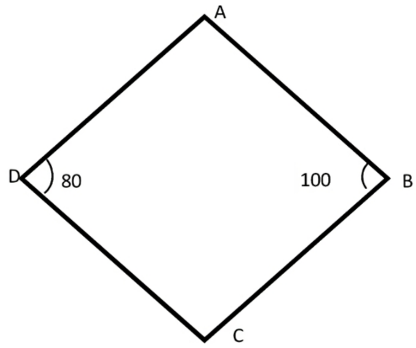

Fig. 2

19. A person wants to study the effects of sunflower growth in pots of different sizes. The graphs in the following figures show four expected results of the experiment.

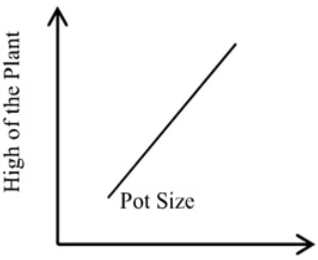

Fig. 1

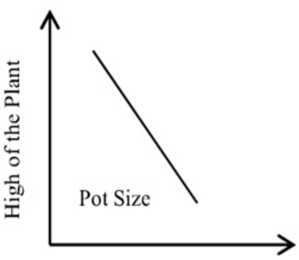

Fig. 2

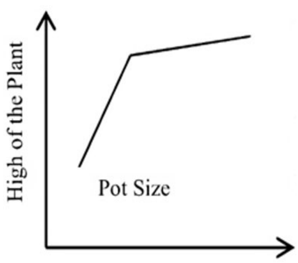

Fig. 3

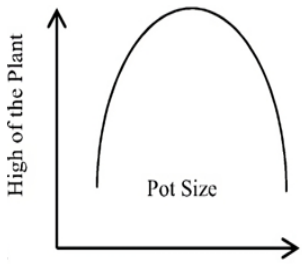

Fig. 4

Which of the above figures best describes the following statement and justifies your answer: "Every larger pot has shorter plant."

20. If the statements F: "The geometric figure is an isosceles triangle" and N: "The angles of the base are equal." Express the following statement in symbols: "If the geometric figure is an isosceles triangle, then the angles of the base are equal."

21. The age of a father is two years more than four times the age of his son. If the age of the father is y and the age of the son is x.
What is the age of the father as a function of the age of the son?

22. We have two numbers x and y.
Express in symbols the following rule: "The sum of the squares of the two numbers is less than or equal to the square of the sum of the two numbers."

23. A rectangular prism tank of water, its width is x meters, its length is 3-times meters more than its width, and its height is 2-times meters more than its width. Write the volume of the tank in terms of its width.