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Transforming science education with artificial intelligence: Enhancing inquiry-based learning and critical thinking in South African science classrooms

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Abstract

In this conceptual paper, we explore how Artificial Intelligence (AI) educational applications can enhance Inquiry-Based Learning (IBL) and Critical Thinking in science classrooms. Despite widespread support for IBL from scholars around the globe, its implementation in classrooms often falls short. Grounded in social constructivist theory, which promotes active participation, collaboration, and inquiry in knowledge construction, this paper presents a case for using AI educational apps as teaching tools to simulate scientific inquiry. Two research questions were addressed: What challenges hinder the implementation of inquiry-based science learning in South African classrooms? And how can AI-infused educational apps promote inquiry-based science learning? The literature suggests that science educators often face challenges such as a lack of knowledge of IBL, negative attitudes towards IBL, and limited resources concerning the use of IBL, which hinder their ability to implement IBL effectively. It is found that AI-infused educational apps like Magic School, Labxchange and Edpuzzle can help overcome these challenges. Their free-to-use nature facilitates the automatic creation of lessons that enable pupils to engage with scientific concepts through inquiry-based prompts, critical thinking questions, and real-world applications. In light of these findings, we argue that teacher development programs must do more to equip science educators with the skills required to integrate AI into their teaching. Future research could explore how AI can be utilized in other subjects such as mathematics to create a more engaging learning experience.

Keywords: artificial intelligence, inquiry-based learning, critical thinking, science education

INTRODUCTION

Inquiry-based learning (IBL) is an active learning approach that engages learners directly in the learning process, rather than having them passively receive information. This method includes various activities such as questioning, making predictions, analyzing data, critical thinking, and communication (Berie et al., 2022). At the core of IBL is the goal of fostering a deeper understanding by encouraging learners to ask questions, explore topics, and construct their own knowledge through investigation. In this approach, how learners acquire knowledge is emphasized more than the specific content they learn (Wale & Bishaw, 2020). In the context of science education, IBL aims to promote a deeper understanding of the natural world (Van Graan, 2020). The importance of IBL in science education is significant. It transforms the learning dynamic, placing learners in the most active role during lessons while educators take on the role of facilitators.

Despite the strong endorsement of IBL by a wide array of scholars worldwide (Akuma & Callaghan, 2019; Attard et al., 2021; Berie et al., 2022; Bogar, 2019; Ferreira et al., 2021), its implementation in classrooms is often lacking. Several studies were conducted by researchers for instance, research conducted by scholars (Baroudi & Rodjan Helder, 2019; Kazeni & Mkhwanazi, 2020; Letina,2021) identified several challenges that hinder the implementation of IBL in science classrooms. One major reason is educators' reluctance to adopt IBL, which stems from a lack of knowledge and a negative attitude toward the approach. Additionally, some educators reported that limited teaching and learning resources adversely affected their ability to utilize IBL in their science

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Contribution to the literature

- This article highlights the potential of AI powered educational tools in overcoming challenges in implementing IBL in under-resourced science classrooms in South Africa.
- The article also emphasizes how AI can enhance learner-centered teaching for critical thinking and problem-solving in science education by providing practical examples of the 5E learning model.
- It also addresses how the 5E learning model fosters engagement, exploration and deeper conceptual understanding while addressing barriers such as teacher preparedness and lack of physical resources

instruction (Ramnarain & Hlatswayo, 2018). Interestingly, a study by Shivolo and Mokiwa (2024) revealed that educators' examination-focused teaching methods often discouraged the use of IBL. Moreover, Anderson and Cha (2019) highlighted a lack of professional development as another barrier to implementing IBL in teaching. Therefore, innovative methods for adaptive learning platforms need to be introduced to educators for them to plan and create learning experiences that encourage critical thinking and inquiry-based learning. Artificial Intelligence (AI) advancements have introduced new methods and possibilities for transforming education, including adaptive instructional support. This study explores how the intersection of AI-infused educational applications can bridge the gap between IBL's pedagogical ideals and the realities of science education, ultimately fostering a more engaging inquiry-driven learning environment.

As innovative methods for enhancing IBL in Natural and Physical Sciences are being explored, the integration of AI presents promising opportunities to address the challenges of implementing the IBL approach (Saúde et al., 2024). AI can function as an educational tool that enriches IBL practices by transforming traditional classrooms, providing personalized learning experiences, facilitating data analysis, and fostering deeper critical thinking. Research indicates that when teaching incorporates AI tools, learners in both higher education and schools can engage effectively in inquiry-based learning under the guidance of their educators. Considering the future direction of education, which aims to create an inclusive and stimulating learning environment, AI-driven inquiry teaching can serve as a valuable instructional strategy. This approach can help nurture and develop learners' abilities through efficient data collection and analysis (Xie, 2023).

The paper begins by problematising IBL in the South African classroom context, highlighting the need to explore alternative approaches, such as AI-driven educational apps, to enhance IBL in science education. It then presents a brief literature review on IBL in science education, examining its relevance to South African classrooms, comparing traditional teaching methods with IBL, and emphasizing the importance of IBL in science education. Following this, the paper addresses the first research question: What challenges impede the implementation of inquiry-based science learning in South African classrooms? The discussion subsequently shifts to how AI can transform science teaching and learning by promoting IBL, thus tackling the second research question.

PROBLEM STATEMENT

The Curriculum & Assessment Policy Statement (CAPS) for Natural Sciences in Grades 7 to 9 in South Africa stipulates the specific aim of "doing science" through conducting investigations and analysing problems. This specified aim encourages the adoption of inquiry-based learning within these grades (Department of Basic Education, 2011a). The knowledge and problem-solving skills acquired in Grades 7 to 9 lay the foundation for Physical Sciences in Grades 10 and 11. The CAPS document for Physical Sciences in Grades 10 to 12 also emphasises the importance of equipping learners with investigative skills related to physical and chemical phenomena. Skills such as designing investigations, problem-solving, and reflective thinking are particularly relevant for studying Physical Sciences in Grades 10 to 12 (Department of Basic Education, 2011b). The CAPS document advocates for inquiry-based learning approaches in science classrooms to realise the specific aims in both Natural Sciences and Physical Sciences (Botes & Philip, 2025). Despite the well-documented educational benefits of Inquiry-Based Learning (IBL) in enhancing critical thinking in science education, its implementation in science classrooms still requires attention, particularly in resource-constrained settings in South Africa (Attard et al., 2021; Berie et al., 2022). Kazeni and Mkhwanazi (2020) reported that barriers such as educators' lack of knowledge about IBL, negative attitudes toward its use, and insufficient resources often hinder their ability to engage learners in inquiry-driven learning experiences. Meanwhile, advancements in artificial intelligence present opportunities to overcome these challenges. For instance, Mkimbili (2022) suggested that AI-powered educational applications can stimulate scientific inquiry. However, the integration of such applications into science education remains an area that requires further exploration. This conceptual paper aims to address this gap by investigating the potential of AI-powered educational apps to enhance IBL in science classrooms.

LITERATURE REVIEW

Inquiry-based learning (IBL) has emerged as a critical approach in modern science education, promoting learner-centred exploration, critical thinking, and problem-solving. As the global demand for 21st-century skills like creativity and analytical reasoning grows, IBL provides a meaningful alternative to traditional, teacher-centred methods (Akuma & Callaghan, 2019; Serafín et al., 2015). In the South African context, the implementation of IBL is particularly significant due to the need to address historical inequalities in education while fostering scientific curiosity and competence. Despite its advantages, the integration of IBL in South African classrooms faces notable challenges, such as resource limitations, large class sizes, and the rigidity of the national curriculum (Ramnarain, 2016; Ramnarain & Hlatswayo, 2018; Mkimbili, 2023). This review explores the theoretical underpinnings of IBL, its relevance to South African education, and the challenges involved in its implementation, highlighting the need for systemic support to fully realize its potential.

Overview of Inquiry-based Learning in Science

There are various definitions of inquiry-based learning (IBL) in science education as found in the literature. Mkimbili (2022) describes inquiry-based science teaching as a learner-centred approach that promotes autonomy by encouraging learners to conduct investigations, collaborate, communicate, and reflect with both their peers and educators. This method empowers learners to take an active role in constructing knowledge through discussion, presenting evidence, formulating explanations based on collected data, connecting those explanations to scientific principles, and communicating their findings. On the other hand, Akuma and Callaghan (2019) define IBL in science education as a reflection of scientific inquiry grounded in social constructivist learning. In this view, knowledge is actively constructed by the learner, contrasting sharply with traditional teaching methods that focus on the direct transmission of information from teacher to student.

As global education increasingly emphasizes 21st-century skills such as problem-solving and creativity, researchers have recognized the importance of fostering a positive attitude toward science learning as crucial for developing scientific abilities. This shift in focus has necessitated changes in teaching methods. While hands-on practical experiments were introduced in science classrooms to improve teaching methods, they were often conducted in a prescriptive, routine manner that stifled critical scientific thinking. Educators would typically provide learners with step-by-step instructions, leading to rote learning without meaningful engagement (Kang et al., 2016). Recognizing the limitations of this approach, educational authorities worldwide have embraced IBL in science education. IBL enhances the effectiveness of teaching and learning by allowing learners to engage with data, use evidence and logic, and collaborate in a social setting (Kazeni & Mkhwanazi, 2020). The above researchers argue that IBL is a student-centred approach that focuses on the construction of knowledge through problem-solving, thereby fostering learners' critical thinking skills.

IBL aims to engage learners in an authentic scientific discovery process. A widely used approach to IBL is the 5E learning model, which consists of five phases: engage, explore, explain, elaborate, and evaluate, as explained by researchers. These phases immerse learners in genuine scientific inquiry, support their learning, and underscore essential aspects of scientific thinking (Mupira & Ramnarain, 2018; Stott & Hobden, 2010). The five phases of the 5E learning model can be elaborated as follows. In the 'engage' phase, the teacher assesses the learners' prior knowledge, stimulates their interest, and encourages them to ask questions or develop investigative inquiries. The second phase, 'explore', involves the teacher facilitating while learners actively collaborate with their peers in hands-on, minds-on activities. During the third phase, 'explain', the teacher poses questions based on the learners' activities and encourages them to articulate their ideas and understanding of concepts using evidence from their experiences. At this stage, the teacher also guides the learners, urging them to take an active role in constructing their own knowledge. The fourth phase, 'elaborate', allows learners to demonstrate their ability to apply the skills and knowledge acquired during the explain phase to real-life situations. Finally, in the 'evaluation' phase, a summative assessment is conducted to determine whether the objectives of the inquiry lesson have been met.

According to the researchers, inquiry-based learning, such as the 5E model explained above, enables learners to ask questions, formulate hypotheses, develop experimental methods, collect data, and analyse it, which leads to a deeper understanding of concepts. South Africa is among the countries embracing the potential of IBL in science education, with the aim of implementing this approach in classrooms to promote more effective learning and enhance scientific understanding (Ramnarain, 2023).

Relevance of IBL to South African Classrooms

The South African basic education system has undergone significant reforms to address the lasting effects of apartheid policies. According to Ramnarain (2016), these effects are particularly evident in the disparities between schools in different regions. Schools historically designated for white learners tend to be well-resourced, while those in township areas, where many previously disadvantaged communities reside, continue to struggle with a lack of even basic educational materials. As previously mentioned, the introduction of the CAPS reflects the South African government's efforts to tackle these inequities, particularly by promoting inquiry-based learning in science education (Department of Basic Education, 2011a). Science is offered as Natural Sciences in Grades 8 and 9 and as Physical Sciences in Grades 10-12 within the South African Basic Education Curriculum. The CAPS framework recommends learning science through inquiry-based methods that emphasize learner-centred approaches.

The CAPS document for Natural Sciences outlines subject content designed to foster teaching and learning in science that nurtures enjoyment and curiosity about the world and natural phenomena. The first specific aim of this document is to encourage "Doing Science" focusing on investigations, data collection, and data analysis while promoting cognitive and practical skills through inquiry (Department of Basic Education, 2011a). For Physical Sciences, the CAPS document states that "the purpose of physical science is to make learners aware of their environment and to equip them with investigative skills related to physical and chemical phenomena" (Department of Basic Education, 2011b). This specific aim supports teaching and learning through inquiry, where learners engage in practical investigations, critical thinking, and problem-solving - all considered essential skills for the 21st century (Mkimbili, 2023). The shift to inquiry-based learning moves from traditional rote memorisation towards a more learner-centred model that actively engages learners in the learning process. By tackling real-world scientific challenges, learners develop critical thinking skills and a deeper understanding of scientific concepts. CAPS aims to produce not only competent learners but also future scientists capable of contributing to South Africa's development. However, various contextual challenges, such as a lack of laboratories and lab equipment, limit the implementation of inquiry-based science teaching, particularly in rural schools (Mkimbili, 2023).

Traditional Teaching Approach vs Inquiry-Based Science Teaching

Traditional teaching approaches and inquiry-based science teaching differ in several significant ways. According to Ramnarain and Rudzirai (2020) and Ncala (2020), traditional teaching is a teacher-centred approach focused on content objectives, emphasizing the transmission of scientific knowledge. In this model, learners play a passive role while the teacher plays an active role, dominating the communication during lessons. This approach often relies on rote learning and memorization of facts, resulting in a product-oriented focus where learners simply memorize information by adhering to a rigid curriculum. Unfortunately, this may lead to improved performance without developing a deeper conceptual understanding (Mkimbili, 2023).

In contrast, inquiry-based learning (IBL) fosters intellectual autonomy among learners by encouraging them to take active roles in their education. In this framework, the teacher transitions from being an expert to acting as a facilitator. Learners engage in constructing their own knowledge by formulating questions, stating hypotheses, designing investigations, testing these hypotheses, and finding solutions to their inquiries (Ncala, 2020). According to Dagys (2017), as cited in Ncala (2020), "Inquiry-based learning takes place through constructive, science-based knowledge structures. The transfer of knowledge focuses on the process, combining both conscious and unconscious perceptions. Knowledge is constructed by the learners themselves, ensuring that it is reliable and sustainable both now and in the future."

IBL is fundamentally a learner-centred approach that actively involves learners in their learning activities, facilitating their educational experiences and leading to conceptual development (Ncala, 2020). In summary, IBL is rooted in constructivism, emphasizing active student participation, problem-solving, and process-oriented learning, while the teacher serves as a facilitator. Conversely, the traditional approach aligns with behaviourism, where learners adopt a passive role, focus on following directions, and aim for product-oriented outcomes, with the teacher functioning as a director or transmitter of knowledge.

The Need for Inquiry-Based Learning in Science Education

The significance of critical thinking and problem-solving skills was discussed earlier. Critical thinking is defined as "the purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, as well as the explanation of the evidential, conceptual, methodological, criteriological, or conceptual considerations upon which that judgment is based" (Facione, 1990, in Lai, 2011). Inquiry-based science education is described by Ramnarain and Hlatswayo (2018) as "a teaching approach that allows learners to develop key scientific ideas by learning how to investigate and build their knowledge and understanding of the world, using skills employed by scientists such as asking questions, collecting data, reasoning, reviewing evidence, and drawing conclusions." Both definitions underscore a methodological approach to constructing knowledge.

In inquiry-based learning in science, learners must think critically as they engage in activities that require evaluating evidence and reasoning through data, reflecting Facione's concept of "self-regulatory judgment." As learners ask questions, collect, analyze data, and draw conclusions, they participate in interpretation and inference, which are key components of critical thinking. This process motivates learners to not only absorb facts but also to challenge assumptions, reflect on their methods, and revise their understanding based on the evidence, thereby refining their problem-solving skills. Consequently, inquiry-based learning fosters critical thinking by making learners active participants in the learning process. It encourages them to move beyond rote memorization and develop more profound analytical abilities essential for addressing complex problems, both in science and other contexts (Berie et al., 2022). Therefore, implementing scientific inquiry in classrooms is crucial, as it promotes skills such as analysis, critical thinking, and evaluation for the sustainable development of education.

Research has also indicated that inquiry-based science enhances learners' interest in the subject (Crawford, 2014; Jiang & McComas, 2015; Ramnarain & Hlatswayo, 2018). As a result, curricula worldwide strongly encourage inquiry-based science teaching and learning. The CAPS document for the physical sciences curriculum in South Africa advocates for teaching and learning science through inquiry and requires learners to engage in practical investigations. This is also emphasized in the Natural Sciences curriculum, as inquiry-based learning develops learners' scientific skills, such as observing, questioning, predicting, investigating, and interpreting data. This approach enables learners to understand the scientific process, promotes critical thinking and problem-solving, and fosters curiosity and active learning (Akuma & Callaghan, 2019). However, the reality is that South Africa falls significantly short in implementing these practices. The purpose of the coming section is therefore to explore the challenges that restrict science educators from implementing IBL in their teaching, hence responding to the study's first research question.

RQ1 What challenges impede the implementation of inquiry-based science learning in South African classrooms?

The first research question aims to identify the challenges that prevent science educators from implementing Inquiry-Based Learning (IBL) in their teaching practices. Understanding these challenges will provide a foundation for exploring how AI-powered educational apps can transform science teaching and learning by promoting IBL, which addresses the second research question. Despite the reforms suggested in the curriculum, the full implementation of the Curriculum and Assessment Policy Statement (CAPS), with a focus on IBL, encounters difficulties, particularly in under-resourced schools. The successful implementation of IBL in the school curriculum is shaped by a variety of factors, as outlined by Ramnarain (2016) such as:

1. teacher professional development,
2. class sizes,
3. teacher perceptions and beliefs,
4. rigid curriculum, and
5. lack of laboratories and equipment.

Schools in the different contexts of South Africa are affected differently by these factors. Continuous and relevant professional in-service training is crucial for educators to effectively implement the curriculum as recommended. While some educators are prepared, there is a lack of necessary training and support limiting the ability of many educators to apply inquiry-based strategies in the classroom.

The educators' views and perspectives about science pedagogy such as inquiry-driven beliefs versus traditional teaching strategy views are another important factor in implementing IBL in classrooms. The success of inquiry-based teaching and learning depends heavily on science educators' mastery of scientific processes and concepts and the ability to convey scientific theory in a meaningful manner to learners in class by using appropriate pedagogy. This can be achieved to an extent by providing in-service training based on practical experiments (Botes & Philip, 2024). The current CAPS document, which recommends strict timelines and lack of flexibility in the curriculum also limits the scope for open-ended inquiry and investigations. Another important factor is many South African schools' lacks laboratories and equipment. Several under-resourced schools in South Africa do not have the necessary laboratory facilities and equipment to conduct practical investigations. As a result, in these schools, hands-on scientific inquiry becomes almost impossible. Oversized classrooms with high teacher-to-learner ratios are another factor that hinders educators from engaging learners in hands-on activities and providing individual guidance to effectively implement inquiry-based learning (IBL) (Ramnarain, 2016). A study conducted by Ramnarain (2023) revealed that although educators in these schools possess a positive attitude towards inquiry-based teaching and learning, they are unprepared to involve learners in inquiry-based activities due to limited teaching and learning resources, large class sizes, and insufficient time to cover the curriculum. The structured experimental procedures supplied to educators by the Department of Basic Education (2011b) for conducting practical experiments, as prescribed in the Curriculum and Assessment Policy Statement (CAPS), were found to be overly prescriptive, limiting learners' opportunities for engagement in line with how inquiry-based learning should occur (Mkimbili, 2023). As a result of these factors, traditional teaching methods continue to be implemented in many schools across South Africa to teach science, particularly in rural areas.

Social Constructivism as a theoretical framework for AI-powered education

Before addressing the second research question – concerning how AI-powered educational apps can transform science teaching and learning by promoting Inquiry-Based Learning (IBL)-it is crucial to first clarify the appropriate theoretical framework for employing AI-powered educational apps within the science classroom context. The theoretical paper emphasises the promotion of inquiry-based learning (IBL) and critical thinking in STEM education, utilising educational tools informed by artificial intelligence. To support this approach, the paper adopts social constructivist learning theory as its theoretical framework. Social constructivism emphasizes the active participation, collaboration, and inquiry of learners in the construction of knowledge. Researchers Akuma and Callaghan (2019) and Mkimbili (2022) report that a central component of this social constructivist framework is IBL, a pedagogical approach that mimics scientific inquiry by engaging learners in activities such as questioning, data collection, and hypothesis testing. These activities foster critical thinking and problem-solving skills. IBL has become a cornerstone of modern science education, shifting the focus from rote memorization to active, learner-centred exploration of scientific concepts. Scholars such as Ramnarain and Hlatswayo (2018) and Kazeni and Mkhwanazi (2020) highlight that despite the benefits of IBL, its adoption in South African classrooms has been limited due to traditional barriers such as a lack of laboratory resources, rigid curricula, and teacher preparedness.

In this context, the integration of artificial intelligence (AI) serves as a transformative tool to enhance the IBL model. Xie (2023) and Bianchi (2024) discuss AI's potential to personalize learning experiences, promote critical thinking, and enable resource-constrained classrooms to implement IBL effectively. AI tools not only bridge resource gaps through virtual simulations and data analysis but also enrich the inquiry process by personalizing learning experiences and fostering critical thinking. Additionally, Mupira and Ramnarain (2018) describe the 5E model as a structured framework for inquiry-driven teaching that enhances engagement, exploration, and conceptual understanding. Therefore, this theoretical framework combines social constructivism and the 5E model to explore the potential of AI-enhanced IBL. It recognizes AI as both a facilitator and enhancer of inquiry, supporting educators, particularly in school contexts facing the aforementioned challenges. This framework provides a foundation for examining how AI can address systemic challenges in South African science education while advancing a learner-centred approach that aligns with the Curriculum and Assessment Policy Statement (CAPS) recommendations for inquiry-driven teaching. The synergy between IBL and AI demonstrates the transformative potential of technology in empowering both educators and learners. With the social constructivist theory as a theoretical footing, the coming section will explore how AI-powered educational apps can transform science teaching and learning by promoting IBL, therefore addressing the study's second research question.

TRANSFORMATION OF SCIENCE TEACHING AND LEARNING WITH AI TO PROMOTE INQUIRY-BASED LEARNING

An innovative approach to enhancing IBL in science classrooms is the integration of artificial intelligence (AI), which shows great promise. AI technologies can transform traditional teaching methods by offering personalized learning experiences, encouraging deeper critical thinking, and improving problem-solving skills, thus enriching the inquiry process. Integrating AI into a subject's offerings can enhance the visual presentation of teaching materials. This approach enriches the content and provides learners with a unique, engaging, and interactive learning experience. AI-driven inquiry teaching can create a stimulating environment that promotes higher-level learning activities, engaging learners in efficient data analysis and algorithmic decision-making (Xie, 2023). As educators explore innovative methods to enhance learning outcomes, the integration of AI has shown to be particularly effective in critical thinking curricula and inquiry-based learning (IBL). AI allows for personalized learning experiences that cater to each student's strengths and weaknesses (Bianchi, 2024).

Several studies underscore the role of AI tools as facilitators of higher-order cognitive skills in 21st-century education. These studies emphasize the importance of emotional and psychological aspects of learning, self-confidence in learners, the development of critical thinking skills, and diverse pedagogical approaches (Darwin et al., 2024). AI tools can support various phases of IBL, such as automated data collection, enabling virtual labs, and assisting in the evaluation of scientific data (Philip et al., 2023). AI-powered educational platforms like Magic School, PhET Interactive Simulations, Edpuzzle, Labster, LabXchange and ChemCollective offer interactive simulations of experiments, allowing learners to conduct virtual experiments without the need for physical equipment. The above-mentioned platforms provide virtual laboratories for experiments in physics, chemistry, and biology.

It is found that such applications can simulate lab setups using smartphones or tablets, providing immersive hands-on experiences (Darwin et al., 2024). When integrated into teaching and learning, these simulations utilize visual information to address challenges in understanding difficult concepts, thereby

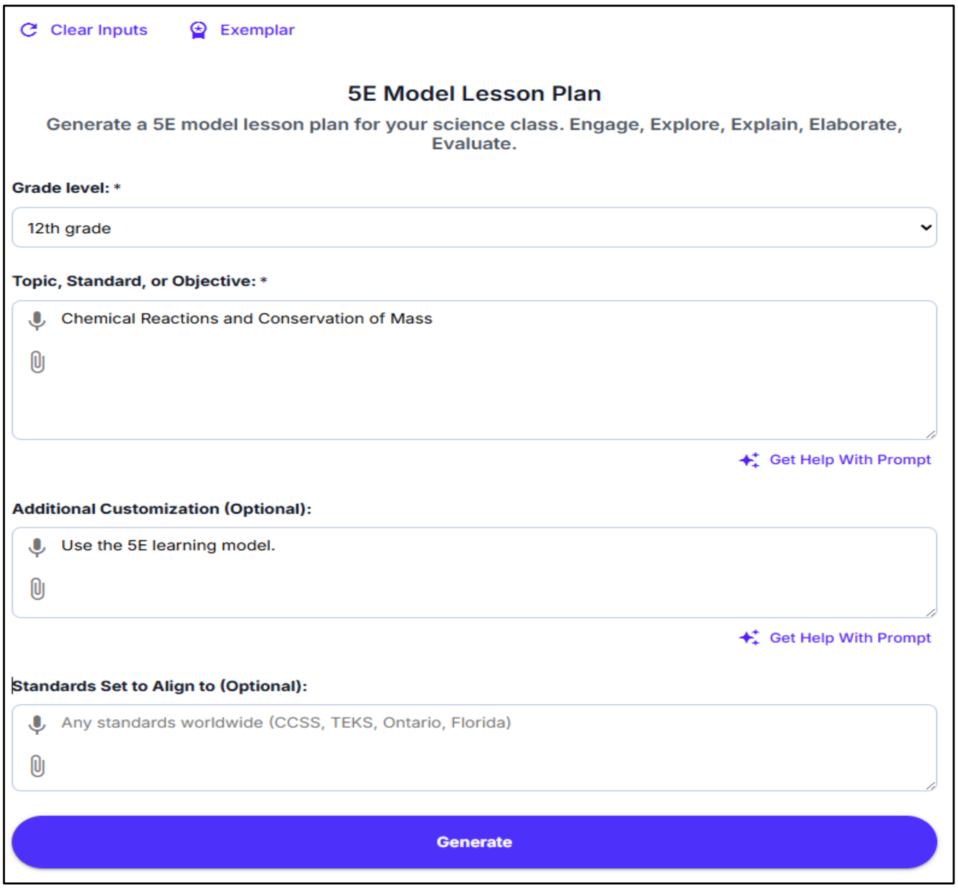

Figure 1. How the Magic School AI can be utilized to teach the topic 'Chemical Reactions and Conservation of Mass' (https://app.magicschool.ai/tools/5e-science?slug=5e-science&thread=77653365)

enhancing learners' ability to conceptualize subject content and improve their performance (Dieck et al., 2021; Philip et al., 2023). AI can adapt science content to different levels, ensuring that learners with varying abilities can grasp complex scientific concepts. It enhances personalized learning by providing virtual science tutors who answer questions, explain theories, and guide learners through experiments (Qin & Zhang, 2024). Furthermore, AI systems can identify and organize high-quality, free scientific resources tailored to a school's curriculum, helping learners collect, record, and analyze experimental data without the need for laboratory equipment (Yi, 2024).

Thus, using Open-Educational Resources (OERs) in a student-centric manner aligns with the learner-centred philosophy of IBL, promoting problem-solving and enhancing critical thinking skills. The latter aligns with the theoretical understanding of social constructivism, as a learning theory. In this manner, AI can make scientific investigations more accessible and inclusive, especially in schools lacking science laboratories or equipment for conducting experiments or investigations. The availability of virtual labs and simulations allows learners to engage in investigations and develop critical thinking skills, even in under-resourced environments. The following section explores how the integration of specific AI tools, such as Magic School (https://www.magicschool.ai/), Edpuzzle (https://edpuzzle.com/discover), and LabXchange (https://www.labxchange.org/), can enhance inquiry-based learning in science classrooms using the 5E learning model.

Teaching with Magic School: AI-Enhanced Personalized Learning in Science

This section argues for the use of innovative tools offered by the Magic School AI application to support educators and learners in the subject of science, particularly in enhancing Inquiry-Based Learning (IBL). A key feature of the Magic School app is its lesson planning capability, which aligns with the 5E learning model. In particular, the app stimulates IBL by prompting learners to 'engage', 'explore', 'explain', 'elaborate' and 'evaluate' topics related to the science syllabus. Educators can seamlessly integrate Magic School AI into their lesson plans and science teaching, particularly in under-resourced environments. The 5E model lesson plan generator in the Magic School app enables educators to develop lessons on specific concepts. Additionally, educators can incorporate experiments using the Science Labs tool within the application, helping them address the challenge of limited laboratory resources.

Figure 1 illustrates how Magic School AI effectively supports inquiry-based learning in chemistry by automating lesson planning, enhancing data analysis, and providing personalized learning experiences.

Lesson plan for the teacher

The teacher can use the 5E model to create a lesson on chemical reactions with the aid of Magic School's lesson plan generator. After planning and preparing the lesson, the teacher can implement it the next day in class. The different phases of the 5E model lesson can unfold as follows:

Phase 1 - Engage

To start this phase, the teacher can pose a question such as, "What happens to the mass when vinegar reacts with baking soda?" The Science Labs tool in the Magic School app can generate an introductory video. The teacher can also provide an informational text to spark curiosity among the learners.

Phase 2 - Explore

After engaging the learners, the teacher can then guide them to virtually simulate the reaction using an integrated virtual lab tool in Magic School. Learners can observe the formation of gas (carbon dioxide) and record changes in mass.

Phases 3 & 4 - Explain and Elaborate

In these phases, which take place during the same lesson session, Magic School's data collection tools allow learners to input experimental data, such as initial and final mass measurements. The AI analyzes this data, helping learners recognize patterns that reinforce the Law of Conservation of Mass. The teacher can use Magic School's assessment generator to create multiple-choice questions or open-ended prompts, such as: "Explain why the total mass remains constant even though gas is produced." The AI can provide instant feedback and personalized hints to support the development of critical thinking. During this phase, the teacher can offer further explanations beyond the AI's feedback. For learners needing additional support, the experiment can be broken down into simpler steps, such as measuring reactants precisely and predicting outcomes based on prior knowledge of chemical equations.

Phase 5 - Evaluate

The final stage, evaluation, can be conducted through a summative assessment along with follow-up questions facilitated by the teacher. This phase can be concluded with a statement about the Law of Conservation of Mass in a chemical change.

Integrating Magic School AI into lesson delivery allows learners to engage in a virtual, inquiry-driven exploration of chemical reactions. This approach helps learners develop critical thinking skills and understand complex concepts, such as the conservation of mass, even in classrooms without physical lab resources. The AI can also provide additional video demonstrations of the experiments to support learners with learning differences. This ensures that all learners actively participate in the scientific inquiry process and have opportunities to build their knowledge through various stages of the 5E learning model.

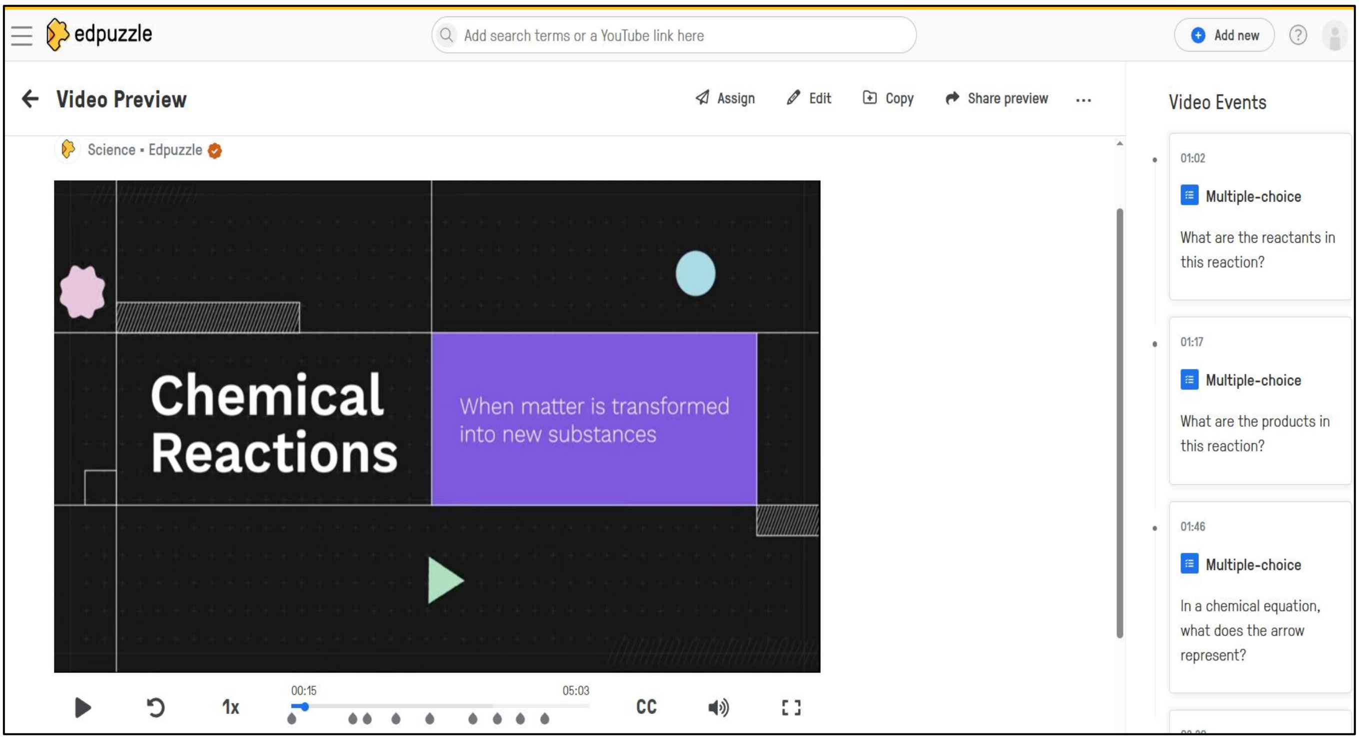

Figure 2. Introduction of the concept of chemical reactions (https://edpuzzle.com/media/6077c1075f703141b0a50365#:~:text=Edpuzzle,00:0021:52)

Edpuzzle: Interactive Video Learning for Critical Thinking

Edpuzzle is an innovative platform that promotes inquiry-based learning through educational videos and formative assessments. When used in the science classroom, video watching evolves from a passive activity into an engaging, inquiry-driven learning experience. This is achieved by embedding interactive questions, prompts, and assessments directly into the videos. Such an approach enhances student engagement, promotes critical thinking, and improves the formative assessment process, thereby supporting inquiry-based learning (IBL) in science education. On **Figure 2** is an example of how Edpuzzle can be utilized to teach a chemistry lesson. With this lesson, the teacher can teach a lesson on 'limiting reagents' in an interactive, inquiry-driven manner where learners will be exposed to and guided by questions to ease their understanding of limiting reagents. The lesson unfolds as follows:

Phase 1 - Engage: Introducing the concept with a video

The lesson begins with a short video explaining chemical reactions and the concepts of limiting and excess reagents. The Edpuzzle tool can be utilised to embed inquiry prompts at suitable points in the video, as illustrated in **Figure 2**. Observe the prompts on the right side of **Figure 2**.

For example, the teacher can embed the following question:

> What do you predict will happen to the amount of product if one reactant is completely used up?

This question encourages learners to hypothesize, initiating inquiry by engaging them with the fundamental concepts. The teacher can also add follow-up questions to enhance student engagement.

Phase 2 - Explore: Simulating a reaction

In the second phase of the lesson, the teacher can show a video demonstrating a reaction such as the formation of water from hydrogen and oxygen ($2H_2 + O_2 \rightarrow 2H_2O$), emphasizing the role of limiting reagents. An interactive question could be:

> If 4 moles of H_2 react with 2 moles of O_2, which reactant will be used up first? Explain your reasoning.

This question encourages learners to apply stoichiometry and think critically about the relationship between reactants and their mole ratio in the balanced equation.

Phase 3 - Explain: Analyzing the reaction

After explaining how to calculate limiting reactants, the teacher can use Edpuzzle's AI to embed multiple-choice or open-ended questions that ask learners to perform similar calculations, such as the following:

> If you start with 5 moles of A and 3 moles of B in a reaction where $2A + B \rightarrow C$, how many moles of C can be formed? Which reactant is limiting?

AI-generated feedback can reinforce learning by providing tailored guidance based on learners' responses.

Phase 4 - Elaborate: Applying to real-world contexts

In the next phase, a video segment that explores real-world applications, such as limiting reagents in industrial chemical production or cooking, can be shown to learners. This can prompt discussion with questions like:

> How might understanding limiting reagents be beneficial in industries like pharmaceuticals or food production? Provide an example.

This open-ended question allows learners to extend their understanding to practical contexts, encouraging deeper inquiry.

Phase 5 - Evaluate: Formative assessment and reflection

In the final phase of the 5E learning model, Edpuzzle can be used to track learner responses and provide real-time analytics for educators to assess understanding. At the end, a follow-up question can be posed:

> How does identifying the limiting reagent help predict the amount of product formed?

The educator can then review learners' responses to assess comprehension and provide feedback, adjusting if misconceptions arise. By utilizing Edpuzzle, educators can actively engage learners with concepts through inquiry-based prompts, critical thinking questions, and real-world applications. This approach not only enhances understanding but also develops problem-solving and analytical skills that are essential in science.

Teaching with LabXchange: Enhancing Inquiry-Based Learning

LabXchange is an AI-powered virtual laboratory platform suitable for use in classrooms. It allows learners to explore complex scientific concepts. Below is an example of how a teacher can design an inquiry-based learning (IBL) experience by implementing the 5E learning model to teach about series and parallel circuits.

Phase 1 - Engage: Introducing the concept with a real-world scenario

The lesson can begin by presenting a real-world problem using LabXchange's resources. For instance, the teacher might ask learners to consider how household wiring circuits are designed to prevent electrical failures. A guiding question could be:

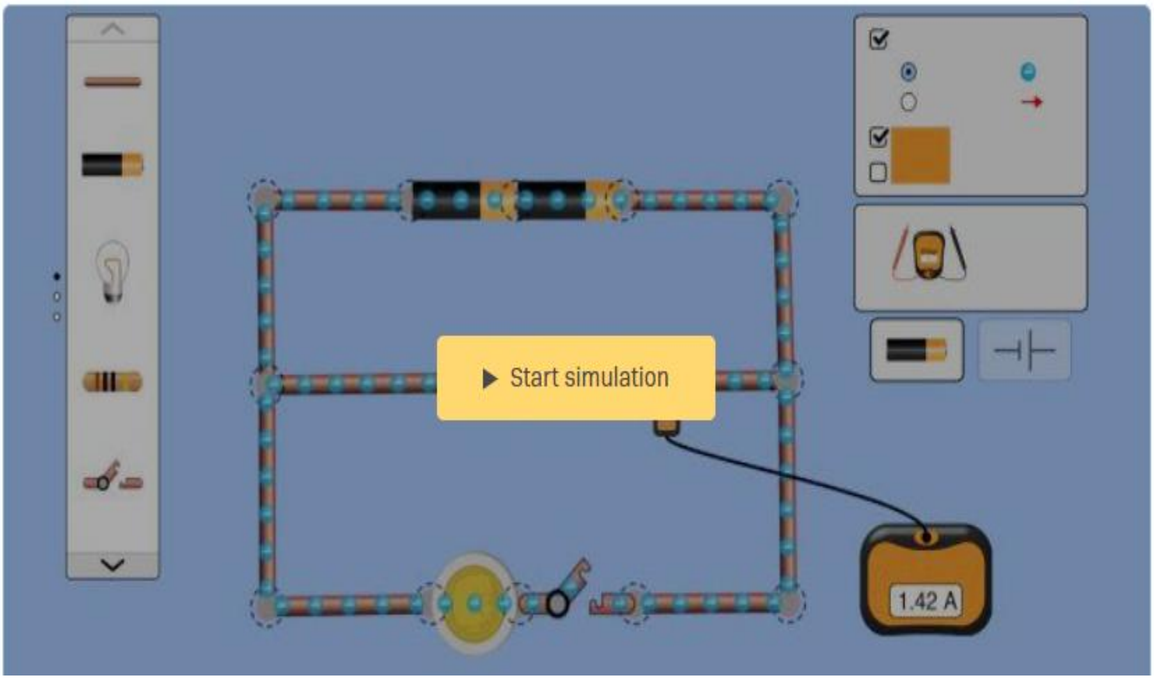

Figure 3. Virtual lab to construct a circuit (https://www.labxchange.org/library/items/lb:LabXchange:e188dda7:lx_simulation:1?t=ea140949-d0ba-4c0f-82e8-c0c1b93f34be)

> Why do the lights in your house remain on when one bulb burns out, but in some string lights, one failure causes the entire set to go out?

This question encourages learners to hypothesize and recognize the relevance of different circuit types in their everyday lives.

Phase 2 - Explore: Virtual lab for circuit construction

LabXchange provides an interactive virtual lab where learners can build and manipulate both series and parallel circuits, as witnessed in **Figure 3**.

Learners can connect resistors, light bulbs, and batteries to observe how current, voltage, and resistance behave in each configuration. The teacher can prompt them to construct both a series circuit and a parallel circuit using virtual components, measuring the voltage across each component and the current in various parts of the circuit. Example questions might include:

> What do you observe about the brightness of the bulbs in the series circuit compared to those in the parallel circuit?

> How does the total resistance change when additional resistors are added to each type of circuit?

These questions encourage learners to think critically about the behavior of current and voltage in different circuit types, fostering hands-on inquiry.

Phase 3 - Explain: Feedback and adaptive content

During this phase, the teacher can facilitate learning by discussing the circuits constructed using the LabXchange application. They can provide feedback as learners experiment with different circuit configurations. The platform offers additional resources such as videos, tutorials, and interactive diagrams to reinforce concepts that learners may find challenging. A follow-up question could be:

> If you add more resistors to the parallel or series circuit, what happens to the total resistance?

This question helps scaffold learners' understanding, allowing them to build a solid grasp of the material at their own pace.

Phase 4 - Elaborate: Application of knowledge in a new context

In this phase, learners apply their knowledge to solve a practical problem. For example, the teacher could ask them to design a circuit for a flashlight that uses both series and parallel connections to optimize brightness and battery life. Learners can use the LabXchange virtual lab tool to create designs where two bulbs shine equally brightly, and the circuit remains functional even if one bulb is removed. Discussions can also be encouraged to justify their solutions during this phase.

Phase 5 - Evaluate: Formative assessment and reflection

The teacher can utilize embedded quizzes and prompts to assess learners' understanding through reflection questions and performance data. A potential question for this phase might be:

> Why is it more advantageous to use parallel circuits in home wiring systems rather than series circuits?

Learners can submit their responses through the LabXchange app, where its AI tracker can monitor their progress. After this, the teacher can provide feedback to clarify any misconceptions and deepen understanding.

In conclusion, the AI-driven platform LabXchange enhances inquiry-based learning by offering interactive simulations and feedback, effectively engaging learners throughout the process. It helps develop a deeper understanding of concepts while fostering critical thinking and problem-solving skills.

DISCUSSION

This section discusses the benefits of AI tools, such as Magic School AI, Edpuzzle, and LabXchange, the challenges of using these tools, recommendations for their effective implementation, and suggestions for future research.

Benefits of the AI Tools

The three AI tools explored successfully connect the resource divide that obstructs the adoption of inquiry-based learning in schools with limited lab equipment and resources. The examples provided in the previous sections demonstrate how AI tools offer opportunities to integrate the 5e learning model, incorporating inquiry-based learning, virtual laboratories, and simulations. This enables learners to conduct experiments without physical equipment, addressing one of the primary barriers identified by Ramnarain (2016) and Mkimbili (2023). The virtual circuit builder and the simulations for chemical reactions explored above provide hands-on experimental experiences that would be impossible in schools without laboratory facilities. The adaptive lesson planning and the interactive simulations support differentiated instruction in large classes, which is another challenge highlighted in the South African context (Ramnarain, 2023). It also enables personalised learning, fostering deeper engagement with scientific concepts to improve their proficiency in the subject content. These AI platforms also promote critical thinking and problem-solving activities through the 5e learning model and interactive prompts in the simulations, encouraging higher-order thinking skills such as analysis, evaluation, and creation (see sections Teaching with Magic School: AI-enhanced personalized learning in science, Edpuzzle: Interactive video learning for critical thinking, and Teaching with LabXchange: Enhancing inquiry-based learning). These features align with the social constructivist framework, where active learner participation in knowledge construction is emphasised (Akuma & Callaghan, 2019). Apart from the above benefits for learners, the AI tools also provide substantial support for teachers in implementing inquiry-based learning (IBL) approaches. The lesson planning guidelines and virtual experiments using the 5e learning model, developed by Magic School, LabXchange, and Edpuzzle, address the challenges of teacher preparedness in implementing IBL methodologies, as identified by Anderson and Cha (2019). Apart from the above benefits, AI platforms integrate assessment tools that provide learners with immediate feedback and assist teachers in monitoring learner progress, identifying misconceptions, and providing targeted interventions.

Limitations of the AI tools

Despite the significant benefits mentioned above, AI-powered tools such as Magic School, LabXchange, and Edpuzzle also have challenges. For the effective use of AI tools, reliable internet connectivity and suitable devices are necessary. South African schools, particularly in rural areas, face limitations in these resources, and the digital divide could potentially exacerbate education inequalities if the infrastructure limitations are not properly addressed. As asserted by Ramnarain and Hlatswayo (2018), some teachers lack competence in implementing teaching strategies using technological tools. Without appropriate training, the teachers may be hesitant to use these tools or may implement them ineffectively. Another limitation is the risk of teachers' over-reliance on these tools, which reduces the teacher's role as a facilitator of learning. If technological assistance is taking over teacher guidance in the teaching and learning of the concept, the effective implementation of IBL will be compromised. The cultural context and the lived experiences of South African learners, as well as the examples provided by AI tools, may have a potential disconnect, which can impact learner engagement and the importance of gaining hands-on experience. This is another limitation which highlights the need to contextualise the AI-generated content.

Suggestions for Future Research

The exploration of the AI-powered tools for teaching and learning in the field of science opens opportunities for future research. The long-term impact that these AI tools have in sustaining learners' scientific knowledge, critical thinking skills and problem-solving could be researched. The above study focused on how AI tools can assist in inquiry-based learning in science. However, an investigation could be conducted on how the same tools can be used across other STEM disciplines, such as mathematics, to create integrated learning experiences that bridge the nature of scientific and mathematical concepts. The disconnect between the cultural context and the lived experiences of South African learners, as illustrated by the examples provided by the AI tools, was acknowledged as a limitation. Hence, the development of these AI tools in designing culturally responsive and contextually relevant examples and scenarios relevant to the South African learners could be explored. A study on developing different pedagogical models by integrating AI tools within the existing educational framework that fosters the development of critical thinking skills essential for 21st-century learners could also be done.

CONCLUSION

This conceptual paper investigated the potential of using AI educational applications to promote inquiry-based learning (IBL) and critical thinking in the science classroom. While IBL is globally recognized as an effective pedagogical approach that enhances learners' educational experiences, its practical implementation faces significant challenges (Attard et al., 2021; Berie et al., 2022), particularly in South African classrooms. Grounded in Vygotsky's social constructivist theory, the paper highlights the role of AI educational apps in fostering scientific inquiry by engaging learners in lessons that involve *engagement*, *exploration*, *explanation*, *elaboration*, and *evaluation*. The study found that science educators encounter substantial obstacles, including limited knowledge about IBL and inadequate resources in the classroom, which hinder their ability to effectively implement IBL strategies. To address these challenges, the study demonstrated that free AI educational applications like Magic School, LabXchange and Edpuzzle offer promising solutions by automatically creating interactive lessons that encourage scientific inquiry, critical thinking, and the practical application of concepts. In conclusion, integrating AI into science education presents a significant opportunity to overcome the difficulties associated with implementing IBL. To fully realize this potential, teacher development programmes must focus on equipping educators with the necessary skills and confidence to effectively use AI tools. Future research should build on this foundation by exploring how AI can similarly transform mathematics education, thereby creating dynamic and engaging learning environments across various disciplines.

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