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Teaching Science with Chatbots: Enhancing Concepts and Passion in Middle School Students

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This research aimed to examine the effect of chatbots in science instruction to promote developing scientific concepts and scientific passion for third intermediate grade students. The study used experimental research, which involved a quasi-experimental design with two groups experimental or control with pre- and post-measurements. Purposive sampling was used from Educational Complex in Qibah supervised by the Qassim Education Department, where two classes were selected from the third intermediate grade, totaling (50) students. One class consisted of (25) students in the experimental condition with chatbots instruction, and the other class (25) was assigned to control condition receiving traditional instruction. Research tools were used to measure scientific concepts and science passion by using a Scientific Concepts Test and a Science Passion Scale. Data were analyzed using paired sample and independent sample t tests, which showed significant improvements in scientific concepts and scientific passion among students taught with chatbots. Results indicated significant effectiveness of chatbots in science instruction on improving both scientific concepts and scientific passion for the third intermediate grade students. The study recommended that science education programs use chatbots or digital applications in science education to enhance students' scientific engagement, spark scientific passion, and increase students' understanding of scientific concepts.

Keywords: science education, chatbots, artificial intelligence, scientific concepts, scientific passion

INTRODUCTION

Science education has long been a priority for educators worldwide, who continually seek more effective and engaging instructional methods. Modern technologies, particularly AI tools, are increasingly viewed as promising means to enhance content delivery and improve students' mastery of scientific learning outcomes.

AI, or artificial intelligence, is one of the most identifiable markers of the digital age, with capabilities that offer quicker, smarter, and more efficient methods across several

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disciplines, including education. As a result, the use of AI applications in science education has become a necessity (Al-Dajah, 2024). One of the novel applications of AI is chatbots, which produce assistance and support by expecting a human-like conversation with users. Chatbots have become more and more capable due to substantial educational technology research related to AI, which mimics natural human language and quickly and accurately understands user input (Al-Najjar & Habib, 2021; Hobert & von Wolff, 2022).

AI-powered chatbots have recently revolutionized the field of education owing to their diverse capabilities. They offer immediate support to both students and teachers by answering questions, explaining lessons, and providing supplementary learning resources. Furthermore, chatbots serve as virtual teaching assistants, aiding educators in their instructional practices (Labadze, Grigolia, & Machaidze, 2023).

Chatbots support continuous learning by answering students' questions and offering immediate feedback. They assist with language accuracy, promote collaborative problem-solving, and create a safe space for experimentation without fear of mistakes. These features collectively enhance students' motivation and engagement. Chatbots also personalize students' learning experiences by tailoring content to individual needs, preferences, and interests. As a result, they serve as an effective means of improving learning outcomes, deepening students' understanding of scientific concepts, and promoting self-assessment through tests, feedback, and reflection on strengths and weaknesses (Al-Dajah, 2024).

From a theoretical perspective, the integration of chatbots in science instruction is supported by several established learning frameworks. Constructivist learning theory posits that students actively build scientific knowledge through exploration, questioning, and meaning-making rather than passive reception (Piaget, 1970; Fosnot, 2013). Chatbots facilitate such active construction by enabling continuous inquiry, immediate feedback, and iterative refinement of misconceptions. Additionally, social interactionist theory emphasizes that cognitive development is mediated through dialogue and guided interaction (Vygotsky, 1978; Mercer & Howe, 2012). Chatbots simulate interactive academic discourse and scaffolding, thereby supporting students' scientific reasoning processes. Cognitive Load Theory further suggests that structured guidance and timely feedback reduce extraneous cognitive load when learners process complex scientific concepts (Sweller, Ayres, & Kalyuga, 2011). Moreover, self-regulated learning frameworks highlight the role of autonomy, feedback, and adaptive support in sustaining motivation and deep engagement (Zimmerman, 2002). Accordingly, chatbot-based environments offer theoretically grounded affordances that promote conceptual understanding, inquiry engagement, and sustained scientific motivation, making them particularly suitable for science learning contexts.

A growing body of research has examined the educational applications of chatbots across different learning domains. A first strand of studies has focused on learning outcomes and conceptual understanding, reporting positive effects of chatbot-based instruction on academic achievement and concept acquisition in science and mathematics (Al-Omari, 2019; Al-Far & Shaheen, 2019; Al-Hadeed, 2024; Suleiman et al., 2024). A second strand has explored motivational and affective dimensions, showing that chatbots can enhance students' engagement, enjoyment, and willingness to learn (Liu et al., 2022; Jea et al., 2024; Yang & Chen, 2023). A third strand has addressed skills development and instructional support, demonstrating that chatbots contribute to research skills, critical thinking, self-regulated learning, and teacher support (Al-Najjar & Habib, 2021; Basta & Al-Ajmi, 2024; Labadze et al., 2023).

Recent research has begun to explore the educational potentials of AI-chatbot technologies, including ChatGPT, for enhancing student learning experiences, psychological well-being, and task support (Alshammari, 2025; Dertli & Yildiz, 2025). Despite these promising findings, existing studies have typically examined either cognitive outcomes or motivational variables in isolation (Wangdi & Pelden, 2025; Huang et al., 2025), and most have been conducted in higher education or non-science subjects (Debets et al., 2025; Martin et al., 2023). Empirical evidence remains limited regarding the combined impact of chatbot-based instruction on both scientific concept development and scientific passion at the middle-school level (Abu-Seif & Sanalla, 2025; Aldous et al., 2025). This gap highlights the need for focused experimental research exploring how chatbot integration in science classrooms simultaneously supports conceptual understanding and fosters sustained scientific motivation. The present study addresses this gap by investigating the effectiveness of teaching science using chatbots in developing scientific concepts and scientific passion among third-grade intermediate students.

Despite the documented benefits of chatbots in supporting learning, recent discussions in the literature have highlighted concerns regarding students' increasing dependence on AI tools (Kasneci et al., 2023). Some studies suggest that excessive reliance on chatbots may reduce students' independent problem-solving, critical thinking, and self-regulated learning skills (Zawacki-Richter & Latchem, 2023; Rudolph et al., 2023). Other scholars warn that when students depend heavily on AI-generated explanations, they may engage less deeply with scientific content, potentially weakening conceptual understanding and analytical reasoning (Susnjak, 2023). These emerging concerns underscore the need for empirical studies—such as the present research—to examine not only the potential benefits but also the practical implications of integrating chatbots into science education.

Statement of the Problem

The growing availability and educational potential of chatbots highlight the need to integrate them into science instruction, particularly to strengthen students' scientific concepts and foster scientific passion.

Several studies have emphasized the importance of employing chatbots in education. For instance, Al-Najjar and Habib (2021) recommended promoting awareness of AI and chatbots in pre-university education. Al-Omari (2019) called for further research to examine the effectiveness of chatbots in teaching. Similarly, Al-Harithi et al. (2024) recommended employing AI-powered chatbots in educational settings, while Jea et al. (2024) suggested using chatbots across various courses and conducting further studies to verify their impact and effectiveness in the educational process. Basta and Al-Ajmi (2024) also recommended incorporating chatbots in science education.

To explore the current situation, a pilot study was conducted to assess the level of chatbot use in science teaching. The study included (30) intermediate school students. Results revealed that (22%) of the students had no knowledge of what chatbots are or how they can be used in the educational process, while (84%) reported that they do not use chatbots in learning science. Moreover, (86%) of the students indicated that their science teachers do not ask them to use chatbots in studying science. These findings indicate a significant lack of chatbot integration in science education, underscoring the importance and relevance of the present study.

A review of previous research further revealed a scarcity of studies examining the effectiveness of chatbots in developing students' scientific concepts and scientific passion. Based on practical experience in teaching science, a clear need was identified to explore how chatbots can enhance scientific understanding and increase students' enthusiasm for science learning. Accordingly, the problem of this study is formulated in the following main research question:

What is the effectiveness of teaching science using chatbots in developing scientific concepts and scientific passion among third-grade intermediate students?

Research Questions

This study seeks to answer the following main question: What is the effectiveness of teaching science using chatbots in developing scientific concepts and scientific passion among third-grade intermediate students?

From this main question, the following sub-questions are derived:

1. What is the effectiveness of teaching science using chatbots in developing scientific concepts among third-grade intermediate students?
2. What is the effectiveness of teaching science using chatbots in developing scientific passion among third-grade intermediate students?

Research Objectives

The study aims to:

1. Identify the effectiveness of teaching science using chatbots in developing scientific concepts among third-grade intermediate students.
2. Identify the effectiveness of teaching science using chatbots in developing scientific passion among third-grade intermediate students.

Research Hypotheses

The study is based on the following hypotheses:

1. There is a statistically significant difference at the level ($\alpha \leq 0.01$) between the mean scores of the experimental group students in the pre- and post-tests of scientific concepts, in favor of the post-test.
2. There is a statistically significant difference at the level ($\alpha \leq 0.01$) between the mean post-test scores of the experimental group students and those of the control group students in the scientific concepts test, in favor of the experimental group.
3. There is a statistically significant difference at the level ($\alpha \leq 0.01$) between the mean scores of the experimental group students in the pre- and post-measurements of the scientific passion scale, in favor of the post-measurement.
4. There is a statistically significant difference at the level ($\alpha \leq 0.01$) between the mean post-measurement scores of the experimental group students and those of the control group students on the scientific passion scale, in favor of the experimental group.

Significance of the Study

1. This study may provide a theoretical and scientific background on the use of chatbots in science teaching.
2. The results of this study may assist science teachers in effectively integrating chatbots into science instruction.
3. The findings may help those responsible for professional development programs for science teachers to design training sessions on employing chatbots in science education.
4. This study could serve as a starting point for future research addressing the use of chatbots in teaching science.

Delimitations of the Study

The study was limited to the following:

- **Subject Delimitations:** The study focused on teaching the unit *"Foundations of Life"* from the science textbook prescribed for third-grade intermediate students. The chatbot *Migo Chat* was used in teaching science, as it enables interactive communication with students, evaluates their responses, and provides corrective feedback.
- **Spatial Delimitations:** the researchers conducted the study at Qibah Educational Complex (Intermediate Level), affiliated with the General Department of Education in the Qassim Region.
- **Temporal Delimitations:** The study was implemented during the first semester of the academic year 1446 AH.
- **Human Delimitations:** The study was limited to third-grade intermediate students at one of the intermediate schools for in Qibah, under the supervision of the Qassim Education Department.

- **Generalizability**: The study sample was drawn from one educational complex using purposive sampling to ensure controlled implementation of the experimental intervention; consequently, while the findings provide strong evidence of the effectiveness of chatbot-based instruction within this context, generalization to broader student populations should be approached with caution.

Definitions of Terms

- **Chatbots:** Mahmoud (2022) defines a chatbot as "a computer program that conducts a dialogue with the user through natural language, assisting in conversation via written or spoken text. It not only mimics human conversation in its natural form but also processes user input and data to generate appropriate responses."

Operational Definition: In this study, chatbots are defined as interactive applications designed for use via smart devices and computers, allowing natural-language conversation about the *'Foundations of Life'* unit from the third-grade intermediate science textbook. The chatbot includes a sequence of interactive activities employed in teaching this unit.

- **Scientific Concepts:** Abu Ouda and Hallas (2022) define a scientific concept as "a word, name, or term that represents a set of attributes or characteristics shared among objects."

Operational Definition: In this study, scientific concepts refer to the abstraction of common features shared among a set of elements, representing a distinct mental image of an object. These may include names, terms, or scientific symbols contained in the *"Foundations of Life"* unit for third-grade intermediate students. Scientific concepts are measured by the score obtained by the student on the scientific concepts test developed for this purpose.

Scientific Passion

Abu Lubbah and Al-Rassai (2024) defined scientific passion as "a strong inclination of the students toward scientific activities that they are interested in, driven by a desire to attain truth and knowledge, and to achieve the highest levels of performance and creativity" (p. 8). Likewise, Daqamseh (2023) defined scientific passion as a strong tendency toward an activity that the student loves, perceives as important, and dedicates time to pursuing.

For the purposes of the present study, scientific passion is operationally defined as students' feelings of enjoyment, deep interest, and strong desire toward learning activities in the science curriculum, through which they invest their time and energy in studying science—an experience that brings them pleasure and a sense of fulfillment, and becomes an essential component of their personal identity. This construct was measured using a Scientific Passion Scale developed specifically for this study.

METHOD

Research Design

The present study employed a quasi-experimental research design using a pre-test–post-test control group structure. Two intact classes of third-grade intermediate students were selected from Qibah Educational Complex and randomly assigned to either an experimental group or a control group. The experimental group received science instruction using chatbot-based learning activities, whereas the control group received instruction through traditional teaching methods.

The research procedure followed a clear sequence. First, both groups completed the Scientific Concepts Test and the Scientific Passion Scale as pre-tests to ensure group equivalence before the intervention. Next, the experimental group participated in chatbot-supported science instruction for the "Foundations of Life" unit, while the control group studied the same unit using conventional instructional methods. After completion of the instructional period, both instruments were administered again as post-tests to measure changes in scientific concepts and scientific passion.

This quasi-experimental pre-/post-test design is appropriate for the present research because the study aims to determine the causal effect of chatbot-based instruction on students' scientific concept acquisition and scientific passion. Using a control group allows comparison with traditional instruction, while pre-testing ensures equivalence between groups before the intervention. This design therefore provides a robust structure for examining whether observed post-test differences can be attributed to the chatbot-based teaching approach, directly addressing the study's research questions.

Participants

The population of the study consisted of all third-grade intermediate students enrolled in public daytime schools under the supervision of the General Department of Education in the Qassim Region, totaling 8,254 students across 184 intermediate schools, according to official statistics from the Planning and Development Center, Qassim Department of Education (2024).

The study sample was drawn from Qibah Educational Complex (Intermediate Level), affiliated with the Qassim Department of Education. Two intact classes of third-grade intermediate students were selected to participate, comprising a total of 50 students. Class (B), consisting of 25 students, was assigned as the experimental group, while Class (C), consisting of 25 students, served as the control group. Inclusion criteria required students to be enrolled in the third-grade intermediate level at the selected school and to attend regular science classes during the implementation period. Students who were absent during either the pre-test or post-test administrations were excluded from the final data analysis to ensure completeness of measurements.

To assign groups, the two selected classes were randomly designated as experimental and control groups to ensure unbiased group allocation while maintaining intact classroom structures, which is consistent with quasi-experimental procedures in school-based research.

The average chronological age of participants was approximately 15 years, as recorded in school enrollment records at the beginning of the academic year. To control for baseline differences in prior knowledge and motivation, both groups completed the Scientific Concepts Test and the Scientific Passion Scale as pre-tests before the intervention. Independent samples t-test results confirmed no statistically significant differences between the two groups in pre-test scores for scientific concepts or scientific passion, indicating baseline equivalence before implementing the instructional intervention.

Materials and Intervention

Science Unit and Teacher's Guide

The instructional content of the study was based on the science unit "Foundations of Life", prescribed for third-grade intermediate students. This unit was selected because it contains essential scientific concepts related to students' daily lives, including photosynthesis, cellular respiration, fermentation, cell division, and reproduction. The unit aims to develop students' conceptual understanding and promote engagement with scientific inquiry.

To support implementation of the intervention, a Teacher's Guide was developed specifically for this study. The guide included an introduction to chatbot-based instruction, learning objectives for each lesson, structured teaching procedures, and student activities designed to promote interaction with the chatbot. It also outlined assessment methods, including classroom tasks, assignments, and the Scientific Concepts Test and Scientific Passion Scale, to evaluate students' learning outcomes and engagement.

The initial version of the Teacher's Guide was reviewed by a panel of experts in curriculum and science education, as well as intermediate-level science teachers. The reviewers evaluated the clarity of objectives, appropriateness of activities for students' level, and alignment between instructional procedures and assessment methods. Based on their feedback, revisions were made to improve clarity of instructions, refine learning outcomes, and ensure suitability of activities for the target student group. The final version of the guide was then used in the experimental implementation.

Chatbot Design (MigoChat)

The study employed the MigoChat chatbot as the main instructional tool for the experimental group. The chatbot was designed to provide interactive, text-based dialogue with students related to the "Foundations of Life" unit. Students engaged with the chatbot by entering questions or selecting predefined response options, to which the chatbot provided automated explanations, clarifications, and feedback on scientific concepts covered in the unit.

The chatbot content was structured to present scientific information in short instructional segments, followed by interactive questions and immediate responses to support concept understanding and correct misconceptions. In addition, the chatbot incorporated multimedia learning materials, such as images and short video clips, to illustrate scientific processes and reinforce explanations. This interactive environment enabled students to review content, ask follow-up questions, and receive continuous feedback throughout the learning process.

The chatbot therefore functioned as a conversational learning assistant that guided students through the unit content, promoted active engagement with scientific concepts, and supported individualized pacing during instruction.

Study Instruments

Each research instrument is presented with a detailed description of its conceptual basis, item construction, response format, scoring method, validation by subject-matter experts, pilot testing procedures, and statistical evidence of validity and reliability to ensure clarity and methodological rigor.

Scientific Concepts Test

A Scientific Concepts Test was developed to measure students' cognitive achievement regarding the scientific concepts included in the "Foundations of Life" unit. The test comprised 26 multiple-choice questions, each with four answer options, only one of which was correct. Each question carried one point. Clear instructions were provided for the students.

The test was reviewed by a panel of experts, including specialists in curriculum and science teaching, as well as science teachers and educational supervisors across various science disciplines. The panel evaluated each item for validity, appropriateness for measuring scientific concepts, clarity of wording, and suitability for the students' level. Based on their recommendations, some items (e.g., items 2, 4, and 5) were revised.

A pilot test was then conducted on a sample of 25 students from Qibah Educational Complex (not part of the main study sample) to determine test duration, calculate internal consistency, and assess test reliability.

- The average test duration was 45 minutes, divided as follows: 5 minutes for preparation and 40 minutes for answering the test questions.
- Internal consistency was assessed using the Pearson Correlation Coefficient, to determine the degree of correlation between each item and the total test score. Table 1 presents the correlation coefficients between each item score and the total test score.

Table 1
Correlation Coefficients Between Each Item Score and Total Score of the Scientific Concepts Test (N = 25) Scientific Concepts Test for Third-Grade Intermediate Students

Item No.	Correlation Coefficient	Item No.	Correlation Coefficient
1	0.695**	14	0.695**
2	0.788**	15	0.695**
3	0.765**	16	0.695**
4	0.784**	17	0.695**
5	0.591**	18	0.788**
6	0.746**	19	0.746**
7	0.788**	20	0.757**
8	0.757**	21	0.695**
9	0.695**	22	0.695**
10	0.695**	23	0.788**
11	0.695**	24	0.765**
12	0.695**	25	0.695**
13	0.695**	26	0.695**

Note: Significant at $\alpha = 0.01$

It is evident from Table (1) that the correlation coefficients between each test item and the total score ranged from 0.591 to 0.788, all statistically significant at the 0.01 level. This confirms a high level of internal consistency for all items of the Scientific Concepts Test.

Test Reliability

The reliability of the test was calculated using two methods:

1. Cronbach's Alpha (α)
2. Split-Half Method with Spearman-Brown and Guttman adjustments

Cronbach's Alpha Method

Cronbach's alpha was used to assess the reliability of the total test score. The results are presented in Table (2).

Table 2
Reliability of the Scientific Concepts Test Using Cronbach's Alpha (N = 25)

Scale	Number of Items	Reliability Coefficient
Scientific Concepts Test for Third-Grade Intermediate Students	26	0.938

As shown in Table (2), the Cronbach's alpha coefficient for the Scientific Concepts Test was 0.938, indicating a high degree of reliability.

Split-Half Method

The split-half method involves dividing the test into two equivalent halves. Odd-numbered items constitute one half and even-numbered items the other. The Pearson correlation coefficient was computed between the scores of the two halves. The length of the test was then adjusted using the Spearman-Brown and Guttman formulas to estimate the overall reliability of the test.

The results of this analysis are presented in Table 3.

Table 3
Reliability Results of the Scientific Concepts Test Using the Split-Half Method (N= 25)

Scale	Correlation Coefficient	Split-Half Reliability Coefficient
		Spearman-Brown
Scientific Concepts Test for Third-Grade Intermediate Students	0.815	0.898

It is evident from Table (3) that the reliability coefficients of the Scientific Concepts Test using the Spearman-Brown formula reached 0.898, and using the Guttman formula reached 0.837, confirming a high level of reliability. After verifying the validity and reliability of the test, it was finalized for use.

Test Validity

Statistical validity was established through internal consistency analysis. Item–total correlations ranged from 0.591 to 0.788 ($p \leq 0.01$), indicating strong construct validity.

Development of the Scientific Passion Scale

To construct the Scientific Passion Scale, previous studies on scientific passion measurement were reviewed (Al-Jarrah & Al-Rabee', 2020; Masri, 2022; Breik, 2022; Saud & Mohammed, 2023; Al-Harithi, 2015; Chichekian & Vallerand, 2022), along with Vallerand et al.'s (2003) Passion Scale, translated into Arabic by Fares (2021). Based on these references, the scale was developed with two dimensions:

1. Harmonious Passion – items 1 to 17
2. Obsessive Passion – items 18 to 25

The items were formulated in clear, comprehensible language suitable for middle school students, totaling 25 statements. To ensure face validity, the questionnaire was reviewed by a panel of experts and revised according to their feedback.

To verify the psychometric properties (validity and reliability), the scale was piloted with 25 third-grade intermediate students. For internal consistency, Pearson correlation coefficients were calculated between each item and the total score of its respective dimension.

Table 4
Internal Consistency Validity of the Scientific Passion Scale Items (N = 25) Scientific Passion Scale for Third-Grade Intermediate Students

Item No.	Correlation Coefficient	Item No.	Correlation Coefficient
1	0.719**	14	0.457*
2	0.780**	15	0.818**
3	0.869**	16	0.741**
4	0.753**	17	0.704**
5	0.673**	18	0.820**
6	0.751**	19	0.742**
7	0.609**	20	0.518**
8	0.723**	21	0.658**
9	0.557**	22	0.581**
10	0.700**	23	0.743**
11	0.760**	24	0.502*
12	0.589**	25	0.695**
13	0.821**		

Notes: *Significant at α = 0.01; Significant at α = 0.05

It is evident from Table (4) that the correlation coefficients between each item and the total score of its respective dimension ranged from 0.457 to 0.869, all statistically significant at 0.01 and 0.05 levels. This confirms that all items of the Scientific Passion Scale exhibit a high degree of internal consistency for third-grade intermediate students.

Reliability of the Study Instruments

The reliability of the scale was calculated using Cronbach's Alpha, as shown in Table 5.

Table 5
Reliability Results of the Scientific Passion Scale Using Cronbach's Alpha (N = 25)

Scale	Number of Items	Reliability Coefficient
Scientific Passion Scale for Third-Grade Intermediate Students	25	0.954

It is evident from Table (5) that the Cronbach's Alpha for the Scientific Passion Scale was 0.954, indicating that the scale exhibits a high degree of internal consistency and reliability.

Scientific Passion Scale

Statistical validity was confirmed through item–total correlations for each dimension, all statistically significant at p ≤ 0.01, demonstrating adequate construct validity.

Implementation of the Research Experiment

The pre-test was administered for both research instruments—the Scientific Concepts Test and the Scientific Passion Scale—on the research sample. Following this, the experimental group was taught using chatbots, while the control group was taught using the conventional method. The instructional period for the unit lasted 4 weeks, with 4 sessions per week, each session lasting 45 minutes, in line with the Ministry of

Education's standard schedule. After instruction, the instruments were post-tested on both the experimental and control groups.

FINDINGS

The equivalence of the two groups was verified through the pre-test of scientific concepts, using the Independent Samples T-Test to assess differences between the group means. All assumptions for the t-test were met, and the results are shown in Table 6.

Table 6
Equivalence of the Experimental and Control Groups on the Pre-Test of Scientific Concepts (df = 48)

Scale	Group	N	Pre-Test Mean	SD	t-value	p-value
Total Scientific Concepts	Control	25	16.280	3.857	0.333	0.741
	Experimental	25	15.960	2.865		

It is evident from Table (6) that there were no statistically significant differences between the experimental and control groups in the pre-test of scientific concepts, confirming the equivalence of the two groups. Therefore, any significant differences observed in the post-test can be attributed to the effectiveness of teaching science using chatbots in developing scientific concepts among third-grade intermediate students.

The equivalence of the two groups was also confirmed through the pre-test of scientific passion, using the Independent Samples T-Test, as shown in Table 7:

Table 7
Equivalence of the Experimental and Control Groups on the Pre-Test of Scientific Passion (df = 48)

Scale	Group	N	Pre-Test Mean	SD	t-value	p-value
Harmonious Passion	Control	25	2.440	0.253	1.040	0.304
	Experimental	25	2.342	0.393		
Obsessive Passion	Control	25	1.952	0.357	-5.63	0.576
	Experimental	25	2.029	0.585		
Total Scientific Passion	Control	25	2.288	0.251	0.489	0.627
	Experimental	25	2.242	0.408		

Table (7) shows no statistically significant differences between the experimental and control groups in the pre-test of scientific passion, confirming the equivalence of the two groups. Therefore, any differences in the post-test can be attributed to the effectiveness of teaching science using chatbots in enhancing scientific passion among third-grade intermediate students.

To answer the first research question and test the first hypothesis, a paired-sample t-test was used to examine the significance of differences between the pre- and post-test means of the experimental group on the Scientific Concepts Test. The results are presented in Table 8:

Table 8
Significance of Differences Between the Pre- and Post-Test Means of the Experimental Group on the Scientific Concepts Test (df = 24)

Scale	Test	N	Pre-Test Mean	Mean Difference	SD	t-value	p-value
Total Scientific Concepts	Pre-Test	25	15.96	8.24	2.865	10.659	0.01
	Post-Test	25	24.20		2.432		

It is evident from Table (8) that there is a statistically significant difference at the 0.01 level between the pre- and post-test means of the experimental group in the Scientific Concepts Test, in favor of the post-test. This supports the effectiveness of teaching science using chatbots in developing scientific concepts among third-grade intermediate students.

To test the second hypothesis, an Independent Samples T-Test was conducted to examine the significance of differences between the experimental and control groups on the post-test of scientific concepts. In addition, Eta Squared (η^2) was calculated as an indicator of effect size, following the criteria of Mansour (1997):

- Small effect: $\eta^2 < 0.06$
- Medium effect: $0.06 \leq \eta^2 < 0.14$
- Large effect: $\eta^2 \geq 0.14$

The results are presented in Table 9.

Table 9
Significance of Differences Between the Post-Test Means of the Experimental and Control Groups on the Scientific Concepts Test (df = 48)

Scale	Group	Mean	SD	t-value	p-value	Effect Size (η^2)
Scientific Concepts	Control	16.84	2.982	9.564	0.01	0.656
	Experimental	24.20	2.432			

Table (9) shows a statistically significant difference at the 0.01 level between the post-test means of the experimental and control groups on the Scientific Concepts Test, in favor of the experimental group. The effect size is large, as indicated by the Eta Squared value of 0.656 (> 0.14).

These results confirm the effectiveness of teaching science using chatbots in enhancing scientific concepts among third-grade intermediate students.

Answering the Second Research Question:

To answer the second research question and verify the third hypothesis, a paired-samples t-test was conducted to examine the significance of differences between the pre- and post-test means of the experimental group on the Scientific Passion Scale. The results are presented in Table 10:

Table 10
Significance of Differences Between the Pre- and Post-Test Means of the Experimental Group on the Scientific Passion Scale (df = 24)

Scale	Test	N	Pre-Test Mean	Mean Difference	SD	t-value	p-value
Harmonious Passion	Pre-Test	25	2.34	0.53	0.393	5.943	0.00
	Post-Test	25	2.87		0.232		
Obsessive Passion	Pre-Test	25	2.03	0.56	0.585	3.379	0.02
	Post-Test	25	2.59		0.649		
Total Scientific Passion	Pre-Test	25	2.24	0.54	0.408	5.071	0.00
	Post-Test	25	2.78		0.308		

Table (10) shows statistically significant differences at the 0.00 level between the pre- and post-test means of the experimental group for the overall scientific passion and its subscales (Harmonious and Obsessive Passion), in favor of the post-test, confirming that teaching science using chatbots positively influenced students' scientific passion.

To verify the fourth hypothesis, an Independent Samples T-Test was conducted to examine differences between the experimental and control groups on the post-test of scientific passion. Additionally, Eta Squared (η^2) was calculated as an indicator of effect size (Mansour, 1997):

- Small effect: $\eta^2 < 0.06$
- Medium effect: $0.06 \leq \eta^2 < 0.14$
- Large effect: $\eta^2 \geq 0.14$

The results are presented Table 11.

Table 11
Significance of Differences Between the Post-Test Means of the Experimental and Control Groups on the Scientific Passion Scale (df = 48)

Scale	Group	Mean	SD	t-value	p-value	Effect Size (η^2)
Harmonious Passion	Control	2.457	0.180	7.018	0.00	0.506
	Experimental	2.869	0.232			
Obsessive Passion	Control	1.947	0.282	4.569	0.00	0.303
	Experimental	2.593	0.649			
Total Scientific Passion	Control	2.298	0.136	7.208	0.00	0.520
	Experimental	2.783	0.308			

Table (11) indicates statistically significant differences at the 0.00 level between the post-test means of the experimental and control groups for the overall scientific passion and its subscales, in favor of the experimental group. The effect sizes are large, as all Eta Squared values exceed 0.14.

These findings confirm the effectiveness of teaching science using chatbots in enhancing scientific passion among third-grade intermediate students and indicate a clear positive impact of chatbot-based instruction on student outcomes.

INTERPRETATION AND DISCUSSION

The findings of the present study indicate that chatbot-based instruction significantly enhanced students' scientific concept acquisition and scientific passion compared with traditional teaching methods. Rather than merely confirming statistical differences, these results can be understood through contemporary learning theories and research on artificial intelligence in education. Chatbot-supported instruction created an interactive learning environment where students actively engaged in questioning, receiving explanations, and revisiting content, which aligns with constructivist views of knowledge construction through social and dialogic interaction (Vygotsky, 1978; Graesser et al., 2005). This interactive dialogue likely supported conceptual change and reduced misconceptions in science learning.

One key mechanism explaining the effectiveness of the chatbot intervention is the provision of immediate feedback and continuous formative support. Intelligent conversational systems can respond instantly to students' inquiries, clarify misunderstandings, and reinforce correct reasoning, which promotes deeper processing of scientific concepts (Woolf, 2010). Such feedback-rich environments are well established as powerful drivers of learning, particularly in domains that require conceptual understanding rather than rote memorization.

Another contributing factor is personalized and self-paced learning. Unlike whole-class traditional instruction, chatbot interaction allowed students to access explanations and practice opportunities according to their individual needs and learning speed. This individualized support reduces cognitive overload and strengthens self-regulated learning behaviors (Clark & Mayer, 2016). Prior research on AI-supported learning environments similarly reports that adaptive guidance enhances achievement and knowledge retention in science education (Chen et al., 2020; Ouyang et al., 2022).

The significant improvement in scientific passion can be attributed to increased engagement and motivational appeal. The dialogic and interactive nature of the chatbot transformed students from passive recipients into active participants. From the perspective of self-determination theory, such environments foster autonomy and competence, which in turn promote intrinsic motivation and sustained interest in learning (Deci & Ryan, 2000). Empirical reviews of AI applications in education also confirm that conversational agents enhance learner engagement and positive attitudes toward academic subjects (Zawacki-Richter et al., 2019; Hwang & Tu, 2021).

Furthermore, the integration of visual and textual explanations within the chatbot likely strengthened comprehension of abstract biological processes included in the "Foundations of Life" unit. Multimedia learning theory explains that combining verbal and visual information facilitates dual-channel processing and deeper understanding (Mayer, 2009; Moreno & Mayer, 2007). The chatbot's multimodal presentation therefore provided a richer cognitive experience than conventional textbook-based instruction.

Overall, these findings suggest that chatbots serve not merely as technological tools but as pedagogical mediators that promote interactive knowledge construction, personalized support, immediate feedback, and motivational engagement. This combination of mechanisms explains the observed improvements in scientific concepts and scientific passion. Consequently, the present study contributes empirical evidence to the growing body of literature supporting the integration of AI-powered conversational agents as effective instructional tools in science education (Luckin et al., 2016; Ouyang et al., 2022).

Strengths, Limitations, and Implications

A key strength of the present study lies in its experimental comparison between chatbot-based and traditional instruction using pre- and post-measures, which allowed a clear examination of the impact of chatbot-supported learning on both cognitive (scientific concepts) and affective (scientific passion) outcomes. The use of validated measurement instruments and baseline equivalence between groups further enhances the internal validity of the findings. In addition, the study provides context-specific empirical evidence on the use of AI-based conversational agents in intermediate science education, an area that remains underexplored in current literature.

Despite these strengths, certain limitations should be acknowledged. First, the sample size was relatively small and drawn from a single school, which limits the generalizability of the findings to broader student populations. The use of intact classes, although appropriate for school-based quasi-experimental research, also means that the sample may not fully represent the diversity of intermediate-level learners in different educational contexts. Second, the intervention was implemented within a specific unit ("Foundations of Life") and over a limited time frame; therefore, long-term retention of learning outcomes and transfer to other science topics were not examined. Third, contextual factors such as teacher familiarity with technology, school infrastructure, and students' prior exposure to digital learning environments may have influenced the effectiveness of the chatbot intervention and should be considered when interpreting the results.

These limitations suggest directions for future research. Larger-scale studies involving multiple schools and diverse student populations are recommended to enhance external validity. Longitudinal research could also examine the sustained impact of chatbot-based instruction on science achievement and motivation over extended periods. Additionally, future studies may explore variations in chatbot design, levels of adaptivity, and integration with classroom pedagogy to identify optimal implementation models.

From a practical perspective, the findings offer meaningful implications for educational practice. The results indicate that integrating AI-based chatbots into science instruction can promote interactive learning, immediate feedback, and personalized support, which are critical for developing conceptual understanding and learner motivation. Educators and curriculum designers may therefore consider incorporating conversational AI tools as supplementary learning resources within science classrooms. However, successful implementation requires adequate teacher training, reliable technological infrastructure, and thoughtful alignment between chatbot content and curriculum objectives.

Policymakers and school leaders should also ensure equitable access to digital learning tools to maximize the benefits of AI-supported education.

CONCLUSION

The present study examined the impact of chatbot-based instruction on intermediate students' acquisition of scientific concepts and scientific passion in science learning. The findings demonstrate that students who learned through chatbot-supported instruction achieved significantly higher levels of conceptual understanding and showed greater enthusiasm for science compared with students taught through traditional methods. These results indicate that conversational AI can serve as an effective pedagogical tool for enhancing both cognitive and affective learning outcomes in science education.

From a theoretical perspective, the study provides empirical support for the role of interactive and personalized learning environments in promoting knowledge construction and learner motivation. The findings contribute to emerging literature on artificial intelligence in education by demonstrating how chatbot-based learning facilitates immediate feedback, self-paced learning, and active engagement—mechanisms that strengthen conceptual development and positive attitudes toward science.

From a practical perspective, the results suggest that integrating chatbots into science instruction can enrich classroom practice by offering continuous academic support, individualized guidance, and engaging learning experiences. Educators and curriculum designers are therefore encouraged to incorporate AI-powered conversational tools as supplementary instructional resources to enhance student learning and motivation. However, effective implementation requires adequate teacher preparation, appropriate technological infrastructure, and alignment between chatbot content and curricular objectives.

While the findings of this study demonstrate the positive impact of chatbots on students' scientific concepts and scientific passion, chatbot-based instruction also presents potential limitations and risks. Recent literature has highlighted concerns related to excessive reliance on AI tools, which may reduce independent problem-solving and critical thinking when learners depend heavily on automated feedback. In addition, chatbots may occasionally generate inaccurate or incomplete responses, which can lead to misconceptions if not monitored by teachers. Ethical and practical concerns such as student data privacy, unequal access to digital devices, and varying levels of teacher readiness may also affect the effectiveness of chatbot integration. These considerations underscore the importance of implementing chatbots in a balanced, supervised, and pedagogically guided manner.

Moreover, the generalizability of chatbot-based instruction to intermediate schools in developing countries should be interpreted cautiously. In many low-resource contexts, schools may face limited internet connectivity, insufficient technological infrastructure, and restricted access to digital learning materials, particularly in public schools. As a result, reliance on locally available instructional resources remains common, which may reduce the feasibility of chatbot integration at scale. Future research should therefore explore implementation models suitable for low-resource environments, including offline or locally hosted chatbot systems, blended approaches, and teacher-mediated strategies that minimize dependence on continuous internet access.

In conclusion, chatbot-based instruction represents a promising approach for advancing science education by improving students' understanding of scientific concepts and nurturing sustained interest in science learning. Further large-scale and longitudinal research is recommended to expand generalizability and explore long-term educational impact.

PRACTICAL RECOMMENDATIONS

Based on the findings that chatbot-based instruction significantly improved students' scientific concepts and scientific passion, science teachers are encouraged to integrate educational chatbots as supplementary instructional tools to provide immediate feedback and interactive concept reinforcement during classroom and homework activities. Curriculum designers should consider embedding chatbot-supported tasks within science units to promote self-paced learning and sustained student engagement. School administrators are advised to provide teacher training on effective pedagogical use of AI tools and ensure adequate technological infrastructure to support chatbot implementation. Educational policymakers should support the controlled adoption of AI-based learning tools in science education while establishing guidelines that promote balanced use and prevent overreliance on automated support.

Suggestions for Future Research

Since this study was conducted with a small sample from a single school and within one science unit, future research should examine chatbot-based instruction across larger and more diverse student populations to enhance generalizability. Further studies are needed to investigate the long-term retention of scientific concepts acquired through chatbot learning and their transfer to other science topics. Future research should also explore how different chatbot designs (e.g., adaptive vs. non-adaptive feedback) influence learning outcomes and motivation. Finally, given emerging concerns about overdependence on AI tools, additional studies should examine the balance between chatbot support and independent problem-solving to identify optimal integration models in science classrooms.

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