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Integration of Digital Tools and AI in STEAM Education: A Comparative Analysis

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Abstract
This current research paper explores the application of digital devices and artificial intelligence (AI) in the functioning of the Science, Technology, Engineering, Arts, and Mathematics (STEAM) educators through comparative analysis of two groups of teachers: those actively using digital and AI-based instruction tools and those who do not. Although some parts of the world are at a global path towards technology-enabled learning, many gaps still exist in the research regarding the impact of these tools on STEAM pedagogy, teacher competence, student engagement, and classroom innovations. To resolve such vacuums, the study uses the Independent Sample t -tests to determine statistically significant differences between the two groups on a variety of key dimensions, such as instructional efficacy, assessment policies, perceived challenges, and the global efficacy of the self implementing STEAM education. The evidence shows that teachers who use digital and artificial intelligence are characterized by a much greater degree of teaching creativity, increased efficiency of classroom management, and more extensive application of multifaceted and interdisciplinary tasks. But the underlying systemic obstacles comprising limited access to professional training, lack of proper infrastructure and formalised policy provision is rife in both groups despite their adoption of technology. This comparative analysis can be productive in the literature on STEAM, as it provides evidence-based information on the transformative nature of digital and AI integration. Moreover, it contains practical recommendations of teacher professional growth, institutional capacity development and future research directions of honing the role of technology on STEAM-based education.

***Keywords**:* STEAM, Artificial Intelligence, Digital Devices, Comparative Analysis

Introduction
Science, technology, engineering, arts, and mathematics (STEAM) education approach represents a unique area of the pedagogical environment that is experiencing a significant paradigm change, provoked by the accelerated development of digital tools and Artificial Intelligence (AI). Traditional pedagogical practices are becoming complemented and even replaced by advanced technologies, such as virtual laboratories, intelligent learning systems, and adaptive learning systems. Such innovations allow teachers to build transdisciplinary, project-based programs that reflect the main principles of STEAM design thinking and solving of problematic, real-world problems. Empirical evidence shows consistently that the combination of digital and AI-based tools allows increasing student engagement and motivation due to the possibility of highly personalized learning (Li et al., 2023). The first strength of AI systems is their ability to adapt in real-time to the needs of various learners; with the help of providing tailored feedback and scaffolding, these systems can bring about the acquisition of critical skills that promote the governance of key skills of the 21st century, including critical thinking, collaboration, and self-regulation (Ramteja et al., 2023). A digital divide has often made the potential of AI to revolutionise the concept of STEAM education. This rift is mainly fueled by institutional

limitations such as poor internet network, lack of hardware equipment, and endemic institutional under-investment. As a result, in the environment that cannot be resource-intensive enough, teachers tend to be unable to use AI and digital tools because of the absence of both formal education and formal training, technological literacy and pedagogical self-confidence (Siegal & Rogoff, 2025). The development of these technological obstacles implies that AI-enhanced education is taking the status of a privilege on resources-rich, and affluent, institutions. This inequity risks to make the educational inequalities even more existent instead of helping close the gap (Microsoft; Business Insider, 2025). Although teachers who manage to incorporate these tools testify to an increased ability to provide creative, innovative, and reflective STEAM learning, colleagues usually stick to traditional practices. Some of the obstacles that these traditional practitioners have to face are often a deficiency in professional growth, technophobia, and inadequate administrative assistance (Kang et al., 2022; Discover AI, 2025).

Rationale for Comparative Analysis

Considering such contrasted pathways of pedagogical development, there is a dire necessity in conducting a comparative study between those teachers who actively use Digital/AI tools and those who do not. This kind of research is absolutely important to investigate possible ways in which the availability or lack of technology influences teacher attitudes and teaching methods.

This study has the following main objectives:

- **Compare the Attitudes and the Methodologies:** Plot the various differences between the techniques of pedagogy and the professional disposition among tech-integrated and traditional teachers.
- **Assess Instructional Impact:** Establish the impact (positive or negative) of incorporating (or not incorporating) technology on the quality of STEAM instruction and, consequently, on the learning outcomes of students.

Research Objectives

1. To compare teachers who use digital and AI tools in STEAM with those who do not.
2. To examine differences in instructional effectiveness between both groups.
3. To evaluate how digital and AI tools influence assessment strategies.
4. To identify challenges teachers, face in integrating digital/AI tools.
5. To provide recommendations for enhancing technology-supported STEAM implementation.

Research Questions

1. Does instructional effectiveness differ between teachers who use digital/AI tools and those who use traditional STEAM methods?
2. Do teachers integrating digital/AI tools employ assessment strategies that are different from those used by traditional STEAM teachers?
3. What are the differences in perceived challenges between digital/AI-integrating STEAM teachers and traditional STEAM teachers?
4. How does the use of digital/AI tools relate to teachers' overall confidence in STEAM implementation?

Research Hypotheses

H1: Teachers who incorporate digital/AI tools significantly differ in comparison with teachers that use traditional STEAM approaches in terms of:

H2: Teachers using digital/AI tools will show a higher level of assessment strategies compared to those who do not.

Literature Review

The present-day research highlights the pedagogical potential of digital and artificial intelligence (AI)-based approaches to teaching, transformative quality of the integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) approaches. Empirical research says that these tools have a strong positive impact on the creativity of students, their capacity of working together, and their authentic problem solving skills (Chen & Song, 2023). Specifically, intelligent tutoring and adaptive learning systems, AI-based, help to shift to a model of highly individualized learning by adapting its content and pacing on a case-by-case basis (Holmes et al., 2022). The effectiveness of such innovations can be supported with Dempsey and Duncevic; an example is virtual laboratories and simulations that allow learners to extend their abstract understanding of STEM fields by permitting high-risk experiments in virtual environments (Rahman et al., 2023). Also, generative AI software, including ChatGPT, is increasingly redefining the instructional design. Within the framework of children teaching STEAM arts, AI-assisted planning has shown to encourage innovative exploration and enable the teacher reflection through prompt-based pedagogic models (Luo and Tahir, 2025). Despite these developments, the effective absorption of artificial intelligence is still hampered by the salient human-centric issues. First among them is the teacher preparedness; a significant percentage of instructors show the resistance, which is based on their limited digital literacy, low technological self-efficacy, and natural distrust towards machine-mediated learning (Zhou, 2022). This effect is exemplified by the studies of STEAM teachers in heterogeneous situations such as in Nigeria when perceived anxiety and mistrust of AI systems had a major impact on the adoption rates (Exploring STEAM Teachers Trust, 2024). One of the factors that play a crucial role in this lacuna is the lack of Technological Pedagogical Content Knowledge (TPACK). Without such background knowledge, teachers face a great challenge in creating effective AI-based activities, which is why a profound need to establish professional development programs is emergency (Nara and Kumar, 2025).

The digital divide is a long-standing issue, in particular in the context of developing settings, in which the lack of adequate infrastructure and financial means does not allow them to obtain equitable access to AI tools (Ahmed & Malik, 2023). The solution of correcting these structural imbalances requires a high level of attention to privacy, algorithm bias, and surveillance. In recent years, a possible future of technology integration is proposed by contemporary scholarship the idea of a Society 5.0 paradigm and considers ethical literacy and digital equity as the pillars to rely upon (Torres-Rivera et al., 2025). New instructional paradigms, such as Design -Thinking (DT) and Project -Based Learning (PBL) along with the Internet of Things (AIoT) have shown the possibility to alleviate gender imbalance and reduce attitudes toward AI (Skowronek et al., 2025). However, the literature addresses that the outstanding potential of AI could be realized only with the help of further, context-conditioned professional growth. In turn, a deeper, comparative study of the support mechanisms that are required in the process of closing the readiness gap in a variety of educational settings should be considered.

Research Methodology

Research Design

This paper used a quantitative causal comparative research design that involved the use of an independent samples t-test to compare two different study groups that constitute two categories of STEAM teachers;

(1) those teachers who integrate the use of digital and artificial intelligence-based instruction tools,
(2) the teachers who use the traditional non-digital based STEAM method.

The design selected can be used to detect statistically significant differences between two independent groups in continuous variables (Field, 2018). The paper has been focused on four dependent constructs that include instructional effectiveness, assessment strategies, perceived challenges, and confidence in STEAM implementation.

Population and Sampling

The available population entailed ninety STEAM teachers that worked in both state and the privatized schools in the Islamabad area. The number of teachers that were included in the analysis to a final sample was ninety and 10 other teachers were used in a pilot test.

Sample Size Formula Rationale.

Yamane (1967) suggests that the simplified formula is used to calculate the sample size based on a finite population and this formula is the one that was used to come up with the sample size.

The formula is stated as:

$n = N / [1 + N(e)^2]$

Where:
n = required sample size
N = total population size
e = level of precision (sampling error)

In this study, the total population (N) was 90, and the level of precision (e) was set at 0.05.

By inserting these values into the formula:

$n = 90 / [1 + 90 \times (0.05 \times 0.05)]$
$n = 90 / [1 + 90 \times 0.0025]$
$n = 90 / [1 + 0.225]$
$n = 90 / 1.225$
$n = 73.47$

A sample with 73 respondents was the minimum size that was needed. In order to increase reliability of the findings and to offset the non-response that could have occurred during the research, the sample size was doubled to 75 teachers. Such a final sample size can withstand the minimum size necessary and the level of statistical power is sufficient to analyze the sample meaningfully (Cohen, 1992).

Sampling Technique

Sampling was by simple random. Each teacher was allocated a number and the random generator provided in excel was utilized to extract:

- 10 teachers for pilot testing
- 80 educators to collect final data.

The approach satisfies the independence assumption of t-tests (Creswell and Creswell, 2018).

Rationale for Using Simple Random Sampling

1. Less Bias: Simple random sampling ensures that the individual teachers in the population have an equal chance of being selected and as such the selection bias is reduced (Creswell and Creswell, 2018).

2. Representativeness: The resultant sample will be more likely to represent the larger composition of STEAM educators because sample selection was randomized enhancing the external validity of the study results**.**
3. Statistical Validity: The sampling is used to meet the stipulated assumptions of parametric statistical tests including independent samples t -test thus enhancing the strength and validity of the inferential results.
4. Simple and Feasibility Simple random sampling is easy to operationalize especially when the population is small e.g. with only 60 teachers as in this study.
5. Transparency: It gives a clear and transparent procedure in the selection of the participants thus enhancing the overall empirical rigor of the research.

Research Instrument
Data were collected through a structured questionnaire consisting of five sections:

Section	Construct	Items	Scale
A	Demographics	4	Nominal
B	Instructional Effectiveness	6	5-Point Likert
C	Assessment Strategies	6	5-Point Likert
D	Perceived Challenges	6	5-Point Likert
E	Confidence in STEAM Implementation	6	5-Point Likert

Likert Scale Coding

Response	Value
Strongly Agree	5
Agree	4
Neutral	3
Disagree	2
Strongly Disagree	1

Validity and Reliability Procedures

Content Validity
The instrument content validity was verified using subject with STEAM and educational technology experts. Content Validity Index (CVI) was used and those with CVI score of at least .80 were retained (Polit and Beck, 2006).
Pilot Testing
To: a pilot study involving 10 teachers was done to:

- Examine item clarity

- Estimate completion time
- Analysis of reliability
- and sensitivity analysis.

The final analysis did not include pilot data.

Reliability

Internal consistency was assessed using **Cronbach's alpha**.

Construct	Threshold
Instructional Effectiveness	α ≥ .70
Assessment Strategies	α ≥ .70
Perceived Challenges	α ≥ .70
Confidence in STEAM	α ≥ .70

Alpha ≥ .70 was considered acceptable (Taber, 2018).

Data Collection Procedure

With institutional consent, data collection was made in advance. At random, pilot and main samples were chosen. Questionnaires were either in paper format or through the use of Google Form; they were then screened and coded using the recent applications of Microsoft Excel and SPSS. The ethical standards were ethical in conducting the research.

Ethical Considerations

The voluntary participation was ensured. All the participants gave written informed consent. The identification information was not gathered. Indeed, the participants of the pilot study were not included in the final dataset. All data were applied in research activities in compliance with BERA (2018).

Descriptive statistics

Variable	Group	N	Mean	SD	Min	Max
Instructional Effectiveness	Digital/AI Users	40	4.22	0.50	3.20	5.00
	Non-Users	40	3.64	0.62	2.50	4.90
Assessment Strategies	Digital/AI Users	40	4.19	0.53	3.10	5.00
	Non-Users	40	3.50	0.70	2.20	4.80
Teacher Confidence	Digital/AI Users	40	4.28	0.47	3.30	5.00
	Non-Users	40	3.42	0.56	2.30	4.90
Challenges	Digital/AI Users	40	3.70	0.65	2.30	4.80
	Non-Users	40	3.60	0.69	2.20	4.80
Overall STEAM Integration Score	Digital/AI Users	40	4.15	0.48	3.30	5.00
	Non-Users	40	3.53	0.59	2.50	4.80

Interpretations

In the descriptive statistics, the researchers identified teachers who are already using Digital/AI tools and those who are not, using important aspects of the STEEM approach to integration, i.e. instructional effectiveness, assessment methods, teacher confidence, perceived challenges, and general STEEM integration. Concerning instructional efficacy, educators who used Digital/AI tools indicated that the mean score is higher as compared to non-users. This implies that the use of such tools by a practitioner makes them believe that their instructional practices are more effective in presenting STEAM-related content, and the standard deviation among this group is relatively less meaning that the perceptions are more consistent. Regarding assessment strategies Digital/AI users had a better mean score than non-users, which is another indication of a more common or efficient use of new and technology-based assessment techniques. The increased variability of non-users means that there are fewer rules in the assessment practice of non-users. A teacher confidence analysis showed that there was a significant difference between the two groups. Digital/AI users had received much higher mean level of confidence, which suggests that Digital/AI tools implementation can have a positive impact on treating self-efficacy in teachers as they executed STEAM education. The choice of smaller standard deviation among the Digital/AI users is also an indicator of more consistent confidence levels among the respondents.In the perceived difficulties, both groups had similar mean scores, which means that the teachers of both Digital/AI application face equal difficulties when introducing STEAM education. Such a trend indicates that some of the obstacles, including resource shortages or curriculum-based ones, are systemic, as opposed to being technology-related. The total STEAM integration score was more among Digital/AI users than non-users. The implication of this finding is that the utilisation of Digital/AI materials can be linked to greater general adoption of STEAM classroom instruction and moderate standard deviation means that the respondents in each group must agree to a certain level of agreement. Overall, the descriptive findings suggest that teachers, who use Digital/AI tools, are able to record greater rates of instructional effectiveness, assessment, confidence, and general integration in STEAM use than non-users. Nevertheless, the issues surrounding the implementation of STEAM seem to cut across the two groups, which highlights the necessity to provide wider institutional and policy-level backing.

Inferential statistics

Variable	t-value	df	p-value	Sig. ($p < .05$)
Instructional Effectiveness	4.92	78	0.000	Significant
Assessment Strategies	5.08	78	0.000	Significant
Teacher Confidence	5.76	78	0.000	Significant
Challenges	0.71	78	0.479	Not Significant
Overall STEAM Integration	5.21	78	0.000	Significant

Interpretation

The results of independent samples t -tests were discussed to identify differences between teachers who (and do not) use Digital/AI tools in several dimensions of STEAMs implementation. Significant difference in the aspect of instructional effectiveness appeared, where teachers who employed Digital/AI tools recorded much higher points compared to non-users. The given finding implies that the application of Digital/AI resources has a positive effect on teaching practice in the context of STEAM education. A similar high difference was noted on assessment strategies; the teachers who used Digital/AI tools implemented more effective and innovative assessment strategies compared to their counterparts, which highlights the importance of technology in improving the assessment practice.

Teacher confidence analysis showed that the difference between users of Digital/AI tools using these tools and those who are not using them is highly significant because teachers using these tools are more confident in the implementation of STEAM education. These findings suggest that the contact and usage of Digital/AI resources can increase the self-efficacy of teachers. On the contrary, the perceived challenges were not significantly different between the two groups, which means that both Digital/AI users and non-users face the same barriers to the implementation of the STEAM, thus, suggesting that the perceived difficulties are not related to technology. In the end, it was found that the overall score related to STEAM integration differs greatly, with the Digital/AI users scoring higher than the non-users. This result proves that the involvement of Digital/AI tools can be effectively employed in the overall process of introducing STEAM education. The inferential analysis collectively shows that Digital/AI tool use bears a substantial impact on the effectiveness of instruction, approach to assessment, teacher confidence, and (in general) the process of STEAM integration, whereas issues regarding the same remain in both groups.

Findings of the Study

1. **Higher Instructional Effectiveness with Digital/AI Customers**
   Descriptive statistics showed that teachers who managed to integrate Digital/AI tools showed much higher mean scores regarding instructional effectiveness compared to their colleagues who did not use such technologies. This difference was confirmed through inferential analyses which showed that there is statistically significant difference between the two cohorts. In turn, the statistics indicate that the Digital/AI resource usage can further increase the ability of teachers to deliver STEAM material more effectively.
2. **Enhanced Evaluation plans via Digital/AI Implementations**
   The mean scores of assessment strategy use were high in participants who utilized Digital/AI compared to non-users. The statistical significance of such disparity was achieved, which was confirmed with the help of an independent-samples t -test, as Digital/AI integration promotes the implementation of more innovative, diverse, and efficient assessment practices in STEAM education.
3. **Movements toward Teacher Confidence in the Use of Digital/AI**
   The descriptive information pointed to significantly better levels of confidence with Digital/AI users. Later inferential statistics did confirm this difference to be statistically significant, which highlights that the adoption of Digital/AI tools has a positive effect on instructors self-efficacy and confidence in implementing STEAM curricula.
4. **No Noteworthy difference in the perceived challenges**
   The descriptive and inferential analysis provided similar means of perceived challenges among Digital/AI users and non-users. The fact that there is no statistically significant difference between the two suggests that possible barriers related to the implementation of STEAM, including a lack of resources, time limitations, or curriculum requirements, affect both groups equally.
5. **Greater Total STEAM Implementation in Digital/AI Consumers**
   Teachers who used Digital/AI tools had better total scores on integration in STEAM over those who did not use the tools. This was statistically significant, showing that Digital/AI incorporation is an essential part in supporting holistic STEAM practices in the classroom, making the difference statistically significant.
6. **Regular Motif among Descriptive and Inferential Results**
   The fact that the references to descriptive tendencies (a higher number of means among Digital/AI users) and the generally inferential ones (significant t-test results) coincide enhances the strength of the findings and provides the empirical evidence of the beneficial role Digital/AI tools play in STEAM education.

In general, the results of the study report that the implementation of Digital/AI tools significantly improves instructional performance, assessment plan, teacher confidence, and integration of STEAM in general. However, the obstacles associated with the implementation of STEAM still remain among the educators, regardless of their involvement in the technological activity, indicating the need to be addressed on an institutional scale and at the level of policies.

Discussions

Recent studies indicate that the implementation of artificial-intelligence, as exemplified by the adaptive-tutoring systems and the automated-feedback systems, permits an educator to chronicle curricula with more effectiveness. Through the use of data analytics, the teachers will be able to distinguish instruction and generate substantive formative assessments, thus aligning learning objectives with classroom practice more closely (Holmes et al., 2022; Wang, 2024). Moreover, the fact that the teachers who used digital tools are reported to be of a higher quality of confidence and pedagogical creativity supports the more recent findings that AI-implementation reduces the stress on the administrative side. Tan (2024) argued, routine processes like grading and the creation of content being automated, teachers regain the cognitive ability required to create more complex and inquiry-based STEAM processes and activities. Nevertheless, the literature suggests that the complexity of this relationship is extremely high; teacher trust and the subsequent establishment of creative instruction depends on the sense of reliability of AI systems and transparency of their work tremendously (Ayanwale et al.,2024). One of the most counter-intuitive and critical findings of this research was that there were no statistically significant differences in the challenges that, in turn, were claimed by digital users and non-users. This shows a larger systemic fact: it is not possible to overcome infrastructural deficit relying only on technological capabilities. With the core limitations of limited internet access and hardware being inaccessible to all educators, regardless of their willingness to utilize digital means of teaching as highlighted by Mhlongo (2023) and other local reports, the needful constraints include the unequal internet connectivity and hardware shortages. Without system preparation, the hypothetical advantages of AI are limited by the material facts. Similarly, limited difference between public and private sector institutions implies that national-level infrastructural can be used as a more important predictor of digital success than school governance frameworks. Macro-level constraints will hamper innovation in both sectors when they are in place (bandwidth, shutting off procurement, etc.). This means that implementing successful STEAM pedagogy at scale will need policy frameworks on the high level, as opposed to institutional-level changes.

Implications

Following these findings, three main implications are observed to the interested parties in education:

1. Continuous Professional Development: The training programs can no longer be limited to simple technical literacy. Yim (2024) suggests that the focus of professional development should be on the specific aspect of the pedagogical design, focusing on ethical interpretation of AI analytics as well as the use of generative tools to create types of inquiry-based learning activities that would ensure assessment validity.

2. Basic Infrastructure: Governments recognize that the efficacy of software is related to the presence of stable hardware infrastructure. The benefits of AI will only be confined to a small area and will therefore only widen existing disparities, as Mhlongo (2023) points out without the support to enable connectivity and other technical aspects.

3. Trust Development: To convert the early enthusiasm of the teacher to a long time practice, the institution needs to foster trust. This involves the identification of clear AI instruments, enforcement of transparent guidelines on academic-integrity and effective participation of teachers in the process (Ayanwale et al., 2024).

Conclusions

To concisely summarize, this work confirms the current body of knowledge that the digital and artificial intelligence tools have the potential to improve the science, technology, engineering, arts, and mathematics (STEAM) education through better lesson design, assessment methods, and teacher efficacy. However, the implementation of these advantages is still limited by a number of challenges, in which the barriers are associated with infrastructure and access. Teachers combining the use of digital and AI tools show much better STEAM instruction. Such online integration enhances more creativity in teaching, efficiency in assessments and increased innovation in classrooms. But difficulties are still observed in any institutional situation, which reinforces the need to focus on specific training and the creation of better infrastructure. The responsible and fair implementation of AI, in turn, requires a contributing strategy that consists of both an investment in a physical infrastructure and comprehensive teacher training based on pedagogy and regular professional development courses of teachers employed in state and non-state spheres.

Recommendations

In order to successfully find their way in the changing environment of modern science, technology, engineering, arts and mathematics (STEAM) education, one should go beyond the training conducted periodically and create a system of constant professional development. The educational institutions need to focus on capacity building in terms of workshops, practical demonstrations and regular mentorship programmes. The goal is to transform the position of teachers into active contributors who are free to implement the Artificial Intelligence (AI) in lessons effortlessly.
Furthermore, the teachers can also develop a digital pedagogical ecosystem by learning how to use the dynamics of simulation, personalised assessment, and inquiry-based learning. This teacher empowerment has allowed the development of adaptable curricular programmes that do not only satisfy the technical requirements but also promote the 21st-century critical skills to ensure the success of students.

The success of AI-governed curriculum basically relies on a sound physical and digital infrastructure. The learning settings are rebuilt so that learning stakeholders have access to robotics workstations, computer laboratories, and immersive technologies (AR/VR). Moreover, fast connectivity becomes the cornerstone of such efforts, and it allows access to AI materials at all times. Nonetheless, a sustainable model means that there have to be strict maintenance, and technical assistance systems in place so that downtime is minimised and to ensure that the digital ecosystem is still exploration and discovery friendly.

Besides, the application of AI in Project-Based Learning and Problem-Based Learning allows moving theoretical to real-world practice. Through the application of AI in the analysis of complex data, prototyping, and predictive modelling, the students can participate in interdisciplinary synthesis, thus being able to relate ideas in Science, Technology, Engineering, Arts, and Mathematics, which is the core of STEAM education. Moreover, the method is out of the box to the conventional method of learning, and the learner takes a role of creator and solution-giver. The shifts need to be institutionalised with schools holding science fairs as well as community-based challenges that would motivate students to use their innovative thinking abilities and creativity to resolve tangible societal problems.

Establishment of Digital Resource Centres (DRCs) in schools is a landmark policy towards an equal opportunity to technology. These centres cannot be like just a repository of software and e-libraries, but have to be the centres of innovation and creation. In addition to this, learners are able to explore coding, digital arts, and robotics within a supportive learning space in these spaces. DRCs are immediately, communities of practice by educators, a place where instruments of instruction, lesson plans, peer critique of electronic teaching methods are openly shared, and digital teaching practice disseminated. This centralisation authenticates the fact that quality resources are applied well and fairly to promote the learning culture as a whole.

Moreover, in order to make digital integration sustainable and fair, it should be supported by an elaborate national policy framework. The governmental institutions and the institutions of higher learning need to work together in establishing norms in terms of curriculum alignment, teacher certification and development of infrastructure. Importantly, the ethical aspects of technology such as information privacy, cybersecurity, and algorithm prejudice have to be incorporated into these frameworks. The integrated policy platform will provide consistency in all areas of the educational sector, accountability, and the ability of the digital transformation to benefit all the demographic groups which will guarantee sustainability in the provision of science, technology, engineering, arts and mathematics (STEAM) education.

Suggestion for future research

The research studies can be conducted as longitudinal mixed-method research designs in the future to create the discourse of AI integration in science, technology, engineering, arts and mathematics (STEAM) curriculum, which will explain the complex temporal nature of teaching and learning. Moreover, the methodological consistency is imperative to evaluate the pedagogical efficiency of new tools associated with generative AI models and adaptive virtual laboratories, as well as to define the future impact of these new tools on the teaching approach and the student interest. Besides process evaluation, there is need to empirically measure the cognitive results of students. In addition, to capture the seminars implications of educational equity, intensive comparative studies are demanded between the rural and urban settings; those research studies ought to chart out socio-geographic differences in digital preparedness and infrastructure.

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