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ORIGINAL PAPER

Teaching and learning science as inquiry: an outlook of teachers in science education

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Abstract

For years, educators have recognized inquiry-based learning as a cutting-edge and promising approach in science education. However, the connection between teachers' beliefs and practices and students' attitudes within inquiry-based classrooms has not been fully explored. This study employs a mixed-methods approach, combining quasiexperimental and descriptive research designs with quantitative data analysis. The results indicate a statistically significant difference in the performance of students who participated in a Chemistry Achievement Test between the control and experimental groups ($t = 5.66$, $p < 0.05$). Furthermore, our research highlights teachers' optimistic views and eagerness to embrace inquiry-based learning. They perceive it as a means to ignite students' enthusiasm for science subjects and foster the acquisition of essential science process skills through practical activities. This study contributes to a deeper understanding of the interplay between teacher perspectives, instructional methods, and students' grasp of the scientific process in science education, emphasizing the potential benefits of inquiry-based learning for enhancing science education.

Keywords Inquiry-based learning · Science education · Teachers' beliefs · Students' attitudes · Classroom practices

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Introduction

In the realm of science education, the teaching and learning process stands as a cornerstone of knowledge dissemination and skill acquisition, captivating the attention of educators, researchers, and policymakers alike (Kuhn and Pease 2016). A prominent pedagogical paradigm in contemporary science education, inquiry-based learning (IBL), has emerged as a powerful catalyst for fostering deep understanding and enthusiasm for science subjects.

IBL emphasizes active exploration, critical thinking, and student-centered discovery, aligning with the evolving needs of today's students who seek more interactive and meaningful learning experiences (Furtak et al. 2012). However, as the benefits of IBL have gained recognition, the pivotal role of teachers in shaping the IBL experience has come under increasing scrutiny. Teachers' perspectives, beliefs, and instructional practices significantly influence students' attitudes, engagement, and mastery of scientific concepts within an IBL framework. This study embarks on an exploration of this critical nexus, offering a comprehensive outlook on how teachers in science education perceive and enact IBL, with profound implications for both pedagogy and curriculum development.

Teaching in the current era necessitates a suitable teaching method to achieve promising learning outcomes and imparts 21st century skills to students. Teaching science subjects in particular has been revolutionized due to technology advancement (Kalolo 2019; Oke and Fernandes 2020; Castro and Tumibay 2021). Teachers' ability to deliver instruction by using a proper teaching and learning approach facilitates students' learning, and they go through the education systems confidently with a skill package to help them cope with an ever-changing world. Inquiry-based learning shows favorable learning results when it is applied in teaching and learning science subjects. As inquiry-based learning (IBL) has been valued from a global perspective as appropriate in teaching science subjects, this approach has been an area of exploration in different aspects. Numerous studies that validate the effectiveness of IBL exist in the field of science education (Turner et al. 2018; Kuo et al. 2019).

A large and growing body of literature in science education provides considerable modern instructional approaches as substitutes for traditional modalities of instruction delivery. The most influential instructional modalities include inquiry-based learning (Rutherford 1964; Cabe Trundle et al. 2010), constructivist learning (Cheng and Tsai 2013; Alt 2015), and problem-based learning (Hmelo-Silver 2004; Yew and Goh 2016). In all these modern instructional methods, students are situated at the center of learning, and the teacher serves as the facilitator of learning.

A recent study conducted by Nsengimana et al. (2017) on how to contextually analyse the perceptions of teaching quality in Rwandan secondary schools revealed that teachers encounter various difficulties, including the choice of a suitable teaching and learning method, particularly in science subjects. Furthermore, the study carried out by Nsengimana et al. (2014) showed that science teachers were still dominating in the lessons than learners who remained passive during the learning process.

Other studies (Srisawasdi and Panjaburee 2019; Kang 2022) have emphasized that instructors view IBL as a promising strategy for science teaching. Although aspects of instructional quality, the learning environment, and the availability of learning materials have not been sufficiently explored, they can hinder the implementation of IBL. A plethora of studies exist in view of the influence of IBL on students' achievement, attitudes, and teachers preparedness toward implementation; however, the effort made in improving science teaching by researchers worldwide and guidance on how to achieve quality teaching and learning using IBL still presents a skill gap on the side of teachers (Wale and Bishaw 2020; White et al. 2020; Carter et al. 2021).

Therefore, this study sought to consider secondary school science teachers for two reasons. First, in the Rwanda education system, especially secondary schools, teachers use monotonous teaching approaches, although few are aware of IBL but do not use it appropriately. Second, this study was conducted to inform secondary school science teachers about the benefits of using IBL in teaching and learning processes. For these reasons, researchers explored three areas of interest, namely, the application of IBL followed by the measurement of its effect on student achievement in chemistry subjects, exploring how IBL affects students' attitudes toward IBL applications, and finally gathering the views of secondary school science teachers about IBL implementation.

IBL as a student-centered method

The last decade has witnessed remarkable efforts aimed at the adoption of competence-based curricula within sub-Saharan countries, with a particular focus on Rwanda. In 2015, the Rwandan government, in collaboration with the Ministry of Education and key stakeholders, embarked on a pivotal shift away from traditional pedagogical approaches. This transformation ushered in a new era of contemporary, student-centered classroom activities, effectively challenging the conventional perception of teachers as the solitary "sage on the stage." Instead, educators were reimagined as facilitators of student learning, aligning with global trends towards more engaging and participatory educational experiences (Ministry of Education, Rwanda, 2015).

The pursuit of educational curricula reforms necessitated multifaceted adjustments, encompassing various dimensions of the educational landscape. These encompassed the reorganization of content, innovative instructional delivery methods, the optimization of teaching and learning resources, and a fundamental reevaluation of the relevance of knowledge and skills imparted to students. Crucially, these reforms were driven by the recognition that education should extend beyond the classroom to prepare students for employability and real-world challenges after their formal schooling period.

Within this reformative framework, a paramount emphasis was placed on the facilitators' capacity to effectively implement the newly designed instructional content. Their role transcended mere dissemination; it became instrumental in advancing students' active involvement, enhancing their comprehension of instructional procedures, and nurturing the application of acquired skills. This emphasis underscored the vital role of facilitators in bridging the gap between curriculum design and students' practical understanding and competence.

Our study's significance is intrinsically linked to the broader context of educational transformation in Rwanda and the sub-Saharan region. It underscores the pivotal role of facilitators as they navigate this educational shift towards more student-centered methods, particularly Inquiry-Based Learning (IBL). By exploring the facilitators' ability to implement these changes effectively, this research contributes to our understanding of their vital role in shaping students' educational experiences and enhancing their future prospects within a competence-based curriculum framework.

Evidence from previous studies (Krajcik et al. 1998; Sandoval 2005) indicates that inquiry in science education refers to a method of questioning to acquire, create and devise approaches towards understanding questions through data generation followed by analysis and interpretation and, subsequently, conclusions based on findings. According to Linn et al. (2004) as quoted by Rodríguez-Arteche and Martínez-Aznar (2016)

> Inquiry-based science education is defined as the intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments.

Madhuri et al. (2012) maintains that IBL can be conducted through interlinked processes, specifically those involving laboratory practical activities, including the context, prelaboratory, laboratory and postlaboratory sessions. Findings obtained through these inquiry session procedures affirmed that students' understanding of concepts in science and improved capacities of inquiry have been attained, integrated, and applied in real-life situations in a social context. More importantly, the conducive environment stemming from the IBL method facilitated students to experience outstanding achievement with better grades, whereas in most conducted experiments, students received A+ and B grades.

It could be an accepted truth that students in an enabling, conducive and motivating environment can construct their own understanding from interaction with the learning materials at hand. This view is supported by Bryson and Hand (2007), who maintain that students experience various levels of engagement depending on the support received during learning. Hofstein and Lunetta (2004) also emphasized that the nature of the learning environment is essential to facilitate science education, and as reported elsewhere. Guo (2018) stressed that there are prospective benefits of an augmented reality-mediated learning atmosphere that may lead to effective teaching and learning in engineering-related courses. Other studies considered IBL as a promising method to make science content easily perceptible by students of various backgrounds (Cuevas et al. 2005; Akerson and Hanuscin 2007). Therefore, it is imperative to use IBL in teaching and learning to improve students' performance and attitudes during classroom practices.

The 5E model as a learning cycle approach to IBL

Despite the effort that has been made by global researchers to advance the idea that IBL could be beneficial in teaching and learning science, instruction facilitators' perceived knowledge of instructional design is controversial in the implementation process. For the last two decades, great effort has been devoted to the study of the 5E model as a learning cycle to facilitate the inquiry process. The adoption of an approach that emphasizes constructivist philosophies is fundamental. The 5E instructional model has previously gained the attention of educational researchers (Duschl and Bybee 2014; Hew et al. 2018; Lai et al. 2018; Leung 2019). The cycle involves five sequential steps, which are briefly described herewith.

Engagement. Students are facilitated to recall prior knowledge through probing questions, which make them engage actively

Exploration. The facilitator challenges the preliminary knowledge of students about the subject matter to create new ideas.

Explanation. Students become able to explain phenomena based on new knowledge gained from collaborators on the same learning team.

Elaboration. Students apply new knowledge to new challenging situations, thereby expanding horizons of creative and innovative thinking

Evaluation. Students' reflection on acquired knowledge seems to be the key in team-based learning and assessment to ensure that understanding and retention should be fostered in this step.

Teachers' knowledge of the appropriate learning cycle, preferably the 5E described above, can help in the effective imaplementation of inquiry-based teaching and learning.

Benefits of inquiry-based learning

Facilitating science instruction within an inquiry-based learning (IBL) classroom milieu both incites and mirrors educators' endeavours to cultivate student learning, thereby constituting the fundamental tenet of science pedagogy over recent decades.

Previous studies have affirmed that inquiry-based learning exposure improves science students' interest in learning science subjects (Veloo et al. 2013; Gillies and Nichols 2015). Conceptual understanding of science content (Duran et al. 2009; Kanter and Konstantopoulos 2010; Decristan et al. 2015) has been associated with IBL implementation, active participation (Abdi 2014; Inel-Ekici and Ekici 2022), students' motivation (Bayram et al. 2013), mastery and retention of instructions (Alake-Tuenter et al. 2012; Marshall and Alston 2014). The scenario of inadequate instructional methods could be seen as a key factor in students' loss of appreciation and choice of science-related careers. IBL could be an alternative suitable method to innovate classroom practices.

Inquiry-based learning versus students' attitudes

The idea that inquiry-based learning enhances students' engagement by promoting active participation has attracted the attention of researchers on a broad spectrum. The American Association for the Advancement of Science (AAAS) has validated IBL as a suitable approach for science content delivery (Pozo and Luna 1993; Gibson and Chase 2002). In addition to active classroom participation, students gain self-confidence when facing tasks requiring abilities in scientific approaches (Gormally et al. 2009). A plethora of investigations have indicated that practicing inquiry in lab-related learning activities promotes the authentication of science content exposure (Holbrook et al. 2014; Lewthwaite 2014; Cowden and Santiago 2016). On the other hand, previous studies have reported reasons behind students' resistance towards learning practical courses through inquiry (Prince and Felder 2006; Crawford 2007). Therefore, IBL challenges students as novice and practicing future scientists due to complexity and frustrations while interacting with inquiry-focused curricula.

Practice and difficulties during inquiry-based learning implementation

Reinventing science education through inquiry-based learning has faced a couple of challenges not only in sub-Saharan Africa but also internationally (Mtika and Gates 2010).

Contemporary advances in science education have revolutionized instructional methods, including learning environment (Duschl 2008), learning resources, and instructional materials (Engelbrecht et al. 2020). Therefore, the education systems of various countries have become sophisticated to instill in students the fundamental skills that are believed to respond to societal needs. One of the shared aspects of science curricula in many countries is students' appreciation of the process through which scientific knowledge and skills are acquired (Jiménez-Aleixandre and Erduran 2007; Bayram-Jacobs et al. 2019; Zidny et al. 2020).

Inquiry-based teaching and learning epitomizes a learning approach by which teachers, as primary implementers of curricula content, can help students develop such a sense of appreciation. Science rules, principles and norms (Longino 2018; Li and Schoenfeld 2019) are of paramount significance for teachers to impart the body of science process skills into students' various cultural diversity. The central and crucial feature in this regard is that teachers' efficiency and effectiveness depend on the aptitude to transfer within a variety of skills to students in meaningful, comprehensible, creative and innovative scientific exchanges.

Despite the tremendous synergy of stakeholders in education to improve the conceptual understanding of teaching and learning science as an inquiry during classroom practices, the efficiency and effectiveness of the fruitful enactment of IBL has long been associated with difficulties (Kim et al. 2013). It is a continuum of science teachers' wrestle on a daily basis. Data from several sources (Quigley et al. 2011; Litmanen et al. 2012; Mumba et al. 2015) have identified difficulties often observable among secondary school science teachers, including but not limited to the preliminary knowledge and skills in teaching and learning approaches, absence of exposure to science teaching leading to the lack of teaching experiences prior to starting teaching as a profession, difficulties in subject content mastery, inadequate school and classroom environment, inadequate and insufficient instructional materials and resources.

Difficulties are not an issue of preservice and novice teachers only; instead, it has also been indicated in ample research that in-service and experienced teachers encounter constraints such as the absence of administrative encouragement and support, negative attitudes towards science process skills explanation, conservative mindset and lack of accountability of classroom science teachers (Teig et al. 2018; Abdurrahman et al. 2019). The research conducted herewith reports experiences of secondary school science teachers concerning the 5E Instructional Design in the Inquiry-Based Learning Environment towards Shaping Students' Attitude in Science Education.

Although abundant literature concerning IBL exists from a global perspective and regarding the use of IBL during lesson delivery among university students, learning results are common. This study was conducted in response to problems observed in relation to teaching methods in secondary schools. As teaching science subjects require teachers' ability to use a variety of teaching approaches that in turn improve students' performance and attitudes, awareness of the benefit of IBL can bring about positive change among secondary school science teachers in Rwanda. The current study investigates the effect of teaching and learning science as inquiry by considering the outlook of teachers in science education. Specifically, the authors were guided by the following research objectives.

1. To examine the effect of IBL on year five students' performance in chemistry.
2. To explore how IBL can affect students' attitudes towards learning chemistry.
3. To gather the perspectives of science teachers about the implementation of IBL during classroom practices.

Design and methods

This research adopts a mixed approach employing quasiexperimental and descriptive research designs employing quantitative data. Fifteen secondary school science teachers were requested to participate in the research on a voluntary basis. Participants were from three private secondary schools, one in a rural area and another in an urban area in Muhanga district of Rwanda, and the third school was from Bugesera district in the Eastern province of Rwanda. The inclusion criteria of the participants included being in a position of teaching natural science subjects/ subjects such as chemistry, physics, and biology or a combination of two natural science subjects. Prior to online survey administration, the researcher collaborated with one experienced chemistry teacher in each school to ensure that participating teachers and students understood the concept of inquiry-based learning. This preliminary task helped teachers relate daily teaching practices to IBL.

A questionnaire as a research instrument was composed using adapted item statements from PRIMAS. The intention of using the content of PRIMASS was built on the evidence that it contains relevant items of interest in relation to teachers' beliefs and practice in the inquiry science teaching-learning classroom atmosphere. Additional item statements corroborating the exploration of students' attitudes in the same umbrella were self-designed. Methodically, the questionnaire contained eleven items, of which six were adapted from PRIMAS, with three in connection with teachers' beliefs and the other in relation to teachers' practices. The self-designed items to gather information about students' attitudes comprised five items. Together with demography-related items, the questionnaire of the online survey using Google Forms was distributed to participants via communication means, specifically E-mail and WhatsApp. The return of all administered online survey questionnaires took a period of three weeks from September 09 to September 30, 2022. Thirteen questionnaires were returned, corresponding to a return rate of 86.6–87%.

Sample of the study

This study sought to understand the perspectives of eleven secondary school science teachers from College Sainte Marie Reine and College Saint Jean Nyarusange on teaching science as inquiry. For two reasons, we employed the purposive sampling technique. First, the researchers who were conducting the research had easy access to the involved science teachers; in fact, one of the researchers had them as colleague teachers. Second, participation was guaranteed to be voluntary because science teachers from the selected secondary schools were open to participating in the research. Students in two-year five classrooms from Maranyundo Girls School who were enrolled in physics, chemistry, and math (PCM) and physics, chemistry, and biology (PCB) combinations were specifically targeted. There were 20 students in each class.

The team of investigators took great care to thoroughly understand the participants' demographic data, which included their gender, age, taught subject, affiliation, and teaching experience. These factors were investigated as important criteria to assure the accuracy of the data that were obtained. Three female participants (27.3%) and eight male individuals (72.7%) made up the participants' gender. Physics, biology, and chemistry were the subjects that were taught, accounting for 3 (27.3%), 4 (36.4%), and 1 (9.1%) of the total, respectively. Five participants (45.5%) were under the age of 30, four (36.4%) were between the ages of 31 and 35, and two (18.2%) were over the age of 40. Four participants, representing 36.4%, belonged to the College Saint Jean Nyarusange, while seven participants, comprising 63.6%, were from the Sainte Marie Reine Kabgayi College in Muhanga district. Notably, participants' teaching experience ranged from less than two years with 3 (27.3%), 2–4 years with 3 (27.3%), 5–7 years with 1 (9.1 %), 8–10 years with 2 (18.2%), and above 10 years of experience with 2 (18.2%).

Lesson delivery for experimental and control groups

In this pedagogical investigation, we elucidate the instructional methodologies employed in the context of the experimental and control groups. The experimental cohort of students was subjected to an instructional framework founded upon inquiry-based learning principles, affording them the opportunity to acquire knowledge through active engagement in experimentation, data acquisition, and the articulation of findings. Within this didactic milieu, students within the experimental group were encouraged to actively interface with the course content, engendering a symbiotic relationship between theory and practice, as they ventured into the realms of experimentation, observation, meticulous data recording, and the judicious formulation of inquiries to elucidate points of uncertainty.

Conversely, students constituting the control group were subjected to a more conventional pedagogical approach, characterized by didactic instruction wherein the instructor disseminated knowledge employing the traditional medium of chalk and chalkboard. This traditional paradigm restricted the control group's educational experience to the passive reception of didactic content, without opportunities for active engagement, hypothesis testing, or the pursuit of experiential learning modalities. It is noteworthy that the pedagogical sessions pertaining to the chemistry subject were led by one of the principal researchers involved in the study.

The rationale underpinning this comparative educational paradigm was predicated upon the hypothesis posited by the authors of this study. Namely, it was conjectured that the application of inquiry-based learning (IBL) would furnish the experimental group of students with an enhanced capacity to retain scientific knowledge when juxtaposed against their counterparts in the control group, who were predominantly exposed to the passive reception of didactic lectures.

Measurement tools and administration of chemistry achievement test (CAT)

A quasiexperimental study using a pretest-posttest design was used to collect experimental data from students in year five at Maranyundo Girls School to investigate the effect of IBL on students' achievement in chemistry. The chemistry achievement test comprised open questions of volumetric titration in relation to the national curriculum of year five of the advanced secondary level. The administration of the test was conducted in two phases. First, the intention was to explore the effect of teaching science as inquiry in the inquiry-based learning environment through 5E phases. Researchers in this study are in-service chemistry trainers and biology trainers in secondary schools. Second, two groups that correspond to Class 1 (year five, Physics, Chemistry and Mathematics combination) and class 2 (year five, Physics, Chemistry and Biology combination), each class comprising 20 students, were purposively selected. Afterwards, class 1 and class 2 were referred to as the control and experimental groups, respectively. Students were taught the same learning unit employing different treatments (i.e., the Lecturing method and inquiry-based learning). The lessons were from learning unit 11 extracted from year five students' chemistry book "Solutions and titration".

The teaching and learning cycles took 20 days, which was 40 h for each group. Thereafter, students were given 5 days to revise what they had been taught. A practice-based pretest was administered prior to normal rounds of teaching and learning to be aware of students' prerequisite knowledge about solutions and titration, while a practice-posttest was conducted after complementing usual teaching with treatment, which is inquiry teaching leading to inquiry-based learning herein abbreviated as IBL. Students' performance during the pretest and posttest was kept in an Excel datasheet for further analysis.

The achievement test items were initially created by the researcher himself to assess students' understanding of volumetric titration to validate the development of the chemistry achievement test as the research tool for gathering data from students. The developed test items were sent to three experts holding a master's degree with a specialization in science education in particular and chemistry education to review the relevance of the test items. In this regard, they found the two items of pretest-posttest valid to measure what the research wanted to measure. Both the test items for the control and experimental groups were administered twice to two master's student researchers from the University of Rwanda, the African Center of Excellence for Innovative Teaching and Learning Mathematics and Science, to check for consistency in the answers to the chemistry achievement test, and they obtained consistent answers. Therefore, the researcher relied on the feedback of three experts in education and two master's student-researchers to consider the developed CAT valid.

Data collection tool from teachers

The second aim was to collect raw data for investigating teachers' beliefs about IBL and practice when teaching science as inquiry. To achieve this, the researchers used the adapted questionnaire herein referred to as PRIMAS, meaning Promoting Inquiry-based Learning in Mathematics and Science Education. PRIMAS is a large-scale survey instrument intended to explore the perspective of teachers about IBL in twelve European states concerning three constructs, namely, beliefs, practice and difficulty, as worked on by Engeln et al. (2013). From 37 item statements in the scale in relation to teachers' beliefs, practice and difficulty in the inquiry-based teaching and learning environment, three items about teachers' beliefs, and three items related to practice. Moreover, self-designed five-item statements intended to evaluate teachers' noticed students' attitudes when teaching science as inquiry and students learning science as inquiry were used. The reliability test for combined constructs using Cronbach's alpha produced a value of 0.992, which is above the minimum acceptable value of 0.70, indicating a high degree of reliability (Robinson et al. 2016). In addition, close and low standards as the measure of central tendency confirm a desirable internal consistency of participants' replies.

Data analysis

Students' pretest and posttest scores and constructs to test for differences in teachers' beliefs, practices and students' attitudes about IBL were performed using Statistical Package of the Social Sciences software (SPSS 26.0). The analysis was based on collected raw data using students' chemistry achievement tests (Appendices 2 and 3) and eleven constructs, as postulated in Table 1. The understanding of the inquiry process during teaching and learning is still a gap in science education in context-based research (King 2012). The analysis and scrutinization of the investigated constructs about IBL were performed using Statistical Package of the Social Sciences software (SPSS 26.0) to test for differences in teachers' beliefs, practices and students' attitudes. The item statements that sought to collect raw data were items 1, 6, and 10 for teachers' beliefs, 12, 13, and 15 for teachers' practices, and five items designed by the researcher (see Table 4); therefore, demographic information was interpreted using frequencies and percentages, while correlation analysis was performed to generate inferential statistics that formed the basis of interpretation. The process of reporting results considered each construct in the research instrument.

Result interpretation

The results from teachers' questionnaires about beliefs and practices as well as students' attitudes in the IBL classroom environment were complemented with results from chemistry achievement tests carried out during lesson delivery in a quasiexperimentally designed investigation with an intention to understand the effect of IBL on students' classroom performance. Table 2 shows constructs used to collect data related to in-service teachers' beliefs and practice questionnaires about IBL.

Table 1 Reliability test item-total statistics

Survey items	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
Item 1	44.3636	134.855	0.938	0.992
Item 2	44.4545	135.273	0.928	0.992
Item 3	44.5455	134.873	0.957	0.991
Item 4	44.1818	133.964	0.979	0.991
Item 5	44.3636	134.055	0.969	0.991
Item 6	44.1818	133.964	0.979	0.991
Item 7	44.2727	134.418	0.955	0.991
Item 8	44.7273	135.818	0.894	0.993
Item 9	44.1818	133.964	0.979	0.991
Item 10	44.2727	134.018	0.971	0.991
Item 11	44.6364	135.655	0.946	0.991

Source Researcher's primary data

Table 2 Views on teachers' beliefs and practices towards IBL

S. No.	Questionnaire items	S.D	A	S.A
1	I would like to implement more IBL practices in my lessons	1 (9.1%)	2 (18.2%)	8 (72.7%)
2	IBL is well suited to overcome problems with students' motivation	1 (9.1%)	3 (27.3%)	7 (63.6%)
3	IBL is well suited to approach students' learning problems	1 (9.1%)	4 (36.4%)	6 (54.5%)
4	Learners learn through doing exercises	1 (9.1%)		10 (90.9%)
5	Learners start with easy questions and work up to harder questions	1 (9.1%)	2 (18.2%	8 (72.7%)
6	Learners are given opportunities to explain their own ideas	1 (9.1%)		10 (90.9%)

Source Researcher's primary data

Teachers' beliefs and practices towards IBL

Teachers' IBL implementation perspective questionnaire: The following questionnaire communicates researchers' investigative assertions related to inquiry-based learning (IBL) in chemistry. Participants were allowed to respond with the help of a five-point Likert scale: "Strongly disagree = 1, Disagree = 2, Remain neutral = 3, Agree = 4, strongly agree = 5".

The examination of teachers' beliefs and practices towards IBL was conducted with the help of predetermined assertions, as referred to in Table 2. Eight respondents, corresponding to 73%, revealed strong adherence to implementing more IBL practices in the course of lesson facilitation. The intention of the researchers in this study extended the understanding of IBL through the lens of students' motivation, where the 10 respondents matching with 91% demonstrated the awareness of IBL as a tool suited to overcoming problems of students' motivation. Students experience different difficulties during the learning process that might have been linked to inappropriate teachers' choice of teaching strategy, and IBL was considered by 10 surveyed teachers to be equivalent to 91% as the alternative approach to redeeming students' encountered problems in the learning journey. Additionally, 10 out of 11 participating teachers in this survey, consistent with 91%, recognized the benefit of IBL in terms of students working on assigned tasks. Furthermore, 10 participants asserted that the IBL environment provides students with the stage to express their own ideas (Table 3).

Students' attitudes towards IBL

Teachers' outlook on students' attitudes in IBL-mediated classroom practices questionnaire: The following questionnaire communicates researchers' investigative assertions related to inquiry-based learning (IBL) in chemistry subjects. Participants were allowed to respond with the help of a five-point Likert scale: "Strongly disagree = 1, Disagree = 2, Remain neutral = 3, Agree = 4, strongly agree = 5".

Table 3 Descriptive statistics

Questionnaire items	N	Mean	Std. deviation
1. I would like to implement more IBL practices in my lessons	11	4.45	1.214
2. IBL is well suited to overcome problems with students' motivation	11	4.36	1.206
3. IBL is well suited to approach students' learning problems	11	4.27	1.191
4. Learners learn through doing exercises	11	4.64	1.206
5. Learners start with easy questions and work up to harder questions	11	4.45	1.214
6. Learners are given opportunities to explain their own ideas	11	4.64	1.206
Valid N (list wise)	11		

Source Researcher's primary data, 2022

The researcher explored the effect of IBL on students' attitudes towards learning science subjects. The attitudes were examined under five indicators, which included students' participation, the sense of curiosity, communication skills, students' confidence, and students' positive mindset towards science education. The findings portrayed in Table 4 indicate that nine (82%) teachers who participated in the survey strongly agreed that IBL improves students' participation during classroom practices. On the other hand, 9 (82%) of the participants were certain that students develop a sense of curiosity because of learning through the testing of theories, while 10 (91%) maintained that IBL improves students' communication skills. In addition, nine (82%) emphasized that IBL increases students' confidence. Additionally, 10 (91%) of all participants preserved that IBL develops in students with a positive mindset towards science education (Table 4).

Teachers' beliefs about the rationale of implementing IBL and teachers' perspectives about attitudes exhibited by students in the IBL environment were explored. In line with the findings in Table 6, descriptive statistics show that teachers hold positive beliefs about IBL and promising outcomes in terms of attitudes towards learning science subjects, with mean responses of 4.46 and 4.40, respectively, on a five-point Likert scale ranging from strongly disagree = 1 (highest disagreement up to strongly agree = 5 (highest agreement)). As stipulated in Table 7, a statistically significant relationship between teachers' beliefs about IBL and students' attitudes developed during IBL implementation ($r = 0.974$, $p < 0.05$, $p = 0.001$) was obtained (Tables 8 and 9).

Table 4 Views of teachers on students' attitudes exhibited in the IBL environment

S. No.	Questionnaire items	S.D	N	A	S.A
7	IBL improves students' participation during classroom practices	1 (9.1%)		1 (9.1%)	9 (81.8%)
8	IBL develop in students the sense of curiosity through testing of theories	1 (9.1%)	1 (9.1%)	4 (36.4%)	5 (45.5%)
9	IBL improves students' communication skills	1 (9.1%)			10 (90.9%)
10	IBL increases students' confidence	1 (9.1%)		1 (9.1%)	9 (81.8%)
11	IBL develops in students positive mindset towards science education	1 (9.1%)		5 (45.45%)	5 (45.45%)

Source Researcher's primary data, 2022

Table 5 Descriptive statistics

Questionnaire items	N	Mean	Std. deviation
7. IBL improves students' participation during classroom practices	11	4.55	1.214
8. IBL develops in students the sense of curiosity through testing of theories	11	4.09	1.221
9. IBL improves students' communication skills	11	4.64	1.206
10. IBL enhances students' confidence	11	4.55	1.214
11. IBL develops in students' positive attitudes towards science education	11	4.18	1.168
Valid N (list wise)	11		

Source Researcher's primary data, 2022

Table 6 Descriptive statistics between variables

Variables	Mean	Std. deviation	N
Teachers' beliefs	4.4697	1.17099	11
Students' attitudes	4.4000	1.16276	11

Table 7 Pearson's product moment correlation between variables

Variables		Teachers' beliefs	Students' attitudes
Teachers' beliefs	Pearson correlation	1	0.974
	Sig. (2-tailed)		0.000
	N	11	11
Students' attitude	Pearson correlation	0.974	1
	Sig. (2-tailed)	0.000	
	N	11	11

Table 8 Descriptive statistics between groups

	Control and experimental groups	N	Mean	Std. deviation
Posttest performance out of 20 scores	Control group	20	14.2148	2.31261
	Experimental group	20	16.4882	1.46028

Table 9 Mean differences of independent samples t test between posttest performance of two groups (N = 20) for each group

		LTEV		*t* test for equality of means			
Posttest performance out of 20 scores	Control and experimental groups	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference
	Equal variances assumed	7.535	0.009	−3.717	38	0.001	−2.27334
	Equal variances not assumed			−3.717	32.073	0.001	−2.27334

Notes LTEV: Levene's Test for Equality of Variances, and mean difference is significant at $^{**}p < 0.05$

Table 10 Pearson correlation between groups' posttest performance

		PoPCG	PoPEG
PoPCG	Pearson correlation	1	−0.344
	Sig. (2-tailed)		0.137
	N	20	20
PoPEG	Pearson correlation	−0.344	1
	Sig. (2-tailed)	0.137	
	N	20	20

Notes PoPCG and PoPEG mean posttest performance for the control group and posttest performance for the experimental group, respectively, and the correlation is significant at $^{**}p < 0.05$

We further conducted the teaching of chemistry as the science subject to examine the effect of IBL on year five students' achievement in chemistry. First, prerequisite knowledge of students was tested through a pretest administered to students in the control and experimental groups in a quasi-experimentally designed investigation (Appendix 1). The pretest was followed by rounds of teaching and learning sessions enhanced by the implementation of IBL, and students were given the posttest to measure their achievement in chemistry after being exposed to the treatment herein referred to as the IBL approach. The findings of the independent samples t test ($t = -3.317$, $p < 0.05$, $p = 0.001$, with the mean difference of −2.27) revealed that the achievement of students in the experimental group made a statistically significant difference compared to students in the control group who were treated by using the traditional teaching approach herein referred to as the lecturing method (Table 9).

The analysis of the relationship of the achievement of students in the control and experimental groups ($r = -0.344$) was negative, which confirmed that the two groups performed differently during the posttest, thus validating the positive effect of IBL in teaching science subjects and chemistry subjects in particular (Table 10). The nonsignificant correlation between posttest scores of the two groups is further confirmed by $p > 0.05$ as the standard significance level $p < 0.05$.

Therefore, it is imperative to use IBL in engaging students in the learning process to construct their own understanding of the content under the guidance of the teacher.

Discussion

Teachers' beliefs regarding IBL and practices

The implementation of promising teaching and learning methodologies necessitates teachers' willingness to engage in creative and innovative classroom practices (Henriksen et al. 2021). Previous research indicates that teacher beliefs about students and student learning, the nature of science, epistemology, and the role of the teacher are all significant elements of teacher belief systems that may affect views of inquiry.

The findings of this study substantiate those obtained by Haney et al. (1996), as cited in the work published by Wallace and Kang (2004), in which teachers' beliefs were reported as strong predictors of their intentions to implement reform-based strategies. They determined that the following four beliefs were most salient to teachers' intention to initiate inquiry: (1) increase student enjoyment and interest in science; (2) foster positive scientific attitudes and habits of mind; (3) help students learn to think independently; and (4) make science relevant to the students' everyday lives. The study further indicated that experienced teachers wanted training in the inquiry approach and that the most powerful component of lasting reform may be the opportunity to experience success with inquiry-based teaching. The findings revealed that secondary school science teachers who participated in this study hold an optimistic view of IBL implementation and practices, thus encouraging preservice and in-service teachers to use IBL in classroom sessions.

Students' attitudes in the IBL environment

IBL has proven effective in improving students' attitudes towards learning not only in this study but also in previous studies that have emphasized the role of mobile inquiry and inquiry-based science learning (Inel-Ekici and Ekici 2022). Participants demonstrated a promising degree of enjoyment of the instructions received through the inquiry-based science learning process in the formulated questionnaire. Participants' satisfaction with the teaching and learning modes validated how easy knowledge and skills could be acquired; thus, the IBL environment developed into participants' sense of likeness of science subjects. The findings of this study revealed a strong positive correlation between teachers' beliefs about IBL practices and teachers' observed students' attitudes ($r = 0.974$, $p = 0.001$); therefore, students' positive attitudes towards learning science subjects could be enhanced in the IBL active learning environment.

IBL and student achievement

The quintessence of inquiry-based learning in science education is to support students in developing science process skills through independent investigation beyond normal traditional classroom practices. Despite this aspect of IBL, previously published research has indicated that inquiry-based teaching exhibits a very weak relationship with students' achievement (Jerrim et al. 2022). A study conducted by Jerrim et al. (2022) advanced that poor guidance and overuse of IBL has a recurring little effect on students' achievement. The findings of the current study indicated that IBL with maximum guidance and moderate use during classroom practices improves students' achievement ($p < 0.05$, $p = 0.009$). Moreover, a negative correlation ($r = -0.344$, $p = 0.137$) between the performance of students in the control and experimental groups showed a positive effect of IBL on students' achievement in chemistry; hence, teachers should avoid the frequent use of unguided IBL. These findings are in line with existing research-based evidence that asserts that direct forms of instruction would be more beneficial than IBL

(Kirschner et al. 2006; Alfieri et al. 2011) unless this approach is offered under maximum guidance (Lazonder and Harmsen 2016).

Implication of results

The results obtained from the current research propose that IBL implementation depends largely on teachers' beliefs and practices as well as students' attitudes. The implementation of IBL necessitates the effort of the academic community, particularly teachers, as they are directly concerned with instructions and their mode of delivery. A conducive academic and particularly classroom environment is necessary as a promoter of students' motivation and active participation; thus, IBL helps teachers and students experience a high level of critical thinking, creativity, and innovation in science education. The concern is not only to emphasize teachers' and students' experience in teaching and learning science as inquiries but also to consider school factors that could hinder the implementation of IBL in a suitable manner. The results reported herein are believed to facilitate a wide range of teachers in understanding the essence of using IBL and its associated positive outcomes in science education. Raising awareness of IBL in facilitating students' learning among teachers is a potential implication of the findings of this research. Moreover, this research serves as a guide indicating the area of improvement on the side of those in charge of curriculum design and development as well as the director of studies (DOS). Attention should be given to teachers' adaptation of teaching endeavors to IBL following its power in easing science teaching and learning in secondary schools. With the help of this trending teaching and learning approach, a considerable and broad understanding of teachers' involvement, preservice teachers and novice educational investigators could be able to evaluate IBL instruction in science subjects.

Conclusion and future perspectives

This study investigated the outlook of teachers on teaching and learning science as inquiry. Teachers' beliefs, practices and teachers' observed students' attitudes developed in the IBL classroom environment were key indicators to evaluate the use of IBL in teaching science subjects. The findings revealed that participating teachers hold positive beliefs about IBL and that they are willing to improve classroom practices. Moreover, a part of the action research conducted using the IBL approach among year five chemistry students significantly improved students' achievement. Furthermore, the findings encourage teachers to devise and use approaches that help in shifting from traditional teacher-centered teaching approaches to student-centered pedagogy. Based on the findings of the current study, we suggest that future investigations could be undertaken in the area of instructional orientation to IBL in science education.

Appendix 1

See Tables 11 and 12.

Table 11 Descriptive statistics between groups

	Control and experimental groups	N	Mean	Std. deviation
Pretest performance out of 20 scores	Control group	20	12.0800	1.37366
	Experimental group	20	11.9150	1.33032

Table 12 Mean differences of independent samples t test between pretest performance of two groups (N = 20) for each group

		LTEV		*t* test for equality of means			
Posttest performance out of 20 scores	Control and experimental groups	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference
	Equal variances assumed	0.013	0.908	0.386	38	0.702	0.16500
	Equal variances not assumed			0.386	32.073	0.702	0.16500

Notes LTEV: Levene's Test for Equality of Variances, $**p < 0.05$

Appendix 2: First chemistry achievement test

Aim: To determine the molarity of sulfuric acid

The following are provided:

- BA_1 was made by dissolving 8.0 g sodium hydroxide in 1 dm^3 of solution.
- BA_2 is sulfuric acid

Procedure

(a) **BA1** (25.0 cm^3) was pipetted, and 2–3 drops of methyl orange indicator were added.
(b) Fill the burette with BA_2 solution
(c) The mixture in (a) above was titrated with BA_2 until the colour of the solution changed from yellow to orange–red.

The titration was repeated three more times to obtain consistent results.

Experimental results and calculations involved

The results are then recorded as shown below: /4 marks

Volume of pipette used = 25.0 cm^3

Experiment number	1	2	3	4
Final burette reading in cm^3	17.80	34.30	30.75	47.25
Initial burette reading in cm^3	0.00	17.80	14.20	30.75
Volume of BA_2 used in cm^3	17.80	16.50	16.55	16.50

Titre values of BA_2 used for calculating the average are 16.50 and 16.50 cm^3

$$\text{Average titre value} = \frac{16.50 + 16.50}{2} = 16.50\,\text{cm}^3$$

Calculations

Calculate the molarity of NaOH solution

$$M = \frac{m}{Mm \times V} = \frac{8.0\,\text{g}}{40\,\text{gmol}^{-1} \times 1\,\text{dm}^3} = 0.2\,\text{mol}\,\text{dm}^{-3}$$

(a) Calculation of the number of moles of NaOH that reacted in 25.0 cm^3 of BA_1

n of NaOH reacted $= M \times V = 0.2\,\text{mol}\,\text{dm}^3 \times 0.025\,\text{dm}^3 = 0.005\,\text{mol}$ /4 marks

Write the balanced equation of reaction that takes place.

$$H_2SO_{4(aq)} + 2NaOH_{(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

(b) Calculation of the number of moles of H_2SO_4 that reacted in BA_2 with NaOH in BA_1

From the equation the mole ratio H_2SO_4:NaOH = 1:2

No of mole of H_2SO_4 that reacted $= 0.0025\,\text{mol} \times \frac{1}{2} = 0.0025\,\text{mol}$ /4 marks

(c) The concentration in mol dm^{-3} of H_2SO_4 in BA_2 solution was calculated.

$$16.50\,\text{cm}^3 \text{ of } BA_2 \text{ contain } 0.0025 \text{ mole of } H_2SO_4$$

$$1000\,\text{cm}^3 \text{ of } BA_2 \text{ contain } \frac{0.0025\,\text{mole} \times 1000\,\text{cm}^3}{16.50\,\text{cm}^3} = 0.15\,\text{mole of } H_2SO_4 \quad /4\,\text{marks}$$

$$\text{Hence, Molarity} = 0.15\,\text{mol}\,\text{dm}^{-3}$$

(d) Calculate the concentration in g per dm^3 of H_2SO_4 in BA_2 (S=32, O=16, H=1)

$$\begin{aligned}\text{Concentration of NaOH in gdm}^{-3} &= \text{molarity} \times \text{Formula mass of } H_2SO_4 \\ &= 0.15 \times 98\,\text{gdm}^{-3} \quad /4\,\text{marks} \\ &= 14.7\,\text{gdm}^{-3}\end{aligned}$$

Appendix 3: Second chemistry achievement test

Aim: To standardize sodium hydroxide solution using 0.1 M hydrochloric acid solution.

The following are provided:

- $BA_{1,}$ which is 0.1 M hydrochloric acid solution
- $BA_{2,}$ which is sodium hydroxide solution

Procedure

(a) **BA1 (**25.0 cm^3) was pipetted into a clean conical flask and added to 3 drops of methyl orange indicator.
(b) Fill the burette with BA_2 solution.
(c) Now, BA_2 is run from the burette until the color of the solution changes from red–orange to yellow.
(d) The titration is then repeated three more times to obtain consistent results.

Experimental results and calculations involved

Volume of pipette used = 25.0 cm^3 /4 marks

Experiment number	1	2	3	4
Final burette reading cm^3	21.10	41.15	19.95	23.50
Initial burette reading, cm^3	0.00	21.10	0.00	3.30
Volume of BA_2 used, cm^3	21.10	20.05	19.95	20.20

The Titre values used to calculate the average volume of BA_2 were 20.05 and 19.95 cm^3.

$$\text{Average titre value} = \frac{20.05 + 19.95}{2} = 20.00\,\text{cm}^3$$

(a) Calculation of the number of moles of HCl that reacted in 25.0 cm^3 of BA_1 /4 marks

$$n\,\text{of HCl reacted} = M \times V = 0.1\,\text{mol dm}^3 \times 0.025\,\text{dm}^3 = 0.0025\,\text{mol}$$

(b) Write the balanced equation of reaction that takes place. /4 marks

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

(c) Calculation of the number of moles of NaOH that reacted in BA_2 with HCl in BA_1 /4 marks

$$\text{From the equation the mole ratio HCl : NaOH} = 1:1$$

$$\text{No of mole of NaOH that reacted} = 0.0025\text{ mol} \times \frac{1}{1} = 0.0025\text{ mol}$$

(d) Calculate the concentration in mol dm^{-3} of NaOH in BA_2 solution.

$$20.0\,\mathrm{cm}^3 \text{ of } \mathrm{BA}_2 \text{ contain } 0.0025 \text{ mole of NaOH}$$

$$1000\,\mathrm{cm}^3 \text{ of } \mathrm{BA}_2 \text{ contain } \frac{0.0025\,\text{mole} \times 1000\,\mathrm{cm}^3}{20\,\mathrm{cm}^3} = 0.125 \text{ mole of NaOH} \quad /4\text{marks}$$

$$\text{Hence, Molarity} = 0.125\,\mathrm{mol\,dm}^{-3}$$

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Data availability All data and materials are available upon request.

Declarations

Ethical approval This study does not require ethical approval based on the Rwandan context. This study, was conducted by in-service teachers in Rwanda private schools, is exempt from ethical approval where educators are permitted to engage in research without explicit permission. This exemption is warranted by recognizing that school leaders possess the authority to authorize teachers, who they oversee, to conduct research within their respective schools.

Informed consent Informed consent was obtained from all participants.

Competing interests The author has no relevant financial or nonfinancial interests to disclose.

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