MODESTUM
EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(6), em2644
ISSN:1305-8223 (online)
OPEN ACCESS
Research Paper
https://doi.org/10.29333/ejmste/16416

The effectiveness of using augmented reality technology in science education to enhance creative thinking skills among gifted eighth-grade students

Rommel AlAli [1*], Yousef Wardat [2*], Yusra Zaki Aboud [1], Kamal Aldeen Alhayek [3]

[1] The National Research Center for Giftedness and Creativity, King Faisal University, SAUDI ARABIA
[2] Faculty of Educational Sciences, Yarmouk University, Irbid, JORDAN
[3] College of Business Administration, Mutah University, JORDAN

Received 07 Feb 2025 ▪ Accepted 24 Apr 2025

Abstract

This study explores the effectiveness of augmented reality (AR) technology in science education for enhancing creative thinking skills among gifted eighth-grade students. Employing an experimental design, the research divided the participants into two groups: A control group taught using traditional methods and an experimental group instructed through the AR-based Aurasma application. The validity and reliability of the creative thinking assessment were rigorously evaluated before implementation. The results showed great improvements in post-test marks for the experimental group. This is strongly supported by Black's gain ratio which demonstrates that AR is very effective in enhancing favorable creative thinking skills. In these terms, it is necessary to implement AR technology in all science subjects, and also offer relevant studies and teacher training workshops that prepare educators to incorporate AR technology efficiently into the teaching process.

Keywords: augmented reality, science education, creative thinking skills, gifted students, experimental approach, aurasma application, educational technology

INTRODUCTION

Information and ideas are spread at lightning speed with the use of smartphones and social media and this has led to the rapid development of the digital world. It has led to an explosion of information, making it difficult to comprehend. Constructive approaches to education are now in place which focus on self-responsibility, creativity, and making use of modern digital resources. Traditional education is no longer sufficient. Experts have started revising teaching strategies and curricula to accommodate the needs of modern learners and advancements in technology. The development of technologies has made education more agile and adaptive through the use of active modern learning strategies (Jayasinghe, 20224; Zajda & Zajda, 2021).

Li et al. (2022) highlighted how sensory inputs are crucial in the process of thinking, for example, 80% of people's input is through sight, 40% is through hearing and about 50% is via touch and taste combined. These results reveal the need for a comprehensive approach that aims at stimulating the learners' attention, resources, and mental actions. There is a need to use modern tools and new methods that make students think in order to develop imagination and creativity. Alali (2020) describes a student's creative skill as the ability to think and act in new ways that enable them to assess their own experiences and tackle problems to yield helpful results which serves the needs of society.

Previous research on creative thinking and educational technology offers a foundation for this study, yet a critical examination reveals both contributions and limitations that our work seeks to address. Pizzingrilli et al. (2015) developed a tool to measure creative thinking in primary school students, emphasizing its assessment but not its enhancement through technology, leaving a gap in practical application. Similarly, Al-Anzi and Al-Husein (2017) analyzed mathematics textbooks for creative thinking elements but focused on content analysis rather than instructional methods, limiting insights into active

✉ ralali@kfu.edu.sa **(*Correspondence)** ✉ yousef.wardat@yu.edu.jo **(*Correspondence)** ✉ yozaki@kfu.edu.sa
✉ hayekk733@gmail.com

Contribution to literature

- This study contributes to the existing literature by providing empirical evidence on the effectiveness of augmented reality (AR) technology in enhancing creative thinking skills among gifted students, an area that remains underexplored in science education research.
- By employing a rigorous quasi-experimental design and validating creative thinking assessments, the study offers a robust framework for future investigations into AR-based instructional strategies.
- The findings of this study extend the body of knowledge on technology-enhanced learning by demonstrating the substantial impact of AR on fostering higher-order cognitive skills in science education.
- This research not only underscores the pedagogical benefits of AR but also emphasizes the need for its integration into science curricula and teacher training programs, bridging the gap between technological innovation and effective classroom practice.

learning strategies. Studies on educational technologies, such as Schmoelz (2018) on digital storytelling and Al-Ghashm and Alhamadi (2017) on virtual labs, demonstrate improved creativity among students; however, they either target broader populations or lack a specific focus on gifted learners, who may require tailored approaches due to their advanced cognitive abilities. Mushtaha (2015) explored AR's effectiveness for ninth-grade students in Gaza, finding gains in creative thinking, but its descriptive approach and lack of a control group weaken causal claims. In contrast, AlAli and Al-Barakat (2024a) and Chen et al. (2019) highlight AR's benefits for engagement and motivation across various subjects, yet they rarely isolate creative thinking as a primary outcome or test it experimentally in science education for gifted students.

Our study builds upon these works by integrating AR into science education for gifted eighth-grade students, using the Aurasma application to deliver the 'Weather and Space Science' unit within a rigorous experimental design. Unlike Mushtaha (2015), we employ a control group and a validated creative thinking test targeting fluency, flexibility, and originality, providing stronger evidence of AR's impact. We extend AlAli and Al-Barakat's (2024a) focus on engagement by measuring cognitive outcomes specific to creativity, addressing a gap in their broader pedagogical emphasis. Additionally, our study challenges the implicit assumption in prior research (e.g., Al-Ghashm & Alhamadi, 2017) that AR benefits are uniform across learner types; by focusing on gifted students, we test whether AR's efficacy varies with cognitive ability, offering a nuanced contribution to the field. This critical synthesis positions our work as both an advancement of AR's evidenced potential and a challenge to its one-size-fits-all application in education.

Educators and researchers have incorporated AR technologies relative to the nature of the subject being taught, which ranges from chemistry, mathematics, and biology to physics and even astronomy. Augmented reality adds a new dimension to the learning environment by facilitating perception and as a result, stimulates active interaction and participation in the process of learning unlike traditional boring passive forms of teaching. It adds to motivation and engagement alongside sensory perception, hence making the process of learning active and interesting (AlAli & Al-Barakat, 2024a; Al-Hajili, 2019).

Creative thinking is a vital cognitive process used to solve problems and navigate challenges in life. Defined as a mental activity involving unconventional approaches to addressing gaps and resolving issues, creative thinking emphasizes flexibility and fluency in real-world environments. It is a composite of various skills and abilities that, when developed and practiced, can enhance an individual's creative capacity (Montag-Smit & Maertz Jr, 2017).

Ritter et al. (2020) highlighted the critical components of problem sensitivity, imagination, and many others, whereas creativity entails skills such as intuition, synthesis, transformation, and maintaining focus. The Guilford and Torrance tests specify fluency, flexibility, and originality as critical edges of creative thinking. These skills are different for every person but can be developed with proper education. With the intent of the educational program and child's development stage, the study narrows its focus to fluency, flexibility, and originality. These core skills support structured creative thinking at the content of the study unit and within the students' age caps.

The use of modern technology, particularly interactive media, is very vital in the development of thinking skills like reflective and creative thinking. This is done by fostering an interaction between the learners and the digital programs (Alzahrani & Al-Hafdi, 2021). Khamparia and Pandey (2018) note that computer programs based on interactive multimedia have changed the face of teaching and learning. These learners of all ages can now move from traditional automated learning systems to a more advanced and self-directed paradigm. Such programs blend together text, graphics, sounds, music, animation, and even video in an integrated and interactive manner which makes learning very exciting and new. This interaction is thought to spark students' interest on the subject and even better their understanding of practical science. Therefore, these programs promote the development of scientific and creative thinking skills (AlAli & Al-Barakat, 2024b).

Researchers suggest that augmented reality technology, as a form of interactive multimedia, further advances creative thinking and other cognitive skills. Its dynamic approach to presenting information makes it an effective tool for cultivating various types of advanced thinking abilities.

While prior research has explored the use of AR in education to enhance engagement (AlAli & Al-Barakat, 2024a), motivation (Chen et al., 2019), and specific cognitive skills like visual thinking (Elsayed & Al-Najrani, 2021), its application to foster creative thinking skills among gifted middle school students, particularly in science education, remains underexplored. Studies such as Mushtaha (2015), and Al-Ghashm and Alhamadi (2017) have demonstrated AR's potential for creativity in broader student populations or virtual lab contexts, but they lack a targeted focus on gifted learners and a rigorous experimental design tied to specific science curricula. This study addresses this gap by investigating AR's effectiveness in enhancing creative thinking skills-specifically fluency, flexibility, and originality-among gifted eighth-grade students within the context of the 'Weather and Space Science' unit, using the Aurasma application and a validated assessment tool.

Study Problem

Despite the growing integration of augmented reality (AR) technology in education, a clear gap exists in understanding its specific impact on developing creative thinking skills among gifted eighth-grade students in science education. Previous studies have broadly examined AR's role in improving student engagement and cognitive outcomes (e.g., AlAli & Al-Barakat, 2024b; Pérez-López & Contero, 2013), yet few have focused on gifted learners or systematically measured creative thinking within a science curriculum using a controlled experimental approach. This study advances prior research by addressing the primary question: What is the effectiveness of employing AR technology in science education to develop creative thinking skills among gifted eighth-grade students? By doing so, it provides empirical evidence on AR's potential to nurture creativity in a high-ability population, contributing to the literature on educational technology and gifted education.

The primary research question guiding this study is:

RQ1 What is the effectiveness of employing augmented reality technology in science education to develop creative thinking skills among gifted Eighth-grade students?

From this central question, the following sub-questions emerge:

1. Are there statistically significant differences between the average post-test scores of students in the control group and those in the experimental group regarding creative thinking skills?
2. Does the use of augmented reality technology lead to high effectiveness (as indicated by Modified Black's Gain Ratio) in developing creative thinking skills?

Significance of Study

The significance of this study lies in its alignment with contemporary global trends by integrating augmented reality technology into general education teaching. It offers valuable insights for curriculum developers, aiding in the incorporation of augmented reality into the development of general education curricula. The study also benefits educational supervisors by providing opportunities for seminars and training sessions to enhance teachers' skills. Furthermore, it serves as a useful resource for general education teachers by offering lesson models for Eighth-grade subjects, thereby supporting the teaching and learning process. Additionally, the study contributes to future research, exploring modern technologies to advance general education teaching practices.

METHODOLOGY

The researcher in this study employed the experimental method, defined as the approach used to investigate existing events, phenomena, and practices by intentionally introducing changes to one or more variables to observe the resulting effects (Al-Barakat et al., 2022). An experimental design with two groups and pre-post measurements was selected. In this design, the independent variable, which is "augmented reality technology," was manipulated and tested to assess its impact on the dependent variable, "creative thinking skills."

This study adopted a quasi-experimental design with pre- and post-measurements involving two intact groups-an experimental group exposed to augmented reality (AR) technology and a control group taught using traditional methods-rather than a fully randomized controlled trial (RCT). This choice was deliberate and guided by practical and ethical considerations within the educational context of King Abdullah Schools for Excellence. Randomly assigning individual students to groups was not feasible, as it would have disrupted existing class structures, potentially affecting student cohesion, teacher workflows, and the school's operational norms. Instead, we utilized two pre-existing eighth-grade classes, randomly assigning one as the experimental group ($n = 41$) and the other as the control group ($n = 40$), ensuring group equivalence through a pre-test of creative thinking skills ($t = 0.325$, $p = 0.46$). While an RCT offers greater internal validity through randomization at the individual level, the quasi-experimental approach allowed us to maintain ecological validity by preserving naturalistic classroom dynamics, which are critical for assessing AR's real-world applicability in science education. Moreover, ethical concerns precluded withholding a potentially beneficial intervention from half the students via random assignment, given the school's commitment to optimizing outcomes for gifted learners. Although this design limits causal inference compared to an RCT due to potential confounding variables (e.g., teacher effects), the pre-test equivalence and controlled implementation mitigate these risks, making the quasi-experimental approach a practical and contextually appropriate choice for this study.

Participants

The study sample comprised 81 eighth-grade gifted students from King Abdullah Schools for Excellence in Jordan during the second semester of the 2023/2024 academic year. The school was purposefully chosen based on the consent and interest of the principal and teaching staff. A simple random sampling method was employed to assign participants from two eighth-grade classes into two groups: An experimental group consisting of 41 students and a control group comprising 40 students.

Preparation of the Study Tool

To achieve the study objectives and test its hypotheses, as well as answer its primary question, the following steps were taken in preparing the study tool:

First: Creative thinking test

The creative thinking test was designed based on the "Weather and Space Science" unit in creative writing. It includes ten open-ended questions as its initial version. This test evaluates creative thinking skills through questions aligned with three main criteria: originality, fluency, and flexibility, and the solution consists of four main points.

Steps to develop the test

Defining the purpose of the test

The focus is on recognition of creative thinking capacities of the students with special emphasis on the three principle factors of creative thinking that is originality, fluency, and flexibility. One unit was taken from the eighth-grade science book as the foundation because it would meet the requirements of the study. After the piloting of the tool, the creativity measurement standards and success thresholds were developed. In order to corroborate the test's theoretical and empirical validity, various studies and primary data were reviewed. Some of such works include Abu Bashir (2016), Ahmed (2015), and Mushtaha (2015), which aided with methodological queries.

Defining the test content

The test content was designed to evaluate the level of creative thinking in the participants specifically in the tasks related to the creative writing. The unit "Weather and Space Science" was used for developing specific tasks aimed at evaluating originality, fluency, and flexibility.

Formulating test items

Test questions to evaluate creative thinking were developed on the basis of reviewed literature and validated instruments. All the questions were constructed to be clear, pertinent and stimulating to each and every respondent.

Developing instructions for the test

The test instructions were created to be straightforward and user-friendly for the learners. It focused on how students are supposed to respond to the questions, the need to read prompts, and comprehend the criteria (originality, fluency, flexibility).

A draft of the test

The first attempt of formulating the creative thinking test version was prepared with 10 questions seeking for an open answer and was intended to measure the level of creative thinking ability. The test was divided into three categories; originality, fluency, and flexibility. The initial draft of the test was prepared by reviewing existing literature and was subjected to experts in the area. The experts were asked to provide their opinions in terms of relevance, clarity, and scope of the study. With respect to what they shared, adjustments were made so that the questions on creativity were appropriate.

The test was conducted on a nonrandom sample of twenty-one gifted students in the eigth grade in King Abdullah II Schools for Excellence. The objectives of this pilot study were to analyze the clarity of items in the test and to ascertain the internal consistency of the test items to ensure reliability. The time needed for students to complete the test was also established before giving it to the main study sample. Observations and data collected during this stage of the test construction were then used to improve and finalize the content of the test for maximum validity and reliability.

Measuring test duration

After conducting the test with the subjects, the researcher noted how much time was used by each of the participants to answer the test. The average response time was calculated from the answers given by the first five and last five students as follows:

$$\begin{aligned} &Average\ Time \\ &= (Sum\ of\ score\ of\ first\ five\ students \\ &+ Sum\ of\ score\ of\ last\ five\ students)/10 \end{aligned} \quad (1)$$

To the average response time 5 additional minutes have been added which were set aside for reading and providing instructions before the start of the test. The computed average reponse time assume that the reading

Table 1. Indicators and coefficients used to assess construct validity

Scale	Constructs	Items	Macdonalds Omega	CR	AVE	$\sqrt{\text{AVE}}$
Creative thinking test	Fluency	3	0.89	0.88	0.68	0.82
	flexibility	3	0.89	0.87	0.68	0.82
	Originality	4	0.88	0.88	0.67	0.82

and clarifying of instructions takes 5 extra minutes. The orientation along with expectation setting added up to 5 minutes. Hence, the participants receive a total of 50 minutes plus the extra five minutes at the beginning. This is more than sufficient to allow each of the participants to complete the test comfortably, accurately, and without any worries regarding time.

Grading the responses of the test items

In order to measure the reliability of the creative thinking test questions (originality, flexibility, and fluency) sought in this research: The entire cumulative score for the examination is put together to form the final score of 40 marks and a maximum of 4 per individual question awarded based on 4 different rubrics for different sets of questions.

The Creative Thinking Test encompasses a variety of questions aimed at measuring three components of creativity: fluency, flexibility, and originality. Participants' experiences and the variety of ideas proposed are examined in two parts; flexibility and fluency, which cover six questions throughout them. The other four questions challenge the participant's claim of novelty and originality. These criteria combined create a multi-faceted measure for creative thinking.

Instrument validity and reliability

A panel of experts from Saudi Arabian universities specializing in science curricula, pedagogy, and evaluation instruments checked the validity of the two tests. These experts vetted items regarding accuracy, levels of clarity, and overall appropriateness to children's developmental cognitive levels. Possible additional changes were made to the instrument's structural outline so that the specifications given by these experts added up towards the final test.

In a pilot study with 21 participants, levels of clarity, timing length, and reliability estimates were all checked. The average time needed for the test was 45 minutes. The difficulty indices were calculated at 0.78, whereas the discrimination indices reached 0.75. The reliability coefficient was equally calculated, concluding with a high coefficient of 0.87. This level of consistency shows that the test would be suitable to measure the respective constructs.

To ensure transparency in assessing creative thinking skills, the scoring of the test was operationalized based on three core criteria-originality, fluency, and flexibility-with a maximum of 40 marks distributed across ten open-ended questions (4 marks per question). Each criterion was defined and evaluated using specific rubrics developed from established frameworks (e.g., Guilford, 1950; Torrance, 1974) and refined through expert input during the test's validation process.

Originality, assessed in four questions, measured the novelty and uniqueness of responses, awarding 0-4 points based on the degree of uncommonness relative to the pilot sample's answers: 0 (common response), 1-2 (moderately unique), 3-4 (highly novel, e.g., a solution not seen in >90% of pilot responses).

Fluency, evaluated in three questions, quantified the number of relevant ideas generated, with scores ranging from 0 (no ideas) to 4 (four or more distinct, relevant ideas), emphasizing productivity within the 'Weather and Space Science' context.

Flexibility, assessed in three questions, gauged the variety of approaches or perspectives, assigning 0-4 points based on the diversity of categories represented in responses: 0 (single approach), 1-2 (two approaches), 3-4 (three or more distinct perspectives, e.g., scientific, practical, and imaginative).

Responses were scored independently by two trained raters, with inter-rater reliability established at 0.85 via Cohen's kappa, and discrepancies resolved through discussion. This structured scoring system underpinned the test's high reliability (coefficient = 0.87) by ensuring consistent and objective evaluation of each dimension, aligning with the study's goal of measuring creative thinking comprehensively.

For construct validity purposes, the test was subjected to McDonald's Omega and Composite Reliability (CR) as well as checks of discriminant and convergent validity of the test. **Table 1** presents factors 1 and 2 which indicate that McDonald's Omega and CR were 0.89 and 0.88. These exceed the set thresholds of 0.70, which means the test is reliable. Also, the Average Variance Extracted (AVE) value was 0.682, above the cut-off threshold of 0.50. In addition, the AVE which is the discriminant validity coefficients were more than the cross correlations of the latent variables which satisfied the requirement. This was verified by factor loading values that were higher than the lowest accepted limits. All these aspects together indicate the scales validity and reliability (Alali, 2020).

Confirmatory Factor Analysis (CFA) was conducted using SPSS Amos to establish the factor validity of the measurement tool. As a key component of Structural Equation Modeling (SEM), CFA assesses the relationships between latent variables, uncovering underlying patterns within the data. This statistical approach is indispensable during various stages of

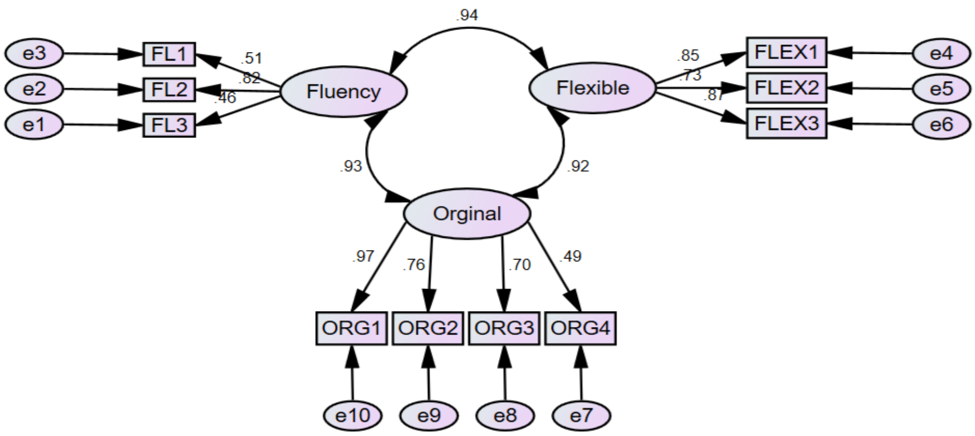

Figure 1. The findings from the confirmatory factor analysis determine the association between the questions in the test and their respective dimensions, as well as the extent of their loading (Source: Authors' own elaboration)

Table 2. Pre-test results for creative thinking

Variable	Mean of Experimental Group (n=41)	Mean of Control Group (n=40)	t-value	Sig.	Cohen's d
Pre-creative thinking test	6.92	6.54	0.325	0.46	0.07

Note: Cohen's d was calculated using the formula d = (M_1 - M_2) / SD_pooled, where SD_pooled is the pooled standard deviation of the two groups

instrument development, including the creation of measurement tools, validation of constructs, and evaluation of methodological influences. By confirming the primary dimensions and factor loadings embedded in the instrument, CFA plays a pivotal role in substantiating the latent structure of the tool. Consequently, it significantly enhances the psychometric robustness of the measurement instrument (Alwaely et al., 2024).

To ensure factorial construct validity, the final version of the test was administered to the study sample. CFA was utilized to evaluate the alignment of scale items with their corresponding dimensions, focusing on the loading values of each item as depicted in **Figure 1**. Items with loading factors below the threshold of 0.40 were deemed unacceptable (Alakashee et al., 2024). The analysis revealed that all items achieved loading factors greater than 0.40, thereby meeting the established criteria and confirming the validity of the instrument.

After the validity and reliability of the creative thinking test were confirmed. The final copy of the test includes 10 questions distributed according to the creative thinking criteria: three questions for the originality criterion, three questions for the fluency criterion, and four questions for the flexibility criterion.

Equivalence of study groups in creative thinking test

To ensure the equivalence of the study groups before implementing the experiment using augmented reality techniques, a pre-test was conducted to assess creative thinking skills. The results, presented in **Table 2**, were analyzed using an independent samples t-test to compare the means of the experimental (n=41) and control (n=40) groups. Additionally, Cohen's d was calculated to provide an effect size estimate, offering further insight into the magnitude of any pre-existing differences. The findings indicate no statistically significant difference between the experimental and control groups in the pre-test scores (t = 0.325, df = 79, p = 0.46), with a Cohen's d of 0.07, suggesting a negligible effect size. According to Cohen's (1988) guidelines, an effect size of 0.2 is considered small, 0.5 medium, and 0.8 large; thus, a value of 0.07 confirms the groups were highly comparable prior to the intervention. This equivalence supports the validity of attributing post-test differences to the AR intervention rather than baseline disparities.

The findings in **Table 2** indicate no statistically significant difference between the experimental and control groups in the creative thinking pre-test scores (t = 0.325, p = 0.46). This confirms the equivalence of the two groups prior to the intervention.

Study Experiment

The researchers designed and developed a technique based on an augmented reality (AR) model after conducting a thorough review of related studies. The implementation process followed four phases: preparation, design, development, and publication/utilization, with all associated sub-steps carefully executed. The study instrument, a Creative Thinking Test, was validated for reliability and validity on a sample of students before initiating instruction using AR technology (Aurasma) for the experimental group, while the control group continued with traditional teaching methods.

The decision to use the Aurasma application as the AR platform for this study was guided by its specific

Table 3. Results of the T-test for experimental and control groups

Group	N	Mean	Standard Deviation	t-value	df	Sig.
Experimental	41	3.17	2.26	3.72	83	0.00
Control	40	2.75	2.18			

features, practical advantages, and alignment with our objective of enhancing creative thinking skills among gifted eighth-grade students. At the time of the study's implementation (second semester of 2023/2024), Aurasma-though later rebranded as HP Reveal and discontinued in 2020-was still accessible via archived versions and widely recognized in educational research for its reliability (e.g., AlAli & Al-Barakat, 2024a; Mushtaha, 2015). Unlike newer AR platforms such as ARKit or Vuforia, which offer advanced features like real-time 3D rendering and require greater technical expertise or hardware capabilities, Aurasma provided a straightforward, free-to-use interface compatible with the smartphones and tablets available to our participants and educators. Its core functionality-overlaying videos, images, and animations onto trigger images-directly supported our goal of delivering interactive, visually rich content for the 'Weather and Space Science' unit, fostering fluency, flexibility, and originality in student responses. For instance, Aurasma enabled the integration of dynamic weather simulations and space exploration videos, which encouraged students to generate novel ideas and explore scientific concepts creatively. While newer platforms might offer enhanced immersion, Aurasma's simplicity ensured minimal setup time and broad accessibility, critical for a five-week intervention in a school setting with limited technical resources. This choice balanced efficacy with feasibility, aligning optimally with our study's focus on cognitive skill development rather than cutting-edge AR sophistication. Nonetheless, future studies could explore newer tools to assess whether advanced features further amplify creative outcomes.

The "Weather and Space Science" unit was taught to gifted eighth-grade students in the experimental group using AR technology, while the control group received instruction through conventional methods. The following steps were undertaken:

1. **Group selection and equivalence:** Two groups (experimental and control) were randomly selected from Gifted Eighth-Grade Students. The equivalence of the groups was confirmed using a pre-creative thinking test.
2. **Study implementation:** The researchers implemented the intervention over approximately five weeks. The experimental group utilized augmented reality technology during lessons, while the control group followed traditional teaching methods.
3. **Post-testing and data collection:** At the end of the intervention, a post-creative thinking test was administered to both groups. The test results were scored, recorded, and subjected to statistical analysis.
4. **Results and recommendations:** The findings were thoroughly analyzed and interpreted. Based on the results, detailed recommendations and suggestions were developed to guide future applications of augmented reality in education.

FINDINGS

To address the first research question regarding the presence of statistically significant differences at the 0.05 significance level between the mean scores of the control and experimental groups in the post creative thinking test. An independent samples T-test was conducted, and the findings are summarized in Table 3.

The t-value of 3.72 with a significance level of 0.00 ($p < 0.05$) confirms statistically significant differences between the two groups.

The results in the previous table indicate that the number of students in the experimental group is 41, with a mean score of 3.17 and a standard deviation of 2.26. In contrast, the control group consists of 40 students, with a mean score of 2.75 and a standard deviation of 2.18. The calculated T-value is 4.84, with degrees of freedom (df) of 83, and the significance level (Sig) is 0.00, which is below the 0.05 threshold.

To calculate the effect size of augmented reality technology in enhancing creative thinking skills, the following formula was applied:

$$\eta^2 = t^2/df + t^2 \tag{2}$$

where: t^2 is the square of the t-value, df is the degrees of freedom, η^2 is the variance ratio.

The reference framework for determining effect size levels based on η^2 values and their corresponding descriptions. A small effect size is defined as $\eta^2 = 0.01$ with P of 0.2, indicating minimal impact. A medium effect size corresponds to $\eta^2 = 0.06$ and P = 0.5, representing a moderate effect. A large effect size is characterized by $\eta^2 = 0.14$ and P = 0.8, indicating a significant effect. Finally, a very large effect size is noted at $\eta^2 = 0.2$ and P = 1.0, reflecting a substantial impact of the intervention.

The findings in Table 4 reveal that augmented reality technology has an effect size of 0.97 on developing creative thinking skills among gifted eighth-grade students, which is classified as a very large effect. This substantial impact underscores the significant role of augmented reality in enhancing creative thinking. The variance observed in the dependent variable (creative

Table 4. Effect size of augmented reality technology on developing creative thinking

	Experimental Group	N	η^2	Effect Size
Augmented Reality Technology	pretest	41	0.96	Very Large
	posttest	41		

Table 5. Gain ratio calculation

Test Type	M2	M1	P	M2-M1	P-M1	Gain Ratio
Achievement Test	33.47	9.35	39	24.12	29.65	1.4

thinking skills) is strongly attributed to the independent variable (augmented reality technology). These results demonstrate the potential of augmented reality as a transformative educational tool, effectively fostering creativity and supporting innovative teaching practices.

To address the second question,

RQ2 Does the use of augmented reality technology lead to high effectiveness (as indicated by Modified Black's Gain Ratio) in developing creative thinking skills?

to validate this hypothesis, the researcher utilized the gain ratio formula:

$$MG = (M2 - M1)/(P - M1) + (M2 - M1)/P \qquad (3)$$

where, M2 is the post average, M1 is the pre average, and P is the maximum test score.

Table 5 demonstrates a significant improvement in students' creative thinking skills after the use of AR technology. The average score of gifted students on the pre-application of the creative thinking test was 9.35, while their average score in the post-application increased to 33.47. Given that the maximum possible score on the test was 39, the calculated gain ratio for the creative thinking test was 1.4. This data indicates a substantial enhancement in the students' creative thinking abilities, highlighting the positive impact of augmented reality technology on their cognitive development.

Augmented reality technology is deemed acceptable and effective when the gain ratio exceeds 1 (Saleh & AlAli, 2024). According to the findings, we reject the null hypothesis and accept the alternative hypothesis; the use of Augmented Reality technology results in a high effectiveness rate (Modified Black's Gain Ratio = 1.2) in developing creative thinking skills.

DISCUSSION

The findings reveal that the experimental group, taught using augmented reality (AR) techniques, achieved significantly higher scores on the creative thinking test compared to the control group, which was taught using traditional methods. This demonstrates the efficacy of AR in enhancing students' creative thinking skills.

The study underscores the importance of integrating innovative technologies, such as AR, in educational settings to foster creativity and improve learning outcomes. These findings are consistent with prior research that highlights the benefits of interactive and immersive learning environments in promoting engagement, enhancing creativity, and fostering deeper understanding among students.

By providing a dynamic and interactive platform, AR enriches the educational experience, enabling students to better grasp abstract concepts and actively participate in the learning process. This underscores its potential as a transformative tool in modern education.

In addition, the reasons the researcher provided in the first question's response can be attributed to the following important elements:

- Integrated knowledge building: Students utilizing augmented reality technologies develop, construct, and integrate information systematically considering multiple facets of a topic. Ideas can be visualized much more clearly; thus, new concepts are formed.
- Diverse participation styles: The various modes of interactions among learners, involving dialogues among peers, enable students to devise original and creative solutions enhancing their creative thinking skills.
- Access to diverse content: The use of smart devices by learners which are enabled by augmented reality technologies permits the use of digital content such as videos and images, at their convenience. Such access enables learners to devise innovative ideas.
- Effective interaction: With augmented reality, learners can be placed within an interactive environment where they can hold discussions and share views on different topics. Such interaction widens their thinking, enabling the application of scientific principles which help them draw sound conclusions and thus encouraging constructive thinking.

According to the findings, the use of augmented reality technology results in a high effectiveness rate (Modified Black's Gain Ratio= 1.2) in developing creative thinking skills. The researcher attributes this to augmented reality technology, which helps learners acquire knowledge and skills in a simple and effective manner, as well as enhancing the relationships and internal components of information. The properties and features that augmented reality technology offers when teaching students the unit "Weather and Space Science" include:

- The Aurasma application contains video presentations and images that interact with the students, helping to develop their creative thinking.
- It provides opportunities for creative thinking, allowing students to interact individually or in groups.
- Technology's ability to capture the students' attention.
- Technology includes presentations that are difficult to find in textbooks.

The results of the current study align with previous studies such as AlAli and Al-Barakat (2024a, 2024b), Alzahrani and Al-Hafdi (2021), Chen et al. (2019), Dünser et al. (2012), and Pérez-López and Contero (2013) confirming the impact and effectiveness of using augmented reality technology.

The study proves AR technology improves creative thinking abilities among gifted eighth-grade students but its exclusive focus on this population makes it difficult to generalize the results. Gifted students with their superior cognitive abilities and high motivation levels could have different reactions to AR interventions than students with average or different learning abilities. The interactive and self-directed nature of AR through the Aurasma application might create overwhelming experiences for students who have lower baseline skills or less intrinsic motivation which could produce different results. The study took place at King Abdullah Schools for Excellence in Jordan which has unique educational conditions that might not match other educational settings worldwide. The study shows promise for gifted students in science education through AR but its effectiveness needs further testing across different student populations and educational settings. Future research should include studies with students of mixed abilities and special needs populations and different socio-economic and cultural settings to fully understand AR's educational potential.

Even though the study applied the concepts to AR integrating lessons with gifted pupils in grade eight, they also offered a narrowed scope of possibilities to other learners. As mentioned, AR applies through the Aurasma app adds interactivity and visuals which enhances learning for students with creative thinking skills. The 1.4 gain ratio pertaining to the gifted students' AR Aurasma Application results pointed to a greater learner flexibility, originality, and fluency suggests that average ability learners may also benefit. Other studies (e.g. AlAli & Al-Barakat, 2024a; Chen et al., 2019) have documented the effects of AR on motivation and cognition suggesting that stratum diversity may not be an issue. The focus of the gifted students was underlined as possibly benefiting more because of the advanced cognitive skills possessed. Students with low skills or less self-driven need to construct achieve pointers beyond materials set for them like simpler content or more instruction to attain the same levels of impact. The context also matters, for example, King Abdullah Schools for Excellence have trained teachers and other resources which may not be available in other educational settings. This stratifies the scope of generalizability to technology and preparedness of teachers. Therefore, although AR has potential for enhancing creativity in a broader demographic, its impact may be influenced by the student's abilities, guidance, and surrounding environment. Further investigation in curricula with learners of varying abilities, as well as different educational contexts, is required to validate these claims and establish the adjustments that need to be made.

RECOMMENDATIONS AND FUTURE DIRECTIONS

Considering this study's results, the researchers have suggested a few modifications with the purpose of incorporating augmented reality (AR) technology into the educational methods used in teaching activities.

To begin with, AR technology as a creative stimulating tool should be used in instructional units of all topics at all educational levels to enhance learning outcomes.

Secondly, training seminars should be conducted to prepare teachers to incorporate AR technology in the classrooms with an emphasis on stimulating thinking, especially creative thinking, in general studies.

Third, there is an urgent need to promote the awareness of AR technology in education technology and to encourage cooperation between schools and universities to create a program within a website that promotes its use.

Fourth, there is a need to motivate educators to apply AR technology in teaching Palestinian studies because of the benefits gained in creative thinking skills development.

Finally, developing flexible learner-centered strategies focusing on teaching diverse creative thinking skills using modern digital technologies is imperative.

Because of the existing study, the researchers have proposed new areas of exploration. One additional research could analyze the effectiveness of different forms of digital technologies, including AR and holograms, in skill development such as critical and reflective thinking, metacognition, and other thinking related competencies.

Further research should also apply the use of digital technologies to other educational subjects apart from integrated studies to further deepen their impact. A comparative research study on the effectiveness of contemporary digital technologies on various educational parameters may prove to be useful in figuring out the relativity and usefulness of these technologies. There should also be an in-depth examination on the level of integration of contemporary digital technologies into the educational resources and materials for teaching general studies in Palestinian schools. Finally, research studying the obstacles encountered by educators in integrating digital technologies into teaching will help resolve some of the implementation issues.

Author contributions: RA: conceptualization, methodology, supervision, writing – original draft; **YW:** conceptualization, methodology, formal analysis, writing – original draft; **YA:** validation, resources, writing – review & editing; **KA:** formal analysis, resources, and writing – review & editing. All authors agreed with the results and conclusions. All authors have agreed with the results and conclusions.

Funding: This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Grant No KFU251697].

Ethical statement: The authors stated that this study has been approved on 5 April, 2024 (Approval no: IRB/2024/251697) and complies with the guidelines of the education program at King Faisal University. The authors further stated that this study was designed without personal identifiers or violations of privacy.

Declaration of interest: No conflict of interest is declared by the authors.

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

REFERENCES

Abu Bashir, A. (2016). *The effect of using computer simulation on developing creative thinking skills in the course of principles of chemistry among students of the department of television arts at Al-Azhar University – Gaza* [Master's thesis, Al-Azhar University – Gaza].

Ahmed, I. (2015). *The effectiveness of a program based on augmented reality technology in developing visual thinking skills in the subject of general science among ninth-grade female students* [Master's thesis, Al-Azhar University, Palestine].

Alakashee, B., Al-Barakat, A., Al Karasneh, S. M., El-Mneizel, A. F., Al-Qatawneh, S. S., AlSalhi, N. R., & AlAli, R. (2024). Enhancing active learning through educational characteristics of social networking applications: Faculty perspectives. *Revista Electrónica de LEEME, 53*, 12-27.

Alali, R. M. (2020). Developing a scale for creative teaching practices of faculty members at King Faisal University. *Universal Journal of Educational Research, 8*(5), 2129-2142. https://doi.org/10.13189/ujer.2020.080552

AlAli, R., & Al-Barakat, A. (2024a). Effectiveness of augmented reality technology in enhancing primary school students' acquisition of creative reading skills. *Journal of Curriculum and Teaching, 13*(5), 344-356.

AlAli, R., & Al-Barakat, A. A. (2024b). Impact of augmented reality-based learning on preparing children for creative reading skills in childhood education stage. *Forum for Linguistic Studies, 6*(5), 226-238. https://doi.org/10.30564/fls.v6i5.7161

Al-Anzi, A., & Al-Husseif, A. (2017). The extent to which mathematics textbooks include creative thinking skills. *General Studies Journal, 33*(2), 465-502.

Al-Barakat, A., Al-Hassan, O., Al Ali, R., Al-Hassan, M., & Al sharief, R. (2022). Role of female teachers of childhood education in directing children towards effective use of smart devices. *Education and Information Technologies, 27*(9). https://doi.org/10.1007/s10639-022-11481-y

Al-Ghashm, K., & Alhamadi (2017). The impact of using virtual science laboratories technology in developing creative. Thinking of talented students at Jamal Abdulnaser high school in Sanaa, Yemen. *Arab Journal of Scientific and Technical Education, 6*, 41-74. https://doi.org/10.35677/0552-000-006-005

Al-Hajili, S. (2019). The effectiveness of augmented reality in achieving and developing motivation in the computer and information technology course for secondary school female students. *Arab Journal of Specific Education, 3*(9).

Alwaely, S. A., Almousa, N. A., Helali, M. M., Alali, R. M., Rashed, R. M., Mashal, A. A., Saleh, S. G., Darawsheh, S. R., & Khasawneh, M. A. S. (2024). Teacher-student rapport and gamified learning: Investigating the role of interpersonal variables in classroom integration. *International Journal of Data and Network Science, 8*(2024), 1319-1324. https://doi.org/10.5267/j.ijdns.2023.11.003

Alzahrani, A., & Al-Hafdi, F. (2021). Effectiveness of augmented reality in developing the reflective thinking skills among secondary school students. *Multicultural Education*, *7*(8).

Chen, C. H., Huang, C. Y., & Chou, Y. Y. (2019). Effects of augmented reality-based multidimensional concept maps on students' learning achievement, motivation and acceptance. *Universal Access in the Information Society*, *18*, 257-268. https://doi.org/10.1007/s10209-017-0595-z

Dünser, A., Walker, L., Horner, H., & Bentall, D. (2012). Creating interactive physics education books with augmented reality. In *Proceedings of the 24th Australian computer-human interaction conference* (pp. 107-114). https://doi.org/10.1145/2414536.2414554

Ebadi, S., & Ashrafabadi, F. (2022). An exploration into the impact of augmented reality on EFL learners' reading comprehension. *Education and Information*

Technologies, *27*(7), 9745-9765. https://doi.org/10.1007/s10639-022-11021-8

Elsayed, S. A., & Al-Najrani, H. I. (2021). Effectiveness of the augmented reality on improving the visual thinking in mathematics and academic motivation for middle school students. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(8), Article em1991. https://doi.org/10.29333/ejmste/11069

Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*(9), 444-454. https://doi.org/10.1037/h0063487

Jayasinghe, S. (2024). Promoting active learning with ChatGPT: A constructivist approach in Sri Lankan higher education. *Journal of Applied Learning and Teaching*, *7*(2). https://doi.org/10.37074/jalt.2024.7.2.26

Khamparia, A., & Pandey, B. (2018). Impact of interactive multimedia in E-learning technologies: Role of multimedia in E-learning. In *Digital multimedia: Concepts, methodologies, tools, and applications* (pp. 1087-1110). IGI Global. https://doi.org/10.4018/978-1-5225-3822-6.ch052

Li, Y., Kim, M., & Palkar, J. (2022). Using emerging technologies to promote creativity in education: A systematic review. *International Journal of Educational Research Open*, *3*, Article 100177. https://doi.org/10.1016/j.ijedro.2022.100177

Montag-Smit, T., & Maertz Jr, C. P. (2017). Searching outside the box in creative problem solving: The role of creative thinking skills and domain knowledge. *Journal of Business Research*, *81*, 1-10. https://doi.org/10.1016/j.jbusres.2017.07.021

Mushtaha, A. (2015). The effectiveness of employing augmented reality technology in developing creative thinking skills and attitudes toward science among ninth-grade students in Gaza [Master's thesis, Islamic University, Palestine].

Pérez-López, D., & Contero, M. (2013). Delivering educational multimedia contents through an augmented reality application: A case study on its impact on knowledge acquisition and retention. *Turkish Online Journal of Educational Technology*, *12*(4), 19-28.

Pizzingrilli, P., Valenti, C., Cerioli, L., & Antonietti, A. (2015). Creative thinking skills from 6 to 17 years as assessed through the WCR test. *Procedia-Social and Behavioral Sciences*, *191*, 584-590. https://doi.org/10.1016/j.sbspro.2015.04.498

Ritter, S. M., Gu, X., Crijns, M., & Biekens, P. (2020). Fostering students' creative thinking skills by means of a one-year creativity training program. *PloS One*, *15*(3), Article e0229773. https://doi.org/10.1371/journal.pone.0229773

Saleh, S., & AlAli, R. (2024). Constructing and development of the psycho-computing traits scale: A psychometric analysis of computer users and students in the field of computer science. *Cogent Social Sciences*, *10*(1), Article 2344231. https://doi.org/10.1080/23311886.2024.2344231

Schmoelz, A. (2018). Enabling co-creativity through digital storytelling in education. *Thinking Skills and Creativity*, *28*, 1-13. https://doi.org/10.1016/j.tsc.2018.02.002

Torrance, E. P. (1974). *The Torrance Tests of Creative Thinking: Norms-Technical Manual*. Personal Press.

Zajda, J., & Zajda, J. (2021). Constructivist learning theory and creating effective learning environments. *Globalisation and education reforms: Creating effective learning environments*, 35-50. https://doi.org/10.1007/978-3-030-71575-5_3