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Integration of Artificial Intelligence Tools to Enhance Conceptual Understanding in Elementary Science

Dr. Muhammad Anees ul Husnain Shah

Associate Professor, Department of Education, University of Education Lahore, D.G Khan Campus, draneesulhusnain@ue.edu.pk

Hafiz Muhammad Rizwan Khan

M.Phil. Education, IER, University of the Punjab, Lahore, Pakista

rizwanc1984@gmail.com

Dr. Sabir Hussain

Department of Educational Training, The Islamia University of Bahawalpur

sabirjanmarri@gmail.com

Abstract

Children do not understand science concepts well at the elementary level, as this stage introduces difficult scientific terms and concepts. Therefore, the traditional teaching method is no longer proving effective. The purpose of this research was to examine the results of integrating artificial intelligence tools into teaching. For this purpose, the artificial intelligence tools Kahoot and PhET Interactive Simulations were used. These tools not only provide free services in Pakistan but are also easy to use. Government Boys High School Gaddai, D.G. Khan District, Punjab, Pakistan, was selected for this experimental research, and the experiment was conducted with students of Class 8th. A total of 60 average-scoring students were included in this experiment. Then, two groups were formed through fishbowl random sampling, and pre-testing was conducted. One group was taught using traditional methods, and the other group was taught using artificial intelligence tools for three months. Then, the children were given a post-test, and the concepts of the children who were taught using artificial intelligence tools were much better. It is recommended that integrating artificial intelligence tools into elementary-level science subjects can increase children's conceptual understanding.

Keywords: *Artificial Intelligence, Interactive Learning, Kahoot, PhET Simulations.*

Introduction

The core purpose of elementary science education lies in aiding children to make sense of the natural world going beyond memorizing isolated facts to construct coherent and useful scientific concepts (e.g. of matter, energy, forces, living systems, weather and processes on Earth). However, decades of research and classroom practice indicate that much of elementary learning has come to science lessons with fairly strong everyday explanations (misconceptions) which are internally consistent but scientifically false. All preconceived

notions may be very difficult to shift, particularly when teaching is based on memorization of the words as opposed to exploration, description, and critical presentation of evidence. Conceptual understanding in the modern curriculum is therefore not being able to know the correct definition of a term; rather it is the capacity to relate concepts, to use them in new contexts, to describe phenomena and to make revisions when faced with evidences (Saeedullah, 2021; Akbar, 2022; Qamar & Ullah, 2025; Scholar & Akbar, 2020; Saeedullah, 2020; Ullah et al., 2025; Ullah et al., 2023; Khan et al., 2024; Ullah et al., 2025; Ullah et al., 2023; Khan; Khan et al., 2025). It is not easy to establish this sort of understanding in elementary classrooms since the existing conceptions amongst students are diverse, the time available in classroom is minimal (in comparison to the time required to develop the conceptions), the teachers need to deal with varied learning needs, and most science concepts cannot be detected or seen (e.g., the models of matter as particles, energy transfer, or the processes occurring in microscopes). These ancient limitations have inspired the application of digital solutions-simulation, multimedia and interactive enquirer environments as a way of making scientific phenomenon more visible and easy to learn.

Over the past few years, the question of how technology can be used to support conceptual understanding has re-emerged with the development of artificial intelligence (AI) especially adaptive learning systems, conversational agents (chatbots), AI-enhanced simulations, and generative AI (GenAI) based on large language models (LLMs). Research and policy circles are becoming aware of the fact that AI is quickly becoming integrated within the educational technologies and classroom practices, both presenting substantial opportunities and posing new risks to K-12 teaching and learning (U.S. Department of Education, Office of Educational Technology, 2023). Simultaneously, syntheses of evidence with a particular early childhood and elementary setting emphasize that, despite the increase in AI applications usage, the research is still unequally distributed, the interventions are frequently short in duration, and the critical issues, such as privacy, equity, teacher roles, and the long-term impact of AI applications on children, need to be better empirically addressed (Boulhrir & Hamash, 2025; Hussain, 2023; Hussain & Abbas, 2023; Hussain & Khoso, 2021; Hussain & Khoso, 2022; Hussain et al., 2024; Perveen & Hussain, 2023; Sheeza et al., 2024; Zafar et al., 2024; Hussain, 2024). In science education, new systematic reviews also indicate a growing exploration of AI-based learning support, assessment, feedback, and learning analytics, although they also note that these tools require more articulation and thoughtful analysis of learning outcomes other than on-the-surface performance (Almasri, 2024).

An influential factor that is driving the interest in AI tools in elementary science is the potential to offer personalized scaffolding, which is a type of prompts, explanations, and feedback that a single teacher in an inquiry-based learning activity can hardly offer to many students at the same time. In the case of intelligent tutoring systems (ITS) with AI applications, the practice, hints, and explanations can be adjustable according to the learner response. According to a recent systematic review of AI-based ITS in K-12 education, the overall effects are positive in terms of learning and performance, and the fact that many studies are based on quasi-experimental designs with limited durations is also mentioned (Letourneau et al., 2025). This piece of evidence applies not just to science, but to

elementary science in particular because conceptual change often involves repetitive practice with feedback, specific attention to conceptual errors, and progressive improvement of explanations mechanisms that potentially can be assisted by adaptive systems at large scale.

In addition to tutoring systems, virtual agents which are AI-powered in simulations are a promising avenue of conceptual learning. Already, simulations have been known to allow learners to investigate dynamic systems and experiment with what-if scenarios but it is still possible that students attempt to unproductively test and learn through a trial-and-error method or to misinterpret what they see. The AI-based agents could also act as rescuers by questioning, highlighting pertinent variables, and requesting clarifications. A meta-analysis of 2024 conducted on the topic of the impact of AI-powered virtual agents on learning outcome in computer-based simulations showed a medium positive effect of agent-supported simulation environments on learning compared to non-AI agent conditions, which are moderated by the length of an intervention and agent design options (Dai et al., 2024). In elementary science, it is significant that simulations do not ensure conceptual learning; the learners are usually required to have a system of guidance to help them relate visualized processes to scientific principles.

The extremely fast dissemination of chatbots and GenAI tools has created a new model of interaction: students are able to pose questions in natural language, get clarifications in various forms, and even have a conversation that is more akin to tutoring. Dialogue-based tools can be especially useful in science learning, where questions and explanations of students play a central role in sensemaking, provided that they are correct, developmentally fit, and instructionally appropriate. A scoping review dedicated to chatbots in science education found that chatbot application is on the rise but the evidence base is in its infancy, with more discovery research and fewer intervention designs; it also found that chatbot systems such as ChatGPT had high language skills but weak scientific accuracy and analytical depth, which supports the role of AI literacy and teaching critical thinking, as well as their integration with chatbots (Calvo-Utrilla et al., 2025). To be more general, a systematic review of chatbots in education found that the majority of chatbots are utilized to teach and are typically assessed based on perceptions, and that these gaps in the theory-supported design and impact measurement (Debets et al., 2025).

Positively, in the elementary science setting, there is growing empirical evidence that the well-scoped chatbot design can be used, as a means of supporting conceptual outcomes. To take one example, a classroom experiment to design and implement a rule-based AI chatbot to support a sixth-grade optics unit showed beneficial results in terms of science performance and interest, although results were quite beneficial to lower-performing students (Lee et al., 2023). This type of domain-constrained, curriculum-specific chatbot is contrasted with open-ended general-purpose GenAI: it can be designed to go after known misconceptions and needed clarifications, and some of the risks of hallucinated or off-topic outputs may be reduced. Meanwhile, the use of LLM-based tools in education is increasingly growing; a systematic review of empirical studies of LLMs in education (since the release of ChatGPT in November 2022 through March 2025) reported the following benefits such as improved performance and engagement, and such challenges as the over-

reliance, privacy, fairness, and technical reliability (Shi et al., 2026). Such issues are especially relevant in elementary science since young students tend to be more inclined to believe in the authority of fluent explanation where reasoning is incomplete or inaccurate and because science knowledge is based on feasible evidence-claim coordination not persuasive writing.

The endemic obstacle to the conceptual knowledge in elementary science is that most of the phenomena of interest are imperceptible (such as the movement of molecules), too big or small to be seen (such as the change of geological formations), or too complicated to be physically manipulated in classrooms (such as interactions within systems). Immersive and multimodal technologies, in particular, augmented reality (AR) and 3D visualization, can be used to assist the process of abstract-externalization and spatialization of abstract processes. Although not all AR is necessarily itself AI, a large number of current AR based learning systems are starting to add AI elements (e.g. adaptive prompts, object recognition, guided interactions), and AR is a subset of a broader AI-enhanced ecosystem that is influencing the science learning experiences. The literature on the primary science environment suggests that the AR-based embodied interaction with 3D models might enhance the students involvement and understanding of the intricate concepts as the learners can be provided with the opportunity to interact with the representations and perceive the phenomena in different ways (Mansour et al., 2024). These affordances are in line with the teaching requirement to relate practical experiences to abstract explanations; a necessary bridge in the elementary learner.

The potential of AI tools is not as bright as it may seem, and their implementation into elementary science education should be done with due consideration to pedagogy and child-centered ethics. On the policy-level, the U.S. Department of Education points to the fact that AI in education elicits critical concerns regarding privacy, bias, transparency, and the necessity to work on supporting designs that would enhance learning as opposed to substituting important human aspects of teaching (U.S. Department of Education, Office of Educational Technology, 2023). In providing practitioner-oriented advice, it is likewise emphasized that generative AI tools are frequently less reliable at finding facts than at creative exploration unless providing them in settings of tight constraints as well as well-developed safeguards; explicit directions are favored, as well as to creatively design and factor privacy settings in tools utilized with children (Cipolla & Lenhart, 2024). These concerns are relevant in the understanding of science concepts directly: as AI tools can give incorrect explanations, or simplify causal processes, or encourage answers-seeking (as opposed to sensemaking), they can be counterproductive to the learning objectives they are meant to promote.

Thus, it is not the question of whether AI tools can be implemented into elementary science classes, but rather whether it is possible to design them in ways that unquestionably facilitate conceptual development, namely, allowing students to express existing notions, challenge them with evidence, get feedback on them that addresses false assumptions, and construct generalizable explanations that are consistent with, as well as safeguard, the rights of teachers and their students.

Reasons and Purpose of the Current Research

The recent literature suggests (a) the increasing attention to AI in elementary education, combined with knowledge gaps in the long-term and child-specific research (Boulhrir and Hamash, 2025); (b) the growing research on AI in science teaching and learning, as well as benefits and challenges in its implementation (Almasri, 2024; Jia et al., 2023); (c) promising outcomes of AI-powered guidance in the simulated setting (Dai et al., 2024); and (d) the rise of empirical research in Combined, these strands indicate that there is an opportune necessity to adopt a concept-based, selective investigation into how AI tools can be chosen, designed and deployed to support conceptual learning in elementary science and ways such integration may be assessed by outcomes that are indicative of profound learning and not just short-term performance.

Statement of the Problem

In spite of the current attempts to advance the learning of elementary science, it is still observed that many students fail to have profound knowledge of the scientific concepts due to the memorization effect instead of the ability to have coherent and transferable explanations of natural phenomena. The notions of persistently held misconceptions, lack of opportunities in providing individualized feedback and time factors in inquiry based classrooms, and the fluctuation of teachers ability to meet varied needs of the learning population are all perceived contributors to the discrepancy in conceptual knowledge at the elementary level. Despite the evidence of potential benefits of artificial intelligence (AI)-based tools (e.g., adaptive tutoring systems, simulations, conversational agents) in helping learners access a personalized scaffold and immediate feedback, their application to elementary science education is a relatively untapped area, especially in terms of their long-term effect on students conceptual knowledge instead of short-term accomplishments or engagement. In addition, issues of pedagogical and alignment, correctness of AI-based explanations, developmental suitability, and ethical issues also complicate their implementation to classes. Accordingly, the systematic investigation of the ways AI tools can be responsibly and successfully incorporated into elementary science classes to contribute to better conceptual knowledge of students and help overcome learning obstacles is highly needed.

Objectives of the Study

1. To examine how the integration of artificial intelligence tools influences elementary students' conceptual understanding of key science concepts.
2. To identify effective instructional strategies for using AI-based tools to support conceptual learning and address misconceptions in elementary science classrooms.

Research Questions

1. How does the integration of artificial intelligence tools influence elementary students' conceptual understanding of key science concepts?
2. What instructional strategies are most effective for using AI-based tools to support conceptual learning and address misconceptions in elementary science classrooms?

Methodology

Research Design

The research design was the pretest-posttest control group, which is an experimental research design. This design was chosen to identify the efficiency of the introduction of artificial intelligence tools into the elementary level science instruction in order to improve conceptual knowledge of the students. The study was designed to cover two groups of students, one group experimental and the other one control. A pre-test was conducted on both groups prior to the intervention followed by post-test after the intervention. The results comparison between the two groups allowed determining the effect of AI-based instructional tools on the learning outcomes of students.

Research Setting

The study took place in Government Boys High School Gaddai, which is situated in Punjab, Pakistan in the District of Dera Ghazi Khan. The school was chosen as it offers a suitable setting to carry out an experimental research and access to simple technological tools needed to introduce AI tools, i.e. Kahoot and PhET Interactive Simulations.

Participants

The study sample was comprised of Class 8 students who were enrolled in the sampled school. The experiment involved 60 average students with average scores. Mediocre students were selected to ensure that there was homogeneity in the academic capability and to prevent any extreme fluctuations in performance which would invalidate the results. The participants were all learning the same elementary level science program.

Sampling Methodology and Grouping

Students were randomly grouped in two equal groups by fishbowl sampling. The names of 60 students were typed in slips of paper and put in a container in this approach. They randomly selected thirty slips and formed an experimental group and the rest thirty students were the control group. This randomized assignment made it fair and reduced the selection bias.

Instructional Intervention and Tools

The intervention was a duration of three months. The two groups had the same science concepts but the mode of delivery varied at this time based on the Class 8 curriculum.

Experimental Group: The members of the experimental group had been taught with artificial intelligence tools, namely Kahoot and PhET Interactive Simulations. Interactive quizzes, formative assessments and classroom competitions were done using Kahoot which increased student engagement and gave instant feedback. There were the PhET Interactive Simulations that helped the students to visualize and explore abstract scientific concepts in terms of interactive models and virtual experiments. Such tools aided a clear conceptualization as it enabled the students to be active in the learning experience instead of passively absorb learning information.

Control Group: The control group students were exposed to the traditional teaching methods, that is, teaching based on lectures, reading of textbook, explanations on the board and regular questioning. The control group did not use any AI tools and digital simulations.

The same teacher taught these two groups so that there was uniformity in the delivery of the content as well as to counter-check the differences that might be associated with the teachers.

Research Instrument

The achievement test designed by researchers served as the main tool of studying the conceptual knowledge of the science concepts among the students. The test was conducted in the form of the pre-test and the post-test. It was a series of multiple-choice and short-answer conceptual questions, which were aimed at the evaluation of the understanding of scientific concepts, reasoning, and their application instead of mere memorization.

The test items were checked by the experts of subjects and teachers of science with many years of experience to guarantee content validity. Their feedback was used to make the necessary revisions.

Data Collection Procedure

Data collection was conducted in three major phases. The intervention was preceded by the pre-test of both experimental and control groups to determine their initial conceptual level in order to compare them. Second, the experimental intervention used the instructional treatment that lasted three months, where the experimental group was given AI-supported instruction and the control group was given traditional instructional treatment. Lastly, post-test was conducted on both groups after the intervention was complete to determine the conceptual understanding improvement.

Data Analysis

The collected data of the pre-test and post-test were analyzed through descriptive and inferential statistical tools to establish the effectiveness of the integration of artificial intelligence tools in the teaching of science on the elementary level. First, descriptive statistics were used to describe the general performances of students in the experimental and the control group by calculating mean scores and the standard deviations.

To perform the inferential analysis, paired sample t-test was used to test the difference between the pre-test and post-test scores of each group. This analysis was used to establish whether there was a significant improvement in the students in each group following the instructional intervention.

Further, the post-test mean scores of experimental group and control group were compared with the help of an independent sample t-test. The reason behind conducting this test was to determine the existence of statistically significant difference in the conceptual understanding among the students who learned using AI tools and students who learned using traditional tools.

Moreover, it was determined that the level of significance would be 0.05. In case the p-value calculated was below 0.05, the difference between groups was taken as significant. Effect size (Cohen d) was also used to assess the extent of the intervention impact. This gave further evidence of the strength of the AI-based approach of teaching in affecting the conceptual learning of the students.

Results

Table 1: Descriptive Statistics of Pre-Test and Post-Test Scores

Group	Test	N	Mean	SD
Experimental Group	Pre-Test	30	48.20	6.45
Experimental Group	Post-Test	30	78.60	7.10
Control Group	Pre-Test	30	47.75	6.80
Control Group	Post-Test	30	61.30	7.55

Mean scores in the pre-test groups of both groups were almost similar, which indicated homogeneity prior to the interventions. Nevertheless, the experimental group (M = 78.60) and the control group (M = 61.30) had significantly different post-test mean scores, which indicates that AI tool integration helped to improve the scores after the implementation.

Table 2: Paired Sample t-Test (Within-Group Comparison)

Group	Mean Difference	t-value	df	p-value
Experimental Group	30.40	15.82	29	.000*
Control Group	13.55	7.64	29	.000*

*Significant at $p < 0.05$

The result of the paired sample t -test revealed statistically significant improvement of both groups. Nonetheless, the means of gains were significantly greater in the experimental group (30.40) than in the control group (13.55), which showed greater conceptual development in the AI-assisted classroom.

Table 3 Independent Sample t-Test (Post-Test Comparison Between Groups)

Variable	Experimental (M ± SD)	Control (M ± SD)	t-value	df	p-value	Cohen's d
Post-Test	78.60 ± 7.10	61.30 ± 7.55	9.21	58	.000*	2.37

*Significant at $p < 0.05$

The independent sample t-test provided the statistically significant difference between the post-test scores of experimental and control groups ($t(58) = 9.21$; $p < .05$). The remarkable effect size (Cohen d =2.37) shows the significant influence of the integration of AI tools (Kahoot simulator and PhET simulator) to the conceptual grasp of the students.

Findings

The statistical analysis demonstrated that while both traditional and AI-supported instruction improved students' conceptual understanding, the improvement in the experimental group was significantly greater. The high mean gain, statistically significant t-values, and large effect size confirm that integrating artificial intelligence tools such as Kahoot and PhET Interactive Simulations substantially enhanced students' understanding of science concepts.

These findings support the conclusion that AI-based instructional strategies are more effective than traditional teaching methods in promoting conceptual understanding at the elementary level.

Discussion

The current research examined how the conceptual knowledge of the science concepts in elementary students could be enhanced by the use of artificial intelligence (AI) applications,

namely, Kahoot and PhET Interactive Simulations. The results showed that experimental students who received instruction with the use of AI-assisted instruction scored considerably higher on the post-test evaluation and exhibited higher levels of conceptual development than students taught by conventional means. Such findings indicate that AI-based learning environments have become increasingly relevant to help resolve longstanding problems in the field of elementary science education, specifically in developing nations like Pakistan where lectures tend to be the main approach to teaching science.

The obtained findings strongly indicate that AI-based tools can be used to promote the conceptual knowledge of students by providing abstract scientific concepts with a higher level of interaction, visual, and engaging elements. The experimental group registered a significantly higher number of mean gains in post-test and pre-test scores than the control group, which shows that AI-supported instruction led to in-depth learning, as opposed to superficial memorization. The finding conforms to the previous studies that highlight that AI-based learning technologies offer scaffolding and instant feedback that are crucial in conceptual change during science education (Almasri, 2024). Science in the elementary level is usually challenging due to the fact that the processes that occur are invisible like transfer of energy, intermolecular interactions or forces. Simulation tools such as PhET simulations enable the learner to solve the variables and see cause and effect relationships and hence can contribute to clarity of concepts and less misconceptions.

In a comparable study, the authors of the meta-analysis conducted by Dai et al. (2024) discovered that AI-driven virtual assistants and simulation-based learning have significant positive impacts on the learning outcome of students. The authors came to the conclusion that AI-guided simulations are specifically effective since they promote exploration through inquiry and offer some systematic assistance. This can be used to corroborate the outcome of this present study because PhET simulations helped students to visualize complex phenomena, something that is, in most cases, not possible using textbooks alone.

The study involved Kahoot as an AI-based formative assessment tool that encouraged participatory and immediate feedback. The high enhancement of the experimental group indicates that AI platforms that use games can support conceptual learning by encouraging motivation and active memorization. According to previous research, it was found that Kahoot can improve student engagement and facilitate meaningful learning since it enables assessment to be turned into a fun and competitive learning process (Wang and Tahir, 2020). Interactive quizzes can reinforce the retention and comprehension of the essential idea in science education, wherein the learner often experiences a lack of understanding with new vocabularies and concepts due to novelty, so through repetition and exposure to the idea in a positive setting, the student will gain a stronger comprehension of the idea.

In addition to that, Lee et al. (2023) have shown that AI-based chatbots and interactive tools can enhance the achievement and attitudes in science, especially among mean and low-achieving learners. This aligns with the present paper, which particularly involved the use of average-scoring students and discovered that AI tools promoted their conceptual growth to a large extent.

Control group of this study improved between pre-test and post-test but margins were much less as compared to the experimental group. This means that although conventional teaching

might enhance the level of factual knowledge, it might not be sufficient in facilitating deeper conceptual knowledge. Traditional approaches based on lectures and focused on memorization and teacher-centered presentation usually do not provide students with the possibility to experiment and create their vision of science. Studies have always revealed that the traditional approach is not enough to rectify the myths and assist conceptual change in learning science (Jia et al., 2023).

In learning science, students are expected to make inquiries, make explanations, reason, and think logically and provide evidence. Tools that are AI-powered create the potential of such engagement, as they enable learners with opportunities to work with content, experiment with ideas, and get adaptive feedback. Thus, the results support the thesis about the necessity to integrate technology in the elementary science classes to convert them into the setting that favors the conceptual understanding.

The significance of this research is that it is applicable to the Pakistani educational situation. Kahoot and PhET are open-source AI tools that can be readily installed and used in resource-limited environments, which is a realistic solution to the problem. The reported high effect size of the results indicates that even low-cost AI tools may result in meaningful learning gains when used in a proper way. The U.S. Department of Education (2023) has pointed out that AI can be used to personalize the learning experience and make the learning process more strong, but its successful adoption is possible only with respect to its Pedagogical objectives and accountable use.

Boulhrir and Hamash (2025) also noted that the use of AI in elementary education is growing at a high rate, but the empirical evidence behind it is scarce, particularly in non-Western countries. The present paper contributes to the growing research literature by offering experimental data that AI tools can play a vital role in conceptual learning outcomes in elementary schools during a science lesson in Pakistan.

Conclusions

The current research has found that the combination of artificial intelligence (AI) tools, namely, Kahoot and PhET Interactive Simulations helped to assist the students in their conceptual knowledge of science concepts at the elementary level significantly. The results proved that students taught using AI-supported instruction strategies were significantly improved in post-test scores as compared to those taught using traditional teaching methods. The high improvement of the mean scores and the big statistical difference proved that AI-based tools are effective to promote deeper conceptual learning.

The research also found that AI tools helped enhance learners through better learning because they were more interactive, visual, and engaging of abstract scientific concepts. The PhET simulations allowed the students to investigate intricate phenomena by virtual experimentation that empowered their conceptual clarity. On the same note, Kahoot added to the learning process by enhancing both the motivation and active engagement of students in learning, by means of interactive formative testing and instant feedback. All of these aspects facilitated quality learning instead of memorization.

The other significant finding is that the conventional lecture-based learning, with the potential to enhance the basic knowledge, was not as effective in developing profound conceptual knowledge. The relative weakness of the control group was one of the

indications of the weaknesses of traditional teaching strategies in solving misconceptions and encouraging inquiry-based learning.

Another finding of the study was that the freely available and user-friendly AI tools can be effectively introduced in the government schools of Pakistan without expensive infrastructure. This implies that the implementation of AI is a viable and expandable method of augmenting science learning in the circumstances that have resource constraints.

Recommendations of the Study

1. Schools should integrate AI tools such as Kahoot and PhET Interactive Simulations into elementary science teaching to enhance students' conceptual understanding.
2. Teachers should receive professional training on effectively incorporating AI-based tools into inquiry-based science instruction.
3. Educational authorities should provide adequate technological infrastructure in government schools to support the successful implementation of AI-supported learning.

Educational Implications

The study results have significant implications to teachers, curriculum developers and policymakers. To begin with, the application of AI tools can help teachers to support various learning needs with the help of interactive and adaptive learning. Second, formative assessment platforms and AI-based simulations can aid in eliminating wrong beliefs and encouraging a more in-depth understanding of the concept. Lastly, educational authorities and schools are also advised to think of offering training and resources that will promote the successful usage of AI tools in the science lesson.

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