Cómo referenciar este artículo / How to cite this article

Al-Harbi, H. S. (2026). Augmented Reality for Developing Computational Concepts among Elementary Female Students. *Espacio, Tiempo y Educación, 13*(1), pp. 215-232.
doi: http://dx.doi.org/10.14516/ete.13112

Augmented Reality for Developing Computational Concepts among Elementary Female Students

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Abstract: This research investigated how learning with the help of augmented reality (AR)-supported instruction using Assembler Edu affected the development of the computational concepts among the fifth-grade female students enrolled in a Digital Skills course. The first semester of 1447 AH (2025) implemented a quantitative quasi-experimental pretest-posttest comparison-group design in an elementary school in Al-Kharj Governorate. Two intact classes were involved: one of the classes was taught in a conventional way, and the other one was taught with the help of AR with the use of Assembler Edu. Before and after a three week intervention, a 20 item multiple-choice test of computational concepts was developed, validated by experts, piloted and administered. Pretest results revealed that no statistically significant difference between groups existed ($t = 0.26$, $p = 0.79$) and the baselines were equal. Posttest comparison indicated that the AR-supported class scored significantly higher ($M = 14.50$, $SD = 2.82$) as compared to the traditionally taught class ($M = 6.77$, $SD = 2.98$), with a large effect size ($t = 10.40$, $p <.001$, eta 2 =.65). These findings suggest that AR-supported instruction can enhance students' understanding of computational concepts. Nonetheless, due to the fact that the intervention was performed at intact classes but not randomly, they should be used cautiously, and further research with stricter experimental designs would be suggested.

Keywords: Achievement, Intervention, Technology, Elementary, Assessment.

Received: 10-11-2025
Accepted: 29-03-2026

1. Introduction

The elementary level is a critical period since it solidifies the cognitive, skill-based, and affective backgrounds of learners that influence subsequent social adaptation and career advancement in the long term, as well as accumulating systematically in the areas of literacy, numeracy, and the newly emerging digital competencies. Digital skills are not an option in the modern labor market because most of the future jobs will require information technology in addition to working knowledge of robotics, cybersecurity, artificial intelligence, and applied computer science (Quttainah & Singh, 2024). European Commission coverage also demonstrates a continued increase in the demand for workers in a position to use digital devices with confidence and handle electronic data effectively. In addition to employability, digital competence reinforces the ability of learners to interact, engage, and integrate in a highly interconnected global space where interaction is gradually spreading beyond the local community. It also promotes building of core 21st-century skills, such as problem-solving and self-directed learning, and strengthens higher-order thinking with the help of analysis, synthesis, and creative production (Jia & Huang, 2023). In this regard, the interpretation of digital skills in the context of elementary education is most likely to be perceived as a priority in the learning process as well as an investment in the future workforce's preparedness.

In the Kingdom of Saudi Arabia, the Ministry of Education has embarked on the modernization of the curricula to make sure that the schooling is kept abreast of the interests and emerging technology in the society (Saudi Ministry of Education and National Curriculum Center, 2025).

This modernization has also involved more concern with digital skills in general education, where emphasis is placed on information management, digital citizenship, proper use of technologies, and simple computational thinking. These changes can be observed in formal exposure to computers, computer programs, and code in lower education, such as Scratch and introductory ideas of AI (Saudi Ministry of Education and National Curriculum Center, 2025). In spite of these policy efforts, the courses designed to impart digital skills to young students usually entail abstract and procedural lessons that should be taught sequentially, having clear models, formative assessment, and pre-practice to be mastered successfully (Byeon et al., 2022).

Infrastructural and organizational difficulties, including lack of essential resources to operate labs, restricted access to devices, unstable connectivity, and slow maintenance, are challenges that interfere with continuity in learning (Aljanazrah et al., 2022). The given issues represent a larger issue of the digital divide undermining the introduction and integration of technology in less-privileged schools, making it more difficult to create and measure the outcomes of AI literacy in primary school (Yim & Su, 2025). Teachers react by improving teaching methods by realizing that content structuring and practice influence the comprehension of students. With the number of children using smart devices since their childhood, the combination of technology-intensive practices out of the classroom and classroom routine enabled the emergent technologies, such as the Internet of Things, gamification, and augmented reality, to become more applicable to instructional design.

Augmented reality (AR) is considered a pedagogical innovation that will convert traditional learning into interactive experiences according to educational aims. AR, conceptually, is a combination of digital overlay with the physical environment, which allows learners to engage with virtual elements without leaving their physical environment. Syntheses of evidence have revealed that AR-based teaching may lead to diverse learning outcomes in disciplines, but the design and context of the study have a substantial effect on the observed findings. According to meta-analyses, AR interventions tend to positively affect the learning performance in the interactive setting, which proves the significance of the pedagogically based integration rather than the technology-focused adoption. Recent studies also point to AR becoming the most efficient when implemented in the context of pedagogical strategies that are in line with the subject matter and curriculum (Chen & Kouhsari, 2025). Accordingly, the research paper will be a systematic study on the influence of augmented reality-based teaching on the growth of digital skills in

Saudi elementary students. Based on this, the current study examines the hypothesis of whether AR-supported instruction is related to the differences in the achievement of computational concepts among female students in the fifth grade who have undertaken the Digital Skills course at a school in Saudi Arabia. The research is expected to provide context-related evidence on the instruction of AR in elementary digital skills learning, especially in the context of abstract computational content.

1.1. Research Problem

Although digital education has undergone recent curricular changes, a large number of fifth-grade learners are still facing challenges with the way the basic concepts of computational skills are taught in the Digital Skills course, especially in the school setting where teaching resources and guidance on the subject are scarce. Educational significance of this issue lies in the fact that the elementary level offers the foundation of further learning in computational thinking and other digital literacy skills. Low levels of conceptual knowledge at this level can go on to limit future developments and have more of a requirement to reteach the basics. Field observations and teacher feedback have also indicated that these challenges could be more apparent in certain governorates and semi-remote regions where the restriction of laboratory facilities, lack of teaching materials, and specialist personnel could influence the quality of the instruction. In this case, the concept of computations has been considered one of the most challenging to be taught, which makes the issue of unequal learning opportunities in different school settings a matter of concern.

An augmented reality (AR) has been identified as a potentially useful tool in teaching and learning in educational studies as a tool for assisting conceptual knowledge and student interaction, particularly in STEM-based settings. According to the systematic reviews, AR has the potential to facilitate learning with the help of interactive visualization, exploration, and feedback-rich experiences, yet the educational usefulness of AR is highly dependent on the quality of instructional design and implementation (Taher, 2023). Bibliometric and synthesis studies also revealed that the research on AR is still growing, and the evidence in the field of elementary digital skills education remains relatively scarce, especially in the classrooms of the fifth grade and under-resourced or semi-remote locations.

1.2. Research Objectives

1. To test the hypothesis of whether AR-based teaching was linked with disparities in the achievement of the computational concepts among female learners at the elementary level.
2. To test the post-test difference in computational concepts between AR and traditional instruction.
3. To estimate the magnitude of augmented reality's effect on computational concepts achievement using η^2\`
4. To provide an integrated pre–post statistical summary of group equivalence and AR impact using t-test results and (η^2)

1.3. Key Concepts and Terminologies

Augmented Reality Supported Instruction (AR): AR-supported instruction can be defined as technology mediated through the use of digital data that is presented in the physical environment to form interactive learning environments. AR only works well in education when it is purposefully designed to reflect learning outcomes, structured activities, and facilitated interaction instead of serving novelty functions (Zhang et al., 2022). 4. Computational Concepts (Basic Concepts in Computer Systems) Computational concepts are the key concepts used in the operation of computing systems, which are hardware, software, data representation, and system operations. These ideas are used at the elementary level as critical pre-research knowledge in the subsequent development of computational thinking and programming (Li et al., 2025).

4.1. Digital Competence (Primary-School Level): Digital competence refers to a combination of knowledge, abilities, and attitudes that one needs to possess to successfully, responsibly, and productively use digital tools. To inform instruction and curriculum planning, it is normally measured in domains of information processing, communication, content creation, and safety in primary school (Sakr & Abdullah, 2024).

4.2. Quasi-Experiment Pretest-Posttest Control-Group Design. A quasi-experimental A pretest-posttest control-group study that tests the effect of the intervention is done by comparing the level of change in outcomes in an intervention group and a similar control group not fully randomized. This design is mainly aimed at cases where random assignment is limited in school based research and probably will help in structured group comparison although the capability of the causal interpretation is dependent on the limit to which the confounding effects in schools are controlled (S. Wang et al., 2024). Instructional Impact Effect Size (η^2) Effect size (η^2) is a statistical index that approximates the amount of variance in outcomes that an intervention can cause. In education research, η^2 is a useful complement to a significance test because it suggests useful impact, but this interpretation needs to take into account design sensitivity (Walan & Enochsson, 2024).

2. Theoretical Framework

2.1. Rationale and Single-theory Alignment

Elementary digital-skills learning can also be facilitated by augmented reality (AR), in which explanations are provided alongside interactive, situated visualizations, but there is limited evidence on curriculum-driving concepts in the fifth grade that are grounded in AR. The mechanism-oriented explanation is thus needed to explain the situation when the conceptual learning is enhanced by AR and when the attention is disrupted. In this paper, the selected theoretical framework is the Cognitive Theory of Multimedia Learning (CTML), as it is the only theoretical framework since it determines the manner in which learners build knowledge based on words and pictures with cognitive limitations. In its turn, CTML clarifies why learning of computer components and operation relations can be supported by using AR in cases when messages do not exceed the processing abilities of learners. This unitarist stance guarantees that constructs and anticipated relationships are all based on CTML processes and not coalesced explanatory traditions.

2.2. Core Assumptions of CTML and Theoretical Relevance to AR

CTML presupposes two channels of verbal and visual information, the limited capacity of the working memory, and processing of information by selecting, organizing, and integrating it with prior knowledge (Hu et al., 2021). These hypotheses are operationalized according to principles that are meant to control the necessary processing, minimize extraneous processing, and stimulate generative processing. Due to the inability to automatically apply multimedia principles to different environments, principled design choices play a significant role in the interactive environment. Integration in AR can be directed by overlays or cause other visual coordination demands. In this way, the efficacy of AR is supposed to depend on the CTML-compatible design quality and not on technological breakthroughs.

2.3. Key Constructs and Conceptual Boundaries

In the research, AR-supported instruction refers to a multimedia learning space where digital aspects (e.g., labels, 3D models, and short animations) in this case are added to real-world referents with the help of smart devices to facilitate the interpretation of specific content, and its quality in instruction is evaluated based on the principles of CTML. Computational concepts refer to conceptual knowledge about computer architecture and computer operation, such as the connection between hardware and software components and mechanisms of basic data processing and transfer. Bounding of learning outcome is cognitive achievement on a test of computational concepts and interpreted as improved mental-model construction and not simple engagement. The variables in the processes are limited to those that are CTML-consistent measures of cognitive processing: extraneous processing, necessary processing management, and generative integration with no introduction of alternative theoretical explanations. These boundaries take care of the fact that the constructs do not overlap and the explanatory chain is based on CTML processing architecture.

2.4. CTML-derived Logic for Expected Relationships

CTML postulates that AR enhances the learning of computational concepts in situations where strong spatial and temporal contiguity between explanations and relevant structures occurs as a result of overlays, which subordinates split attention and aids integration among representations. AR-based worked-example instruction has also been found to result in better learning, as the instruction focuses attention on the features of relevance and prevents unproductive searching, which is aligned with reduced extraneous processing (Radianti et al., 2020). According to eye-tracking evidence, attention shifts that are not controlled during AR learning may disrupt the process of comprehension, which is why it is essential to signal and pace. The interface strategies with lower visual switching requirements are thus compatible with the design logic of CTML. In line with this, the study variables are considered to be CTML-consistent variants of how the message design constitutes the processing in AR messaging and, as a consequence, success (Kölemen, 2024).

3. Literature Review

According to recent sources, augmented reality (AR) is not just a technological innovation but a pedagogical platform whose instructional potential hinges on its ability to help students to comprehend concepts, coordinate their focus, and further the objectives of the curriculum. Throughout the conducted research, AR has usually been linked to positive effects of achievement and motivation, in general, especially in the field of STEM; the effects have not been reported to take place automatically or consistently. Rather, the literature repeatedly mentions that the teaching worth of AR is determined by the design

Espacio, Tiempo y Educación, v. 13, n. 1, January-June / Enero-junio 2026, pp. 215-232.
ISSN: 2340-7263

quality, progression of actions, and the level at which implementation is structurally based on pedagogy rather than technology. This difference is critical as it changes the emphasis from AR as a tool to AR as an educational environment, the success of which depends on design and context. One of the most significant themes in the literature is the alignment of instruction and orchestration of classrooms. AR seems to be best put into practice when it relates to particular representational obstacles in the text and when its interactive nature links implicitly to defined learning goals. Research has demonstrated many times that guided use, teaching pace, and evident integration into lesson framework enhance the learning value of AR, but haphazard integration applications could result in distractive effects, entertainment, or enthusiastic motivation that can be harder to partition than real conceptual learning. In this regard, the assumption that AR is effective per se is not supported by the literature Rather, it denotes that when the technology is well-coordinated with the application of a coherent system of pedagogy, it will become efficient.

A second theme that recurs is that of outcome conditionality. Meta-analytic and synthesis studies list overall positive average effects of AR although they also indicate a high degree of variability between studies based on the degree of their interactivity, the length of the intervention, the age of learners, the type of content used, and how learning outcomes are conceptualized. Such variability means that the effect of AR reported is extremely dependent on methodological and instructional decisions. It also indicates that generalizations should be approached with care when making generalized claims concerning the effectiveness of AR, particularly in cases where the interventions are short-term or have results that are specific. This problem is further escalated in elementary school, where issues of developmental suitability and practicality in the classroom are the key factors of consideration. Studies of younger learners suggest that mobile AR can be a possibility, and we can take advantage of it at least in cases when tasks are well-designed and goals are well-focused, but the very fact of whether it is possible to implement it is included in the explanatory question itself instead of a secondary provision (Gumaelius et al., 2024).

Neither is there a dearth of methodological enrichment nor methodological limitation in the literature. On the one hand, systematic reviews, bibliometric analyses, and meta-analytic studies help the field with the systematic synthesis of trends and findings. Conversely, several primary AR investigations have also been chronicled on many occasions to lack procedural transparency, clear dosage, and small samples as well as lack consistent outcome measures, which diminish replicability and causal interpretation (Selwyn, 2024). It is not merely the case that AR studies are not comparable to each other, but rather that most of them lack sufficient fidelity to implementation, assessment fidelity, or comparator fidelity. This can frequently result in a lack of understanding of whether recorded gains are due to conceptual learning, momentary involvement, novelty effects, or larger classroom effects. This methodological heterogeneity is the key to the given research since the educational value of AR is not only whether gains are achieved but also whether the achievement of gains can be viewed as plausible.

The literature reviewed, however, justifies an explanatory model in which AR has the potential to enhance learning by visualization and guided interaction and offering organized representative support. Externalizing ideas expressed in complex or abstract ways by using interactive, visual forms can help learners better organize information and interact with content in significant ways. This can be especially true with computational concepts where learners may have to grasp invisible processes, relationships between systems, and abstract processes. In this case, AR would allow the development of pedagogical possibilities that traditional exposition alone is not able to achieve. However, as the literature also reveals, it is not the presence of these affordances that enables transfer or learning-loving conceptual mastery unless it is supported by a sound instructional design and valid measures (Howard & Davis, 2023).

This body of knowledge generates three huge research gaps. To begin with, elementary and curriculum-specific evidence is still underrepresented in comparison with the general syntheses in STEM. Secondly, there remains a weak point, reporting fidelity, dose of intervention, and instrument validity, which limits the strength of interpretation. Third, there are still some inconsistencies about to whom and under which conditions AR is optimal, partly due to the fact that moderators and mechanisms were not modeled uniformly across studies (Lacka et al., 2021). Collectively, the stock of literature underpins and upholds the educational potential of AR and at the same time cautions against the methodological drawbacks of inflating scores and obscuring explanatory processes. The current research was thus poised to add context-dependent evidence to the teaching of computational concepts using AR in elementary learning in digital skills, without ignoring the fact that there must be careful application and cautious interpretation.

4. Methodology

4.1. Study Approach

The research design was a quantitative quasi-experimental pretest-posttest comparison-group design that tested the achievement of computational concepts in two instructional conditions. AR-supported teaching with Assembler Edu served as the independent variable and achievement on the test of computational concepts as the dependent variable. Since the intervention was executed in intact classes in a school, the design facilitated structured group comparison without necessarily ruling out the potential class-level effects on student performance.

4.2. Research Design and Procedures

A quasi-experimental design (pre-testing) that involved two nonequivalent groups (control and experimental) was carried out. The first unit, which is Learning the Basics, of the fifth-grade curriculum in digital skills was targeted in the intervention. Research procedures were chunked in that order to guarantee validity and replicability as given below.

4.2.1 Identification of Methodology and Literature Review

The methodological basis was decided via the choice of an appropriate quasi-experimental model and the thorough review of the previous studies on the subject of augmented reality in the classroom. This was a foundation of all the consequent stages of research design, material development, and instrument validation.

4.2.2 Preparation of Instructional Materials

The first unit that was chosen as the educational content to be used in the intervention was the unit Learning the Basics, which covered the basic computer components as well as the mechanisms of their functionality. The Assembler Edu augmented reality application was installed to carry out the design of individual and group tasks in the app by creating a project account.

- Teacher Guide: The guide for the teacher was organized in such a way that it described the instructional plan to deliver the target unit, such as the introduction, the objectives of the guide, the process of using augmented reality, proposed teaching methods and activities, a description of the topics covered in the unit, overall unit goals, the implementation timeline, the implementation of lessons through the use of augmented reality, and lesson plans. To attain content validity and suitability to the research objectives, the guide was reviewed by experts in computer curriculum and teaching digital skills as well as in educational technology. Every suggestion and recommendation was considered.
- Student Activity Book: The student activity book consisted of eight various activities, both individual and collaborative ones distributed over the main topics of the unit, and aimed to facilitate the learning goals.

4.2.3. Development and Validation of the Research Instrument

Computational Concepts Test: A computational concepts test was the main research tool that was used to evaluate the achievement of the students in the target unit. The test included 20 multiple-choice questions, which had four possible answers, and each question was directly related to the material of the unit of Computer Basics. Questions were well developed to make them clear, precise, and relevant to students in the fifth grade. Every correct answer was counted, and the overall score was used to signify the level of mastery of the student in the concepts of computation.

Content Validation: The test was sent to the panel of digital skills teachers with advanced academic degrees in order to test its content validity. Depending on their comments, the wording, relevance, and the overall quality of the items were revised a number of times. Pilot Testing and Psychometric Analysis: The initial test was pilot-tested with a sample size of 40 students that were not part of the main study sample. This process enabled the determination of the appropriate test duration, which was 30 minutes on the basis of the average time taken to complete it during the pilot administration, and tested the clarity of the items. The analysis of the items was then done by computing the difficulty and discrimination indices. The item difficulty indices were between the acceptable range of 0.30 to 0.70, and the overall ease and difficulty indices were 0.36 and 0.64, respectively (Jovanovska, 2018, p. 35). Discrimination index of single items was between 0.26 and 0.68, and the general discrimination index was 0.49 (Jovanovska, 2018, p. 36). The Kuder-Richardson Formula 20 was used to evaluate internal consistency with an acceptable reliability coefficient of 0.798. After these processes and the subsequent amendments, the test was ready to be administered.

4.2.4. Population and Sampling

The population was represented by all fifth-grade female pupils in primary schools in Al-Kharj Governorate of the first semester of the 1447 AH/2025 academic year. A single school was randomly selected; two intact fifth-grade classes in the school were selected as the control group (n = 30) and the experimental group (n = 30), generating a sample of 60 students. The differences at the post-intervention should be approached with care because the assignment was done at the classroom level instead of the student level, so classroom-level variables may have contributed to the observed difference. All the students were aged 10-11 years old, frequently used smart devices, and had not learned the fifth-grade Digital Skills curriculum before.

4.2.5. Preparation for Implementation

The course instructor was thoroughly oriented on the usage of the teacher guide and student activity book before they were implemented. The suitability of the school setting was checked, in particular, for access to smart devices and stable internet connectivity. The school administration and parents of the students were approached on all matters dealing with ethics.

4.2.6. Data Collection Procedures

The baseline was conducted with the pre-test of the computational concepts to find out the initial equality between the two groups. The experimental group received instruction in the augmented reality style, whereas control group received instruction in the traditional means and this was after the installation of Assembler Edu and an introductory orientation. The intervention was three weeks long in the first semester of 1447 AH/2025 CE. Once this was done, both groups would undertake the post-test under the same conditions and determine the scores as a cumulative sum of correct answers.

4.2.7. Data Analysis

Group performance was summarized using descriptive statistics (means and standard deviations) to describe the performance of the groups on pre and post tests. The t-tests were essentially independent in nature to compare baseline equivalence and post-intervention differences and statistical significance of p 0.05 was predetermined. It has calculated effect size (eta squared, η 2) so as to measure the practical effect of the intervention. Check of assumptions was done in Kolmogorov-Smirnov test of normality and the test of homogeneity of variance by Levene. All the statistical tests were done in SPSS (Version 30) to have standardized and reproducible reporting.

5. Results

In this section, the primary findings of the research based on the statistical analysis of the data collected in accordance with the research goals and hypotheses are discussed. The following manner will be used to report the findings: to demonstrate the equivalence of the control and experimental group, the pre-test scores will be used; the post-test scores will form the second step to demonstrate the differences in the achievement of the computational concept in both conditions (control and experimental); the third step will be determining the effect size of the augmented reality intervention. The results are all included in organized tabular and brief analysis commentary, giving the overall understanding of the findings. The results will be presented in this section as follows:

5.1. Research Objective (1): To examine the effectiveness of augmented reality in improving computational concepts achievement among elementary-stage female students. The baseline of the scores was established by an independent-samples t-test of the pre-test results to ensure baseline comparability of the control and experimental groups on the achievement of the computational concepts and to avoid the presence of an independent group difference in the post-test results. Based on this, Table (1) presents the pre-application comparison of control and experimental groups in order to create an initial equivalence as the precondition of investigating the efficacy of augmented reality in enhancing computational concepts achievement.

Table 1: Results of t-test for Significance of Difference between Results of Experimental and Control Groups in Computational Concepts Test in Pre-application.

Group	N	Arithmetic Mean	Calculated "t" Value	Significance Level
Control	30	6.77	0.26	0.79
Experimental	30	6.6		

Results in Table 1 show that there was no statistically significant difference between the control and experimental groups on the pre-test on computational concepts, indicating the initial equivalence of the two groups. Thereafter, the training was conducted on the control group through conventional teaching strategies and the experimental group through the application of the augmented reality learning technique after the teacher gave a general review of the application of assembler Edu and ensured that the application was installed on the device of all students. The second research objective, which is the discovery of the effectiveness of the use of augmented reality in increasing the achievement of the computational concepts, was fulfilled at the end of the instructional unit; both groups were given a post-test to evaluate the level of learning, just as the first research objective which is the finding of the effectiveness of the use of augmented reality in increasing the achievement of the computational concepts. To answer the research question, it was hypothesized that there is a statistically significant difference at level (<=0.05) between the means of the scores of the experimental and control groups in the test of computational concepts in Favor of the experimental group in post-application. The means, standard deviations and t-test values of the two independent groups were extracted based on Table (1) to create a baseline reference point of how to interpret the differences after the application.

5.2. Research Objective (2): To test the post-test difference in computational concepts between AR and traditional instruction.

To address this objective, an independent-samples t-test was applied to compare the post-test mean scores of the control group (traditional method) and the experimental group (augmented reality). In addition, eta squared (η^2) was calculated to estimate the magnitude of the AR effect on students' computational concepts achievement.

Table 2: Comparison of the Mean Scores of the Control and Experimental Groups on the Post-Test of Computational Concepts, with Effect Size (η^2).

Group	Arithmetic Mean	Standard Deviation	Calculated "t" Value	Significance Level	Eta Squared (η^2)
Control	6.77	2.98	10.4	0.01	0.65
Experimental	14.5	2.82			

The figures that are reflected in the table above show that there is a statistically significant difference at the level of 0.01 between the mean post-test scores of the experimental and control groups in computing concepts, with the advantage being in favor of the experimental group. The eta squared value ($\eta^2 = 0.65$) shows that the effect size in terms of improvement of the instruction using the augmented reality technology in the Learning the Basics unit has a significant magnitude, as the effect increased significantly in the development of the computational concepts among the fifth-grade female students taking the Digital Skills course.

This finding is in line with other studies and adds to the plausibility of the current findings, which emphasizes the validity of the application of modern technological applications in education.

The superiority that was observed in the experimental group might be caused by several factors. To begin with, the introduction of augmented reality in education is one of the most popular tendencies in e-learning because it has a variety of benefits, such as enhanced engagement, the ability to study with all of the senses, and the motivation of students. Augmented reality is achieved through the combination of virtual images, videos, and animated models with real-life situations and attracts the attention of students and allows a better understanding of the material, turning the learning process into a more pleasant and interactive experience.

Also, augmented reality in the unit of Learning the Basics was used to demystify abstract concepts related to the computer hardware, e.g., the processor, memory, and graphics card, and also the process of how computers work and how to transfer data. The augmented reality, through its multimedia capabilities, bridged the gap between theory and reality, and thus the enjoyment of the students enhanced the meaningful learning.

Moreover, the presentation of the Digital Skills courses in augmented reality enabled the instruction to be more in line with the interests and learning preferences of the students, leaving the traditional teaching methods. This strategy gave the students the ability to access course material using familiar digital gadgets and the internet to accomplish course assignments and activities in an engaging and vibrant atmosphere. The variety of resources provided by augmented reality, such as videos, educational images, and interactive models, gave a possibility to have direct experience, create a discussion, ask questions, and analyze the individual and collective performance efficiently.

Lastly, the augmented reality provided every learner an opportunity to gain practical experience that, otherwise, could be unavailable within the school environment, particularly due to the learning difficulties of assembling and exploring the inside of the computer parts. Another outcome of the AR-supported environment was the supportive, collaborative learning climate that promoted confidence among the students and self-directed learning and minimized the fear of errors. In this environment, students turned into active participants in the center of the educational process; at the same time, the teacher became a facilitator and mentor.

5.3. Research Objective (3): To estimate the magnitude of augmented reality's effect on computational concepts achievement using η^2.

To fulfill this objective, the post-test results of the experimental and control groups were analyzed using an independent-samples t-test, and **eta squared (η^2)** was computed to quantify the strength of the augmented reality intervention. This measure of effect size helps explain whether the difference that is being observed is a real instructional effect, rather than just a statistical effect.

Table 3: Summary of Group Performance (Pre-Test vs. Post-Test) and Gain Scores.

Group	N	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD
Control	30	6.77	2.70	6.77	2.98
Experimental	30	6.60	2.14	14.50	2.82

According to Table (3) the control and experimental groups were quite comparable in their pre-test baseline and therefore represents the initial similarity of the two groups before the intervention. Control group pre-test mean was 6.77, and standard deviation was 2.70 whereas experimental group pre-test mean is 6.60, and the standard deviation is 2.14. This similarity in the means suggests that subsequent differences can not be

Espacio, Tiempo y Educación, v. 13, n. 1, January-June / Enero-junio 2026, pp. 215-232.
ISSN: 2340-7263

attributed to the achievement differences that already exist. The results of the post-test show that there is a shift in the pattern after being taught. The control group average did not vary (6.77) but the variability slightly increased (post-test SD = 2.98), which means that there was no significant change in undergoing traditional teaching despite small variation among individual scores. To the contrary, the post-test mean of the experimental group increased by far to 14.50 (SD = 2.82), which suggests that there has been a substantial achievement in computational concepts after augmented reality based instruction.

This is a more straightforward interpretation when the focus is made at the final column, Gain (Post-Pre), which is the summation of net improvement. The control group shows an increment of 0.00 which proves that there was no change in the overall level of performance between pre- and post-application. Compared to it, the gain of the experimental group is high and of educational value because of the intervention. It is also important to note that the standard deviations of the performance of the experimental group and the control group are relatively close (2.98 and 2.82, respectively) which means that the difference is influenced not by a few high scores. Overall, Table 3 provides clear descriptive data, which the instructional approach based on augmented reality was related to strong learning outcomes, and the performance of the control group did not differ significantly when compared using two measurements.

5.4. Research Objective (4): To provide an integrated pre–post statistical summary of group equivalence and AR impact using t-test results and η^2.

To address this objective, a combined comparison was developed to show the results of the independent-samples t-test between the two pre-test and post-test periods in a single framework. This concomitant presentation allows one to directly check the equivalence of the baselines prior to the intervention and easily evaluate the difference after the intervention, besides reporting the effect size (η^2) to demonstrate the practical significance of the effect produced by augmented reality.

Table 4: Unified t-Test Summary with Effect Size (η^2) for Pre- and Post-Testing.

Test Phase	Control (N=30) Mean ± SD	Experimental (N=30) Mean ± SD	t-value	Sig. (p)	Effect Size (η^2)
Pre-Test	6.77 ± 2.70	6.60 ± 2.14	0.26	0.79	—
Post-Test	6.77 ± 2.98	14.50 ± 2.82	10.40	0.01	0.65

A combined record in Table 4 gives the overall outcome of an independent-samples t-test in each pre- and post-test phase, which enables direct comparison of the group equivalence prior to the intervention and the difference between groups after the intervention. In the pre-test, the control group achieved 6.77 ± 2.70, while the experimental group scored 6.60 ± 2.14. The t-value (0.26) corresponding to the p-value (0.79) shows no statistical significance to the difference, which proves that those two groups were similar at the point of baseline and that the subsequent dissimilarity could not be preconditioned by the initial success differences. There is a considerable change in the statistical pattern in the post-test. The control group reflected 6.77, and the experimental group was 14.50. The t-value (10.40) that has a $p = 0.01$ means that there was a statistically significant difference in favor of the experimental group, meaning that higher posttest performance was observed in the class that received AR-supported instruction than in the class taught through traditional instruction.

The posttest difference was statistically significant and practically substantial, although its interpretation should remain cautious in light of the class-level implementation of the instructional conditions, and this supports the fact that the difference observed in post-test scores is not only statistically significant but also has an educational significance. In general, Table 4 can be used to make two important conclusions: equivalence of the baselines at pre-testing and a significant, high-impact, statistically significant, and high advantage of the experimental group at the post-testing.

6. Discussion

The results of the current quasi-experimental research designate that the better performance on the computational concepts was noted in the class that was provided with AR-supported teaching as compared to the class taught with the help of traditional teaching. An after-test difference was found to be clear, and the effect size observed was high (Almatrafi et al., 2024; Dai et al., 2020). However, there should be some degree of caution with regard to the trend methodologically. Since the two instructional conditions were not applied to the classes in the form of student-level random assignment, the respective difference cannot be viewed as conclusive proof that only the AR component had the entire extent of the gain. Influences at the classroom level, such as contextual, instructional, and implementation-related ones, might have been acting in conjunction with the condition of AR support (Bygstad et al., 2022). The results can thus be viewed as evidence of stronger performance in this classroom setting in AR-supported instruction but not as the conclusive evidence of an independent causal impact of AR (Alhazmy, 2025; C. Wang et al., 2024).

The results obtained in this limitation are still highly meaningful and viable practically and academically. The trend indicates that the structured lessons with AR could provide a valuable instructional guide in learning abstract computational systems in the elementary grades, especially when visualization, directed interaction, and physical representation are the main focus of the learning task. This meaning is consistent with the recent research that has suggested that AR is most educationally helpful in cases where its affordances are best aligned with curricular objectives and conceptually challenging matters (Perales et al., 2020). In the meantime, any indication regarding classroom practice or policy will have to be implemented in the same proportion to the design evidentiary strength. The current findings thus indicate that AR-based lessons should be approached cautiously by pedagogues when teaching conceptually challenging units of digital skills, but more powerful suggestions would be needed based on designs more distinctly isolating instructional effects at the class level (Jendli & Albarakati, 2024).

The orientation of the current results is generally compatible with the previous literature that has shown positive tendencies in the use of augmented reality in the educational process, in particular, in visualizing or STEM-based learning activities (Althubaiti et al., 2022). The consistency is in that direction of the association as opposed to the strength of causal inference. The effect size was rather large in the current study, but this size cannot be overestimated as a sign of a high level of causal certitude. It can be, alternatively, the joint effect of instructional conditions and contextual aspects of the implementation. In this regard, the study falls under the context-based supportive evidence that is contextually aligned with the literature but has a limited range of causal explanatory power as compared to full-scale designs. A number of contextual issues can be used to explain the pattern. The content to be targeted was abstract and computational, which seems particularly well suited to the AR-based visualization and guided explanation. The systematic application of the application, the correspondence of lesson activities and the unit goals, and the application of a validated instrument might also have reinforced the clarity of the identified group difference (Aldhobaib, 2025). But the factors in the classroom cannot be neglected. The Cognitive Theory of Multimedia Learning theoretical framing of the study is also compatible with the discussion. The use of AR-supported instruction can be beneficial as it may allow organizing both verbal and visual information around the hard-to-calculate concepts and arrange the materials in a well-planned manner (Bermúdez Medranda & Cahuasqui Briones, 2025; Mustafa et al., 2024).

7. Conclusion, Practical Implications, and Future Directions

The present study found that higher computational concepts achievement was observed in the class that received AR-supported instruction than in the class taught through traditional instruction in the fifth-grade Digital Skills course. Pretest results indicated baseline similarity between the two groups, whereas posttest results showed a statistically significant difference in favor of the AR-supported class, accompanied by a large effect size (η^2). The gain-score pattern also revealed more learning gains under the instructional AR-supported condition as compared to the traditional instruction. These results should, however, be viewed with care because the conditions of instruction were conducted at the level of intact classes with their differences, thus being unable to be solely explained by the AR component in the total causal sense.

Under these methodological constraints, the research provides classroom-based propositions that organized AR-guided lessons can be a promising instructional strategy to teach a basic understanding of the aspects of computation at the elementary school level. Another strength of the research is the consistency of the instructional goals, testing processes, and pattern of observed results, indicative of the internal coherence of reported results that do not stretch their causal interpretation beyond the capability of the design to substantiate. The research also offers locally based evidence on the ground of elementary education in digital skills in an environment of an abstract curriculum, scarce physical resources, and a necessity to be efficiently visualized.

Practically, the results advocate the prudent pedagogical approach to the use of AR-based instruction for conceptually challenging content, especially when the instruction is mediated by the well-structured learning activities, educator training, and consistency between the learning goals and the evaluation processes. The ability of curriculum developers and school leaders to incorporate carefully designed AR-based tasks into the elementary teaching of digital skills and to maintain the status quo of implementation conditions and the explanatory value of education can be justified. Meanwhile, general practice or policy recommendations must be proportionate to the level of evidentiary strength of the current design.

Future investigation is required to analyze these strengths in a more stringent practice of assignments and in more extensive cadences of implementation. Internal validity would be reinforced with the replication across different classes, teachers, and schools and enhance the broadening of the interpretive potential of the results. Knowledge of retention, transfer to following classes and grades, variability in different AR devices, as well as effects of moderators such as prior digital experience and readiness in the classroom could also be studied in more research.

Acknowledgments

This study is supported via funding from Prince Sattam bin Abdulaziz University project number (PSAU/2026/R/1447).

Compliance Statement

This article is a research paper that is ready to be published. The version is final, and the author agrees to be fully responsible for the contents of the version.

Ethical Approval Statement

The research was carried out by adhering to the accepted ethical guidelines during the study. They were voluntary, and informed consent was given where necessary, and privacy and confidentiality were upheld. This is also mentioned in the manuscript: ethical issues were discussed with the school administration and parents of the students.

Data Availability Statement

The text and tables of the manuscript contain the key results of the research. The raw information and the statistical results can be availed to a reasonable request to review the editorial side or conduct a scholarly validation.

AI Use Statement

The application of AI was only to edit the language and polish manuscripts written by authors, such as clarity, grammar, and formatting. No data collection, data entry, data cleaning, statistical analysis, interpretation, results, or conclusion generation or modification of the study was performed using an AI tool. The author(s) assume complete responsibility as to the content in the manuscript.

Funding Statement

This study is supported via funding from Prince sattam bin Abdulaziz University project number (PSAU/2026/R/1447).

Statement of Conflict of Interest.

According to the author, she has no competing interests and no conflicts of interest regarding this work. The study did not have any financial or non-financial relationship that affected the way it was designed, data was collected, analyzed, interpreted, and reported.

Novelty and Research Contribution

The research paper adds contextualized information about the application of augmented reality in the instruction of computational concepts in the elementary level of teaching digital skills in Saudi Arabia. It contributes to the lack of representation of a classroom situation and the analysis of AR-supported instruction with respect to the achievement of the computational concepts.

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