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Exploring lower secondary school teachers' perceptions of integrating simulations into chemistry instruction

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Introduction: Teachers play a crucial role in guiding students to enhance their learning and achieve academic goals. Understanding their perspectives on educational technology is essential to fostering effective integration into classroom instruction. This study investigates the perceptions of lower secondary school chemistry teachers regarding the ease of use and usefulness of integrating ICBLS into teaching.

Methods: A multiple case study design was employed, involving eight chemistry teachers from four schools where ICBLS had been implemented. Data were collected through semi-structured interviews, group discussions, professional workshops, and classroom observation. The data were transcribed and analyzed thematically using NVivo 14 software.

Results: The findings indicate that teachers hold positive perceptions of ICBLS, citing benefits such as enhanced safety, collaboration learning, and hands-on activities. However, challenges were identified, including limited access to computers and insufficient professional training.

Discussion: The study underscores the importance of addressing technical and training barriers to optimize the use of ICBLS. Recommendations include strengthening professional development, fostering peer collaboration, aligning curricula with ICBLS, and ensuring administrative support and provision of adequate resources.

KEYWORDS

laboratory in science education, technology in science education, computer-based simulations, chemistry education, teaching approach

Introduction

Technology is widely used in various industries, including education and scientific research (Hojeij et al., 2023). It is increasingly employed in classroom teaching because it provides access to interactive tools that enhance students' engagement, comprehension, and critical thinking among others (Nafidi et al., 2018; Najib et al., 2022). With technology, students understand modeling and fundamental epistemic questions in science education (Saudelli et al., 2021). According to the study conducted by Alhadlaq (2023), Almasri (2022), Falloon (2019), Ouahi et al. (2022), and Ndihokubwayo et al. (2020), educational technological teaching tools including interactive computer-based laboratory simulations (ICBLS) play a valuable role in science education. These include the opportunities they provide to students when engaging with inquiry-oriented methods.

However, considering teachers' perceptions when quickly moving to integrating new teaching tools, is sometimes overlooked (Mirzajani et al., 2016). Moreover, for effective integration of ICBLS in the teaching process, there is a need to understand how open teachers are to the idea of incorporating it into the classroom. Therefore, a clear understanding of these perceptions of teachers is required to provide insights into their pedagogical use and how they sustain students' learning experiences. In this current study, we address the concern of how teachers perceive the ease of use and usefulness of ICBLS as well as identify any technical issues and challenges they may encounter when integrating ICBLS into their classrooms. While existing studies have explored the positive impact of computer simulations on students' performance, attitudes, and motivation in learning chemistry, none have specifically examined teachers' viewpoints on using ICBLS to teach chemical reaction concepts. This gap is significant because teachers' perspectives can greatly influence the successful implementation and effectiveness of new educational technologies.

Additionally, several studies have focused on the short-term effects of computer simulations on students' outcomes, leaving a gap in understanding their long-term impact on students' retention and comprehension of concepts (Mihindo et al., 2017; Nsabayezu et al., 2022). Moreover, consulted studies predominately focus on certain educational settings, with insufficient exploration into how these technological tools affect diverse student populations including disadvantaged backgrounds and a limited understanding of ICBLS integration with traditional teaching methods in teaching practical laboratory skills remain unexplored. Few research has explored how the use of simulations affects teachers' professional development, which is a crucial support to reach quality science education. Lastly, more research is needed on different pedagogical approaches to the use of ICBLS in chemistry education.

Therefore, the current research aims to address these gaps by exploring lower secondary school chemistry teachers' perceptions toward the use of ICBLS in chemistry education and learning, specifically, to respond to research objectives of how teachers perceive the ease of use and usefulness of ICBLS in the classroom teaching practice and potential challenges and technical issues they face when incorporating ICBLS in their classroom. Hence, insights from this current study inform professional development programs, to help teachers stay currently updated with technological advancements, guide policymakers and curriculum developers in developing educational technological tools that align with educational standards, and school heads make informed decisions about resource allocation for technology and related training to ensure that teachers have supported enough to produce productive graduates.

Literature review

In science education, including chemistry, laboratories play a significant role as they engage students in activities that enhance their comprehension of scientific principles, develop problem-solving skills, and improve their attitudes toward science. However, socioeconomic challenges make it difficult for developing countries, especially in Sub-Saharan Africa, to access proper and standardized laboratory equipment and materials (Yoldere and Adamu, 2015). Chemistry, like other science disciplines, is a practical subject that considers laboratory instruction as essential. The laboratory not only equips students with scientific skills and knowledge but also facilitates active engagement in their learning process (Etienne and Mujawimana, 2020). In laboratory settings, students explore, test hypotheses, and formulate interpretations of theoretical phenomena, either in a small group or individually (Nkurunziza et al., 2023).

Cossa and Uamusse (2015) argue that when standardized materials are not easily accessible, alternative instructional methods must be considered. Different measures have been implemented to address the shortage of laboratory equipment and materials in Sub-Saharan African countries. For instance, countries like South Africa, Zimbabwe, Rwanda, and Botswana among others, have initiated efforts to introduce science kits and emphasize the utilization of locally available material in science classes to address this challenge. However, science teachers, including chemistry teachers, continue to face significant shortage of equipment (Nsengimana et al., 2020). This situation is exacerbated by a transmission-based teaching approach, which hampers students' acquisition of skills and knowledge from primary throughout to the secondary level, leading to poor performance and retention of concepts.

The government of Rwanda (National Examination and School Inspection Authority, 2020) reports that while students show proficiency in answering theoretical questions, their performance is notably weaker in practical assessments that require the application of practical skills. This gap is attributed to ineffective utilization of the laboratory facilities. Cossa and Uamusse (2015) and Nsengimana et al. (2020) emphasize that laboratories are crucial for acquiring practical skills and knowledge through hands-on activities. Therefore, the failure to utilize laboratories effectively contributes to poor performance and retention of concepts. In response to these challenges, the current study was initiated to investigate the use of ICBLS in classroom practice. These simulations are digitals model that uses mathematical equations and algorithms to simulate system behavior (Asedillas and Quimbo, 2019). Research indicate that the use of computer simulations enhance students' gains and fosters interactions among peers and teachers (Muniandy et al., 2022).

Zendler and Greiner (2020) compared hands-on experiments with computer simulations (CS) in science education, reveal that CS serves as a powerful pedagogical tool and fosters active, engaging, and effective learning experiences comparable to hands-on activities. Further studies (Aziz et al., 2021; Bo et al., 2018; Milla et al., 2019; Studies, 2022) have found that CS promote student engagement, visualizes complex concepts, provide practical real-world experiences, encourage flexible and self-paced learning.

Despite these advancements, the consulted studies have focused on the impact of technology on science teaching in general but not specifically focus on the utilization of ICBLS in chemistry education across some Sub-Saharan African countries (Nsengimana et al., 2020; Sibomana et al., 2021). This implies that there is a notable lack of studies that have focused on the specific use of ICBLS in learning chemical reactions. This study aims to fill this gap by exploring teachers' perceptions and experience of ICBLS in chemistry classroom instruction, with a specific focus on their effectiveness in teaching chemical reactions. This implies that the existing literature does not sufficiently address teachers' beliefs about the integration of ICBLS into their teaching practices. This study seeks to explore these perspectives, highlights both the perceived ease of use and potential challenges lower secondary school chemistry teachers face. As aforementioned, there is a disconnect between students' proficiency and their practical skills in chemistry. By focusing on ICBLS, this study aims to understand how these simulations enhance practical skills acquisition, addressing the challenges highlighted in previous studies. Although it is recognized that ICBLS facilitate the achievement of chemistry learning, research on teachers' perspectives regarding the ease of use and usefulness of integrating ICBLS into grade 8 chemistry classes is scarce. Consequently, this current study seeks to investigate how lower secondary school chemistry teachers perceive the ease of use and usefulness of integrating ICBLS and to identify potential challenges and technical issues teachers face when incorporating ICBLS into the classroom.

Methodology

This study utilizes a qualitative multiple case study design to explore lower secondary school chemistry teachers' perspectives on integrating ICBLS into their instruction. The methodology was chosen to capture in-depth insights from teachers in different schools' context and to allow for comparative analysis. This approach aligns with the research objective of understanding collective experiences of teachers regarding the use of ICBLS.

Research design

This study employs a multiple case study design to explore the perspectives of lower secondary school chemistry teachers' perceptions on the ease of use and usefulness of integrating ICBLS into their instruction. The researcher preferred to use a multiple case study approach because it captures variations in how different teachers in diverse school settings experience the implementation of ICBLS. As Noon (2018) suggests, this approach enables the exploration of both commonalities and differences across cases, providing valuable insights directly from participants. In this study, each school was treated as a distinct case, with two chemistry teachers selected from each of the four schools, resulting in a total of eight cases. This selection allowed for a comparative analysis across different school contexts, helping to identify both school-specific and broader factors that influence the successful integration of ICBLS. In light of this perspective, participants were encouraged to freely express their viewpoints without being limited by designed questions. Therefore, this study adopted an interpretive approach due to its being well-matched for investigating and describing the experience of chemistry teachers within their teaching context.

The simulations utilized in this current study were adopted from online Physics Education Technology (PhET) interactive simulations (https://phet.colorado.edu/en/simulations/category/chemistry) and American Association for Chemistry Teachers (AACT) simulations (https://teachchemistry.org/classroomresources/simulations). While some of these simulations are freely accessible, others are paid. They are designed to replicate real-world laboratory experiments in a digital environment. Before incorporating simulations into the classroom, teachers received training on how to effectively utilize the simulations in the classroom setting. Throughout the study intervention, simulations served as invaluable tools for teachers, enabling them to provide constructive support to students. All teachers utilized the same set of simulation activities, ensuring consistency in the learning experience. A total of 16 lessons were observed across the intervention, focusing on specifics. These simulation activities covered specific topics within unit 5, which covers categories of chemical reactions. These topics are the type of chemical reactions, writing and balancing chemical equations, characteristics of chemical reactions, and classification of chemical reactions (endothermic and exothermic). Each lesson was designed to provide students with consistent exposure to these core concepts through simulation-based activities.

The lesson plans for each observed lesson began with a 10-min introduction in which teachers ensured clarity by presenting clear learning objectives and providing general instructional guidance. This initial step involved projecting all procedures onto the whiteboard, allowing students to familiarize themselves with the task ahead. This was followed by a 20-min interactive lecture and demonstration using simulations to illustrate chemical reactions. During the next 30 min, students engaged in paired practice with guidance, allow them to explore concepts in a simulated environment. Each lesson concluded with a 15 min discussion to review key points and a 5-min assessment to evaluate understanding, with immediate feedback provided by teachers. To assess student proficiency and attainment of learning objectives, teachers used a combination of formative and summative assessment, as well as classroom observational assessment including monitoring students' interaction and engagement with simulated activities.

Sample and sample size

The study purposively focused on lower secondary school chemistry teachers from four schools. The four schools were selected purposively based on specific criteria of being among of few schools equipped with computer labs that would support ICBLS implementation, which was essential for the study's focus on ICBLS integration in teaching practice in Kayonza district, Rwanda. Additionally, the selected schools represented a range of rural settings to capture diverse teaching environments. This purposive selection ensures that the chosen sample aligns with the study's objectives while maintaining relevance and representativeness for exploring the integration of ICBLS in ordinary level chemistry classes. The study target population was 8 (three females, five males) ordinary level chemistry teachers and were considered as the sample size for the study. All participants hold bachelor's degrees in chemistry teaching and have over 4 years of teaching experience. While the sample size may seem limited, it aligns with the qualitative nature of the study, which emphasizes in-depth exploration over breadth

(Creswell and Poth, 2018). As noted by Patton (2015), qualitative research often prioritizes data richness over participants quantity, with smaller purposive samples allowing for detail insights. The purposeful selection of these teachers ensures representativeness and relevance within the target population of ordinary-level chemistry teachers.

Data collection procedures

Data were collected using multiple methods to capture a holistic view of the effectiveness of ICBLS in the classroom. The data collection procedures involved semi-structured interviews, group discussions, classroom observation, and professional development workshops, each designed to capture specific aspects of the teachers' experiences and perceptions.

The data from interviews were collected with each teacher individually and were guided by questions aimed at understanding teachers' experience, challenges, and perceptions of ICBLS on student engagement and learning. For example, a sample question was *In what ways do you believe ICBLS has been effective in improving student learning outcomes?* This method allows teachers to provide in-depth insights into their personal experiences.

For group discussion, teachers participated in group discussions that provided a platform for shared experiences and collaboratively reflections on ICBLS use. These discussions encouraged teachers to discuss specific instances and challenges they faced, adding to the collective understanding of ICBLS effectiveness in various classroom context.

The data from professional development workshop provided hands-on experience with ICBLS and facilitate teacher training on its integration into chemistry lesson. Teachers received guidance on effective utilization of ICBLS and engaged in reflective sessions to share feedback on workshop content. For instance, the sample question was: *What are the most important things you learned from this workshop?*

Classroom observations were conducted to gain a deeper understanding of the practical integration of ICBLS in chemistry instruction. The primary nit of analysis for this observations focused on the dynamic interactions between teachers and students during the implementation of ICBLS, which is crucial for assessing how these simulations influence the teaching and learning process. To ensure the observations were systematic and thorough, a structured framework was developed, targeting specific areas of interest. These include teaching approach, level of students' engagement, and the overall effectiveness of ICBLS in facilitating the understanding of complex chemistry concepts. This approach allowed for a more nuanced exploration of how ICBLS were utilized in the classroom setting. The utilized checklist was designed in way can capture key aspects of the instructional process. This approach not only ensured consistency across observations but also provided a clear basis for comparing findings across different classroom settings. This methodological rigor is essential for understanding the effectiveness of ICBLS in enhancing students' comprehension of chemistry concepts and informing future instructional practices.

Each data collection method was tailored to provide distinct insights while allowing cross-case analysis among the eight teachers participants, ensuring that the study captures a holistic view of ICBLS integration in diverse school settings (Kvale and Brinkmann, 2015). These different approaches to data collection, enable a deeper and more holistic understanding of ICBLS by capturing insights from individual experiences as well as shared perspectives among participants.

Participants were encouraged to freely express their opinions, with the assurance that their inputs would not affect their performance contract and that their data would remain confidential for research purposes. Each participant was provided with an individual consent form, which they signed. There was no other form of remuneration besides facilitation for teachers who attended the workshop on ICBLS. Participants were explicitly informed that their participation was voluntary and their right to withdraw their consent at any time if they felt uncomfortable continuing their study participation. To ensure trustworthiness and credibility, we employed cross-verification and triangulation methods. This involved scrutinization of data from all used data sources to verify findings and enhance the study's validity. In light of these views, attention was paid to identifying areas of agreement and disagreement among participants to provide valuable insights into the complexity of participants' perspectives and experiences and guide future research endeavors.

Additionally, we applied participant validation as a measure to ensure authenticity. Specifically, we crosschecked data interpretations and sought participant validation by returning interview transcripts and interpretations to participants for their validation. This practice ensure that the findings accurately represents participants' perspectives and contributed to the study's credibility (Maxwell, 2020). The study also addressed reflexivity, as we acknowledge the influence of the researcher's backgrounds on the interpretation of the data. The lead researcher's extensive experience in chemistry education and research assistant's expertise in qualitative data analysis shaped how the data were analyzed. This reflective approach assist mitigates potential biases and ensured the transparency of the research process. The dataset detailing the collected data, including the specific questions asked, is publically available and can be accessed at: https://data.mendeley.com/datasets/4rdg2w4kbs/1.

Data analysis framework

The data analysis framework for this study was structured around three key dimensions: teachers' perspectives of ease of use and usefulness of ICBLS, technical issues, and challenges encountered during the integration of ICBLS. Each dimension serves a specific purpose in a comprehensive understanding of the factors influencing the successful integration of ICBLS and developing strategies to address any issue that may arise in selected lower secondary schools. The interviews were conducted by a researcher, a Ph. D. by research student in chemistry education, and a research assistant with over 5 years of qualitative research experience. The analysis process began by transcribing and organizing the interviews, group discussions, and workshop sessions. Concurrently, we organized the observational notes collected during classroom observation, along with observational notes from classroom activities. This was an essential to prepare the data for systematic analysis.

Following this step, we employed NVivo 14 software for thematic analysis. Both the lead researcher and research assistant independently analyzed the data to reduce bias and ensure the reliability of the findings. To enhance the study's rigor, we followed established qualitative standards emphasizing trustworthiness, authenticity, credibility, and dependability (Dahal, 2023). The first step was to get familiar with all transcriptions and observational notes to gain an in-depth understanding of the data. Then, initial codes were created within the transcribed data through inductive thematic analysis. Repeated sequences were identified as patterns, related codes across all data sources were grouped into broader themes, and these themes were further classified into broader categories. This thematic coding served to organize and categorize the data into meaningful units for analysis. This comparative approach facilitates in the identification of both similarities and differences in participants' perspectives, experiences, and insights across data sources.

Theoretical framework

The Technology Acceptance Model (TAM) guided this study, providing a lens to understand teachers' perceptions of ICBLS and the factors influencing their adoption in chemistry education. According to TAM, the acceptance of a technological system by an individual depends on his/her perceptions of its ease of use and usefulness. Within this context, TAM serves as a framework to examine how teachers perceive the ease of use and potential usefulness of ICBLS and how these perceptions may affect their classroom practices. Specifically, this study hypothesizes that teachers who perceive ICBLS as both useful and easy to use would have more positive perceptions of integrating this technology in their instruction. This framework is particularly relevant as it addresses the significant role of teachers' perceived challenges, such as technical difficulties, inadequate training, and time constraints, which impact their overall acceptance and use of ICBLS in the classroom. In light of this, the study explores not only the perceived benefits of ICBLS but also the specific challenges teachers encounter, as these essential to understanding the conditions under which technology integration is successful.

The main purpose of incorporating ICBLS in chemistry teaching and learning is to facilitate students to understand complex phenomena, providing teachers with tools to guide students through abstract concepts by manipulating variables, testing hypotheses, and observing phenomena in a virtual setting (Celik, 2022; Chumba et al., 2020). Research has shown that while computer-aided tools have the potential to enhance science education, successful adoption depends heavily on teachers' perspectives and readiness to use them effectively (Bo et al., 2018; Ouahi et al., 2022). Given this, gaining a more comprehensive understanding of teachers' acceptance and perceived challenges when integrating ICBLS into the classroom is essential for effective implementation.

In summary, this study extends the application of TAM to explore teachers' acceptance of ICBLS by examining both positive perceptions and potential challenges related to its ease of use and usefulness. This dual focus enables an in-depth investigation into how teachers' perceptions influence ICBLS integration, thereby contributing valuable insights into the barriers and facilitators of technology adoption in chemistry education.

Results

This study examined the experiences and perceptions of eight lower secondary school chemistry teachers from four schools. The data analysis reveal four main themes. These are teaching experience and comfort with technology, perceptions of ICBLS and its effectiveness, challenges and technical issues, support and training, and future perspectives with ICBLS integration. Each theme is discussed below with quantified insights based on teachers' responses.

Teaching experience and comfort with technology; the responses reveal a trend in which teaching experience influenced comfort with using ICBLS. Of the eight teachers interviewed, five with over 10 years of experience reported feeling less comfortable and confident when using ICBLS tools, noting challenges in adapting to new technology. In contrast, three teachers with fewer than 10 years of teaching experience demonstrated high confidence and comfort levels, describing ICBLS as intuitive and easy to navigate. This finding align with previous research (Holman, 2021), which suggests that newer teachers are generally more familiar with integrating digital tools into their teaching.

Regarding the theme of positive perceptions of ICBLS, 75% (six out of eight) teachers expressed favorable views on the integration of ICBLS in classroom practice, particularly in enhancing students' understanding of specific chemistry topics. Teachers shared specific examples of the benefits. They had three benefits in common, these are visualization of complex concepts, inclusivity, and inquiry-based learning. Seventy-five percent teachers noted that ICBLS enable student to visualize challenging concepts, such as chemical reaction mechanism. For example, Teacher A shared, "*These simulations provide a dynamic and engaging way to explore complex chemical concepts like types of chemical reactions, that may be challenging to understand when using traditional method alone.*" Teacher D similarly stated, "Integrating these ICBLS into our classroom is a fantastic idea, as they modernize the way we teach and help students to understand abstract concepts such as writing and balancing chemical equations more effectively than conventional methods." 63% (five out of eight) teachers highlighted ICBLLS as a tool for supporting students with different learning pace and styles. For instance, Teacher B stated, "ICBLS allow students who typically struggle with understanding complex reactions such as distinguishing between endothermic and exothermic reactions, to visualize and engage with the material at their own pace."

Group discussions further supported this sentiment, with 63% teachers noting that ICBLS caters to diverse learning preferences, such as visual and kinesthetic learning. Teacher A emphasized, "with ICBLS, students can revisit topic like chemical reaction classification as often as needed, ensuring they understand how to balance equations and identify reaction characteristics correctly." He added, "From my experience, the interactive nature of these simulations spark curiosity among students, improve both engagement and inclusivity." Another teacher shared a similar view emphasize that ICBLS promote inclusivity and arouse students' interest in simulated lessons. "I have observed that

ICBLS enhance students' motivation, interest, and enjoyment. They allow every student to manipulate simulated activities and repeat steps till they get the correct answer." This notion was also reaffirmed during professional development workshops, where teachers express confident in using ICBLS to accommodate diverse learner preferences. The workshop emphasize that ICBLS facilitate students to develop a deeper understanding of abstract concepts, with Teachers particularly valuing ICBLS for their visual representation that explains abstract concepts, and their encouragement of hands-on activities. These findings align with previous research shows the benefits of digital tools in enhancing classroom engagement (Holman, 2021).

Regarding the theme of the effectiveness of ICBLS, 50% (four out of eight) teachers describe how ICBLS foster inquiry-based learning by encouraging students to experiment with variables and observe outcomes independently. For example, teacher F observed, "ICBLS allows students to see the step-by- step process of reactions, which helps them visualize what happens during decomposition or synthesis reactions. This leads to higher engagement and better grasp of reaction types." Post-simulation assessments reveal that students in the experimental group performed better in tasks such as writing and balancing chemical equations compared to the control group, suggesting that simulations enhance conceptual understanding. He added, "*I have observed that ICBLS foster interaction between students and teachers, leading to increased engagement in learning, which has significantly improved their understanding of learning objective*." This aligns with findings by Niyigena and Nzabalirwa (2022), which highlight simulations' role in promoting hands-on learning experiences.

Teachers voiced similar opinions during group discussions, noting that the integration of ICBLS positively influences chemistry teaching practices and leads to more effective learning experiences for students. Another teacher added, "These simulations sparked students' interest, leading to more active participation in class activities and discussion specifically for students with a slow learning pace. With these simulations, students observe molecular interactions during chemical reactions, which helps them understand the concept of reactions at a deeper level." Given the schools limited resources in some schools, such as inadequate laboratory facilities, these simulations help students visualize complex processes, especially chemical reactions. Teachers collectively emphasize that ICBLS facilitate a deeper understanding of molecular interactions, which helps students especially slower learners not fall behind. Teacher E highlighted another potential advantage of ICBLS; promoting inquiry-based learning. He explained "I have started using more inquiry-based learning approaches. Simulations allow students to experiment and discover concepts on their own, fostering a more hands-on and student-centered learning environment." He compared this approach to scientific research, where students conduct research and analyzing the data to advance knowledge and solve problems. Teacher G added, "*This approach not only deepens students' understanding of core concepts but also cultivates critical thinking, decision-making skills essential for success beyond the classroom*." Further, teachers also noted that these simulations bring a dynamic element to the classroom that traditional teaching methods sometimes lack. They allow students to visualize and manipulate chemical processes, provide opportunities to conduct experiments that might be too dangerous, expensive, or time-consuming to perform in a traditional lab setting." One teacher remarked "These simulations have provided us with more opportunities to develop rich learning activities and encourage students to explore chemistry phenomena independently. This supported by findings from Hursen and Asiksoy (2015), which highlight the value of simulations in providing opportunities for hands-on learning and improving individual conceptual understanding."

In summary, teachers highlighted that ICBLS promote inquiry-based learning, enhance interactions between teachers and students, and enable students to test hypotheses, analyze data, manipulate variables, conduct experiments and observe outcomes. This foster critical thinking and problem-solving skills, which are crucial for advancing knowledge.

Regarding the theme of perceived challenges during ICBLS integration, while teachers acknowledge the benefits of ICBLS, they also cited several challenges related to resources constraints, technical limitations, and student difficulties in translating visual simulations into symbolic representations. Eighty-eight percent (seven out of eight) teachers mentioned issues with limited access to technological tool and unreliable internet connections. For instance, teacher C stated, "we face difficulties in accessing enough computers, and sometimes, poor internet connectivity disrupts lesson." Large class size was also cited as a limitation, with four teacher express concerns that overcrowded classroom made it challenging to ensure all students benefit from ICBLS equally. These findings are consistent with previous research suggests that teaching conditions are particularly difficult when resources are limited and class size is large (Fatima et al., 2019; Higgins et al., 2012; Osai et al., 2021). The 50% teachers further reported that while students visualize molecular interactions, they struggle with translating these visuals into chemical symbols, especially in task requiring balancing equations. Teacher D noted, "students do not understand how the visuals translate into chemical symbols and numbers." This challenge becomes especially evident when students are required to apply their understanding to tasks like writing and balancing chemical equations after using simulations. Teacher C added "student can easily see the reaction taking place in the simulations, like zinc reacting with hydrochloric acid, but they struggle to write and balance the chemical equation afterwards." This challenge was consistent across classrooms, particularly in tasks that involve applying the stoichiometry knowledge. Another common challenge that teachers presented is time constraints, where they indicate that there is a need for more time to prepare lesson to incorporate these simulations. Teacher G remarked, "I struggle with shortage of time. This tool requires careful preparation, and we do not have dedicated time for that. The findings are consistent with the results from Bellou et al. (2018), which observed similar challenges in students transitioning from visual to symbolic representations."

Regarding the theme of support and training, 63% teachers expressed a need for ongoing training on integrate ICBLS effectively. Teacher A stressed the need for professional development training focus on educational technology and increase access to computers and related resources. Teacher C added, "*a one-time workshop, mostly once per term, has not been effective in making us comfortable to implement any new technological approach in delivering a lesson effectively.*" Another

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teacher noted "although this tool is the best teaching approach but its effectiveness is limited in large and overcrowded classes settings." These findings are supported by Higgins et al. (2012), which emphasize the role of CPD in supporting teachers' effective use of educational technology. These results are consistent with those from group discussions, where teachers emphasized the need for regular workshops on using educational technology including ICBLS. Participant E said "*Educational technological training should be one of major concern if we want to advance our domain because it can boost our practical knowledge and skills as well as confidence in using those tools and integrate them into our classroom*." Teacher D said, "I believe, there is a lot of potential in incorporating digital resources and interactive activities including these simulations into our teaching, but some of us are not familiar with these tools, as such, we need support to successfully implement them in our lesson." These findings align with Rahman et al. (2020) and Graziano et al. (2017), who highlight the critical role of ongoing professional development in equipping instructors with the necessary skills and confidence to effectively integrate technology into their teaching practice.

In summary, although ICBLS is effective in helping students visualize molecular interactions and engage in inquiry-based learning of chemical reactions, it is clear that additional support is needed to help students understand and represent chemical reaction symbolically. Teachers have recommended that more instructional time be dedicated to bridge the gap between visualizing reactions in simulations and writing and balancing chemical equations.

Regarding the theme of future perspectives, seven teachers suggested that enhanced CPD focused on educational technology would be valued. Teacher H shared, "We believe ICBLS has potential, but we need continuous training to fully harness it." One teacher explained, "*Continuous training helps us stay updated with the latest educational technology and makes us more confident and proficient in using these tools.*" Additionally, 50% teachers recommended curriculum alignment to better integrate simulations with classroom objectives, as well as administrative support to address resources constraints, particularly in schools with large class size and limited access to computers. These insights underscore the importance of supporting teachers with training and resources to maximize ICBLS's impact on student learning.

In summary, the results from all data sources emphasize the importance of ongoing professional training and structured peer collaboration during preparation to effectively integrate educational technology, including simulations, into teaching. Teachers also highlighted the necessity for curriculum designers to align instructional materials with these technologies to ensure coherence and relevance in the learning process. Addressing these factors, along with managing challenges such as overcrowded classrooms, is crucial for enhancing student achievement and optimizing the use of educational technology in the classroom.

Discussion

This current study explored teachers' perspectives on integrating ICBLS into chemistry classroom instruction. To collect data, different sources such as face-to-face interviews, professional development workshops, group discussions, and classroom observations were used. The study examined the effectiveness of ICBLS in teaching practices.

The Findings from this study demonstrate that ICBLS provide substantial benefits for both teachers and students in lower secondary chemistry education. Specifically, the use of ICBLS allow students to visualize and engage with core chemistry concepts such as types of chemical reactions, writing and balancing chemical equations, and classification of reactions into endothermic and exothermic. This align with previous study highlight the effectiveness of digital tools in science education (Holman, 2021). Although teachers expressed positive perceptions of ICBLS for teaching these topics, some challenges were also identified. While simulations are effective in helping students visualize molecular reactions, some students struggled with translating these visual experiences into symbolic representations, particularly in writing and balancing chemical equations. This issue is consistent with previous studies by Bellou et al. (2018), which found that students struggle to move from visual to symbolic forms of understanding. These findings underscore the need for more instructional support to bridge the gap between visualization and symbolic representation of chemical reactions. Teachers suggest that traditional classroom time should be dedicated to reinforce these connections, ensuring that students not only understand chemical process visually but also represent them accurately in written form. The role of ICBLS in promoting inquiry-based learning and engaging diverse learning style was particularly appreciated by the teachers, as it allows them to address varying student needs effectively. Despite these positive perceptions, teachers experienced some challenges while incorporating ICBLS into their teaching practice. Teachers expressed frustration with the time constraints, students' varying levels of basic computer skills, overcrowded classroom as well as their incompetence in using ICBLS which hinder effective integration of it into lessons.

Additionally, the study also reveals that limited access to computers that leads students to share computers hamper individual exploration and interaction with simulated activities. Among other implications, ensuring adequate resources and reducing class size are essential to facilitate the successful integration of simulations into classroom practices. These results are consistent with Lee et al. (2021) findings, which emphasize the value of professional training and how it assists teachers in using technological teaching tools properly. These research findings show that employing interactive computer-based laboratory simulations with other teaching approaches enhances chemistry education and other science subjects, which leads to greater success and improves teacher retention. Despite lower secondary school chemistry teachers demonstrating acceptance of ICBLS integration into classroom practice, it's crucial to address some challenges voiced out by them.

Generally, the study's findings highlight the importance of ICBLS in fostering an interactive and engaging learning environment in chemistry education. However, challenges like limited computer access, unreliable internet connectivity, and insufficient professional development training impede the effective implementation of ICBLS. To address these issues, the study recommends regular training in educational technology training for teachers and the provision of adequate resources to ensure successful incorporation of ICBLS in classroom.

Conclusion

The study results underscore a dominant positivity among lower secondary school chemistry teachers regarding the incorporation of ICBLS into the chemistry teaching and learning process, particularly in the context of chemical reactions. Simulations cover the topics such as type of reactions, balancing chemical equations, and distinguish between endothermic and exothermic reactions. Participants perceive ICBLS as a valuable complement to their teaching approaches. The findings reveal a consensus among teachers regarding the inspirational impact of ICBLS on students' engagement, motivation, interest, and conceptual improvement. This implies that teachers have recognized the potential impact of ease of use and usefulness of simulations in supporting traditional teaching methods characterized by direct instruction, rote memorization, and passive learning whereby catering to diverse learning possibilities. The study's results also shed light on the emerging trend of leveraging technology to improve science teaching in general and chemistry in particular. This is through how ICBLS encourages active learning which marks a departure from conventional teaching methodologies to a learner-centered approach.

Throughout the study, we discovered unique benefits and challenges associated with incorporating ICBLS into the classroom. This has advanced our understanding of the novel application of ICBLS in chemistry education. Furthermore, the insights gained provide valuable implications for policymakers, curriculum designers, school administrators, and teachers about the effectiveness of ICBLS in transforming the learning landscape. This transformation foster deeper conceptual understanding and critical thinking among students, marking a significant shift from conventional methodologies toward a more learner-centered approach (Mwazi et al., 2023). Ultimately, these results contribute to the ongoing discourse on transforming science education, particularly in the realm of chemistry, and reflect a commitment to cultivate an educational environment that prioritize active learning and critical thinking.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The studies involving humans were approved by Directorate of Research and Innovation (DRI). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Software, Writing – original draft. GH: Methodology, Supervision, Validation, Visualization, Writing – review & editing. JN: Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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