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Article

The Impact of an Artificial Intelligence Application-Based Training Program on Developing Sustainable Thinking among High School Biology Teachers

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Abstract

This study investigates the impact of an artificial intelligence (AI)-based training program on fostering sustainable thinking among high school biology teachers. Employing a descriptive methodology focused on AI applications, the training program was designed to cultivate sustainable thinking skills within biology educators. The effectiveness of the program was evaluated using a pre-post experimental design with a single sample. A cohort of 31 biology teachers from high schools was selected through simple random sampling. The analysis revealed a statistically significant difference at the 0.01 level between the mean scores of the biology teachers in the pre-test and post-test assessments of sustainable thinking, with post-test outcomes demonstrating superior performance. Furthermore, the AI-based training program exhibited a notable effect size in promoting sustainable thinking among high school biology instructors. Based on the findings, several recommendations were made, including the revision of the training program for high school biology teachers to align with the rapid advancements in science, particularly in the integration of AI within biology education. Additionally, it was suggested that the training program and associated measurement tools developed in this research be utilized to assist students in cultivating higher-order cognitive skills, such as sustainable thinking. Ultimately, the study advocates for the continuous updating of training programs to incorporate AI and higher-order thinking skills, thereby enhancing teachers' sustainable thinking capabilities and facilitating the transfer of these skills to their students.

Keywords

Artificial Intelligence Applications, Sustainable Thinking, Biology Teachers, Training Program, Secondary Education.

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The educational system is critical to the development and progress of nations because it produces minds that are capable of handling ongoing scientific and technological advancements. Continuously refining this system and its integral components is crucial for meeting the demands of the twenty-first century. Teachers are central to this ecosystem, fundamentally influencing the success of the educational process and achieving its objective. Consequently, revisiting the traditional methods of teacher preparation is essential. We must equip teachers with a wide range of skills and abilities to teach their students to actively contribute to sustainable development. The final report from the seminar on teacher preparation programs for middle and high school teachers in the Arab region stressed the critical need to modernize the teacher preparation system and its elements (Regional Center for Quality and Excellence in Education, 2018). We expect educators of the twenty-first century to take advantage of the educational opportunities presented by emerging technologies such as artificial intelligence. These technologies provide teachers with tools to deeply analyse student behaviour and adapt teaching strategies to cater specifically to identified weaknesses (Bali, 2017). Numerous international forums have recognized the pivotal role of AI in evolving teacher preparation programmes. UNESCO (2019) highlighted that effective, equitable, and comprehensive education requires the incorporation of information and communication technologies to substantially enhance educational frameworks. This recognition has spurred global educational communities to delve deeply into the interactions between AI and education, aiming to harness these technologies to realize significant advancements in educational outcomes. AI's conceptual foundation of AI involves the creation of computer devices and programs capable of emulating human cognitive processes, including thinking, analysis, and decision-making (Ajam, 2018).

This field engages with the development of methodologies, techniques, theories, simulation systems, and applications, all of which are dedicated to the mirroring aspects of human intelligence. Owing to its proven efficacy, AI has garnered extensive interest within the educational sector, facilitating transformative changes and measurable enhancements in the teaching and learning processes (Al-Farani & Al-Hujaili, 2020). According to Al-Ghamdi and Al-Abbasi (2022), AI has seamlessly integrated into computer-based learning environments, automating educational procedures and fostering significant improvements that are quantifiable within the realms of educational processes. The utility of AI in education extends beyond automation. It plays a crucial role in minimizing human errors through sophisticated digital programs and systems that can simulate the critical elements of human intellect. These advanced systems can deduce facts and legal frameworks stored in computer memory, providing instantaneous feedback that assists in fine-tuning decisions and strategies. This optimization ensures that educational projects are directed efficiently, achieving objectives with reduced costs and effort (Al-Yazji, 2019). Many scholars have consistently emphasized the critical importance of integrating AI into educational paradigms to develop students' skills and competencies, aligning them with the demands of modern advancements and contributing to sustainable development goals (Al-Azam, 2020; Al-Muqiti, 2021; Al-Najjar & Habib, 2021; Al-Shibl, 2021). Ahmed (2020) stressed the necessity for AI-based training programs tailored to enhance a variety of teaching skills among high school chemistry teachers. Furthermore, Alshrane (2022) emphasized the need for advanced preparation of general education teachers in the Kingdom of Saudi Arabia to keep up with AI trends.

Similarly, Samili (2023) explored the role of AI applications in boosting the performance of secondary school science teachers in Saudi Arabia, while Shahin (2023) advocated a shift from rote learning to applying tools that ensure educational sustainability through AI. Additionally, Qura and Al-Matse (2023) highlighted the potential of AI to equip teachers to effectively tackle challenges and seize opportunities for sustainable development, in alignment with Vision 2030. Achieving sustainable development hinges on three critical dimensions: understanding the ethics and values associated with sustainable development; viewing the environment as a complex socio-ecological system; and cultivating sustainable thinking skills. Sustainable thinking, a sophisticated form of higher-order thinking, entails the capacity and readiness to critically evaluate the impact of individuals' actions and behaviours. It also empowers individuals with the skills necessary to devise creative solutions to complex challenges and adopt varied perspectives on sustainable development (Hassan, 2022). The development of sustainable thinking is particularly vital among science educators, including biology teachers, because it stimulates them to encourage their students to make sustainable decisions. This process includes assessing the implications of potential threats and opportunities associated with sustainable actions aimed at benefiting humanity and Earth (Al-Baz, 2019). Sustainable thinking also encompasses students' perceptions of the environment and their valuation of it, reflecting how aligned values and resources support both local and global communities in protecting themselves against environmental disruption and achieving prosperity.

Moreover, sustainable thinking incorporates economic and social justice considerations in addition to environmental considerations. This entails understanding the differences in these concepts across cultures and how their integration can help resolve sustainability challenges (Ahmed, 2020). Skills associated with sustainable thinking include organized thinking, which involves analysing complex systems across various sectors of society, the environment, and the economy from diverse perspectives. Strategic thinking focuses on developing plans to realize specific visions by considering each decision's contribution. It also includes examining potential solutions under set assumptions, proposing alternatives and refining these assumptions based on the options provided. Future thinking, or proactive thinking, entails reflecting on future scenarios and their relevance in addressing sustainability issues. Finally, value thinking involves identifying and negotiating the values, principles, and ethical considerations inherent in sustainability, recognizing how these differ by culture, and contributes to solving sustainability problems (Al-Baz, 2019). Numerous studies, including Issa (2023), Metwally (2022), Abu Dahab (2023); Mohamed and Ahmed (2022), and Repanovici, Rotaru and Murzea (2021), have underscored the significance of fostering sustainable thinking in various scientific fields. These studies highlight that sustainable thinking extends beyond mere knowledge transfer. It involves posing critical questions, envisioning optimistic future outcomes, enhancing students' values and systematic thinking, and facilitating applied learning opportunities that explore the interplay between application and innovation. According to studies emphasizing the importance of preparing teachers to leverage AI applications one of the 21st-century essentials it is critical to develop their capabilities, including sustainable thinking, to enable them to impart these skills to students using modern technologies. AI is one of the most important technologies for enhancing educational effectiveness. This recognition has led to current research, which aims to evaluate the effects of a training program based on AI applications on the development of sustainable thinking among secondary-level biology teachers. The transformative potential of artificial intelligence (AI) is increasingly being recognized across various sectors, including education, where it promises to revolutionize teaching and learning processes. This study focused on the application of AI to the professional development of high school biology teachers, specifically through a training program designed to foster sustainable thinking. Sustainable thinking involves the ability to make decisions that consider the long-term impacts on the environment, economy, and society, which is crucial for addressing contemporary global challenges. The integration of AI into educational practices presents a promising avenue for improving teachers' instructional capabilities, and consequently, students' educational outcomes (UNESCO, 2019). In the realm of science education, particularly biology, where ethical considerations and environmental impacts are paramount, the ability to cultivate a sustainable mindset is invaluable. Despite rapid advancements in AI, there is a notable gap in its application to teacher training programs specifically tailored to develop such competencies (Alshrane, 2022). Existing research underscores the significant role of AI in reshaping educational strategies to not only deliver content but also promote critical thinking, problem-solving, and decision-making skills aligned with sustainable development goals (SDG) (Shahin, 2023).

However, there is a lack of literature on the effectiveness of AI-driven programmes in cultivating these competencies among biology teachers. This study aims to address this gap by evaluating an AI-based training program that fosters sustainable thinking among high school biology teachers. By leveraging AI, the proposed training program aims to equip teachers with the skills necessary to encourage and guide students to make sustainable choices. This study contributes to the existing body of knowledge by providing empirical evidence on the program's effectiveness, thereby supporting the integration of AI into teacher professional development. Moreover, it aligns with global educational trends that emphasize the need for educators to adapt to technological advancements and the shifting paradigms of the 21st century (Global AI Summit, 2020).

Statement of the Problem

Saudi Arabia is on a visionary path to positioning human capital as the primary engine of its economic, social, and cultural evolution. The transformation from a natural resource-reliant economy to one that relies on the ingenuity, creativity, and productivity of its population is central to this vision. Recognizing high-quality education as the foundation of this transformative agenda, the goal is to cultivate a generation deeply versed in foundational principles, imbued with noble ethics, and equipped with the skills and knowledge to engage

effectively in national intellectual pursuits and contribute meaningfully to broader economic, social, and cultural transformation (Saudi Vision 2030). To achieve these ends, Saudi Arabia's educational strategy emphasizes enhancing students' understanding of core curriculum concepts through the development of digital content and the augmentation of teachers' capabilities in integrating technology into educational delivery (Ministry of Education, 2021). The technological revolution, specifically the onset of the Fourth Industrial Revolution, signifies a shift in teaching paradigms, necessitating the embrace of artificial intelligence (AI) in all facets of life.

This revolution has prompted the need to prepare educators who are adept at digital methodologies, a necessity underscored by Saudi Arabia's hosting of the Global AI Summit, organized by the Saudi Data and Artificial Intelligence Authority (SDAIA) from September 14th to 15th, 2020. This highlights the critical role of AI in driving digital transformation across various sectors, including education (Global AI Summit, 2020). Driven by the imperative to align educational outcomes with the Fourth Industrial Revolution and its AI-driven imperatives, the Ministry of Education in Saudi Arabia introduced a forward-thinking educational framework. This new framework aims to transform secondary schools into academies that offer diversified pathways and a broad curriculum, including digital technology, cybersecurity, design and modelling, the Internet of Things, digital control, data science, AI, and robotics programming, among others (Ministry of Education, 2019). Despite these robust initiatives, significant gaps remain in Saudi educators' preparedness to meet the evolving demands of the technological era. Studies by Alshrane (2022) and Samili (2023) highlighted these deficiencies, particularly in adapting teaching strategies to effectively incorporate AI applications.

Moreover, Al-Aklabi (2019) pointed out that, across the Arab world, educational institutions lag in their readiness to confront the challenges presented by the Fourth Industrial Revolution, attributable to substantial financial requirements and a lack of adequately trained specialists. Interviews with a group of biology teachers have shown that many of them do not fully understand how AI can be used in the classroom and are unable to use advanced cognitive skills to come up with solutions to problems that will arise in the future. Furthermore, these educators often struggle to synthesize information within comprehensive frameworks that interlink biological concepts with development goals, resulting in a noticeable decline in their sustainable thinking capabilities. The scarcity of studies focusing on fostering such cognitive frameworks among biology teachers at secondary schools in Saudi Arabia underscores this research gap. Therefore, this study aimed to identify and tackle the emerging research problem of enhancing sustainable thinking among biology teachers by implementing a specialized training program based on AI applications. The goal is to equip educators with the necessary skills and insights to navigate and thrive in an increasingly AI-integrated educational landscape.

Study Questions

1. What are the objectives of the training program based on artificial intelligence applications designed to develop sustainable thinking among biology teachers in secondary schools?
2. What impact does a training program based on artificial intelligence applications have on sustainable thinking among biology teachers at secondary schools?

Study Objectives

The research aims to achieve the following objectives:

1. Prepare a training program based on artificial intelligence applications that aims to develop sustainable thinking among biology teachers in secondary schools.
2. Determine the impact of a training program based on artificial intelligence applications on developing sustainable thinking among biology teachers in secondary schools.

Study Hypothesis

The research aims to test the following hypotheses:

Null Hypothesis (H_0): There is no statistically significant difference at the 0.05 level between the pre-test and post-test mean scores of sustainable thinking among biology teachers in the research sample.

Alternative Hypothesis (H_1): There is a statistically significant difference at the 0.05 level between the pre-test and post-test mean scores for sustainable thinking among biology teachers in the research sample, with higher scores observed in the post-test.

Study Significance

Theoretical Significance

This study aligns with both global and local trends in integrating modern technologies, particularly artificial intelligence, within educational systems. By focusing on biology teachers, it addresses a gap in the literature, specifically in developing sustainable thinking skills that educators can then apply in their classrooms. The research also offers valuable insights for future studies on the use of artificial intelligence in science education and its subfields, as well as on the cultivation and practical application of sustainable thinking skills. Developing these skills in biology teachers will ultimately enable them to foster sustainable thinking in their students, contributing to sustainable development and solutions for related challenges.

Practical Significance

This study highlights the importance of designing training programs that incorporate artificial intelligence applications and emphasize sustainable thinking skills, marking a forward-looking approach that can benefit administrators of science teacher training programs. It provides high school biology teachers with a training program and a measurement tool to review and update their practices, aligning with the rapid advancements in artificial intelligence applications in biology education and fostering the development of higher order thinking skills, including sustainable thinking. Through this program, high school biology teachers gain the knowledge and skills to effectively use AI in their lessons, enhancing their capacity to think sustainably and pass these essential skills on to their students. This focus on AI and sustainable thinking underscores a significant trend in modern education.

Study Scopes

i. **Objective Scope:** Developing a training program based on artificial intelligence applications to develop sustainable thinking (organized thinking, strategic thinking, future thinking, and value-based thinking) among secondary school biology teachers.
ii. **Time Scope:** This research was conducted in the second semester of the academic year 1445 AH–2023 AD.
iii. **Spatial Scope:** schools in the Riyadh educational region.
iv. **Human Scope:** A sample of biology teachers in secondary schools.

Concepts and Terminologies

Artificial Intelligence Applications: Holmes, Griffiths and Forcier (2016) describe artificial intelligence as "computer systems designed to interact with the world through capabilities (e.g., visual perception, speech recognition) and intelligent behaviours typically considered human (e.g., evaluating available information and then taking logical actions to achieve a goal)" (p. 14).

Ocaña-Fernández, Valenzuela-Fernández and Garro-Aburto (2019) describes it as "a method to simulate the intelligence capabilities of the human brain, part of computer science that deals with designing intelligent systems capable of mirroring human behaviours in intelligence."

Al-Sobhi (2020) characterizes artificial intelligence applications as "programs, computer devices, and smart applications that emulate the human mind's capability to make decisions and act, similarly, aimed at leveraging these capabilities in education to fulfil educational goals" (p. 331).

Operationally, in this research, it is defined as "a set of applications that biology teachers in secondary education are trained to use in their teaching to develop their sustainable thinking skills, which they in turn impart to their students."

Sustainable Thinking: Deniz (2016) define sustainable thinking as 'the ability to assess the impact of threats and opportunities in any actions taken, prioritizing not only profit but also the benefits for humans and the planet' (p. 77).

ECO System App (2017) describes it as "the mental skills reflected in sustainable behaviours and attitudes, showcasing an individual's capacity to make ethical decisions when evaluating societal threats and risks."

Aldrich (2018) explains it as "reformulating daily operational and communicative decisions to transform the community into a model of sustainability, considering environmental ethics, and contributing to the creation of sustainable local and global communities through employing four patterns of thinking: systemic, strategic, future-oriented, and values-oriented" (p. 84).

Operationally, it is defined in this study as "a suite of skills that secondary education biology teachers must possess to organize their thinking, professional strategies, future behaviours, and values towards sustainability in biology teaching." This contributes to their ability to make informed decisions, evaluate the impact of their actions, address various challenges in their field, and achieve sustainable development. This was measured by the extent to which a biology teacher exhibited these skills in a test prepared for this purpose."

Research Implementation Procedures

The following section provides an overview of the procedures followed to conduct the research, including the research methodology, population, sample, materials, tools, and statistical methods used to analyse the results.

Methodology

This study adopts a comprehensive approach by integrating the following two distinct research methodologies**.** The study employed a descriptive methodology to develop a training program utilizing artificial intelligence applications to foster sustainable thinking skills among secondary biology teachers. Additionally, this methodology was used to create a sustainable thinking skills test. An experimental approach was also implemented, applying a pretest/post-test design with a single sample to assess the effectiveness of the AI-based training program in enhancing sustainable thinking skills among these teachers. A visual representation of the experimental design is provided in Figure 1.

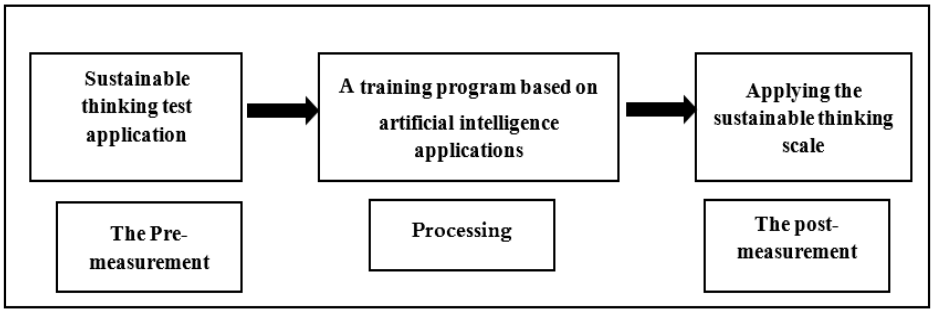

Figure 1: *Experimental Method of Research.*

Research Population and Sample

The study population comprised biology teachers responsible for delivering instruction at the secondary level within the Riyadh region during the academic year 1445 AH/2023 AD. We selected a research sample, which included 31 secondary school biology teachers, through simple random sampling. Initially, we administered a pretest to assess teachers' baseline sustainable thinking skills. Subsequently, we implemented the proposed AI-based training program. After the training, we conducted a post-test to assess how well the program improved participants' sustainable thinking skills.

Study Materials and Procedures

The study developed a training program aimed at fostering sustainable thinking skills among secondary school biology teachers through the application of artificial intelligence. The program was guided by a set of objectives, with the primary goal being to equip biology teachers with sustainable thinking skills by integrating AI applications into their teaching practices. To inform the program's design, relevant literature was identified, including studies by Al-Shibl (2021), Al-Najjar and Habib (2021), Al-Azam (2020); Al-Muqiti (2021), Ahmed (2022), Shahin (2023), Alshrane (2022), Samili (2023), and Qura and Al-Matse (2023), all of which explore the role of artificial intelligence in educational settings. The program was initially organized into six sessions conducted over three days, with each session lasting four hours, including a 15-minute break. Each day concluded with a 15-minute summary and self-assessment period for participants. The curriculum covered topics that linked artificial intelligence to sustainable thinking and

incorporated interactive, biology-relevant activities. The structure of the program included an introduction, general objectives, target audience, session content, implementation timeline, and instructions for trainers. Each session was designed to achieve specific objectives and included relevant content, interactive activities, and opportunities for participant self-assessment and daily summaries. Experts in curriculum development and teaching methodologies reviewed the program to ensure it aligned with the established objectives. Their feedback focused on the appropriateness of the content, instructional methods, session frequency, activities, and assessment techniques in relation to artificial intelligence applications in biology education and the development of sustainable thinking skills. Based on this feedback, revisions were made, particularly to the linguistic and scientific phrasing of certain sections, resulting in a refined version of the program ready for implementation with the primary research sample.

Study Tool

The study employed the Sustainable Thinking test as a primary tool for data collection, developed through a structured process. The test's objective was to evaluate the level of sustainable thinking skills among biology teachers, both before and after their participation in the training program. Its structure was informed by a review of the literature on sustainable thinking, with key sources including Issa (2023), Metwally (2022), Abu Dahab (2023), Mohamed and Ahmed (2022), and Repanovici et al. (2021). This review helped define the critical skills for assessment, specifically organized thinking, strategic thinking, future thinking, and value-based thinking. The test comprised 12 essay-type questions, divided evenly across these four skill areas, with three questions per skill. Each question was designed to prompt teachers to propose sustainable solutions to real-life biological problems, thereby assessing their practical application of sustainable thinking. For scoring, each question was assigned a maximum of four points, based on the originality and logical coherence of the response. Answers were evaluated collectively, with the rarity of a proposed solution influencing its score. Responses that were less common among the group were awarded higher scores, while more commonly suggested solutions received lower scores. This scoring approach reflects the principle that rarer, more innovative ideas demonstrate deeper sustainable thinking. Table 1 presents the criteria used to score each question in the test, based on the statistical scarcity of responses, as outlined by Saif Al-Din (2015).

Table 1: *Criteria for Assessing the Score of Each Question in the Sustainable Thinking Skills Test.*

Idea Repetition	**Less than 5%**	**5% to less than 10%**	**10% to less than 15%**	**15% to less than 20%**	**20% or more**
Authenticity and Logicality Score	4	3	2	1	0

Table 1 provides a scoring system for evaluating responses in the Sustainable Thinking Skills Test based on the frequency of idea repetition, as well as the score for authenticity and logicality. Table 1 divides responses into five groups based on the frequency of idea repetition within a sample: less than 5%, 5% to less than 10%, 10% to less than 15%, 15% to less than 20%, and 20% or more. The scoring system assigns a higher score for more unique or authentic ideas, with 4 points for the least repetition (less than 5%), and a decreasing score down to 0 for the most common responses (20% or more). We use this table to evaluate the creativity and originality of responses, rewarding those that are more unique and logical.

Test Validation

With the same expert panel that reviewed the training program, the test underwent a validation process. They provided feedback on the relevance of the questions to sustainable thinking skills, the precision of the questions' formulation, and the effectiveness of each question in assessing the corresponding skill. We made modifications to enhance the test based on their feedback, which included correcting linguistic inaccuracies and condensing questions to better suit the survey sample.

Pilot Testing

The test was initially administered to a pilot group consisting of 15 teachers who were not part of the main research sample to evaluate the time needed to complete the test, as well as to ensure the clarity of the instructions and comprehensibility of the language used. The pilot phase revealed that the optimal duration for

administering the test to the main sample was 35 min. Furthermore, the reliability of the test was assessed using Cronbach's alpha, confirming its consistency for further application. Table 2 displays the reliability coefficients for various skills within the Sustainable Thinking Test along with the overall test reliability. Each skill organized thinking (0.84), strategic thinking (0.88), futuristic thinking (0.81), and value-based thinking (0.80) demonstrated high reliability, indicating the test's consistent effectiveness in assessing these dimensions of sustainable thinking. The overall test reliability coefficient was 0.89, signifying excellent consistency, making the test a reliable tool for educational researchers and practitioners. Such robust reliability supports the use of the test in evaluating educational interventions aimed at enhancing sustainable thinking, and aids in the development of educational policies and curricula that prioritize these skills in secondary education. This high level of reliability ensures that the test results are dependable and valid, thus facilitating informed decisions regarding educational strategies and the integration of sustainable thinking into educational settings.

Table 2: *Reliability Coefficients of the Sustainable Thinking Test.*

Skill	Reliability Coefficient
Organized Thinking	0.84
Strategic Thinking	0.88
Futuristic Thinking	0.81
Values-Based Thinking	0.80
Overall Test	0.89

Study Implementation

The research experiment was conducted during the second semester of the academic year 1445H, following a series of structured steps. First, the proposed training program and Sustainable Thinking test were developed through a thorough review of previous studies, resulting in their final, refined versions. To establish a baseline, the research sample initially completed the Sustainable Thinking Test, serving as a pre-test measure. Following this, the training program was implemented, focusing on enhancing sustainable thinking skills through artificial intelligence applications. After the program's completion, the research sample took the Sustainable Thinking Test again to assess any changes in skill levels. Systematic data collection and analysis then provided the foundation for the research findings, upon which recommendations and proposals were formulated.

Statistical Methods

The author employed SPSS28 to conduct several statistical analyses in the study. Cronbach's alpha was used to verify the reliability of the Sustainable Thinking Test, ensuring consistency in the measurement of sustainable thinking skills. Means, standard deviations, and paired samples t-tests were calculated to assess the statistical significance of differences between biology teachers' scores in the pre- and post-tests of the Sustainable Thinking Test. To evaluate the impact of the training program based on artificial intelligence applications (the independent variable) on sustainable thinking (the dependent variable), Cohen's equation was applied to calculate the effect size. This calculation was based on the differences observed between pre- and post-test scores within the same group.

$$Effect\ Size = \frac{\text{Post test Mean} - \text{Pre test Mean}}{\text{Standard Deviation}}$$

Results

The author methodically presented the research findings, addressed the study's specific questions, and tested its hypotheses to fulfil the research objective. This study aimed to assess the effectiveness of a training program based on artificial intelligence applications in developing sustainable thinking skills among high school biology teachers. We analysed and discussed the results in the context of previous research to gain a comprehensive understanding of their impact. This discussion led to the formulation of targeted recommendations and practical suggestions derived from the study's findings aimed at enhancing the integration and effectiveness of AI-based training programs in educational settings. We will address the results are as follows.

Findings Addressing the First Research Question

Response to the First Research Question

The first research question explored the structure and content of a training program based on artificial intelligence applications aimed at developing sustainable thinking skills among high school biology teachers. To address this question, we conducted a thorough review and synthesis of the existing literature on artificial intelligence applications in biology education and sustainable thinking. We structured the refined training program to span six sessions over three days. Each session lasted for four hours, with a 15-minute break. Additionally, the program featured a self-assessment and summary at the conclusion of each day to reinforce learning and gauge participant understanding.

Detailed Description of the Training Program

The training program was carefully designed with specific requirements to foster sustainable thinking among high school biology teachers. The overall objective was to cultivate sustainable thinking skills, enabling teachers to integrate these skills into their practice. To achieve this, the program employed diverse teaching strategies, including lectures, open dialogue and discussions, problem-solving exercises, brainstorming sessions, modelling, and cooperative learning. These approaches aimed to actively engage participants and deepen their understanding. To support program requirements, participants and facilitators were provided with electronic copies of all scientific materials. Access to various internet applications and a computer for each participant were also essential, ensuring full engagement with the digital aspects of the program. The program's educational activities were designed to be interactive, focusing on developing sustainable thinking through practical applications of artificial intelligence, both individually and in groups. These activities included hands-on applications, experimentation, testing, and inquiry, encouraging participants to generate sustainable solutions based on the activities conducted. A comprehensive assessment framework was also established. A pre-assessment was conducted before the program to gauge teachers' initial knowledge and skills, followed by a preliminary assessment to introduce key questions that captured participants' attention and elicited their prior knowledge. Formative assessments were embedded throughout, incorporating AI-based activities to encourage sustainable thinking development. Self-assessment at the end of each session encouraged self-reflection and independent learning. Finally, a post-assessment was conducted upon program completion, using a post-test to evaluate the development of sustainable thinking skills among participants. The academic content of the program is detailed in Table 3 below:

Table 3: *Detailed Description of the Content of the AI-Based Training Program for Developing Sustainable Thinking Among High School Biology Teachers.*

Day	Session	Session Title	Session Content	Session Duration
Day 1	**Session 1**	The Nature of Artificial Intelligence	An introduction to the proposed training program. Definition of artificial intelligence, its objectives, and significance. use of artificial intelligence applications in biology teaching.	2 hours
	Session 2	Nature of Sustainable Thinking	Concept of sustainable thinking, its objectives, and significance. sustainable thinking skills. application of sustainable thinking skills in biology teaching.	2 hours
Day 2	**Session 1**	Artificial Intelligence Applications and Organized Thinking Skills	Practical examples of practicing organized thinking skills in biology teaching. use of artificial intelligence applications in practicing organized thinking skills in biology teaching.	2 hours
	Session 2	Artificial Intelligence Applications and Strategic Thinking Skills are essential	Practical examples of practicing strategic thinking skills in biology teaching. use of artificial intelligence applications in practicing strategic thinking skills in biology teaching.	2 hours
Day 3	**Session 1**	Artificial Intelligence Applications and Future Thinking Skills	Practical examples of practicing future thinking skills in biology teaching. use of artificial intelligence applications in practicing future thinking skills in biology teaching.	2 hours
	Session 2	Applications and Values for Artificial Intelligence Thinking Skills	Practical examples of practicing value-based thinking skills in biology teaching. use of artificial intelligence applications in practicing value-based thinking skills in biology teaching.	2 hours

Response to the Second Research Question and Verifying the Research Hypothesis

The second research question explored the effectiveness of a training program based on artificial intelligence applications for fostering sustainable thinking among high school biology teachers. We performed calculations for the mean scores, standard deviations, and a paired-samples T-test to address this question and test the hypothesis that "There is a statistically significant difference between the pre-test and post-test mean scores of teachers in sustainable thinking." These statistical analyses were used to evaluate how the training program affected the development of sustainable thinking skills.

Table 4: *Pre-Post Scores: Mean, SD, T-Test (n=31).*

Skill	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD	T-value	Significance
Organized Thinking	3.68	0.6	4.55	0.96	9.71	0.001
Strategic Thinking	3.87	0.34	4.94	0.25	23.73	0.001
Future Thinking	3.68	0.54	4.68	0.6	21.56	0.001
Values Thinking	3.81	0.48	4.81	0.6	15.25	0.001
Overall Test	15.03	1.45	18.97	1.47	25.66	0.001

Table 4 demonstrates statistically significant improvements in the mean scores of biology teachers' sustainable thinking from pre-test to post-test, with a significance level of 0.01 for each skill assessed and the test overall showing enhanced performance in the post-test. As a result, the research hypothesis stating, "A statistically significant difference exists between the mean scores of teachers in the pre-test and post-test of sustainable thinking."

Table 5: *AI Training Impact on Sustainable Thinking (n=31).*

Skill	Pre-Test Mean	Post-Test Mean	Standard Deviation	Effect Size
Organized Thinking	3.68	4.55	0.5	1.74
Strategic Thinking	3.87	4.94	0.25	4.28
Future Thinking	3.68	4.68	0.26	3.85
Values Thinking	3.81	4.81	0.37	2.7
Overall Test	15.03	18.97	0.85	4.64

Table 5 shows that all effect size values exceed 0.8, which, according to Cohen (1988), classifies them as large. Cohen's scale categorizes effect sizes as small (0.2-0.49), medium (0.5-0.79), and large (0.8 and above). Therefore, the impact of the artificial intelligence-based training program on enhancing sustainable thinking among high school biology teachers is considered large.

Discussion

The research findings illuminate a profound and statistically significant distinction, with a confidence level of 0.01, in the average scores of biology teachers before and after undergoing Sustainable Thinking Test. Notably, post-application scores showed significant improvement. Moreover, a substantial effect size underscores the efficacy of the AI-based training program in fostering sustainable thinking among high school biology educators. The researcher attributed this positive outcome to several key factors intrinsic to the program. First, the program carefully explained the ins and outs of developing long-term thinking skills and how they could be used in biology classes by skilfully utilizing AI tools. This pedagogical approach entailed immersive guided activities aimed at furnishing teachers with hands-on experience, thereby empowering them to incorporate these skills into their instructional practice. Second, the preparatory phase of the program unveiled a glaring gap in teachers' awareness of sustainable thinking skills and their aptitude to tackle related queries. Through the program's interventions, educators were not only acquainted with these vital skills, but also equipped with the know-how to devise assessment methodologies for gauging student proficiency in these areas, leveraging the capabilities of artificial intelligence tools.

Consequently, teachers have emerged with a newfound competence in effectively addressing inquiries and evaluating students' grasp of biological concepts through a sustainable thinking lens. Third, the integration

of artificial intelligence applications into the curriculum provided educators with forward-thinking solutions to real-world scientific conundrums, thereby nurturing their capacity for strategic problem solving. By immersing teachers in scenarios in which artificial intelligence serves as a catalyst for innovative problem resolution, the program instilled a proactive mindset essential for navigating complex scientific challenges. Moreover, the program delved into pertinent societal issues intertwined with scientific values, including equity and ramifications of detrimental habits such as smoking on both human health and the environment. By utilizing artificial intelligence, educators have gained the necessary tools to analyse and tackle these complex issues in the context of biology education, thereby promoting a comprehensive understanding of the relationship between science and societal well-being. Additionally, activities based on artificial intelligence made it easier to organize and combine scientific data into clear systemic diagrams, which allow teachers to easily link different biological ideas. This integrative approach not only improved comprehension but also honed teachers' proficiency in utilizing technology to structure and convey complex biological data effectively. Finally, the program underscored the importance of strategic planning in tackling multifaceted topics such as nutrition and human health. The program empowered educators to devise comprehensive strategies to address diverse scientific inquiries, thereby augmenting their pedagogical repertoire by harnessing the capabilities of artificial intelligence. In essence, the training program's multifaceted approach and strategic integration of artificial intelligence applications have significantly bolstered the capacity of biology educators to foster sustainable thinking among students, thereby enriching the landscape of science education.

This research aligns with an extensive body of literature that underscores the critical significance of crafting robust training programs that harness the potential of artificial intelligence (AI) applications to empower educators and ultimately enhance their educational outcomes. Ahmed's seminal work in 2022 elucidates the pressing need for tailored AI-based training initiatives aimed at equipping high school chemistry teachers with a diverse array of pedagogical skills. Similarly, Al-Rumi and Al-Qahtani (2022) comprehensive study advocates the augmentation of teachers' competencies in AI utilization to optimize learning outcomes among secondary school students, drawing upon insights gleaned from global educational experiments. Moreover, Al-Shahrani's incisive analysis in 2022 underscores the urgency of fortifying the preparedness of general education teachers within the Kingdom of Saudi Arabia, considering the burgeoning AI trends sweeping through the educational landscape. Further bolstering this discourse, Samili (2023) research presents compelling evidence showing AI's transformative potential in boosting the pedagogical performance of secondary school science educators across Saudi Arabia. Likewise, Al-Shahri (2023) emphasizes the importance of conducting targeted workshops aimed at elucidating the myriad advantages and potential of AI applications in addressing teachers' pedagogical challenges.

Additionally, it advocates rigorous procedural research endeavours aimed at mitigating and overcoming these challenges, thus facilitating effective integration and utilization of AI tools in educational settings. Expanding on this narrative, Anaya (2023) contributed underscores the paramount importance of tailoring teacher preparation programs to align with the evolving demands and opportunities of AI technologies. This research seamlessly integrates with broader scholarly inquiries that elucidate the intricate interplay between sustainable development, cultivation of sustainable thinking skills among educators, and their adeptness in leveraging AI applications. Notably, Shahin's groundbreaking study of 2023 advocates transformative shifts in educational paradigms, emphasizing the pivotal role of AI-driven approaches in fostering sustainability within educational ecosystems. Similarly, Qura and Al-Matse illuminating research in 2023 accentuates AI's indispensable role of AI in empowering educators to effectively navigate the multifaceted challenges and opportunities for sustainable development outlined in the Vision 2030 agenda.

Conclusion

The present study has successfully demonstrated the transformative potential of an AI-based training program for cultivating sustainable thinking skills among high school biology teachers. The findings indicate a statistically significant improvement in teachers' sustainable thinking abilities, as evidenced by higher post-test scores than pre-test scores. The large effect size further underscores the efficacy of the AI-driven training program in enhancing critical skills. The study's results highlight the multifaceted benefits of integrating AI applications into teacher-training initiatives. By equipping educators with the tools and knowledge to effectively harness AI in their pedagogical practices, the program empowered them to develop organized, strategic, future-oriented, and

value-based thinking skills. These competencies are essential for fostering a sustainable mindset and enabling teachers to impart these skills to their students, ultimately contributing to the achievement of development goals. This study's added value lies in its innovative approach to bridging the gap between AI applications and sustainable thinking in biology education. By providing a comprehensive framework for AI integration into teacher training programs, this study offers valuable insights and practical strategies for educational policymakers, administrators, and practitioners seeking to enhance the quality of science education and promote sustainable development. Moreover, the findings of this study can serve as a catalyst for further research and investment in AI-driven educational interventions. These positive outcomes underscore the need for extensive collaboration between educational institutions, AI experts, and sustainability specialists to develop robust frameworks and guidelines for the effective integration of AI in science education. In conclusion, this study marks a significant step in the field of AI-driven teacher training and sustainable thinking development. The results demonstrated the immense potential of AI applications in transforming educational practices and empowering educators to cultivate critical skills for a sustainable future. Moving forward, we must prioritize the widespread adoption of innovative training programs to effectively harness the benefits of AI for education and sustainable development.

Recommendations

Reviewing and refining training programs for high school biology educators has become crucial in light of rapid advancements in scientific knowledge, especially in AI applications within biology education. This progression emphasizes the importance of fostering higher-order thinking skills, such as sustainable thinking, among both educators and students. The research's training program and assessment tools are well-suited to meet this objective, providing biology teachers with essential resources and methods. Integrating topics, activities, and instructional resources centred on artificial intelligence applications in biology is a vital step for high school biology curricula. This approach nurtures students' higher-order cognitive abilities and equips them to devise innovative solutions to biological challenges, thereby supporting broader developmental goals. The carefully crafted training program presented in this research offers significant potential for empowering high school biology teachers with the skills needed to integrate artificial intelligence applications into their teaching practices. By enhancing educators' proficiency with AI tools, the program promotes the development of sustainable thinking among both teachers and their students, fostering a culture of critical and forward-thinking approaches in biology education. Beyond the immediate needs of high school biology instructors, it is essential to broaden training opportunities to encompass educators from various science disciplines and educational levels. Comprehensive training programs focused on integrating AI applications into teaching can enable educators across fields to effectively leverage AI's transformative potential in achieving their pedagogical goals.

Study Implications

The research findings emphasize the transformative potential of integrating artificial intelligence applications into training programs for high school biology teachers, enabling them to develop sustainable thinking skills that they can effectively impart to their students. This study highlights the urgent need for educational policymakers and administrators to prioritize the development and implementation of AI-based training initiatives, ensuring that educators are equipped with the skills necessary to navigate the rapidly evolving educational landscape. The positive outcomes of this study act as a catalyst for further research and investment in AI-driven educational interventions, particularly within science education. Such initiatives are essential for fostering sustainable thinking and contributing to the achievement of sustainable development goals.

Study Limitations

This study was conducted with a sample of biology teachers from secondary schools in the Riyadh educational region, which may limit the generalizability of the findings to other regions or educational levels. Additionally, the research specifically focused on the impact of AI applications on sustainable thinking skills, without examining other potential benefits or challenges related to the integration of AI in education. Furthermore, the study utilized a single pre-post experimental design, which may not have fully captured the long-term effects of the training program on teachers' instructional practices and student outcomes.

Future Directions and Suggestions for Future Research

The current study could be replicated across various branches of science and educational levels to determine the broader applicability of the findings and to identify potential variations in the effectiveness of AI-based training programs. Conducting longitudinal studies would be beneficial to investigate the long-term impacts of AI-driven interventions on teachers' pedagogical practices, student learning outcomes, and the cultivation of sustainable thinking skills. Additionally, exploring the development and evaluation of AI-based strategies specifically tailored to enhance sustainable thinking skills among female students in biology education is important, as this demographic may have unique needs and challenges. Collaborative research initiatives among educational institutions, AI experts, and sustainability specialists should be encouraged to create comprehensive frameworks and guidelines for the effective integration of AI in science education, ensuring alignment with emerging technological trends and sustainable development goals.

Conflict of Interest Statement

The author has not included a dedicated conflict of interest statement in the attached manuscript.

Data Availability Statement

The data support this study are available in the manuscript.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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