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ORIGINAL STUDY

The Efficacy of Utilizing Artificial Intelligence Techniques in Developing Critical Thinking in Mathematics among Secondary School Students and their Attitudes Toward it

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ABSTRACT

The aim of this study is to investigate the efficacy of Artificial Intelligence (AI) techniques and programs in developing Critical Thinking Skills (CTSs) in mathematics among secondary school students, as well as their attitudes towards it. This study employed an experimental methodology, which was applied to a sample of 91 students. A critical thinking test and a scale to measure students' Attitudes Towards Mathematics (ATM) were also utilized. This study revealed significant improvements in the mean scores of critical thinking skills among secondary students who were exposed to Artificial Intelligence Techniques (AITs), particularly in deduction, interpretation, inference, and evaluation. Additionally, the experimental group showed enhanced attitudes toward mathematics, as indicated by the post-application of the attitudes towards mathematics scale across all its domains. The findings underscore the efficacy of AI-powered methods in improving both critical thinking skills and attitudes toward mathematics. This study suggests integrating AI programs into curriculum content and providing teacher training to effectively utilize these technologies into mathematics education.

Keywords: Artificial Intelligence, Critical thinking, Mathematics, Attitudes of students, Secondary school students

1. Introduction

The rise of AI has revolutionized diverse sectors, permeating fields from healthcare to space exploration. This rapid technological progress has become a benchmark for national strength and civilization. Confronted with these transformative changes, educational institutions must develop responsive policies, curricula, and strategies. This paradigm shift presents valuable opportunities for educators to enrich the culture of AI and integrate it across educational stages, both theoretically and practically.

The importance of employing AI in education is underscored by recommendations from various scientific conferences. The 4th SEAMEO Strategic Dialogue in 2019 emphasized building policymaker capacity to integrate industrial AI into education policies, and the necessity of partnerships with AI-supporting. The 2019 International Conference on Digital Education reiterated the importance of these strategic

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partnerships [15]. The International Conference on AI and Education in Beijing concluded by underscoring the need for a human-centric approach to deploying AI in education, aimed at enhancing intelligence, protecting rights, and promoting sustainable development through effective human-machine collaboration [2, 13]. These conferences have collectively highlighted the significance of incorporating AI applications in education while emphasizing the importance of a human-centered focus and strategic partnerships.

The importance of AI lies in enhancing human cognitive skills across modes of thinking, such as creative, logical, reflective, and critical thinking, as well as problem-solving [16, 29]. Critical thinking, which involves higher-order skills like inference and analysis, is crucial for academic achievement and understanding complex concepts [29]. Recognizing the significance of these cognitive abilities, modern educational systems have emphasized the application of AI technologies to develop them and actively engage learners in the educational process [9, 28].

Critical thinking is essential for students to acquire key skills in education, teaching critical thinking involves strategies aimed at enhancing students' thinking skills [49]. The encouragement of inquiry and research expands students' cognitive awareness and improves learning outcomes, it is no longer just an option but a necessity in education [36, 44].

1.1. Problem statement

The integration AI technologies into education systems worldwide, including Jordan, is a priority for improving educational quality, developing teachers, and providing schools with the latest technologies. Experts predict significant growth in Critical Thinking Skills (CTSs), particularly in mathematics, due to the incorporation of AI. Educational institutions aim to enhance education quality, critical thinking skills, and positive attitudes through AI integration, which is crucial for meeting international standards. Mathematics teachers realize the importance of AI in developing critical thinking and improving students' attitudes toward mathematics to positively affect academic ability. However, there is a need of a method with strong psychometric properties to measure students' attitudes, the Thurstone scale method of measuring attitude is used. This method is rarely used in scale construction in the Arab countries and Jordan. Based on the aforementioned discussion, this study addresses the issue of students' low critical thinking skills in mathematics and their weak Attitudes Toward Mathematics (ATM). Consequently, the study aims to explore the effectiveness of utilizing AI systems and technologies to enhance students' critical thinking skills in mathematics and improve their attitudes towards the subject. The researchers anticipate that the findings of this study will be positive and will encourage enhancements in the learning process. Specifically, the main question guiding this study is: "**What is the effectiveness of using AIAs in developing students' CTSs in mathematics and improving their ATM**?" This main question has led to the following two sub-questions:

- **RQ1:** What is the effectiveness of using (AIAs) in developing (CTSs) in mathematics among secondary school students?
- **RQ2:** What is the effectiveness of using (AIAs) in developing (ATM) among secondary school students?

1.2. Study significance

The study is significant as it focuses on enhancing (CTSs) and (ATM) among secondary school students using (AITs). It builds upon previous research in mathematics education and aims to provide a framework for developing mathematics curricula, remedial plans, and educational programs based on its findings. It is highly relevant given the ongoing global trend towards digitalization in classrooms and provides empirical data on the efficacy of AI applications in improving critical thinking skills (Deduction, Inference, Evaluation, and Interpretation) and attitudes toward mathematics.

1.3. Study objectives

The objectives of this study are to investigate the effectiveness of using (AIAs) in developing (CTSs) in mathematics and enhancing students' (ATM).

1.4. Limitations of the study

- Human Limitations: The current study is limited to 11th grade students.
- Temporal Limits: This study is carried out during the first semester of the academic year 2023/2024.
- Spatial Limits: This study is limited to government schools in Irbid city, Hashemite Kingdom of Jordan.
- Objective Limits: The limitation of the study is to understand the effectiveness of using AI applications such as: Wolfram Alpha and Microsoft Math Solver, into further developing the critical thinking skills and students' attitudes towards mathematics.

- This study is determined by its tools and the psychometric properties it enjoys in terms of acceptable validity and reliability for the purposes of scientific research that were prepared to achieve the objectives of the study.

2. Literature review

2.1. Artificial intelligence

The term "Artificial Intelligence" (AI) emerged primarily in 1956, and its definitions have multiplied over the years. Cumming [14] defined AI as the science and engineering of making intelligent machines. Likewise, McArthur [22] views it as the ability of a particular system to analyze external data, infer new knowledge rules from it, and harness and exploit these rules to achieve goals and perform operations that did not exist before. Meanwhile, Roll and Wylie [29] defined AI as the ability of digital technologies and devices to perform certain operations and activities that mimic and resemble those carried out by intelligent beings, such as the ability to think, learn from past experiences, or engage in other mental processes. AI is procedurally defined in this study as a system that mimics the behavior and actions of the teacher by processing students' abilities, diagnosing their strengths and weaknesses, addressing them, guiding students in lessons, diversifying explanation methods, interaction styles with students, and addressing the difficulties they face in the subject of mathematics.

Artificial Intelligence Applications (AIAs) perform multiple complex and intelligent functions related to human cognition. AIAs, for example, provide capabilities such as speech recognition, computer vision, decision-making logic, and other smart functions that mimic the human mind. Some experts and specialists [13, 15, 43] have identified that the domains of AIAs as Expert systems, Chatbots, Natural Language Processing (NLP), games, character recognition, pattern recognition, image processing, and learning programs are among the prominent applications of artificial intelligence (AI) in education. Fig. 1 shows these domains.

Expert systems enable computers to perform tasks that only experts can do, supporting learners through interactive environments. Chatbots, such as ChatGPT developed by OpenAI, engage in human-like text-based conversations, providing learners with assistance and support. NLP software allows computers to understand and interpret natural human languages, while character recognition software converts handwritten or printed characters into digital text. Pattern recognition and image processing software identify patterns, shapes, and images. AI-driven learning programs use multiple data inputs to adapt and enhance the learning process, facilitating advancements in education [24, 42].

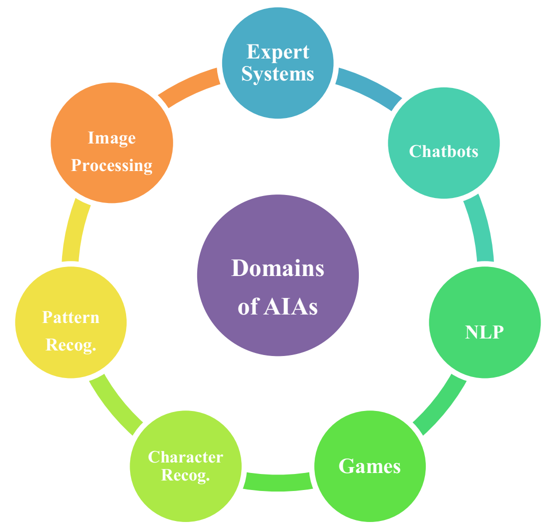

Fig. 1. Domains of AIAs.

Educational systems around the world have been diligent in providing comprehensive growth opportunities for learners within their capabilities and potential, based on the requirements of the modern era, which is characterized by the exponential growth, flow, and acceleration of information [19, 29]. The role of AI as an educational tool is prominent in reinforcing the recent educational trends towards self-directed learning, teaching learning strategies, and increasing the learner's responsibility for their own learning [10]. Additionally, there is an increasing need for personalized education to align with the individual learner's capabilities, needs, and individual differences, given AI's vast and integrated capabilities that combine multiple features of various educational technologies, as well as the ability to program educational content in a psychological and logical sequence, and provide direct interaction with the learning process [31, 43].

The educational literature emphasizes the need to move education beyond mere rote learning and passive instruction, towards a more positive and engaging model where the learner actively participates in the teaching and learning process, becoming a central stakeholder [11, 12, 40]. Over the past two decades, AI technologies have seen widespread adoption across various sectors, including the education domain. This has prompted many startups to apply AI concepts and techniques to provide the best possible learning experience.

2.2. Critical thinking

Critical thinking is crucial for students; it allows them to approach learning differently, leading to a deeper understanding of the material. It transforms passive learning into a mental exercise, aiding in better mastery of content and the ability to connect ideas. Additionally, it fosters independence, boosts self-confidence, and creates opportunities for creative development. Critical thinking also enhances students' ability to analyze information objectively, make sound judgments, and solve problems effectively by asking questions, evaluating facts, and reaching accurate conclusions [17, 34, 47, 49]. Critical thinking is operationally perceived in this study as set of skills that students acquire to help them objectively analyze the knowledge contained in the subject of mathematics, through an educational program based on artificial intelligence and its techniques. It is measured through the students' scores on the critical thinking test in mathematics prepared by the researchers.

There is disagreement among experts regarding the definition of critical thinking, despite its importance. This is because it's a complex, multifaceted concept linked to various behaviors and types of thinking. Paul and Elder [26] viewed critical thinking as a way to present solutions and ideas for complex issues using multiple tools. Also, Papak et al. [25] described it as thinking based on logical rules to analyze hypotheses and make appropriate decisions. Sahin et al. [30] mentioned it as the ability to transfer knowledge between disciplines, involving active learning, problem-solving, decision-making, and information usage.

Critical Thinking Skills (CTSs) have varied due to differences in the ideas of educators and specialists, as well as the nature of their studies and the theoretical foundations they rely on. Learners use (CTSs) in problem-solving, evaluating arguments, and making appropriate decisions about particular beliefs. The following is an overview of some classifications of CTSs according to the opinions of some educational experts [3, 25, 30, 47, 49], which this study is be based on it, see Fig. 2.

The subject of mathematics, with its abstraction and its primary focus on developing learners' minds, training them in critical thinking, problem-solving, and acquiring scientific attitudes related to research, inquiry, inference, and metacognitive skills. Therefore, experts in education [4, 13, 15, 27] believe that there is an urgent need to utilize AIAs in the teaching and learning of mathematics. This necessity arises from the nature and importance of abstract mathematics, which requires inference and critical thinking on the part of the teacher.

Firstly, contemporary educational trends call for the development of curricula and teaching methods to align with current standards and keep pace with the cognitive revolution, especially in mathematics education. Secondly, the deteriorating condition of the educational environment, including teachers, students, curricula, evaluation methods, educational facilities, and the obstacles they pose to achieving educational objectives. Thirdly, the importance of mathematics as a scientific subject that is essential for many other disciplines, such as engineering, sciences, information technology, economics, and business administration, necessitating the development of all elements involved in teaching this subject.

The rise of artificial intelligence has revolutionized numerous fields, and mathematics is no exception. Today, mathematicians, teachers, and students can harness the power of smart tools to simplify complex mathematical operations, improve problem-solving abilities, and enhance learning experiences. Here are some of the best AITs and programs that experts recommend for teaching, according to [7, 42, 46, 49]. These AI-powered mathematical tools offer a wide range of functionalities to assist users in solving mathematical problems efficiently. Wolfram Alpha serves as a comprehensive computational knowledge

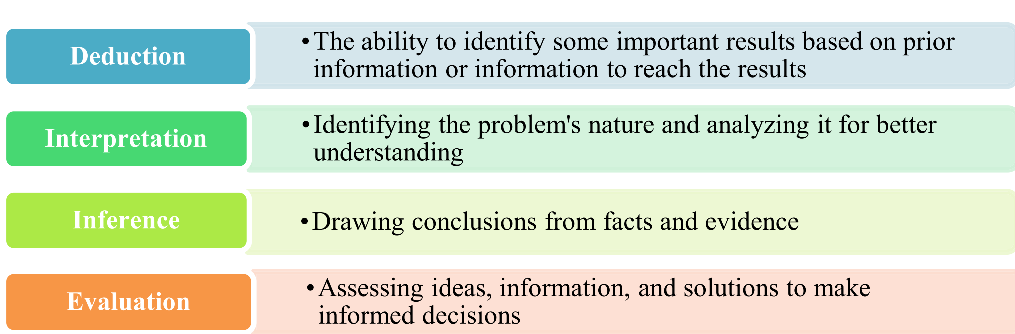

Fig. 2. Critical thinking skills.

engine capable of handling various mathematical operations, including arithmetic, calculus, and linear algebra, providing detailed step-by-step solutions and graphing capabilities. SymPy, an open-source Python library, focuses on symbolic mathematics, allowing users to manipulate symbols and algebraic formulas to solve equations and simplify formulas. Microsoft Math Solver offers an intuitive interface with handwriting recognition and step-by-step solutions, along with interactive graphs and practice exercises. GeoGebra integrates geometry, algebra, and calculus to enhance mathematical visualization and exploration, with features for creating geometric shapes, demonstrating equations, and generating graphs and interactive simulations. Finally, SymbMath conducts symbolic mathematics, managing algebraic equations, calculus, matrices, and various other mathematical domains, providing a robust option for a diverse array of mathematical tasks.

2.3. Attitudes

The study of attitudes is crucial in psychology as they significantly influence human behavior, aiding in adaptation and social compatibility. In education, attitudes towards school subjects, particularly mathematics, greatly impact the learning process and academic achievement. Developing positive ATM is a key educational goal [39, 45]. While advanced countries prioritize understanding and mastering mathematics due to its importance, it remains one of the most challenging subjects for students, often leading to negative attitudes and avoidance. Consequently, fewer students study mathematics compared to other subjects, resulting in a lower success rate in mathematics compared to other sciences [23, 35, 48]. ATM is defined procedurally as students' beliefs and opinions about the subject of mathematics in terms of their support or rejection, measured through the students' scores on the ATM scale prepared by the researchers.

ATM receives more attention than those towards specific scientific subjects. There's an increasing interest in attitudes towards various scientific fields like physics, statistics, biology, and chemistry. The impact of attitudes on academic achievement has led to significant research interest in ATM. Mathematics is crucial for advanced countries as it holds the key to understanding other sciences. However, it is often perceived as challenging by students, leading to negative attitudes and avoidance. Consequently, fewer students opt to study mathematics compared to other subjects, resulting in a lower success rate [23, 37, 48].

There is a growing interest in studying attitudes in today's context, with empirical studies covering various aspects of our lives. Attitudes are seen as indicators of an individual's psychological and cognitive readiness to comprehend, utilize, and interact with learning materials. Moreover, they act as psychological and mental motivators that enhance students' receptivity to educational content [41]. Educational experts emphasize the importance of encouraging positive attitudes towards academic subjects from an early age as attitudes often shape a student's path, behavior, and academic success or failure. Childhood is a critical stage for developing a student's identity and cognitive framework, playing a pivotal role in their behavior and helping them identify their preferences and interests [23, 38].

An attitude is essentially a predisposition or readiness to respond to a particular subject or stimuli in the environment, triggered by specific situations or experiences. This leads individuals to exhibit behaviors during the learning process through which they assess their orientation towards these stimuli. This predisposition can be either temporary or enduring. Attitudes are shaped by experiences and interactions with the learning environment, significantly influencing how individuals respond to situations and stimuli that are the focus of these attitudes [45, 48]. Experts and specialists in education have offered different definitions of attitudes. Attitudes are positive or negative feelings towards a particular subject, person, situation, or idea [48]. Others describe attitudes as a mental and neural state shaped by experience, guiding an individual's responses to all related subjects and situations [45]. Alternatively, attitudes are perceived as the inclination towards specific feelings, behaviors, or thoughts about other people, organizations, subjects, or symbols [41].

In mathematics, attitudes can be described as the collective responses of students towards mathematical subjects, reflecting their acceptance or rejection of the subject. These attitudes vary in their stability, strength, weakness, and fluctuation over time. While some individuals maintain strong and stable ATM for extended periods, others may exhibit weak and fluctuating attitudes [23].

2.4. Previous studies

A comprehensive search of databases and previous studies has revealed a lack of research directly examining the effectiveness of using AIAs and techniques to develop students' CTSs. While there appears to be a dearth of literature on this specific topic, a few studies have explored the impact of AIAs on various other student outcomes, such as deductive thinking, academic achievement, motivation, attitudes, self-efficacy, expected benefits, and behavioral intentions.

In a recent study, Wardat et al. [43] examined UAE math teachers' perceptions of implemented AI systems and applications. Their findings suggest AI can enhance teaching and students' performance if integrated into curricula. However, the study also identified key challenges, including teachers needing to exert more effort using AI tools compared to traditional methods, and significant pressures hindering AI adoption in the classroom.

Yeonju et al. [46] developed and validated an instrument to measure undergraduate students' attitudes towards AI ethics (AT-EAI). Their descriptive study of 196 students found gender differences in perceptions of justice, privacy, and non-maleficence. Additionally, students' views on the ethical principle of justice were shaped by prior AI-related coursework, suggesting education can influence attitudes towards the ethical implications of AI.

Al Darayseh [4] used the TAM model to examine the perceptions of AI in the classroom from science and math teachers. The study founds high acceptability of AI among the teachers, with positive correlations between AI acceptance and factors like self-efficacy, ease of use, expected benefits, attitudes, and behavioral intentions. Additionally, teachers' attitudes could predict 71.4% of their future AI integration in science teaching. Interestingly, the study did not find significant variations in teachers' AI adoption intentions based on gender, experience, or credentials.

Hwang [20] conducted a meta-analysis on the effectiveness of AI in improving elementary students' math achievement. The findings showed a small overall effect size of 0.351. The study examined eight moderating variables, and the results indicated that only math learning topic and grade level significantly influenced the effect of AI on math achievement. Based on these findings, the study provided practical and research implications for further investigating AI's role in elementary mathematics education.

The study by Al-Atal et al. [5] aimed to identify the importance of AI technology in education and the challenges of using it, from the perspective of university students in Kuwait. The results showed that there were significant differences in the perceived importance of AI technology based on academic level, but no differences in the perceived challenges. Additionally, there were differences in the perceived challenges of using AI technology based on gender and GPA, but no differences in the perceived importance of it in education.

Hareri [18] presented a proposed vision for using AI to support education in universities in Saudi Arabia in light of the COVID-19 pandemic, drawing on China's experience. The study used a descriptive approach and surveyed 382 academic staff. The key findings were that Saudi universities utilized AI and e-learning systems to support the educational process during the lockdown, established various educational platforms, and had pre-existing e-learning initiatives. The study recommended conducting further research to identify challenges in applying AI in higher education and developing the educational environment to better integrate AI-based educational support.

Furthermore, Shin and Shin [31] examined primary school mathematics teachers' awareness of AIAs and their use in teaching in Korea. Using a descriptive survey method with a sample of 95 teachers, the results showed that teachers had low awareness of AIAs in education, but mathematics courses had the highest potential for AI application. The study recommended the necessity of providing training for teachers on employing AIAs in their teaching.

AL-Sobhi [8] probed the use of AIAs by faculty members at Najran University and the challenges they face, in relation to variables like gender and academic level. Using a descriptive analytical approach with 301 faculty members, the findings revealed very low utilization of AIAs by faculty, with a consensus on the existence of challenges inhibiting their use, but no significant differences in these challenges based on the examined variables. The study recommended providing training courses for faculty to familiarize them with AI applications and motivate the use of modern educational technologies.

Wang et al. [42] found a low level of use of AIAs by faculty members in a Chinese university for educational purposes. Likewise, Mahmoud [21] identified various challenges in the educational process, administration, teachers, learners, parents, and teacher evaluation during the COVID-19 pandemic, which could potentially be overcome by employing different AIAs in the educational process.

Moreover, AL-Hashmi [6] found a high level of AI technology implementation by academic staff in colleges of Applied Sciences in Oman, but also identified physical and human obstacles that limit its use. The study provided suggestions to improve the effectiveness of AI technology in teaching and revealed a very positive attitude towards its use.

Abu Shamala [1] used a quasi-experimental approach to develop an AI-based program to enhance deductive thinking and academic achievement in mathematics among 11th grade female students in Gaza, with results showing significant improvements in the experimental group.

The review of previous studies indicates that while most used experimental, quasi-experimental or descriptive approaches, similar to the current study, they targeted a variety of samples from different educational levels and focused on the importance and challenges of using AI in education, with limited studies examining its impact on specific variables like critical thinking, which is the focus of the current study.

3. Methodology

3.1. Research design

The present study employed an experimental research design involving two groups. First: the experimental group, which was exposed to AITs and programs. Second: the control group, which was taught using the traditional instructional method. The study also incorporated the administration of a critical thinking test in mathematics and a questionnaire-style scale to assess students' attitudes towards mathematics. The study was applied during the first semester of the academic year 2023/2024 at public schools in the city of Irbid, Hashemite Kingdom of Jordan.

3.2. Study sample

The population of the study consisted of all 11th grade students in the city of Irbid, Hashemite Kingdom of Jordan. The study sample comprised 91 students from one of the secondary schools, who were divided into two groups: an experimental group of 45 students and a control group of 46 students.

3.3. Instruments

3.3.1. Critical thinking test

The researcher developed a multiple-choice critical thinking test in mathematics based on a review of theoretical and empirical literature [9, 26, 44, 49]. This test format was selected due to its ability to comprehensively cover the curriculum content, ease of scoring, and established psychometric properties of high validity and reliability. The initial version of the test included tasks designed to assess the four CTSs: deduction, interpretation, inference, and evaluation. The final test version consisted of 25 items, with each correct response scored as 1 point and each incorrect response scored as 0 points, resulting in a total possible test score range of 0 to 25.

To establish the validity of the instrument, the researcher employed expert validation. The test was presented to a panel of subject matter experts, who were asked to provide feedback on the suitability of the instrument's items in relation to the study's objectives, as well as the linguistic correctness of the items. Based on the experts' recommendations, modifications were made until the final version of the instrument was developed. Furthermore, the authors examined the test questions difficulty and discrimination coefficients of the test by administering it to a pilot sample of 20 students. The analysis of the students' responses revealed that the item difficulty coefficients ranged from 0.58 to 0.79, while the item discrimination coefficients ranged from 0.42 to 0.77. These statistical indices are considered appropriate and acceptable for the purposes of the current study.

3.3.2. Attitudinal towards mathematics scale

Drawing from the theoretical and empirical literature [25, 26, 30], the authors constructed a 30-item Likert-type scale to measure students' attitudes towards mathematics. The scale items were distributed across five domains: (Importance of Mathematics (IOM), Enjoyment of Mathematics (EOM), Student's Perception of Mathematical Competence (SPMC), Student's Positivity (SP), and Teacher's Positivity (TP)). Each item was rated on a five-point scale ranging from (Strongly Agree) to (Strongly Disagree), with corresponding scores of 5, 4, 3, 2, and 1, respectively. The total possible score range for the overall scale was from a minimum of 30 to a maximum of 150.

To establish the validity of the attitudes towards mathematics scale, it was reviewed by a panel of subject matter experts. The experts provided feedback on the extent to which the scale items aligned with the study's objectives, the linguistic clarity of the items, and the overall comprehensiveness and precision of the scale. Based on the experts' recommendations, necessary revisions were made, including the removal of some items and the rewording of others, to finalize the scale.

The reliability of the instrument was assessed through a test-retest procedure. The scale was administered twice to the pilot sample, with a two-week interval between the administrations. The Pearson correlation coefficients were calculated between the participants' scores on the two administrations. The reliability values for the five scale domains (importance of math, enjoyment of math, student's perception of mathematical competence, student's positivity, teacher's positivity) and the overall scale were 0.77, 0.91, 0.92, 0.91, 0.93, and 0.89, respectively. These high correlation coefficients indicate that the scale has reliable measurement properties, supporting its use in the study.

3.3.3. AI tools and instructional activities

This study relied on two AI applications: (Microsoft Math Solver and Wolfram Alpha). The Wolfram Alpha application works as a search engine for mathematical knowledge due to its superior ability to deal with various mathematical operations and

Calculus, which provides detailed step-by-step solutions that, allow students to understand mathematical problems. The Microsoft Math application also works as an intuitive interface that allows handwriting in addition to interactive graphs. The educational material was presented to the experimental group through a set of activities, exercises, homework's and strategies that aim to develop critical thinking skills, in addition to a set of classroom lessons and a detailed description and explanation supported by classroom activities, exercises and homework that were prepared using Microsoft Math Solver and Wolfram Alpha applications.

The educational material was also chosen through the (Calculus) chapter, which consists of five lessons: (Derivative, Geometric Meaning of the Derivative, Derivative Techniques, Implicit Derivation, and Chain Rule). The teaching of the educational material took (6) weeks, with (24) class periods, each lasting (45) minutes.

The researchers also prepared a user guide for using the Microsoft Math Solver and Wolfram Alpha applications, which explains to the students an overview of the application, how to use it, an explanation of its main elements, and a simplified explanation of some of its features. A teacher's guide was also prepared to guide in teaching the (Calculus) chapter using the Microsoft Math Solver and Wolfram Alpha applications, which explains the proposed time plan for teaching, lesson preparation and plan, and assessment.

3.4. Data analysis

The collected data were entered into a computer database and analyzed using the SPSS statistical software. Descriptive statistics, including means and standard deviations, were computed to identify any observable differences in the participants' performance on the study measures. Additionally, the researcher utilized multivariate analysis of covariance (MANCOVA) to analyze the results of both the critical thinking in mathematics test and the attitudes towards mathematics scale. This advanced statistical technique was selected to account for any potential confounding factors and provide a comprehensive examination of the study's dependent variables.

4. Results

RQ1: What is the effectiveness of using AIAs in developing CTSs in mathematics among secondary school students?

The researcher calculated the means and standard deviations to analyze the results of the pre-test and post-test administrations of the critical thinking in mathematics test, as well as its four subscales (Deduction, Interpretation, Inference, and Evaluation), see Table 1.

The data presented in Table 1 indicates that the performance of the participants on the pre-test was relatively similar between the two groups. However, the results of the post-test on the critical thinking in mathematics assessment and its four subscales, i.e., deduction, interpretation, inference, evaluation reveal a notable difference. While both groups showed improvement in their CTSs, the performance of the experimental group was significantly better than that of the control group. The mean scores for the students' CTSs and the overall test for the experimental group were (15.66, 17.32, 16.09, 15.88, 16.29), respectively. In comparison, the mean scores for the control group were (9.95, 10.95, 9.58, 9.14, 10.12), respectively. These results suggest that the experimental group, which was exposed to the AITs and programs, demonstrated substantially higher critical thinking abilities compared to the control group that received the traditional instruction.

To determine the statistical significance of the observed differences, the researcher employed a multivariate analysis of covariance (MANCOVA) to

Table 1. Students' results in the pre and post-test on the critical thinking test.

			Critical Thinking Skills				
Group	Test	Statistics	Deduction	Interpretation	Inference	Evaluation	Total
Control	Pre	Mean	5.62	6.25	6.62	5.92	6.33
		STD	3.65	3.89	3.22	3.62	3.35
	Post	Mean	9.95	10.95	9.58	9.14	10.12
		STD	3.02	2.91	3.35	3.04	2.92
Experimental	Pre	Mean	5.79	6.12	5.67	6.09	6.31
		STD	3.67	3.92	3.26	3.43	3.34
	Post	Mean	15.66	17.32	16.09	15.88	16.29
		STD	2.11	2.09	1.98	1.88	1.96

The maximum score for the critical thinking test in mathematics 30.

Table 2. MANCOVA analysis and effect sizes for the critical thinking test in the post-test.

Source of Variance	Skill	Sum of Squares	df	Mean square	F	Sig	η^2	effect size
MANCOVA	Deduction	505.029	1	505.029	116.178	0.000	0.303	
	Interpretation	318.914	1	318.914	87.039	0.005	0.217	
	Inference	112.746	1	112.746	35.952	0.005	0.350	
	Evaluation	108.325	1	108.325	35.400	0.005	0.275	
	Total	3554.454	1	3554.454	179.935	0.027	0.374	
Post-test	Deduction	143.934	1	143.934	33.111	*0.002	0.273	Great
	Interpretation	83.847	1	83.847	22.448	*0.029	0.206	Great
	Inference	66.896	1	66.896	21.331	*0.017	0.263	Great
	Evaluation	62.905	1	62.905	17.473	*0.022	0.286	Great
	Total	931.139	1	931.139	47.136	*0.000	0.315	Great
Error	Deduction	382.612	88	4.347				
	Interpretation	322.437	88	3.664				
	Inference	275.982	88	3.136				
	Evaluation	269.325	88	3.060				
	Total	1738.411	88	19.754				
Total	Deduction	533.200	90					
	Interpretation	412.128	90					
	Inference	353.472	90					
	Evaluation	348.054	90					
	Total	3008.000	90					

significance level ($\alpha = 0.05$).

analyze the results of the critical thinking in mathematics test. Additionally, the effect sizes for the overall critical thinking test and its four subscales were calculated in the post-test between the study groups (experimental and control), after controlling for the pre-test scores (the covariate). Table 2 presents the results of the MANCOVA and the effect sizes for the critical thinking test as a whole and for each of its four skills.

The findings presented in Table 2 reveal statistically significant differences at the significance level ($\alpha = 0.05$) between the mean scores of the study groups on the critical thinking test and its four subscales, i.e., DIIE. To assess the effectiveness of using AITs in developing critical thinking in mathematics and its skills among the study participants, the researcher calculated the effect size using eta-squared (η^2). The results indicate a large effect size for the four critical thinking skills and the overall test, as the effect size values exceeded 0.14. This suggests that the integration of AITs in the learning process accounted for approximately 27.3%, 20.6%, 26.3%, 28.6%, and 31.5% of the variance in the development of critical thinking and its respective skills among the study participants. The remaining variance, ranging from 72.7% to 68.5%, is unexplained and may be attributed to external factors or other uncontrolled variables.

RQ2: What is the effectiveness of using AIAs in developing ATM among secondary school students?

To achieve this, the means and standard deviations were calculated for the pre-test and post-test administrations on each of the five domains of the attitudes towards mathematics scale (IOM, EOM, SPMC, SP, and TP), as well as for the overall scale, see Table 3.

The data presented in Table 3 pointed out that the means and standard deviations for the study groups were comparable in the pre-test, as well as for the control group in the post-test, on the attitudes towards mathematics scale. However, a more detailed analysis of the results reveals distinct differences in the mean scores and standard deviations of the experimental group's performance on the overall attitudes towards mathematics scale and its five domains (IOM, EOM, SPMC, SP, and TP) in the post-test. Specifically, the mean score for the overall attitudes towards mathematics scale in the post-test was 67.34 for the experimental group, compared to 107.65 for the control group. The standard deviation for the overall scale was 8.751 for the experimental group and 12.837 for the control group. In contrast, the control group's mean scores in the post-test were 24.83 for IOM, 24.15 for EOM, 20.50 for SPMC, 26.82 for SP, and 21.03 for TP. These results suggest that the experimental group, which was exposed to the artificial intelligence techniques and programs, demonstrated more positive attitudes towards mathematics compared to the control group that received the traditional instruction.

The results presented in Table 3 further highlight the differences between the two groups. The mean score for the overall attitudes towards mathematics scale in the post-test was significantly lower for the

Table 3. Students' attitudes towards mathematics in the pre and post-test.

Group	Test	Statistics	Attitudes Towards Mathematics Domains					
			IOM	EOM	SPMC	SP	TP	Total
Control	Pre	Mean	25.77	25.82	20.80	27.05	22.61	112.25
		STD	5.551	5.975	5.752	6.015	5.741	14.982
	Post	Mean	24.83	24.15	20.50	26.82	21.03	107.65
		STD	4.812	4.821	4.909	5.523	4.608	12.837
Experimental	Pre	Mean	25.35	25.54	20.85	26.50	22.90	112.08
		STD	5.125	5.754	5.605	5.886	5.457	13.521
	Post	Mean	16.41	15.52	13.52	18.98	17.23	67.34
		STD	3.952	4.155	3.735	4.560	4.275	8.751

The total score for each of the overall ATM scale is 150.

experimental group at 67.34, compared to 107.65 for the control group. Similarly, the standard deviation for the overall scale was much smaller for the experimental group at 8.751, compared to 12.837 for the control group. This pattern is consistent across the five individual domains of the attitudes towards mathematics scale, with the experimental group consistently scoring lower on measures of IOM, EOM, SPMC, SP, and TP. These findings suggest that the experimental group, which was exposed to the artificial intelligence techniques and programs, demonstrated considerably more positive attitudes towards mathematics compared to the control group that received the traditional instruction. The researcher sought to determine the statistical significance of the observed differences by conducting MANCOVA. This analysis examined the post-test results of the overall attitudes towards mathematics scale and its five domains (IOM, EOM, SPMC, SP, and TP) between the study groups, while controlling for the pre-test scores, see Table 4.

The findings in Table 4 reveal that the computed F-values were statistically significant for the overall attitudes towards mathematics scale and its five constituent domains: IOM, EOM, SPMC, SP, and TP. This indicates that there were statistically significant differences at the significance level ($\alpha = 0.05$) between the study groups in the post-test administration of the overall attitudes towards mathematics scale and its five domains, with the experimental group demonstrating more positive attitudes.

Table 4. MANCOVA analysis and effect sizes for the students' attitudes in the pre and post scale.

Source of Variance	Skill	Sum of Squares	df	Mean square	F	Sig	η^2	Effect size
MANCOVA	IOM	1426.94	1	1426.94	166.69	0.000	0.354	
	EOM	1215.61	1	1215.61	90.17	0.002	0.406	
	SPMC	684.02	1	684.02	86.47	0.002	0.396	
	SP	690.37	1	690.37	18.35	0.000	0.202	
	TP	235.37	1	235.37	10.58	0.000	0.118	
	Total	19750.07	1	19750.07	81.00	0.000	0.379	
Post-test	IOM	1055.52	1	1055.52	123.30	0.000*	0.218	Great
	EOM	825.65	1	825.65	61.25	0.000*	0.178	Great
	SPMC	442.25	1	442.25	55.91	0.032*	0.182	Great
	SP	452.92	1	452.92	11.75	0.020*	0.218	Great
	TP	61.63	1	61.63	2.44	0.066	0.178	Great
	Total	15620.41	1	15620.41	64.06	0.000*	0.182	Great
Errors	IOM	753.91	88	8.56				
	EOM	1187.06	88	13.48				
	SPMC	696.12	88	7.91				
	SP	3310.29	88	37.61				
	TP	1957.61	88	22.24				
	Total	21455.72	88	243.81				
Total	IOM	3647.88	90					
	EOM	3399.32	90					
	SPMC	1927.72	90					
	SP	4647.72	90					
	TP	3246.8	90					
	Total	64338.84	90					

Significance level ($\alpha = 0.05$).

To assess the effectiveness of using AITs in shaping the attitudes towards mathematics among the participants, the researcher calculated the effect size using eta-squared (η^2). The results show that the effect size was greater than 0.14 for the overall scale and its five domains, suggesting a large effect size. This implies that the integration of AITs had a substantial impact on the participants' attitudes towards mathematics.

5. Discussion

The results of the study reveal statistically significant differences in the mean scores, favoring the experimental group that was exposed to AITs, in the post-test administration of the critical thinking test and its skills (Deduction, Interpretation, Inference, and Evaluation). This suggests that the use of AITs positively influences the development of CTSs in mathematics among students.

This finding can be attributed to the significant role played by the AITs that the experimental group students were exposed to. These techniques were designed by the producing companies based on organized, logical algorithms and interconnected steps, aimed at challenging the traditional patterns of thinking. Moreover, the application of smart learning techniques in the educational process provided students with the opportunity to engage in diverse learning activities, actively participate, and explore novel concepts, ultimately enhancing their motivation and driving them to further investigate the significant role of smart learning tools and techniques.

Additionally, the use of AITs helped students to think deeply and consciously about various mathematical problems. It encouraged them to explore different perspectives, consider multiple alternatives, and make comprehensive observations about potential solution approaches. This facilitated their understanding of the problem from various angles and enhanced their ability to select appropriate solutions, while also justifying the exclusion of unsuitable alternatives. Importantly, the use of these techniques prevented students from hastily formulating judgments about the correct solution methods for the mathematical problems they encountered.

In essence, the application of AITs in the learning process enabled students to engage in more profound, multi-faceted, and well-reasoned thinking when approaching mathematical tasks. This, in turn, contributed to the development of their CTSs in the domain of mathematics.

The results of the study indicate that the use of AITs, such as Microsoft Math Solver, provided students with the opportunity to apply their prior knowledge, experiences, and skills to connect new information and insights. This enabled them to effectively navigate novel mathematical situations, thereby enhancing their Deduction skills.

The integration of Wolfram Alpha and Microsoft Math Solver techniques further enhanced the students' critical thinking skills. These tools allowed students to input word problems and engage in a variety of mathematical operations, such as solving algebraic equations, calculating differentiation and integration, and performing equation operations. Importantly, the tools provided step-by-step solutions and simplified the complex mathematical problems, making them more accessible to the students.

Additionally, the integration of interactive animations and practice exercises guided the students to interpret and analyze the mathematical problems they encountered in a more comprehensible manner. This facilitated their understanding of the underlying concepts and enabled them to draw meaningful conclusions. Consequently, this process fostered the development of the students' interpretation and inference skills, which are crucial components of critical thinking in mathematics.

In essence, the integration of these AITs in the learning process empowered students to leverage their prior knowledge and experiences, interpret and analyze mathematical problems more effectively, and draw logical inferences. This, in turn, contributed to the overall enhancement of their critical thinking skills in the domain of mathematics.

The use of the Wolfram Alpha technique by students facilitates their ability to perform symbolic calculations, enabling them to simplify and solve algebraic equations. This makes Wolfram Alpha a valuable tool for both basic and advanced mathematical computations. Additionally, the software can handle matrices, calculate differentiation and integration, and solve mathematical equations, increasing its utility across a wide range of mathematical tasks.

These findings are supported by researchers [16, 29, 33] who found that the significance of AI' lies in improving human cognitive skills across various modes of thinking, including creative, logical, reflective, and critical thinking, as well as problem-solving. Likewise, the study is aligned with [9, 28] who acknowledge contemporary educational systems have prioritized the use of AI technologies to cultivate them and effectively involve learners in the educational process.

This, in turn, enhances the students' ability to evaluate ideas, accept or reject them, and make judgments on the adequacy of information. It also allows them to verify the success in reaching the final solution and make decisions to solve the problem. This process, therefore, fosters the development of the evaluation skill, which is a crucial component of critical thinking and this is consistent with some studies [31, 42]. Furthermore, the diverse range of features covered by the AITs, from image, text, and sound recognition and classification to motivating and engaging students in the learning process, contributed to the repeated and varied use of these tools. This, in turn, led to the development of CTSs among the students. In essence, the integration of Wolfram Alpha and other AITs empowered students to perform advanced mathematical operations, evaluate their work, and engage in the learning process in a diverse and motivating manner, ultimately enhancing their CTSs in mathematics.

Furthermore, the results of the study showed statistically significant differences in the mean scores, favoring the experimental group that was exposed to AITs, in the post-test administration of the overall attitudes towards mathematics scale and its five domains, i.e., IOM, EOM, SPMC, SP, and TP. This indicates that the use of AITs has a positive effect on developing students' attitudes towards mathematics. This finding can be attributed to the fact that the frequent use of AITs and programs by the experimental group students made them feel the importance and necessity of the subject of mathematics, which they now view as deserving of respect and attention [3, 25]. Mathematics is no longer perceived as mere problems and exercises that do not rely on understanding, but rather its study has accustomed the students to precision and certainty in decision-making and judgment. This has significantly contributed to the development of the students' thinking and made them more accurate, productive, and concise in solving mathematical problems, which, in turn, has greatly raised their awareness of the importance of mathematics and developed their positive attitudes towards it.

Regarding the domain of enjoyment mathematics, the optimal and effective use of artificial intelligence techniques has contributed to the development of students' attitudes towards mathematics. This is because the students enjoyed the process of thinking and solving the challenging mathematical problems that contained new and engaging creative ideas. They also took pleasure in working with symbols, numbers, equations, and performing calculus operations.

These findings are confirmed by researchers [7, 42, 46, 49] who reported that the advent of AI has transformed various domains, including mathematics, offering mathematicians, teachers, and students' smart tools to streamline complex mathematical operations and enhance problem-solving skills. According to experts here are some of the top AI tools and programs recommended for teaching mathematics. Moreover, [32, 43] found that AI integration enhances teaching and student performance.

6. Conclusion

In light of this study's findings, a key conclusion was reached that the utilization of AITs in the educational process is considered a successful instructional approach in developing secondary school students' attitudes towards mathematics. Additionally, the study results indicate that organizing the educational content in a motivating and stimulating manner through the use of artificial intelligence techniques and programs led to an increase in the students' self-confidence. They no longer feared competition with their peers and were able to solve most of the difficult mathematical problems. Furthermore, the students felt confident in taking tests at any time without extensive prior preparation, all of which made them perceive mathematics as an easy subject. Moreover, the teacher's guidance in utilizing the appropriate artificial intelligence techniques and programs enabled the students to recognize their high mathematical competence. This, in turn, contributed to the development of their positive attitudes towards the enjoyment of mathematics. Based on these findings, this is a call for decision-makers in educational institutions to work on revisiting curricula to incorporate AI techniques in a captivating manner, in order to motivate students and improve learning outcomes, and to adopting the latest applications of AI and its techniques, and encourage teachers to utilize them in reformulating or modifying the content in a way that contributes to the development of critical thinking skills and attitudes towards mathematics.

7. Recommendations

It is clear that the use of AI is not just about being a facilitated choice, but rather a necessity that cannot be overlooked. AI is an addition to all forms of knowledge, not a substitute. It is a tool and a means that must be utilized correctly in the educational process and scientific research. Based on the positive results demonstrated by this study, the following recommendations are made:

1. Utilizing AITs and programs as an important means to achieve various teaching objectives, particularly the development of critical thinking skills and positive attitudes towards mathematics.
2. Revisiting academic curricula to incorporate artificial intelligence programs and techniques in a captivating manner, in order to motivate students and improve learning outcomes.
3. Organizing necessary training programs and courses to equip and train mathematics teachers

on the use of artificial intelligence, enhancing their skills, experiences, and knowledge towards integrating it in the educational process.
4. Benefiting from the experiences of advanced countries in the field of artificial intelligence by establishing partnership agreements and providing training courses for teachers, as well as regularly monitoring their progress and giving them feedback.
5. Adopting the latest artificial intelligence programs and techniques, as well as encourage teachers to utilize them in reformulating or modifying the content in a way that contributes to the development of critical thinking skills and its various strategies.
6. Conducting further studies and research targeting other samples and variables, such as motivation towards learning, academic enthusiasm, academic achievement, and various types of thinking.

Ethical statement

All the authors demonstrate that they have adhered to the accepted ethical standards of a genuine research study.

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Declaration of interest

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Data sharing statement

Data supporting the findings and conclusions are available upon request from the corresponding author.

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