Understanding the Theoretical Foundations of Inquiry-Based Learning: Pivot for Productive Science Education in Africa

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Introduction

Improving science teaching and learning has been the desire of all practitioners and science policymakers for a long time now. This is because effective science teaching is the bedrock for science and technological development in all nations. Countries that effectively imbibed the scientific culture are envied by other nations. This culture is only possible if science is taught and learned as a process of investigation anchored on inquiry (Wale & Bishaw, 2020; Oguz & Aybars, 2019). Instead of passively receiving information, students are encouraged to ask questions, design investigations, gather and analyze data, and construct their understanding of scientific concepts. This idea rests on the understanding that humans are exploratory, and when placed in real-world problem situations, can think critically and make meanings out of their experiences (Wale & Bishaw, 2020; Minner, et al., 2010). Since science is a real-world activity, the application of inquiry-based learning (IBL) could therefore foster and refine the natural abilities of students to learn science.

While learning science, students are often involved in hands-on experiments, open-ended investigations, and collaborative group work, using research materials and resources. This method of science resonates with the IBL approach, and not only fosters a better understanding of science concepts, but also develops students' skills in effective communication, data analysis, and hypothesis formulation (Bonet, 2021; Costes-Onishi et al., 2020; Gholam, 2019; Frasinescu, 2018). Studies (Käser, & Schwartz, 2020; Wale & Bishaw, 2020; Oguz & Aybars, 2019) have shown that when students are involved in IBL, they take control of their learning as they become motivated and actively involved in the search for answers to scientific questions. Being in alignment with the iterative process of science, IBL holds high implications in science education (Costes-Onishi & Kwek, 2023) as it enables science students to ask questions, make informed guesses, test their guesses, and find evidence on which to anchor their understanding of scientific phenomena. Educating African science students about effective and inventive science for the 21st century and beyond demands that science educators get a good grasp of the fundamental theoretical principles of IBL for adequate implementation of science curricula across the continent.

In addition to the above, understanding the theoretical foundations of IBL is essential as it holds the potential to:

- improve African science educators' knowledge and skills in designing instruction, embedding the iterative nature of science;
- help science educators in African schools draw from the several underlying theories that explain how individuals create and refine knowledge;

- guide science education practitioners to select appropriate learning materials for teaching science productively;
- guide teachers in structuring and implementing engaging lessons by adopting a myriad of strategies and techniques that yield retention of learned concepts, foster critical thinking, and ignite creativity among learners;
- unveil the challenges that could mar inquiry as an approach to science learning and proffer solutions to them;
- help science teachers manage diverse student populations with varied learning needs and challenges in science learning environments thus improving inclusiveness;
- support teachers in structuring activities that align with the African cultural worldview, hence preventing students from developing a phobia of learning science;
- help science educators to develop alternative methods of achieving science learning objectives; and,
- help science educators to continuously refine their thinking about science and become lifelong learners.

It is thus the focus of this paper to create awareness of the importance of IBL as an approach to science teaching and the implication of raising scientists for African economies. It is also to foster an understanding of the theoretical underpinning of IBL and how these theories can be adapted to improve science learning in African schools without cognitive and socio-cultural conflict due to the African epistemology (Tabulawa,1998). Science educators will also utilize the knowledge gained from this exposition to take science students into the realm of innovative science learning and practice.

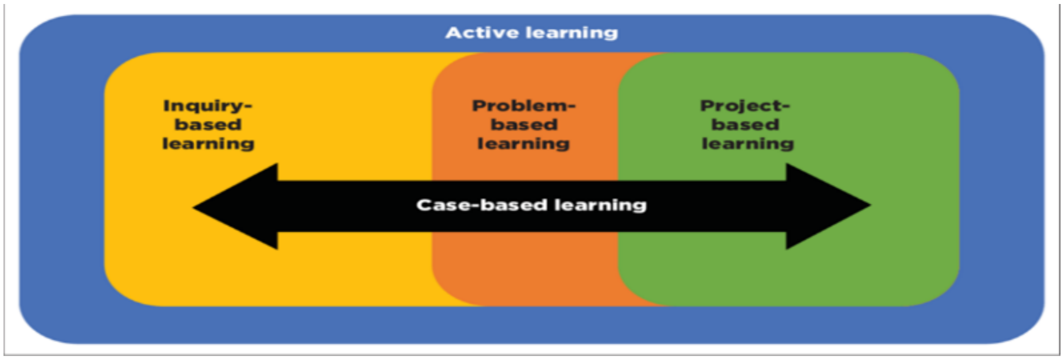
Conceptual Framework

Inquiry-based learning is an approach to learning in which students explore the real world, design, and carry out experiments, and ask and find answers to questions. In IBL, students acquire skills of problem-solving, critical thinking, and curiosity resulting in an in-depth understanding of science concepts as they interact with materials, nature, and scenarios. In IBL, students are allowed to behave like scientists, cultivate scientific attitudes, and unravel scientific wonders. The teacher in IBL performs the role of a facilitator while the students are actively engaged in the scientific process of discovery. Central to inquiry-based learning is the transformed role of students who take control of their learning. Instead of being passive recipients of information, students become the architects of their understanding (Costes-Onishi & Kwek, 2023). Questioning is the guidepost that directs the course of IBL through the sequential process of investigation, experimentation, and analysis (Stender et al., 2018). In this way, theories and hypotheses are tested, confirmed, or challenged. The process of learning science thus becomes an assemblage of puzzles-solving that result in fragments of evidence which, when pieced together correctly, unravels scientific understanding. IBL creates the classroom beyond the walls into the scientific world resulting in the fusion of classroom knowledge with real-world experiences and their applications.

In essence, inquiry-based learning in the context of science education is a vivacious conjugal of intellectual curiosity, hands-on experimentation, and collaborative discovery. It teaches students not just to learn science, but to become scientists with a thirst to unravel the secrets of the universe. Krugar (2017) illustrates the relationship between IBL, problem-based learning (PBL) and project-based learning as innovative pedagogies often grouped as case-based learning, shown diagrammatically in Figure 1. Krugar's illustration depicts science learning as an active process that cuts across different active learning strategies and is case- or situation-defined. IBL, thus, falls within the orbit of case-based strategies of science teaching and learning.

Figure 1

IBL as a Pedagogic Part of Case-Based Learning



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Constructivist Theories as Foundational Framework of IBL.

Piaget's Cognitive Constructivism. Constructivism, a major paradigm of the 20th and 21st centuries, drew attention to the role of mental processes in learning (Piaget, 1954). Piaget's cognitive constructivism emphasizes the role of active mental engagement in the construction of knowledge (Szabó & Csépes, 2023; Suhendi & Purwarno, 2018). Though there are critical issues with his stage theory from which constructivism is rooted (Suhendi & Purwarno, 2018), because of its age–right rigidity, its relevance in understanding cognition and meaning-making remains unrefuted. Piaget's ideas are pivotal to the understanding of inquiry-based learning (IBL). Piaget explains learning as a process of assimilating new information into existing mental structures (schemas) or by accommodating these structures to incorporate new insights. Students being cognitive beings, learn by constant construction and reconstruction of schema so that it fits into the newly acquired knowledge. IBL aligns with Piaget's theory as it encourages students to explore, question, and interact with their environment, thus fostering the development of new schemas or the refinement of existing ones. The iterative process of inquiry mirrors Piaget's notion of equilibration, where cognitive disequilibrium during exploration motivates the reconstruction of understanding, resulting in deeper learning (Adak, 2017).

However, Tabuwala (1998, 2013) presents a critique of the constructivist epistemology from the African socio-cultural perspective about science learning. He argues that introducing constructivism and consequently IBL into the African science education milieu without consideration of the socio-political realities that underlie the assumption about the nature of knowledge and the ways it ought to be transmitted, the teacher's perception of the students and the goals of schooling amounts to a technicist model that is incongruent with the teacher-centred approach reminiscent of colonial education in Africa. In his view, African science classrooms are unlike their Western counterparts where student autonomy is encouraged. In the African classrooms, traditional respect for authority, hierarchy, and communal knowledge transmission is the rule. He questions how student-centred, inquiry-based approaches can thrive in educational environments where the teacher is traditionally viewed as the primary source of knowledge rather than a facilitator of inquiry. He further suggests that constructivism should be recontextualized rather than imposed, ensuring it aligns with African epistemologies, African Indigenous ways of knowing as well as blends with the formal scientific inquiry with local knowledge systems. While these views are not antagonistic in our thinking, they push for a redefinition and deeper understanding of the foundation of constructivism and IBL that will fit the diverse cultural contexts and worldviews, especially in Africa.

This paper is not oblivious to arguments that effective teaching and learning are contextual and anchored in political, social, historical, and cultural contexts (Tabulawa, 1998, 2013). Tabulawa argues that African science education classrooms are value-laden with dominant teaching and learning paradigms, that teachers and students have been socialized into which is antagonistic to the student-centred philosophy of IBL. A confluence of ideas will produce harmony likely to further science education progress in African classrooms. Because they both acknowledge that students are the architects of their knowledge by embracing the power of inquiry, IBL and constructivism together re-frame education as a process of active involvement, empowerment, and profound understanding. Because of this confluence, education is transformed into a dynamic and collaborative process of constructing meaning rather than imbibing knowledge. This review is thus a synthesis of views towards fundamental understanding and creation of IBL that is not only compliant with but able to foster growth and productivity in African science classrooms.

Social Interaction Theoretical Strand of Constructivism. Learning is a social enterprise that takes place through interaction with competent peers or mentors (Vygotsky, 1962, 2012). This theory provided the foundation for the IBL, which was built around group learning activities. Students can achieve what Vygotsky called the *zone of proximal development* (ZPD), which is the stage of learning where students are propelled and able to tackle problems that are beyond their level of ability by working cooperatively. IBL fosters cognitive development through peer interactions, group discussions, and cooperative problem-solving as students work together to scaffold one another's comprehension. In line with Vygotsky's focus on the function of language and cultural resources in learning, the social negotiation of meaning within the ZPD enhances the inquiry process. According to Vygotsky, learning is a social process that is influenced by encounters with people who possess greater knowledge as well as the cultural setting in which those interactions take place (Vygotsky, 2012). Discussions, peer collaborations, and shared problem-solving are essential IBL group procedures that complement Vygotsky's theory by creating a social setting where learning is enhanced by group participation. One amazing advantage of social engagement in IBL is the synergy of learners' minds, where they combine their thoughts, exchange different points of view, and work together to develop a more thorough knowledge of science. In addition to strengthening their understanding, students are opportune to clarify their points of view and justifications to their peers, revealing any misunderstandings or gaps which are often cleared through group discussion. In this way, students challenge each other's presumptions, hone their theories, and collaboratively create knowledge through interaction. The communal nature of many African societies suggests that learning is not just individualistic but deeply social, collective, and influenced by hierarchical social relationships bearing relevance to Vygotsky's idea of co-construction of understanding.

The social interaction theoretical emphasis, that social contact has a significant influence on cognitive development, is important in the setting of inquiry-based learning (IBL) since it stresses the importance of group interactions and the collective creation of knowledge (Ellwood & Abrams, 2018). According to Vygotsky, learning is a social process that is influenced by encounters with people who possess greater knowledge as well as the cultural setting in which those interactions take place. IBL, which frequently entails peer collaboration, group debates, and cooperative problem-solving, fits in well with Vygotsky's theory since it creates a social setting where learning is enhanced by group participation. According to the IBL paradigm, social engagement is important for fostering cooperative discussion. Learning is facilitated by this interface, which brings students' thoughts into harmony with one another (Ellwood & Abrams, 2018). Students can combine their perspectives, exchange differing points of view, and develop a more thorough grasp of scientific ideas through collaborative discussions. This not only confirms their comprehension but also identifies knowledge gaps that require attention.

The social interaction theory relates to the African socio-cultural way of transmitting and sharing knowledge which hinges on community deliberations and negotiations using the power of language and interaction. Leveraging on this group-accepted pattern, the teaching of science in schools when fashioned in line with the IBL theoretical standpoint and the social interaction pathway of learning, is a fulcrum for authentic science education delivery in African schools

Collaborative Learning and IBL Approach to Science Education. Collaborative learning is at the heart of inquiry-based learning (IBL), reflecting the dynamic interplay between students as they jointly navigate the path of exploration, investigation, and knowledge creation. Within the context of IBL, collaborative learning assumes a pivotal role in shaping the educational experience and enhancing the depth of understanding and learning outcomes (Ugwuegbulam, & Achufusi-Aka, 2022; Okoli & Okigbo, 2021).

In IBL, peer interactions are not merely conversations, they are catalysts for knowledge construction. When students engage in discussions, share insights, and critically analyze information collectively, they weave together a rich tapestry of perspectives that contribute to a deeper and more holistic understanding. Peer interactions enable learners to challenge their assumptions, confront cognitive dissonance, and refine their ideas through constructive debates. The act of explaining concepts to peers fosters the articulation of thoughts and generates a deeper level of engagement and comprehension (Ellwood & Abrams, 2018). This mirrors the principles of social constructivism, where learners collaboratively build meaning through dialogue, reflection, and shared experiences.

In IBL, group dynamics are central to the problem-solving process. Collaborative groups become microcosms of scientific teams, where students assume roles, share responsibilities, and collaborate in tackling complex challenges (Sukontawaree, et al., 2022, Moemeke & Omoifo, 2003). The diverse strengths, skills, and perspectives within a group create an environment ripe for creative problem-solving. Through debates, brainstorming sessions, and collective decision-making, students navigate the uncertainties of inquiry while learning to negotiate differing viewpoints—an essential skill in scientific inquiry. Additionally, group dynamics foster peer accountability, where each member contributes to the overall success of the inquiry process, mirroring real-world collaborative scientific endeavours.

Collaborative learning in IBL thrives on the principle of synergy, that the whole is greater than the sum of its parts. It empowers students to harness the collective intelligence of their peers, providing opportunities for deep engagement, critical thinking, and the co-construction of knowledge. As students work collaboratively, they learn not only from their own experiences but from the insights and challenges shared by others. This collaborative spirit mirrors the essence of scientific exploration, where the exchange of ideas and perspectives catalyzes breakthroughs and discoveries. In essence, collaborative learning in IBL is a microcosm of the collaborative nature of scientific inquiry itself that encapsulates and triggers the spirit of curiosity, the power of shared exploration, and the joy of co-creating understanding in a community of learners.

In all these viewpoints, the role of the teacher remains a point of difference. In the African science classroom context, the teacher figure possesses the authority and power to drive the learning process. Constructing, collaborating, and creating knowledge outside the teacher influence posits learning only within the learner and peer community without teacher guidance is a significant departure from the hegemony of African tradition which in essence is counter-productive (Shivolo & Omari Mokiwa, 2024). It therefore important that science education practitioners in Africa redefine inquiry to align with the social exigencies of the African structure, creating a launch pad in the region for authentic science education

Situated Cognition Theory. Situated cognition theory (SCT) (Lave & Wenger, 1991) views learning as context-specific. It emphasizes that learning is deeply rooted and intertwined with the environment, culture, and experiences in which it takes place. SCT aligns perfectly with IBL which advocates and fosters learning in context as a more authentic form of learning. Learners of science often engage by immersing themselves in real-world situations where classroom concepts are found in reality facilitating a richer understanding as students perceive the intricate connections between theories and their applications as mirrored in the contexts where these skills are employed by professionals (Eang, & Na-Songkhla, 2020; Cian, et al., 2017; Zheng, 2010; Harris & Tweed, 2010).

Also closely related to the above in the situated cognition framework is the idea that knowledge and skills are most effectively learned and retained when they are situated within meaningful contexts (Darling-Hammond et al., 2020). This notion has profound implications for the transferability of knowledge which is the ability to apply what has been learned to new and diverse situations. This idea resonates perfectly with the IBL approach to science learning where transferability of knowledge and skills are crucial goals.

IBL Connects with Situated Learning in the following ways.

Learning in Authentic Contexts. Situated cognition posits that the extent of effectiveness of learning is best appreciated and understood when it is judged in an authentic context. This idea from situated cognition resonates strongly with IBL which encourages learners to explore real-world problems and phenomena. Whether in conducting experiments, gathering data, or analyzing evidence, learners engage in science in actual settings that help them draw relevance with scientific practice. Learning is experiential and promotes authentic understanding that enables students to connect abstract ideas to concrete experiences (Bell et al., 2013; Singer et al., 2011). The result is that learners acquire knowledge that is not only theoretical but also practical.

Knowledge Transfer and Application. Knowledge transfer refers to the utility of knowledge acquired in one context in another related or differentiated context. This is a major concept emphasized by situated cognition. IBL intersects with situated cognition principles that not only support, nurture, and foster but promote the application of learned concepts beyond the classroom. When students investigate real-world scientific problems in context, they gain insights into how they can utilize the knowledge to solve practical challenges (Singer et al., 2011; Canova Calori et al., 2013). To achieve this, IBL encourages students to think like scientists by equipping them with skills to tackle complex issues that transcend the disciplinary boundaries of their initial investigation.

In the conceptual framework of inquiry-based learning, the interplay between constructivist theories—such as Piaget’s cognitive constructivism and Vygotsky’s social constructivism—and situated cognition is evident. These theories provide the philosophical basis for IBL’s learner-centred, active, and collaborative approach. Moreover, they reinforce the authenticity of IBL experiences and underscore the importance of knowledge application in diverse settings, aligning seamlessly with the principles that define inquiry-based learning in science education even in an African context.

What is the Role of Inquiry in Knowledge Construction in Science? Inquiry is a dynamic catalyst that propels learners from passive recipients to active architects and constructors of knowledge and understanding. Through a process characterized by questioning, exploration, and curiosity, inquiry-based learning (IBL) becomes a conduit for learners to not only acquire knowledge but to construct it in a deep, meaningful, and lasting manner. This is achieved as follows:

1. Fostering Questioning, Exploration, and Curiosity. Questioning is a powerful tool that transforms the educational landscape by encouraging students to ask “why,” “how,” and “where” about the world around them. This creates inquisitiveness and curiosity thus setting the stage for active engagement, exploration, problem solving, and insight. This process fosters an intimate connection with the subject matter. Curiosity acts as the driving force, fueling the quest for knowledge and allowing learners to delve beneath the surface to uncover the underlying principles. This is what science learning is all about.

2. Building Conceptual Frameworks Through Investigation. Inquiry serves as the architectural blueprint for constructing robust conceptual frameworks. Through investigation, learners transcend the realm of rote memorization and venture into the territory of comprehension and synthesis. They gather data, experiment, analyze patterns, and draw conclusions—analogous to assembling the pieces of a puzzle to form a coherent picture. IBL empowers learners to transform isolated facts into interconnected concepts, building mental models that reflect a true understanding of the subject matter. In this process, learners are not merely passive observers but actively involved in constructing the scaffold that supports their comprehension.

3. Developing Communication Skills that Clarify Meaning in Science. The ability to communicate is what assigns meaning to observations and experimental data and gives interpretation to patterns from which meaning can be abstracted (Moemeke, 2023). Effective science communication is also the hob of peer interaction and collaborative science learning which are entrenched in both IBL and constructivism. In essence, inquiry-based learning transforms science education from a static transmission of facts to a dynamic process of meaning construction. It is important to note here that the attention-compelling attribute of technological media as communicative tools is an asset to IBL as it builds communication into the process of scientific inquiry (Moemeke, 2014). By nurturing questioning, exploration, and curiosity, IBL invites learners to become explorers and investigators, perpetually seeking answers and connecting thoughts. Through this process, learners forge deeper connections with the subject matter, internalize information, and construct intricate networks of understanding. IBL becomes the nurturing ground where curiosity blossoms into understanding and exploration births profound insights, ensuring that knowledge is not simply a gift received, but truly one earned and owned.

Authenticity and Contextualization in IBL. In the realm of inquiry-based learning (IBL), authenticity and contextualization emerge as the twin pillars that bridge the gap between theoretical concepts and tangible experiences. This is done by carefully weaving real-world relevance into the educational tapestry, thus transforming science learning into a vibrant voyage that resonates with students' lives, aspirations, and career success. An authentic learning environment that is IBL-supportive extends learning beyond textbooks and lectures by linking classroom experiences to real-world situations. It lifts students to the podium of scientists, engineers, and problem solvers. When students engage in IBL, they transition from learning about scientific principles in isolation to applying them to authentic, real-world scenarios. This is what happens when students are involved in designing experiments, analyzing data, or solving complex problems as is the case with expert scientists. This connection to reality not only deepens understanding but also cultivates critical thinking skills essential for navigating the complexities of modern life.

Authenticity and contextualization in IBL not only enhance understanding, it also ignites motivation and engagement in science learners. When learners recognize the practical relevance of what they are studying, their curiosity is heightened. Rather than absorbing disjointed information, students become actively motivated by a desire to understand how concepts apply to their world. Thus, the context-rich nature of IBL makes learning feel purposeful and meaningful and turns the classroom into a hub of exploration and discovery motivated by engagement and relevance

In the realm of IBL, authenticity and contextualization harmonize to redefine education as an immersive experience that extends beyond the classroom walls. By anchoring learning in the real world, IBL ensures that education is not an abstract endeavour but a journey with tangible impacts. As students engage with authentic scenarios and experience the relevancy of their studies, IBL becomes a conduit for not only understanding but also empowerment—a transformational force that equips learners with the skills and insights needed to navigate the complexities of a dynamically changing world.

Cognitive Load Theory and IBL. Another theory on which IBL is hinged is cognitive load theory (CLT) which explains how learners process information and engage in learning activities. Within the realm of inquiry-based learning (IBL), understanding cognitive load and its implications can significantly enhance the design of learning experiences and how they are implemented. Cognitive load is defined as the mental input necessary to process information or a text (Ayres et al., 2021; Sweller, 2020; Eitel et al., 2020; Ahmad et al., 2020; Josephsen, 2018; Klepsch et al., 2017; Kalyuga, & Singh, 2016). According to CLT, learners have a limited working memory capacity, and when that capacity is exceeded, it can hinder learning (Skulmowski, & Rey, 2020; Sweller, 2020; Anmarkrud et al., 2019; Cooper, 1990). Cognitive load can be categorized into three types: intrinsic (related to the inherent complexity of the material), extraneous (caused by the instructional design), and germane (focused on meaningful learning). Effective learning occurs when germane cognitive load is maximized, and extraneous cognitive load is minimized. In designing IBL activities, therefore, it is onerous to minimize extraneous cognitive load which can overwhelm learners such as complexities in instructional process, access to material, and mode of presentation while increasing germane cognitive load by focusing learning on knowledge construction.

Criticisms of IBL Theoretical Foundations. While inquiry-based learning (IBL) is a laudable pedagogical approach in science education, it is not without drawbacks for which it has been criticized. The practicality of the implementation of IBL has been questioned by critics. Some of the issues often raised by scholars are:

- Poor Coverage: Since inquiry is student-driven, poor coverage of curriculum requirements due to the slow pace of work can occur. Time is oftentimes a constraint in the IBL approach as gaps in content are often left in student learning. IBL requires extensive class time for the implementation of inquiry activities, experimentation, and student-led investigations, which may reduce content coverage (Mayer, 2004). Scholars also argue that schools in low-resource settings that lack access to laboratories, materials, and trained educators may find it difficult to implement IBL (Abd-El-Khalick et al., 2004; Ramnarain, 2014). Implementing IBL in a way that ensures equity and accessibility for all students can be complex.
- Untimely Feedback: The possibility of implementing IBL successfully in schools with large class sizes such that individualized inquiry is facilitated and timely feedback provided is almost an impossibility.
- Lack of Student Readiness: Sweller (1994) has noted that IBL often overwhelms students, especially novices who do not possess sufficient foundational knowledge of science with excessive problem-solving demands, making science learning cumbersome. Also, Kirschner et al. (2006) argue that minimally guided instruction in open-ended inquiry is often less effective than direct instruction, as learners need structured guidance to avoid misconceptions. Students without prior domain knowledge often struggle in the different steps in the IBL which leads to superficial learning. IBL assumes that students are equipped with the necessary skills to engage in self-directed inquiry. However, there can be significant variability in students' readiness for this approach (Schijndel et al., 2018; Pedaste & Sarapuu, 2014). Some might struggle with formulating research questions, conducting effective investigations, or analyzing data especially where there is limited teacher or expert guidance.

- Time Restraints: IBL can be time-consuming, requiring substantial time for students to explore, investigate, and construct knowledge. This poses challenges in adhering to curriculum timelines and coverage, especially in standardized education systems where content delivery is prioritized. Critics contend that IBL might not be practical within strict time constraints (Milatasari, 2013).
- Balancing Scaffolding: While scaffolding is a core component of IBL, striking the right balance between providing enough guidance and fostering independence can be challenging. If scaffolding is insufficient, students might struggle to navigate complex inquiries. If it is excessive, there is a risk of stifling creativity and autonomy (Aditomo & Klieme, 2019; Scott et al., 2018; Pedaste, & Sarapuu, 2014).
- Assessment Issues: Traditional assessment methods, such as standardized tests, might not align well with the open-ended nature of IBL. Critics argue that this could lead to difficulties in measuring and comparing student performance, potentially affecting accountability and evaluation systems. While traditional assessments focus on content mastery, IBL emphasizes process-oriented skills like critical thinking and problem-solving. Developing reliable and valid assessment tools to measure inquiry skills remains a challenge (Hmelo-Silver, 2004).
- Teacher's Knowledge of IBL Principles: The shift from a content-delivery role to a facilitator of learning can challenge educators. Teachers need expertise not only in their subject matter but also in guiding students through the inquiry process. Teachers often require specialized training to implement IBL effectively, but many science educators lack adequate professional development in this regard and as such often fail to implement it adequately (Furtak et al., 2012). The fear of adequate alignment with assessment strategies oftentimes forces science teachers to jettison IBL for teacher-centred modes. Some educators might find it challenging to relinquish control over the learning process to their learners.
- Emphasis on Science Process and Neglect of Content: Critics argue that IBL's emphasis on the process of inquiry might sometimes overshadow the importance of mastering foundational content. Striking the right balance between teaching essential content and nurturing inquiry skills can be challenging.
- Cultural and Contextual Constraints: In Third-World countries like Africa, where rote learning and teacher authority are predominant, students may struggle with IBL because they are not culturally permitted to question teachers or challenge established knowledge. Parental and societal expectations in certain educational systems favour content-heavy curricula, where students are judged based on standardized tests rather than inquiry-based learning outcomes. Some scholars (Tabulawa, 2013) argue that IBL is Western-centric, with the assumption that all learners from all cultures benefit from student autonomy and self-directed learning, which in his thinking is a fallacy.

A Synthesis of the Theoretical Perspective for IBL in Science Education. Inquiry-Based Learning (IBL) in science education is underpinned by multiple theoretical perspectives that explain how students learn best when actively involved in the process of inquiry. Constructivism, situated cognition, and cognitive load theory (CLT), among others, intersect to provide a holistic understanding of how IBL facilitates deep learning, problem-solving, and knowledge application. Together, these theories offer a balanced framework that ensures IBL is both student-centred, guided, and cognitively manageable, while also contextually meaningful.

Fundamental to the understanding of IBL is the constructivist perspective that learners are actively involved in knowledge construction and can solve problems individually and collaboratively through discussions, peer interaction, experimentation, and idea generation. These activities and engagement should, however, be situated within the context in which the learning is taking place, and align with the socio-cultural realities of the people concerned or in the real world of the learner thus bridging the gap between theory and practice of IBL in science education and diverse cultures and philosophies. This must however be properly managed to eliminate possible cognitive overload that could result when learners are unduly subjected to activities beyond their experiences. CLT, therefore, ensures that IBL is not overwhelming, but instead, effectively structured to support students' cognitive development, striking a balance between exploration and guidance. A resulting cohesion framework for effective implementation of IBL leveraging on its foundational perspective must take cognizance of these intersects while planning and implementing IBL in science education in Africa and other regions with peculiar characteristics. This ensures that inquiry-driven learning is not only engaging and contextually meaningful but also cognitively structured for maximum learning efficiency.

Remediating Misconceptions and Misunderstandings for Effective IBL. A major challenge to the effective implementation of inquiry-based learning (IBL) is student misconceptions and misunderstandings that arise during knowledge construction. These misconceptions originate from deficient prior knowledge, cultural influences, and incomplete or a partial understanding of science concepts. Since IBL gives premium to student-driven exploration, overcoming these misconceptions becomes crucial in fostering meaningful learning experiences from IBL. To adequately address students' misconceptions about science while involved in inquiry-based learning, teachers need to:

1. Recognize the misconceptions and their sources. Students might hold preconceived notions about certain scientific concepts that are inconsistent with the principles of inquiry. Identifying these misconceptions requires active engagement with students, open discussions, and formative assessments that reveal gaps in understanding. Knowing the origin of these preconceptions will enable efforts toward conceptual reconstruction and change.
2. Engage in constructive dialogue. When not properly handled, misconceptions can hinder further learning in science, but when teachers leverage interaction with science learners, they are let into their thoughts. Misconceptions are not barriers but opportunities for learning. IBL encourages educators to engage students in thoughtful discussions about their beliefs, allowing them to articulate their viewpoints. These dialogues provide insights into students' thought processes, enabling educators to address misconceptions by guiding them toward a deeper concept understanding with well-grounded background knowledge.
3. Provide authentic hands-on and explorative experiences. This is an avenue for teachers to counter misconceptions in science learners. When students engage in experiments and investigations, they confront their misconceptions in real-world contexts. Observing conflicting evidence challenges existing beliefs and prompts a reconsideration of previously held beliefs based on evidence.
4. Revisit some key concepts that are fundamental to scientific knowledge. This is essential in addressing misconceptions in science learners. When teachers provide opportunities for learners to re-explore, re-examine, and re-address previous

conceptual issues, they gain a deeper, better, and more authentic understanding of the concept. This automatically exposes and addresses some scientifically incongruent notions held by learners. Also, activities that enable learners to explore a concept from multiple perspectives enable them to gain holistic and more accurate knowledge about the concept.

5. Encourage student self-reflection. Self-reflecting, or thinking about one's thinking, is a principle known to deal with scientific misconceptions. Encouraging students to reflect on their thought processes and compare them with new evidence can help them recognize and refine their previously held views about a concept.
6. Leverage collaboration among science learners through collaborative group discussions and explorations. This creates avenues for learners to share diverse viewpoints, identify certain incongruities that are not group- or community-accepted, and make corrections through corrective problem-solving. This is because science knowledge is group/community negotiated. Collaboration provides a constructive and supportive opportunity to discard misconceptions and replace them with authentic knowledge.
7. Personalize activities and approaches. Science teachers and practitioners also help learners overcome misconceptions by personalizing activities and approaches according to the nature and source of an individual's misconception. Individualizing approaches harnesses the peculiar nature of individual thoughts and challenges to science learning (Schijndel et al., 2018).

Suggestions for Effective Development and Implementation of Inquiry-Based Learning (IBL). For effective IBL curriculum design, development, and implementation, science educators must:

- Grow research-authenticated hybrid models that adapt the tenets of the fundamental theoretical principles in the design of IBL curricula but with the African context in focus. It is also of immense importance that activities designed for learners should involve active exploration, collaboration, and application to real-world contexts. A mix of direct instruction and inquiry activities can ensure students build foundational knowledge before engaging in open-ended exploration.
- Define learning objectives such that both content mastery and the development of inquiry skills derived from IBL desired outcomes are well captured.
- Design a sequence of activities that gradually increase in complexity and depth of inquiry and knowledge base. This scaffold of learning experiences guides students through the inquiry process, offering support as needed while gradually fostering learner independence.
- Develop assessment strategies that evaluate not only content knowledge but also inquiry skills and critical thinking. Diverse performance-based assessment methods such as portfolios, presentations, community advocacy workshops, and town hall explanatory forums can be employed to showcase students' ability to apply their learning in real-world contexts.
- Plan and diligently execute teacher professional development in the IBL pedagogic principles, especially in the areas of fostering a deeper understanding of the IBL theoretical foundation through the regular organization of workshops, seminars, and training. This is to build the teacher's knowledge base of the principles underlying

constructivism, situated learning, cognitive load theory and social learning. The professional development of teachers will also include the acquisition of strategic skills in IBL curriculum design, effective facilitation, and adaptive instruction.

- Deliberately incorporate digital resources into IBL to enhance learning experiences through online databases, interactive simulations, and virtual experiments. Digital collaborative tools that enable students to work together on inquiry projects, whether in-person or remotely using real-time sharing, discussion, and collaborative problem-solving, are of necessity for effective IBL in science. These resources can enhance the authenticity of learning experiences.
- Develop and incorporate into IBL pedagogy data analysis tools by integrating technology which students can use to collect, analyze, and interpret data more efficiently. Incorporating technology into IBL also offers the benefit of clear data visualization necessary for making connections and drawing conclusions from complex datasets.
- Rather than rejecting IBL entirely, balanced approaches that combine structured instruction with inquiry elements can help novice learners transition into IBL. This must be preceded by investing in teacher professional development to equip them with strategies to facilitate inquiry effectively. These adjustments should be context-specific and culturally dynamic.

Procedure/Steps in Inquiry-Based Learning. As a student-centred approach to science teaching, IBL involves a series of procedural steps for effective implementation. Students acquire skills in critical thinking, problem-solving and other process skills of science. The total autonomy granted to the learner—who oftentimes lacks the experiential knowledge to identify and understand some experimental processes and results in this process—has been the subject of criticism in this approach and resulted in advocacy for the inclusion of teacher guidance in the iterative process of the IBL often described as guided inquiry-based learning (GIBL). In this modified approach, students receive foundational knowledge while developing critical thinking skills (see Table 1). The procedure follows these steps:

Table 1
Procedural Steps and Activities in the Two Strands of IBL Activities

Phase	Activity in student autonomy IBL	Activity in guided / blended IBL	Teacher's role in autonomy IBL	Teachers' role in guided / blended IBL
1		The introduction stage is during which the teacher does an exposition of the topic by providing needed background information on key concepts, theories, or procedures through lectures, demonstrations, or multimedia	Nil	Teacher-led

		presentations to ensure students have strong background knowledge of the study.		
2	Engagement is during which the teacher presents tasks, science-related questions, problems, or scenarios and encourages students to find solutions to them by exploring the environment and applying curiosity using available resources. Such questions or problems can also originate from the student's previous experiences.	The questioning and problem identification stage is during which the teacher asks a guiding question or creates a scenario of a real-world problem related to the topic.	Teacher and student-led	Teacher
		Students are encouraged to think critically, make predictions, or brainstorm possible solutions under the teacher's guidance.	Nil	Teacher and students
3	Investigation stage during which students carry out research, explore possibilities, gather information, conduct experiments, and find answers or solutions.	Investigation and exploration stage during which students become engaged with activities such as experiments, case studies, or data analysis while the teacher provides prompts, scaffolding, and targeted feedback so that students stay on track while actively constructing and discovering information.	Solely student	Student with teacher guidance
4	Analysis stage during which students analyze the data already collected to identify patterns, interpret such patterns, and draw conclusions based on their level of background experiences.	The analysis and conceptualization stage is during which students make meaning out of their generated data (interpretation), identify patterns, and relate findings to the topic content. The teacher	Solely student	Student with teacher guidance

		helps students link their findings to align with notable scientific laws and theories of principles in the broader domain of science.		
5		Application phase during which students utilize their newfound knowledge to solve problems, create projects, or explain concepts in their own words. The teacher reinforces learning by clarifying misconceptions and providing additional examples.		Student with teacher support
6	Reflection phase which students synthesize and evaluate their learning as they discuss their findings with peers, receive scaffolding, and refine their understanding.	Reflection and discussion stage where students present their findings, and present their conclusions using acceptable formats. The teacher creates prompts that provide leads to stimulate students to think critically	Student	Student with teacher prompts
7	The communication phase is during which students utilize existing platforms to share their findings, discuss their challenges, and receive encouragement for their endeavour.	while making explanations.	Student and peers	
8	The assessment and feedback phase are where the teachers review and evaluate the student’s understanding using diverse feedback methods and make recommendations for further investigations and improvement.	Evaluation and feedback where the teacher evaluates students’ learning using formative diverse assessment tools and provides feedback that may direct future exploration.	Student and teacher	Student and teacher

In addition to promoting the acquisition of essential skills of critical thinking and problem-solving, the students receive foundational information that guides their search thereby saving time and resources in the guided IBL process.

Case Studies of Successful IBL Implementation in Africa. A quasi-experimental study was conducted in Ghana by Assem et al., (2023). The research investigated the impact of IBL on 40 junior high school students' learning of science. The experimental group received instruction through IBL methods, while the control group experienced traditional teaching approaches. The study revealed that students taught via IBL exhibited significant improvements in academic performance and comprehension of scientific concepts, particularly among those with lower English proficiency.

Another study in South Africa adapted the French LAMAP IBL program within a local educational setting using a qualitative multiple-case study design. Young children and student teachers were the subjects and were engaged in scientific inquiry activities. The study revealed that the LAMAP IBL enhanced scientific curiosity and understanding among students (Ramnarain & Hobden, 2015). Another South African experiment is the LEAP project. The LEAP Science and Maths Schools in South Africa provide a practical example of IBL implementation. Established to address educational inequity, these schools focus on mathematics and science, emphasizing the emotional development of learners alongside academic achievement. By integrating IBL strategies, LEAP schools have successfully increased the number of Black learners pursuing science-based disciplines at the university level, demonstrating the effectiveness of IBL in promoting educational advancement.

A recent study in Namibia reported science teachers' positive perceptions of integrating IBL into their teaching practices. The study, after a survey of 133 participants, revealed a strong preference for IBL methods, emphasizing its effectiveness in engaging learners, fostering critical thinking, and connecting scientific principles to real-world scenarios. This positive attitude toward IBL suggests a readiness among educators to adopt inquiry-based approaches in Namibian science classrooms (Shivolo & Omari Mokiwa, 2024). A quantitative descriptive research design in Rwanda with 82 science teachers concluded that the choice of appropriate teaching and learning approaches, such as IBL, influences understanding in science education. However, it also highlighted teacher capacity as a drawback (Manishimwe et al., 2022; Manishimwe et al., 2023).

These case experiments of IBL in Africa reveal the potential to harness and maximize IBL in implementing science education in Africa but not without drawbacks, especially in teacher competence, resource availability, and assessment procedures.

Discussion

Inquiry-based learning (IBL) stands out as one of the most acknowledged pedagogies in science education, because of its efficacy in fostering deep student engagement, development of critical thinking structures, and real-world problem-solving. Rooted in constructivist theories, IBL emphasizes active learning, where students construct knowledge through exploration, questioning, and collaboration reminiscent of professional scientific practice. Piaget's cognitive constructivism highlights the learner’s role in knowledge construction, while Vygotsky’s social constructivism underscores the importance of peer interaction and scaffolding. Situated cognition theory further strengthens IBL’s foundation by advocating learning in authentic contexts, ensuring that students apply knowledge meaningfully. These theoretical standpoints establish IBL as an effective science education pedagogy.

However, the implementation of IBL is not without challenges. Cognitive load theory cautions against overwhelming learners, particularly novices, by demanding too much self-direction without sufficient foundational knowledge. Additionally, practical constraints, such as limited teacher capacity for implementing IBL, resource scarcity, and learning outcome assessment challenges, raise concerns about the effectiveness of IBL in diverse educational settings including Africa.

In addition to cognitive and implementation concerns, IBL faces socio-political and cultural obstacles that impinge on its widespread adoption, particularly in African contexts. Tabulawa (2013) argues that IBL is Western-centric if all learners benefit from self-directed inquiry, whereas many African educational traditions emphasize teacher authority and knowledge transmission already ingrained in the structure. Moreover, in societies where education is tightly linked to national development goals, standardized testing and rigid curricula leave little room for open-ended inquiry.

Economic and political constraints also shape IBL’s feasibility. Underfunded schools, high student-teacher ratios, and poor resource availability make it difficult for educators to facilitate inquiry-based methods effectively, especially in economically disadvantaged societies. Additionally, policymakers may resist IBL due to concerns about its alignment with existing educational priorities, particularly in nations where science education is geared toward immediate workforce needs rather than long-term scientific achievements.

Irrespective of these concerns, IBL experiments in Ghana, South Africa, Rwanda, and Zambia, provide evidence of the workability of IBL in African science classrooms and can positively improve student engagement and science learning outcomes. The success of these programs makes the case for balanced educational settings where blended and guided inquiry and direct instruction complement each other to the extent of evolving an IBL model suitable for the African science education space.

Conclusion

Inquiry-based learning stands as a powerful pedagogical approach, redefining science education by shifting from passive knowledge transmission to active knowledge construction. By integrating constructivist, situated cognition, and cognitive load theories, IBL provides a theoretically rich foundation for fostering scientific literacy and lifelong learning. However, the challenges surrounding IBL extend beyond classroom logistics to deep-rooted socio-political and cultural factors. The dominance of teacher-centred instruction, the pressure of standardized assessments, and the economic realities of under-resourced schools all present legitimate counterarguments to IBL’s widespread implementation. Moreover, questions regarding IBL’s applicability across diverse cultural contexts highlight the need for localized adaptations rather than one-size-fits-all models.

To bridge the gap between theoretical promise and practical realities, hybrid pedagogical models—blending inquiry-driven exploration with structured guidance—may offer the most sustainable, context-sensitive solution. Education policymakers, researchers, and practitioners must work collaboratively to develop IBL approaches that align with local educational goals, resource availability, and cultural values.

As science education continues to evolve in Africa, cutting-edge research, policy engagement, and reinvigorated teacher training programmes will be essential to build IBL models that balance student autonomy and African epistemology with necessary instructional support. By addressing both theoretical and socio-political complexities, science educators can harness IBL's numerous qualities while ensuring equity, accessibility, and adaptation to lift science education to an envious level in Africa.

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