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RESEARCH PAPER

AI-Driven STEAM Learning and Sustainability Education: Effects on Students' Digital Literacy and Environmental Awareness

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ABSTRACT

This study investigated the impact of AI-driven STEAM learning and sustainability education on students' digital literacy and environmental awareness. The integration of artificial intelligence into STEAM education has transformed modern learning environments by promoting interactive, technology-oriented, collaborative, and problem-solving instructional approaches aligned with sustainable development goals. AI-supported educational practices enhance students' digital competencies while improving their understanding of environmental challenges and sustainability-related issues. The study adopted a quantitative research design to examine the relationship between AI-integrated STEAM learning, digital literacy, and environmental awareness among students in secondary and higher education institutions. Data were collected from 250 students through structured questionnaires using a stratified random sampling technique. The collected data were analyzed using descriptive statistics, reliability analysis, correlation analysis, and regression analysis through SPSS. The findings revealed that AI-driven STEAM learning significantly improves students' digital literacy, technological competence, and critical thinking skills. Similarly, sustainability education positively influences students' environmental awareness and environmentally responsible attitudes. The study concluded that integrating AI technologies and sustainability-focused instructional practices into STEAM education contributes significantly to the development of 21st-century skills and sustainability consciousness among students.

Key Words: Artificial Intelligence, STEAM Education, Digital Literacy, Environmental Awareness, Sustainability Education, AI-Driven Learning, Sustainable Development Goals

Introduction

The role of Artificial Intelligence (AI) in the education sector is significant, especially for the ability to tailor learning experiences, enhance student engagement, and facilitate innovative teaching methods. Classrooms are increasingly incorporating AI-powered learning tools, including adaptive learning systems, virtual laboratories, and intelligent tutoring systems, to enrich students' learning experiences and digital skills (Habib, 2021; Fatima, Malik, & Safdar, 2011). Educational institutions have highlighted the importance of Science, Technology, Engineering, Arts and Mathematics (STEAM) education in recent years to encourage and foster skills necessary for the 21st century such as creativity, problem solving, collaboration and interdisciplinary learning (Pomeroy, 2011). Meanwhile, sustainability education has been put on the global agenda by the Sustainable Development Goals (SDGs), especially SDG 4 (Quality Education)

and SDG 13 (Climate Action). The goal of sustainability education is for students to acquire sustainable behaviors and ecological literacy through education (Pino-Perdomo & Velásquez-Mosquera, 2021). The research shows that the use of AI in sustainability education enhances ecological intelligence and environmental awareness in students, fostering a deeper understanding of sustainability challenges in the real world (Nurmamatova, 2021). (ACM Digital Library)

Digital literacy is essential, in the digital age, for students to use emerging technologies appropriately and assess information effectively. At the same time, awareness of the environment is an integral part of educating students to meet global sustainability challenges. Previous research shows that AI-enhanced STEAM learning has a positive influence on digital literacy, creativity, and sustainability thinking among learners (Mertala et al., 2020; Fatima et al., 2012). While AI has become a crucial part of STEAM and sustainability education, there is limited empirical evidence on the impact of AI on students' digital literacy and environmental awareness. Previous research primarily addresses the problems of technological adoption and effectiveness of teaching, and there are only a few studies that consider the problem of a combination of the competencies acquired and students' awareness of sustainability in learning with AI (Habib, 2021). Consequently, it is essential to research AI enhanced learning environments to determine how they affect students' digital literacy and environmental awareness.

Literature Review

AI in Education

The introduction of Artificial Intelligence (AI) in the modern world has revolutionized the field of education with the generation of personalized, adaptive and intelligent learning systems. AI in education involves using machine learning, intelligent tutoring systems, AI-driven chatbots, and data analysis to enhance teaching and learning practices (Zawacki-Richter et al., 2019). Recent studies indicate that AI-supported educational tools enhance students' engagement, academic performance, and independent learning abilities (Holmes et al., 2019; Malik, et. al., 2013). AI technologies like automated assessment, predictive analytics, and virtual learning assistants enable teachers to deliver personalized learning and feedback to students in real-time (Chen et al., 2020; Fatima et al., 2012). Additionally, AI-driven teaching methods foster a collaborative learning environment, creativity, and critical thinking, which are vital for the 21st-century.

STEAM Education

STEAM education combines the fields of Science, Technology, Engineering, Arts, and Mathematics to foster interdisciplinary learning in a creative manner. In contrast to traditional subject-based learning, STEAM focuses on problem-solving, collaboration, and creativity by using project-based learning (Perignat & Katz-Buonincontro, 2019; Fatima, Hussain, & Malik, 2014). Madden et al. (2013) state that STEAM learning enhances analytical thinking skills and technological abilities in students, and inspires them to creatively address real-world problems. Recent research also shows that AI-enhanced STEAM settings positively affect student engagement and digital learning when technology-integrated approaches to teaching and learning are incorporated into their learning (Adesina, 2020; Malik, et.al., 2013).

Sustainability Education

Sustainability education is a teaching that aims at raising awareness on environmental, social and economic sustainability in line with United Nations Sustainable Development Goals (SDGs). More and more, education is focusing on sustainability to encourage sustainable citizenship and care for the environment (UNESCO, 2020). Research indicates that SE has a positive impact on students' ecological literacy, environmental responsibility, and sustainable decision-making capabilities (Castellanos & Queiruga-Dios, 2021). In addition, the use of digital technologies and artificial intelligence is being introduced to facilitate environmental education by using simulations, virtual laboratories, and interactive environmental projects.

Digital Literacy

Digital literacy is the ability to access, assess, create and share information effectively with digital technologies (Haleem et al., 2020; Ng et al., 2020). It encompasses technical, cognitive, and social aspects that empower students to engage effectively in digital spaces. AI technologies play a crucial role in digital skill development, offering adaptive learning environments, intelligent tutoring systems, and collaborative online platforms (List, 2019; Haleem et al., 2020; Raza & Ahmed, 2017). AI application in learning environments has been shown to enhance students' technological proficiency, information management skills, and digital communication competencies.AI application in learning environments has been found to enhance technological skills, information management skills, and digital communication skills in students.

Environmental Awareness

Environmental awareness is defined as a person's knowledge about environmental issues and willingness to engage in environmentally responsible behaviors. The consciousness of sustainability among students is becoming an important factor, given that climate change and environmental degradation have become great concerns in the world today (Otto & Pensini, 2017; Fatima, et. Al., 2014). A previous study revealed that educational programs that focus on sustainability had a positive impact on students' attitudes towards the environment, ecological responsibility, and pro-environmental behaviors (Aldawsari et al., 2021; Safder et al., 2012). Educational institutions are thus an essential element in raising environmental awareness through sustainability-based curricula and hands-on activities.

AI-Driven STEAM Learning and Digital Literacy

Several empirical studies have shown that AI-based STEAM learning positively influences students' digital literacy. Adesina (2020) discovered that problem-solving abilities and digital competency of students in AI supported STEAM classrooms were enhanced. In the same way, Mertala et al. (2020) found that the inclusion of AI literacy in STEAM education had a positive impact on students' critical thinking and technological understanding. These results indicate that STEAM learning environments using AI are effective in cultivating students' digital skills and innovative thinking skills.

Sustainability Education and Environmental Awareness

Many studies have demonstrated that there is a positive correlation between learning for sustainability and environmental awareness. Castellanos and Queiruga-Dios (2021) found that sustainability educational programs have a significant impact on enhancing the environmental awareness of students and their sustainable attitudes.

Similarly, Aldawsari et al. (2021) concluded that EE activities foster learning in ecological responsibility and awareness. The results of these studies have shown that sustainable education is a must to produce environmentally responsible citizens.

The educational value of this study lies in its contribution to the understanding of how a learning process, based on the use of AI, can improve digital literacy and environmental awareness of students. In essence, the findings could be applied to create new and sustainable learning spaces using AI tools for educators. The study could also have policy implications for policymakers and educational institutions looking to implement AI into their curriculum and ensure it aligns with sustainability objectives and 21st-century learning requirements (Perignat & Katz-Buonincontro, 2019). Policy implications for policymakers and educational institutions planning to incorporate AI into the curriculum and make it relevant to their sustainability goals and the needs of the 21st-century.

Research Hypotheses

H1 AI-driven STEAM learning significantly influences students' digital literacy.

H2 Sustainability education significantly influences students' environmental awareness.

H3 AI-integrated STEAM education significantly affects students' digital competencies and environmentally responsible attitudes.

Theoretical Framework

This study is based on the Constructivist Learning Theory and the Technology Acceptance Model (TAM). The students construct knowledge with interactive and experiential learning, according to Constructivist Learning Theory which is proposed by Mishra (2020). This theory is also supported by AI-driven STEAM learning which encourages hands-on, collaborative, and problem-based learning experiences. Han and Sa (2021) have proposed a model, called the Technology Acceptance Model (TAM), to explain the factors that influence students' acceptance of the use of technology in educational settings. TAM is relevant because the use of AI technologies by students could impact their digital literacy and learning outcomes.

Conceptual Framework

The conceptual model of this research has independent variables in the form of AI-Driven STEAM Learning and Sustainability Education, and dependent variables in the form of Digital Literacy and Environmental Awareness (Peters et al., 2020). The framework takes a working assumption that providing AI-integrated STEAM learning will be able to strengthen students' digital abilities, and that sustainability education will be able to raise student awareness and responsible actions in relation to the environment. In figure 1 presents the conceptual framework of the study, showing the relationship between AI-Driven STEAM Learning, Sustainability Education, Digital Literacy, and Environmental Awareness.

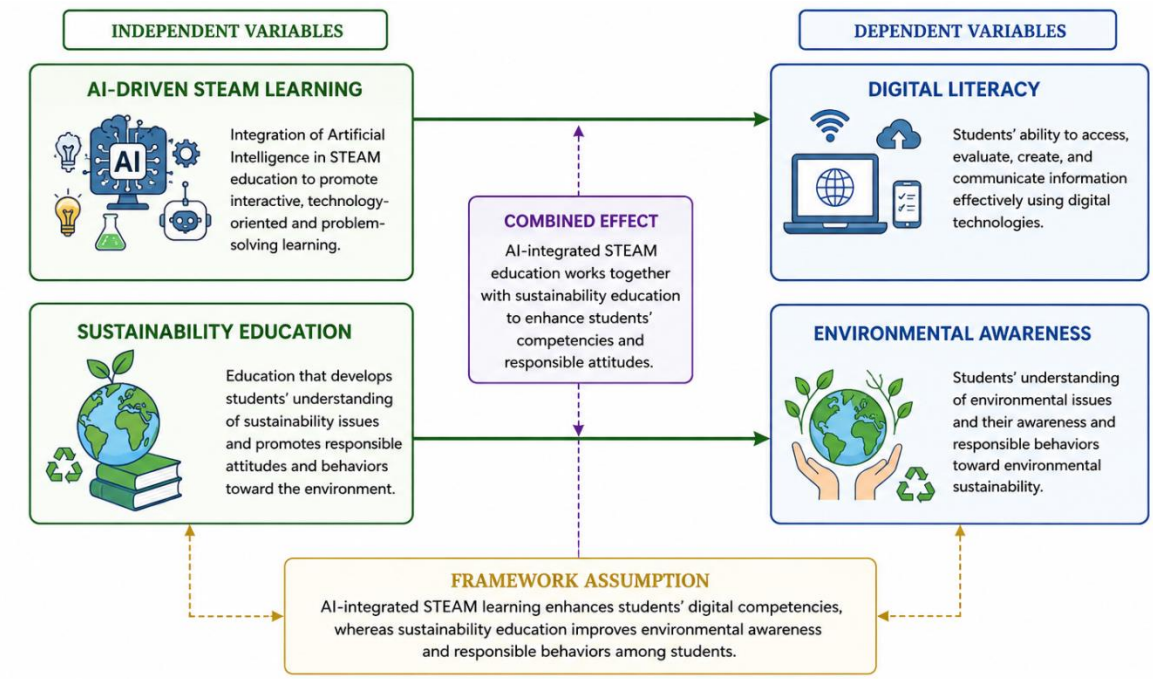

Figure 1. Conceptual Framework Diagram of AI-Driven STEAM Learning and Sustainability Education.

The conceptual framework shows the relationship between the independent variables (AI-Driven STEAM Learning & Sustainability Education) and the dependent variables (Digital Literacy & Environmental Awareness). The framework suggests that the application of AI in STEAM learning will improve student's digital capabilities, and that sustainability education will foster their environmental awareness and environmentally responsible attitudes and behaviors. Moreover, AI-enhanced STEAM education and sustainability-focused learning are expected to have a positive impact on students' technological skills and sustainable development goals (SDGs) consciousness.

Material and Methods

Research Design

The method used in this study is quantitative, which examines the impact of the STEAM learning which is guided by Artificial Intelligence support on students' digital literacy and student awareness of environmental sustainability. The quantitative approach is suitable because it allows the researcher to gather data in the form of numbers and analyze relationships between variables using statistics (Creswell & Creswell, 2017). Students were surveyed about their experiences with STEAM learning and sustainability education practices using a survey method. The surveys are the most commonly applied research methods in education studies because it enables the researcher to obtain standardized responses from a large population in an efficient way (Taherdoost, 2020).

Population and Sample

The respondents in this study were secondary and higher education students. Students were randomly sampled from different levels of education and 250 students were selected as participants using stratified random sampling technique. The chosen participants were involved in various learning and sustainable education efforts using

AI tools. Stratified random sampling was found to be suitable as it allows for more representativeness and less sampling bias (Sharma, 2017).

Instrumentation

Data were gathered using a structured questionnaire, which was designed in accordance with the previous studies related to the AI in education, digital literacy, sustainable education, and environmental awareness. The questionnaire had a 5-point likert scale ranging from "Strongly Disagree" to "Strongly Agree." Likert scales are commonly used in educational research because they effectively measure attitudes, perceptions, and behaviors (Joshi et al., 2015).

Data Collection Procedure

All the necessary permissions were received from the concerned educational institutions before collecting the data. The participants received information regarding the purpose of the study, and questionnaires were handed out and sent electronically. The questionnaire was voluntarily filled out within a set time.

Validity and Reliability

Content validity was assessed by experts which are specialists in educational technology and sustainability education. The instrument was tested for reliability by Cronbach's alpha coefficient with the result of more than 0.70 was considered as good internal consistency (Taber, 2018).

Data Analysis Techniques

All the data collected were then analyzed using the Statistical Package for Social Sciences (SPSS). The data of the respondents were summarized using descriptive statistics of frequency, mean and standard deviation. Correlation analysis was used to check the correlation among the variables, and regression analysis was used to check the impact of AI-based STEAM learning and sustainability education on digital literacy and environmental awareness.

Results and Discussion

Table 1
Gender of Respondents

Gender	Frequency	Percentage
Male	132	52.8
Female	118	47.2
Total	**250**	**100.0**

Table 1 shows the gender distribution of the respondents. Out of 250 participants, 132 (52.8%) were male and 118 (47.2%) were female. The results show an equal number of males and females in the study group.

Table 2
Age of Respondents

Age Group	Frequency	Percentage
15–18 Years	96	38.4
19–22 Years	104	41.6
23 Years and Above	50	20.0
Total	**250**	**100.0**

As shown in Table 2, most of the respondents (41.6%) were in the age group 19-22 years, followed by those aged 15-18 years (38.4%). 20.0% of the participants were 23 years or older.

Table 3
Educational Level of Respondents

Educational Level	Frequency	Percentage
Secondary Level	118	47.2
Higher Education Level	132	52.8
Total	**250**	**100.0**

Table 3 indicates that 47.2 per cent of all the respondents (118) were from secondary level institutions while 52.8 per cent (132) were from higher education institutions.

Table 4
Institution Type of Respondents

Institution Type	Frequency	Percentage
Public Institution	138	55.2
Private Institution	112	44.8
Total	250	100.0

The results show that most of the respondents (55.2%) attended public institutions while 44.8% attended private institutions.

Table 5
Descriptive Statistics of Study Variables

Variables	M	SD
AI-Driven STEAM Learning	4.12	0.61
Sustainability Education	4.05	0.58
Digital Literacy	4.18	0.55
Environmental Awareness	4.09	0.60

Note. M = Mean; SD = Standard Deviation.

Table 5 shows the descriptive statistics of the study variables. AI-Driven STEAM Learning received a mean score of 4.12 (SD = 0.61), which suggests positive perceptions of AI-supported learning environments. Regarding the views on sustainability related educational practices, the mean score obtained by Sustainability Education was 4.05 (SD = 0.58) which is a favorable score.

The mean score for Digital Literacy was 4.18 (SD = 0.55), with high scores signifying a strong technological competence within the students' sample. Environmental Awareness also got a high mean score of 4.09 (SD = 0.60), which indicates positive awareness and responsible attitudes of the respondents with regard to their environment.

Reliability Analysis

Table 6
Reliability Analysis of Study Variables

Variables	Cronbach's Alpha
AI-Driven STEAM Learning	.901
Sustainability Education	.883
Digital Literacy	.914
Environmental Awareness	.892

Note. Cronbach's alpha values above .70 indicate acceptable reliability.

Table 6 presents the reliability analysis results of the study variables. All Cronbach's alpha values were above the recommended minimum value of .70 and ranged from .883 to .914. Thus, the instrument has high internal consistency and reliability.

Correlation Analysis

Table 7
Correlation Analysis Among Study Variables

Variables	1	2	3	4
1. AI-Driven STEAM Learning	–			
2. Sustainability Education	.648**	–		
3. Digital Literacy	.721**	.603**	–	
4. Environmental Awareness	.582**	.744**	.661**	–

Note. **p** < .01.

All the study variables as shown in Table 7, were significantly positively correlated. The correlation between AI-Driven STEAM Learning and Digital Literacy was positive and statistically significant ($r = .721$, $p < .01$), indicating that the use of AI in learning enhancements students' digital skills. Likewise, Sustainability Education had a strong positive correlation with Environmental Awareness ($r = .744$, $p < .01$), showing that introducing practice in sustainability education into the classroom increases students' awareness and responsible actions towards the environment.

Table 8
Regression Analysis for the Impact of AI-Driven STEAM Learning on Digital Literacy
Coefficients Table

Variables	B	β	t	p
Constant	1.214	–	5.842	< .001
AI-Driven STEAM Learning	0.721	.684	14.961	< .001

Model Summary

R	R^2	Adjusted R^2	F	p
.721	.520	.518	223.832	< .001

Note. Dependent Variable = Digital Literacy.

Based on the regression analysis results, it was found that there was a significant prediction for students' Digital Literacy by AI-Driven STEAM Learning with a coefficient of $\beta = .684$ and $p < .001$. The model explained 52.0% of the variance in Digital Literacy ($R^2 = .520$). Hence, the acceptance of Hypothesis 1.

Table 9
Regression Analysis for the Impact of Sustainability Education on Environmental Awareness
Coefficients Table

Variables	B	β	t	p
Constant	1.087	–	5.114	< .001
Sustainability Education	0.744	.711	16.242	< .001

Model Summary

R	R^2	Adjusted R^2	F	p
.744	.553	.551	263.801	< .001

Note. Dependent Variable = Environmental Awareness.

As illustrated in Table 9, Sustainability Education has a significant impact on Environmental Awareness ($\beta = .711$, $p < .001$). The model accounted for 55.3% of the variance in the scores for Environmental Awareness ($R^2 = .553$). Thus, Hypothesis 2 was accepted.

Table 10

Multiple Regression Analysis for the Combined Effect of AI-Integrated STEAM Education and Sustainability Education

Coefficients Table

Variables	B	β	t	p
Constant	0.964	—	4.531	< .001
AI-Driven STEAM Learning	0.512	.482	9.624	< .001
Sustainability Education	0.438	.401	8.117	< .001

Model Summary

R	R^2	Adjusted R^2	F	p
.793	.629	.626	209.416	< .001

Note. Dependent Variables = Digital Competencies and Environmentally Responsible Attitudes.

The results in Table 4.10 indicate that AI-Driven STEAM Learning and Sustainability Education jointly and significantly influence students' digital competencies and environmentally responsible attitudes. AI-Driven STEAM Learning and Sustainability Education were significant contributors with positive results ($\beta = .482$, $p < .001$ and $\beta = .401$, $p < .001$, respectively).

The overall regression model explained 62.9% of the variance in the dependent variables ($R^2 = .629$). Thus, we accepted Hypothesis 3.

Findings

Based on the results of the study, it was found that AI-based STEAM learning positively affects students' digital literacy and technological skills. The students who were part of the AI-supported learning environments had enhanced digital skills, problem-solving capabilities, and understanding of technology. It was also revealed that students' environmentally responsible attitudes and their environmental awareness were significantly improved by the study, sustainability education. Educational practices for sustainable practices were found to enhance the ecological literacy and sustainable behavioral intentions of students.

Furthermore, the effect of AI integrated STEAM learning and sustainability education were found to be significant in students' digital skills and environmental responsibility. In summary, the results of this study align with the notion of implementing AI technologies and teaching models centered on sustainability goals in educational organizations in order to foster the development of 21st-century skills and promote awareness of sustainable development.

Discussion

Based on the results of this study, it is found that digital STEAM learning through artificial intelligence has a positive effect on students' digital competence and environmental awareness. The regression analysis showed that AI-enhanced STEAM education positively impacts students' digital competence, technological understanding, and problem-solving skills. The results align with the previous studies

that found AI-driven learning places increased engagement, critical thinking, and digital learning experiences for students (Holmes et al., 2019; Adesina, 2020; Ali et al., 2020). Likewise, it was discovered that the education of sustainability significantly enhances students' awareness of the environment and attitudinal attitudes towards the environment. The results are in line with other studies that have shown that sustainable education practices promote positive changes in learners' ecological literacy and sustainable behaviors (Castellanos & Queiruga-Dios, 2021; Aldawsari et al., 2021; Ahmad, Thomas & Hamid, 2020).

The findings are also congruent with the theoretical framework of the study. Constructivist Learning Theory focuses on the active participation of students, collaboration and experiential learning activities (Mishra, 2020). AI based learning environments for STEAM learning offer opportunities for problem based learning and interactive learning, which allows students to construct their knowledge. Moreover, the Technology Acceptance Model (TAM) suggests that students will be more inclined to use educational technologies because they judge them as useful and easy to use (Han & Sa, 2021). The positive effects of AI-based learning on digital literacy align with the technology acceptance and learning outcome assumptions of TAM.

AI-Driven STEAM Learning and Digital Literacy

The study showed that by using AI in STEAM learning, students' digital skills are improved a lot. The use of AI tools like smart tutoring, intelligent learning platforms, and virtual simulations enables students to acquire technological skills, creativity, and critical thinking. Students who had access to learning environments that included AI had improved digital communication skills, information management, and technological problem solving (Adesina, 2020). The results align with those of Mertala et al. (2020) who found that integrating AI into STEAM education enhances students' technological knowledge and innovative thinking skills. Hence, the use of AI in education is gaining significance in equipping students in the 21st century with the required skills.

Sustainability Education and Environmental Awareness

The results also showed that the way of teaching sustainability has a positive effect on students' environmental attitudes and actions. Sustainability Education facilitates students' awareness and promotes them to respond to environmental issues in a sustainable way. Climate change, protection of the environment and sustainable development were themes of educational activities, which increased the ecological awareness and sustainability consciousness of students. The findings are in line with the UNESCO (2020) which highlighted that the role of sustainability education in the creation of responsible global citizens to tackle environmental issues is critical.

Educational Implications

This study's results have implications for teachers and curriculum planners. AI technologies should be incorporated into STEAM education in educational institutions to further improve digital literacy, creativity, and problem solving capability of students. Teachers should make use of pedagogical strategies that involve students in interactive and technology-based learning, and promote collaborative and experiential learning. Additionally, curriculum planners should design and integrate sustainable education teaching materials into the curriculum, so as to cultivate students' environmental awareness and sustainable thinking.

Policy Implications

The research recommends that policy-makers create education policies that will facilitate the integration of AI technologies and sustainability education into curricula. Technological resources, digital infrastructure, and teacher training programs should be provided in educational institutions to effectively incorporate AI into learning environments. In addition, policy makers should harmonize education reform with SDGs, specifically SDG 4 (Quality Education) and SDG 13 (Climate Action) to prepare a future generation that is competent in using digital technology and responsible to our environment.

Conclusion

This study examined the effects of AI-driven STEAM learning and sustainability education on students' digital literacy and environmental awareness. The results showed that the use of AI to enhance STEAM learning has a positive impact when it comes to students' digital skills, technological knowledge, and problem-solving skills. Likewise, SE has a positive impact on students' eco-consciousness and environmentally responsible attitudes. Both correlation and regression analysis confirmed the significant contribution of AI-supported learning environments and sustainability-oriented learning processes to academic and social development of students.

The study also highlighted the potential of AI-based tools and applications to improve interactive and student-centred learning, fostering creativity, collaboration, and critical thinking. Meanwhile, sustainability education supports ecological literacy of students and fosters responsible environmental action. AI education and sustainable teaching go hand in hand and help enhance 21st century skills in relation to Sustainable Development Goals (SDGs), with SDG 4 (Quality Education) and SDG 13 (Climate Action) standing out as the two primary goals.

Overall, this study makes a significant impact on the body of research by offering empirical data on the link among AI-supported STEAM learning, digital skills, and environmental consciousness. The study also emphasizes the need for incorporating technological innovation and sustainability education into the contemporary education systems and equipping the students with future academic, technological and environmental challenges.

Recommendations

Based on the findings, it is recommended that educational institutions integrate AI technologies into STEAM curricula to improve students' digital competencies and innovative thinking skills. Sustainability education and project-based learning, as well as activities and experiences in sustainability, should be integrated into school and classroom curricula and introduced as a strategy to foster sustainability concepts among students and other Academy members at the school and university level.

Moreover, teacher professional development programs need to be carefully designed to improve teachers' understanding and competencies in AI technologies, digital pedagogy and sustainability education. Educators can enhance the use of AI in teaching and teaching and learning by participating in training.

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