# Effect of Computer Simulation Method on Gender Perspectives in Learning Chemical Bonding Concepts

*Isaac Sarpong*
*Bawa Mbage*
*Robert Monto*

***Abstract:*** The persistent difficulty students face in understanding chemical bonding in High School chemistry, particularly in the contexts of limited laboratory resources, has prompted the exploration of innovative pedagogy such as Computer Simulation Instructional Method (CSIM). Grounded in Kolb's Experiential Learning Theory, this study examined the effectiveness of the CSIM in teaching chemical bonding and gender-related differences in learning at Senior High Technical School (SHTS). The research adopted quasi-experimental one-group pretest-posttest design with a quantitative approach. A purposive sample of 65 elective chemistry students from the Senior High Technical School participated in a five-week intervention period using an integrated PhET simulations in CSIM. Data were collected through pre- and post-intervention achievement tests and structured questionnaire. Data was analysed using descriptive statistics and paired t-tests. Results showed that CSIM significantly improved students' performance. The findings revealed that both male and female learners benefited equally from the intervention, thus no statistically significant gender differences observed. Students also reported that CSIM enhanced their understanding, motivation, and engagement irrespective of infrastructural challenges such as limited devices and poor internet connectivity. The study concludes that CSIM is an effective and equitable instructional strategy for teaching chemical bonding in resource-constrained contexts. Therefore, it was recommended school management and policymakers within the study area invest in ICT infrastructure and teacher training to support Simulation-based instruction. Future research should investigate the combined impact of CSIM and hands-on laboratory activities on students' conceptual and practical skills.

## INTRODUCTION

The teaching of chemical bonding in the Senior High Technical School (SHTS) chemistry presents persistent challenges due to its abstract nature and the need to integrate macroscopic, symbolic, and sub-microscopic representations. Students often struggle to visualize atomic interactions, distinguish between bond types, and apply bonding principles to molecular structures, difficulties consistently highlighted in the West African Examinations Council (WAEC) Chief Examiner's Reports. In 2021, only 41.2 % of candidates obtained grades between A1 and C6 in Elective Chemistry, with chemical bonding identified as one of the most poorly answered topics (WAEC, 2021). Computer Simulation Instructional Approaches (CSIM) have emerged as promising pedagogical tools to address these conceptual gaps. By offering interactive and visual models of molecular behaviour, CSIM enables learners to manipulate variables, observe atomic interactions, and explore bonding mechanisms in real time (Smetana & Bell, 2012; Yuliati *et al.,* 2018). Tools such as PhET simulations allow students to bridge the gap between theoretical constructs and observable phenomena, fostering deeper understanding and reducing reliance on rote memorization (Levy-Nahum *et al.*, 2010; Kuit & Osman, 2021). Empirical studies across diverse contexts have demonstrated that CSIM improves academic performance in chemistry. For example, Mihindo *et al.* (2017) found significant gains in students' understanding of electrochemistry using simulation-based instruction in Kenyan secondary schools. Similarly, Yuliati *et al.* (2018) reported an improved conceptual understanding in Indonesian classrooms following CSIM integration. However, the distribution of these gains across learner demographics remains underexplored. Research suggested that prior exposure to digital tools, confidence levels and classroom dynamics have influence on how male and female students engage with simulations (Zacharia & Olympiou, 2011). While some studies reported equitable outcomes (Udo & Etiubon, 2011), others highlighted subtle gendered differences in interaction patterns and performance (Smetana & Bell, 2012).

Student perceptions are equally critical in determining the success of technology-mediated instruction. Positive attitudes toward CSIM are associated with increase motivation, engagement, and conceptual retention (Khalid *et al.*, 2023). Yet, low-resource educational contexts like Ghanaian Senior High Schools, the infrastructural limitations including unreliable internet, limited access to devices and insufficient teacher training is observed to constrain the effectiveness of simulation-based learning (Ghana Statistical Service, 2020).

At the SHTS, internal assessments and teacher interviews reveal persistent difficulties in chemical bonding, particularly among female students. Despite growing interest in interactive learning, the schools face challenges such as limited ICT infrastructure and inconsistent pedagogical that integrate simulations teaching. These realities highlight a critical gap in the literature that while CSIM has been widely studied in high-income countries such as the United States, it is different in Ghanaian High School Chemistry. The National Center for Education Statistics (NCES, 2021) reported that approximately 30 % of high school students are enrolled in chemistry courses annually due the fact that it is a requirement for graduation or college entry. Meanwhile, China's New Curriculum Reform requires that chemistry is studied as a core subject in the senior secondary level, leading over 80 % of students learning chemistry courses (Zhang *et al.*, 2020). Although some research works have tried to address this gap in the Ghanaian context, gender effects and student perceptions in elective chemistry classrooms remain under-researched to determine its effect on learning bonding concepts. This study was therefore designed to investigate the effect of computer simulation method on gender perspectives in learning chemistry bonding concepts at Ghanaian SHTS.

This study, therefore, investigates two interrelated questions:

1.Does CSIM produce comparable learning gains for male and female students in chemical bonding?

2. How do both male and female students perceive the use of CSIM in learning chemical bonding?

The study also seeks to test the hypotheses:

H0; There is no statistically significant difference in the performance of male and female students taught chemical bonding using CSIM.

This study contributed to the empirical evidence on both equity and pedagogical effectiveness in simulation-based chemistry instruction on gender point of view. Considering the CSIM benefits that are found to be equitable, the study supported its broader adoption as an inclusive instructional tool. Conversely, the differential benefits emerged from the study were identified and targeted with scaffolding or instructional redesign to ensure all learners benefit from simulation-based instruction

## REVIEW OF LITERATURE

Theoretical Model: Experiential learning

Experiential Learning Theory (ELT) proposed by David A. Kolb in 1984, which is rooted in the constructivist perspective of learning, emphasize the role of experience in the knowledge acquisition process (Kolb, 1984). ELT posits that learning is a continuous cycle that involves concrete experiences, reflective observation, abstract conceptualization and active experimentation. This theoretical framework has been widely applied in science education, particularly in enhancing conceptual understanding through interactive and hands-on learning experiences (Kolb & Kolb, 2017). The application of ELT in teaching chemical bonding through computer simulation aligns with Kolb's model. This model proposed that simulations could provide students with concrete experiences that engage them in real-world scientific processes. Computer simulations offer visual representations of atomic interactions, molecular formations and bond energies which are otherwise difficult to observe during the use of traditional instructional methods (Wieman & Perkins, 2018). Through interactive digital environments, students can manipulate variables, observe the outcomes and develop a deeper conceptual understanding of bonding theories.

According to Kolb (1984), effective learning occurs when students undergo a four-stage cycle. In the context of computer simulation for learning chemical bonding, the first stage (Concrete Experience) could be fulfilled when students engage with virtual molecules, visualise atomic interactions and observe how chemical bonds form and break in real-systems. These interactive experiences could allow learners to bridge the gap between abstract theories and practical applications (Smetana & Bell, 2019). The second stage (Reflective Observation) occurs as students analyze their interactions with the simulation. Reflection is a critical step in the learning process, as it enables students to construct meaningful connections between observed phenomena and theoretical concepts (Kolb & Kolb, 2017; Brinson, 2015). During the third stage (Abstract Conceptualization), students synthesize their observations and formulate general principles about the concepts. Computer simulations enhance this phase by allowing learners to test various chemical principles and observe emergent patterns to reinforce theoretical understanding (Rutten *et al.*, 2012). Researches have indicated that when students explore multiple bonding scenarios through simulations, they develop a more nuanced understanding of ionic, covalent, and metallic bonding (Zacharia, 2015). The fourth stage (Active Experimentation) involves applying newly acquired knowledge to solve problems, predict molecular behavior, and conduct virtual experiments. In the context of chemical bonding, students may use simulations to predict bond strength based on molecular geometry, assess the impact of hybridization, or simulate chemical reactions under different conditions (Wu *et al.*, 2020). The iterative process of hypothesis testing and verification, facilitated by computer simulations, aligns with the principles of ELT and fosters scientific inquiry (Hsu & Thomas, 2022). Empirical studies have supported the effectiveness of computer simulations in science education, particularly in complex topics like chemical bonding. For instance, a study by Sun *et al.* (2021) found that students who engaged with interactive simulations outperformed those who relied solely on textbook-based learning.

Teaching and Learning of Chemistry Concepts

The teaching and learning of chemistry play a crucial role in science education because the subject provides foundational knowledge for understanding natural phenomena and technological development. According to Hofstein (2017), chemistry education benefits significantly from practical laboratory experiences and diverse instructional strategies that allow students to actively engage with scientific concepts. These instructional practices help students connect theoretical knowledge with real-world applications and thereby promotes deeper conceptual understanding.

The effectiveness of chemistry learning is often influenced by the type of teaching strategies and practical activities used in the classroom. Shana and Abulibdeh (2020) noted that students' performance in chemistry-related courses is strongly associated with their ability to integrate theoretical explanations in practical experimentation. As a result, educators increasingly try to adopt innovative teaching strategies that promote active participation and conceptual clarity.

A number of studies across different regions have explored strategies aimed at improving the teaching and learning of chemistry. For instance, Yildizay and Leman (2017) reported that the use of Problem-Based Learning significantly enhanced students' conceptual understanding and problem-solving abilities in chemistry classrooms. Similarly, Sadykov and Ctrnactova (2019) examined the integration of digital technologies in chemistry instruction and demonstrated that digital learning environments helps bridge conceptual gaps by providing visual representations of abstract chemical processes. Digital technologies have increasingly become important tools in science education due to their ability to support interactive learning experiences. Mabweazara (2018) noted that digital tools enhance teaching effectiveness and promote creative learning by allowing students to manipulate and observe complex scientific phenomena in simulated environments. In addition, Kristen *et al.* (2017) highlighted the importance of structured tutorials and targeted instructional support to help students overcome common learning difficulties in chemistry, thereby improving their engagement and confidence in the subject.

The influence of technology in chemistry education has also received considerable attention because of its potential to improve students' academic performance, motivation and engagement in learning activities. Sapriati (2023) emphasized that technological integration can strengthen students' hands-on experiences by providing virtual environments where chemical processes can be explored safely and repeatedly. Such learning environments allow students to experiment with variables and observe molecular interactions that are often difficult to be demonstrated in traditional classroom lessons.

Furthermore, the integration of technology in chemistry education enables scientists and learners to explore intricate phenomena, make informed decisions and develop a deeper understanding of chemical processes (Suleman *et al.*, 2019). Despite these advancements, many chemistry concepts such as chemical bonding remain abstract and difficult for students to visualize using traditional teaching methods alone. This challenge has prompted increasing interest in computer-based simulations that can visually represent microscopic interactions between atoms and molecules, thereby enhancing conceptual understanding. However, there remains limited empirical evidence to examining how such simulation-based approaches influence gender-related learning outcomes in specific chemistry topics such as bonding. This gap underscores the need for further investigation into the effectiveness of computer simulation methods in supporting equitable learning outcomes among male and female students.

Effect of CSIM on male and female students' performance

Several studies have examined the influence of computer simulation instructional methods on students' academic performance, including differences related to gender. In Africa, Gbeleyi (2021) conducted a study in Nigeria and found that the Computer Simulation Instructional Method significantly improved the academic performance of both male and female students in chemistry. The results indicated that simulation-based instruction provided an interactive learning environment that benefited students regardless of gender. Similarly, a study conducted in Rwanda by Irakoze *et al.* (2021) reported that both male and female students demonstrated positive attitudes toward chemistry learning when interactive digital tools were incorporated into lesson instruction. The study also revealed that female students often faced challenges such as lower self-confidence and a lack of female role models in science-related fields. The reports suggested that technology-supported instructional strategies, including computer simulations, could help address these challenges by providing supportive and collaborative learning environments that encourage female participation.

In Ghana, Dodoo (2023) investigated the use of computer simulations in teaching integrated science and found that the strategy enhanced the academic performance of both male and female students. The study attributed these improvements to the ability of simulations to promote realistic visualization of scientific processes, encourage critical thinking and increase students' engagement during lessons. Although these studies demonstrated the positive influence of simulation-based instruction on students' academic performance, the findings also suggest that gender-related factors may influence how students interact with digital learning environments. Many previous studies have focused primarily on general science or chemistry achievement without examining how specific conceptual domains within chemistry may affect gender-related learning outcomes. Additionally, limited research has explored how computer simulation instructional methods influence male and female students' understanding of complex and abstract chemistry concepts such as chemical bonding. Investigating this relationship is important because chemical bonding forms the foundation for understanding many advanced topics in chemistry, yet it remains one of the most challenging areas for students to learn and understand. Therefore, examining the effect of CSIM on male and female students' performance specifically in chemical bonding concepts could contributes to addressing an important gap in the literature.

Students' Perceptions on the Use of CSIM in Chemistry Learning

Students' perceptions of instructional strategies play a crucial role in determining the effectiveness of teaching and learning processes. Owusu *et al.* (2021) reported that students generally perceived simulation-based learning environments as engaging and interactive. The study indicated that simulations help bridge the gap between theoretical knowledge and practical applications by allowing students to visualize chemical reactions and molecular interactions. However, the implementation of simulation-based learning is not without challenges. Owusu *et al.* (2021) also highlighted issues such as limited access to computers and insufficient teacher training in the effective use of simulation technologies to be the challenges associated with the method of teaching.

Similarly, Rutten *et al.* (2020) found that students considered simulations particularly useful for visualizing dynamic chemical reactions and microscopic processes that cannot easily be observed in conventional laboratory settings. Their findings showed that students who supplemented their learning with simulations developed deeper conceptual understanding as compared to those who relied solely on textbooks.

Despite these advantages, some studies have also suggested that students still value traditional laboratory experiences. Wainwright *et al.* (2020) found that while many students recognized the benefits of simulations, a considerable number preferred hands-on laboratory experiments because they are provided with a direct physical interaction with experimental materials. Supporting this view, Mensah and Boateng (2021) reported that students in rural schools with limited laboratory resources appreciated simulations as alternative learning tools, whereas students in well-equipped urban schools inclined towards physical experiments.

The level of instructional support provided during simulation-based learning also influences students' perceptions. Sanger *et al.* (2019) found that male and female students sometimes respond differently to technology-based instructional approaches. Male students often displayed greater confidence in navigating simulation tools, while female students tended to prefer collaborative learning environments when using such technologies. Similarly, Asiedu and Nyarko (2022) observed that female students became more engaged when simulations were integrated into group-based learning activities whereas male students often preferred independent exploration of digital tools. Nevertheless, simulation-based learning continues to demonstrate significant potential in improving students' interest in chemistry. Tüysüz (2020) reported that students who frequently learned through simulation-based instructional methods developed stronger interest in chemistry and were more likely to pursue science-related careers.

While these studies provide valuable insights into students' perceptions of simulation-based learning, there is still limited research examining how students perceive computer simulations use for learning specific and conceptually demanding topics such as chemical bonding. Additionally, few studies have explored whether male and female students differ in their perceptions of simulation-based instruction when applied to such abstract chemistry concepts. Understanding these perceptions is important because students' attitudes toward instructional methods can influence their motivation, engagement, and ultimately their academic performance. Therefore, investigating students' perceptions of CSIM in learning chemical bonding concepts provides further insight into how simulation-based instruction can be effectively implemented to support inclusive and meaningful chemistry learning

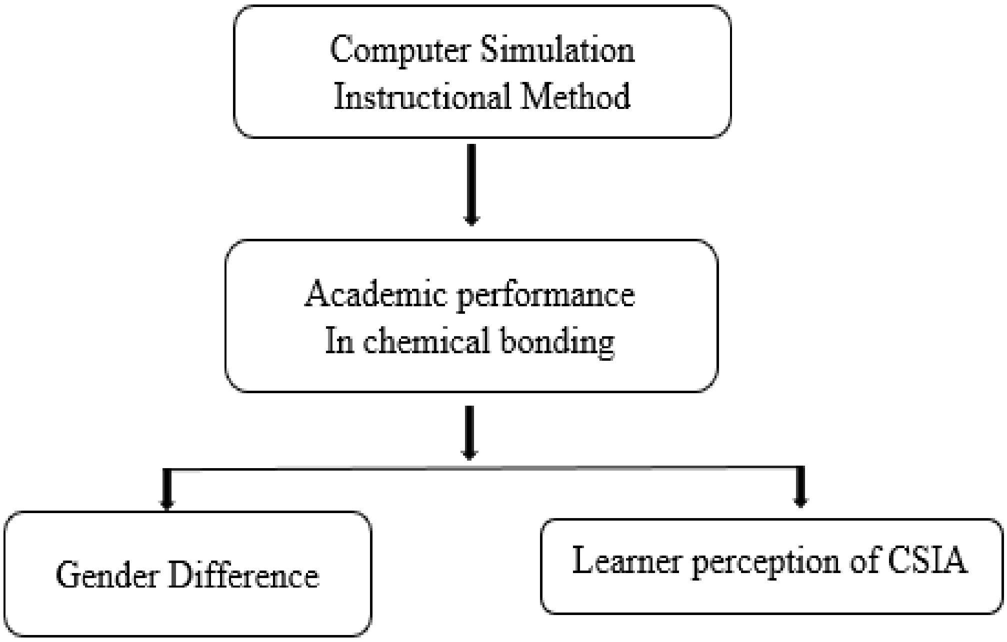


**Fig 1:** Conceptual framework

## METHODOLOGY

Research design and approach

This study employed action research with a quasi-experimental one-group pretest-posttest design to enhance professional teaching practice and generate practical solutions to classroom challenges (Ford *et al.*, 2022). Action research is particularly useful in educational settings because it allows teachers to systematically investigate problems in their own classrooms and implement evidence-based instructional strategies to improve student learning outcomes (Mertler, 2020). The quasi-experimental one-group pretest-posttest design was chosen for this study because students demonstrated persistent conceptual difficulties in understanding chemical bonding concepts. These challenges required the implementation of an instructional intervention aimed at improving students' conceptual understanding. The study therefore introduced the Computer Simulation Instructional Method (CSIM) as an instructional strategy over a four-week intervention period.

The study adopted a quantitative research approach, focusing on measuring changes in students' academic performance before and after the intervention. To address the concern of determining whether the observed learning gains were attributable to the intervention rather than normal classroom instruction, the study adopted a pre-intervention, intervention, and repeated post-intervention assessment structure. The pre-test measured students' baseline understanding of chemical bonding before any targeted instructional strategy was implemented. The post-tests were administered after exposure to the CSIM intervention in order to measure changes in students' understanding following the use of the instructional approach. This structure allowed the researcher to compare students' performance before and after the intervention and determine whether the use of CSIM resulted in measurable learning improvements beyond students' initial conceptual understanding.

Furthermore, the study incorporated two post-tests administered at different time intervals. The first post-test measured immediate learning gains after the introduction of the CSIM strategy, while the second post-test assessed the stability and retention of students' understanding over time. This repeated assessment approach is recommended in educational intervention studies because it helps determine whether observed improvements are sustained rather than temporary (Creswell & Creswell, 2018).

Population and Sample

This study was conducted at Kwahu Ridge Senior High Technical School in Ghana. The school had a student population of 1420 at the time of the researcher's study period. The target population was Form 2 students, who numbered 515 and studied elective chemistry. They were all students in Kwahu Ridge Senior High Technical School. The accessible population of this study was Form 2 Science A, B, and C comprising of 65 students. Asiamah *et al.* (2017) explained that the accessible population refers to the portion of the target population that is reachable and available for research purposes. It encompasses individuals or elements from the target population that can be engaged and enlisted to participate in a study. Those classes were chosen because the students had difficulties with the concept of chemical bonding, and those were the classes the researcher taught. The researcher employed a purposive sampling technique to select all 65 Form 2 Science students. This sampling technique was employed because the researcher teaches in that class and the topic is also treated in Form 2 according to the Ghanaian chemistry syllabus (Ministry of Education, 2010). The technique was also chosen because that was the class where students had significant difficulties in chemical bonding that needed to be addressed.

Research Instruments

This study employed a test and a structured questionnaire to collect data, which was used to answer the research objectives.

Test Scores

According to Adom *et al.* (2020), a test is a research instrument used to evaluate and measure individuals' knowledge, skills, abilities, or understanding in a particular subject area. In this study, achievement tests were used to assess students' conceptual understanding of chemical bonding before and after the implementation of the Computer Simulation Instructional Method (CSIM). A pre-intervention test (pre-test) was administered before the introduction of the CSIM strategy to assess students' baseline understanding of chemical bonding concepts. The test consisted of four essay-type questions, and students were given 20 minutes to complete the assessment.

The essay questions were carefully developed by the researcher based on the curriculum objectives outlined in the Ghanaian Senior High School Chemistry syllabus (Ministry of Education, 2010). The items covered key concepts in chemical bonding, including ionic bonding, covalent bonding, and the formation of chemical bonds through electron transfer and sharing. In order to ensure content validity, the questions were aligned with the learning outcomes expected at the Form Two level. Additionally, the items were structured to assess students' conceptual understanding, reasoning ability, and ability to explain bonding processes rather than simple recall of facts.

To further strengthen the validity of the test instrument, the questions were reviewed by two experienced chemistry teachers and one science education lecturer. Their feedback helped refine the wording, clarity, and difficulty level of the items to ensure that they were appropriate for senior high school students. This process of expert validation is recommended in educational research to ensure that assessment items accurately measure the intended constructs (Fraenkel *et al.*, 2019).

Following the pre-test, the CSIM intervention was implemented during regular chemistry lessons over a five-week instructional period.

Two post-tests were conducted after the implementation of the intervention. The first post-test was administered after two weeks of teaching using the CSIM approach in order to measure the immediate impact of the intervention on students' understanding of chemical bonding. The second post-test was conducted two weeks after the first post-test to determine the consistency and retention of students' learning over time. The purpose of the second post-test was to confirm whether students had developed a stable understanding of the concepts rather than experiencing temporary improvement. Both post-tests consisted of four essay-type questions similar in structure and difficulty level to those used in the pre-test. The items assessed the same conceptual domains of chemical bonding to ensure comparability across the three testing phases. Maintaining similar content coverage and cognitive demand across tests helped ensure that differences in performance reflected learning gains rather than differences in test difficulty (Creswell & Creswell, 2018).

Each essay question was scored using analytic scoring rubric developed by the researcher. The rubric specified key criteria for awarding marks, including conceptual accuracy, clarity of explanation, correct use of chemical terminology, and logical presentation of ideas. Each question carried equal marks, and the total score reflected students' overall understanding of chemical bonding concepts. The use of an analytic scoring rubric helped ensure consistency and objectivity in evaluating students' responses (Brookhart, 2013). The rubric allocated marks for specific components of the answers, such as correct identification of bonding type, accurate explanation of electron transfer or sharing, and appropriate use of diagrams where necessary. This structured scoring approach allowed the researcher to evaluate students' responses systematically and reduced the likelihood of subjective judgement.

Several measures were taken to minimize potential researcher bias in both the development and scoring of the test instrument. Firstly, the test items were reviewed by independent subject experts prior to administration to ensure that they were valid and free from ambiguity. This external review helped ensure that the items measured students' conceptual understanding rather than reflecting the researcher's expectations. Moreover, the scoring rubric was developed before the tests were administered and was applied consistently to all students' responses. This ensured that all scripts were graded using the same criteria and marking scheme.

To enhance scoring reliability, a second experienced chemistry teacher independently marked a sample of students' scripts using the same rubric. The scores from both markers were compared to check for consistency. Where discrepancies occurred, discussions were held to reach a consensus on the appropriate score. Such procedures are recommended in educational assessment to improve scoring reliability and reduce examiner bias (Fraenkel *et al.*, 2019).

Structured Questionnaire

In this study, a structured questionnaire was used to gather data on students' perceptions of the use of CSIM in the teaching and learning of chemical bonding. The questionnaire consisted of 10 carefully constructed items designed to elicit clear and relevant responses aligned with the objectives of the study. The questionnaire used in this study was developed by the researcher. The development process involved a thorough review of relevant literature on instructional strategies in chemistry education and consultation with subject experts to ensure that the items were valid, relevant, and comprehensible to senior high school students (Kuphanga, 2024). Each item was designed to capture students' experiences and perceptions regarding the effectiveness, engagement, and usefulness of computer simulations in learning chemical bonding concepts.

To ensure content validity, the questionnaire items were examined by two science education specialists and one experienced chemistry teacher. Their feedback helped refine the wording of the items, remove ambiguities, and ensure that the statements accurately reflected students' experiences with the CSIM instructional approach.

A 3-point Likert scale was adopted for the questionnaire, consisting of Agree (A), Neutral (N), and Disagree (D) response options. The decision to use a 3-point Likert scale rather than a 4- or 5-point scale was informed by the nature of the respondents and the clarity it offers in interpreting the data. This approach is consistent with the findings of Alhassan *et al.* (2022), who emphasised that fewer response categories can reduce respondent confusion, particularly among younger participants such as senior high school students. Their findings suggested that 3-point scales encourage respondents to make deliberate choices without feeling overwhelmed by too many response options, which can sometimes lead to response fatigue or inconsistent answers.

Moreover, the use of a 3-point Likert scale helps provide clearer and more interpretable results with limited ambiguity. Dolnicar (2021) noted that when conducting perception studies among high school students, simplified response scales often produce more reliable responses because they reduce indecision while still allowing respondents to indicate neutrality when necessary. The simplicity of the 3-point scale also facilitated straightforward statistical analysis and clearer interpretation of students' perceptions regarding the effectiveness of the CSIM instructional approach in learning chemical bonding concepts. The 3-point Likert scale employed could result in statistical limitations such as low reliability and lower effect size. This limitations in other works could be catered for by increasing the Likert scale range to 5-7, otherwise an interview guide could be used to supplement this quantitative approach.

Data Collection Procedure

Data were collected in three stages: pre-intervention, intervention, and post-intervention. In Week 1, a supervised pre-test (four essay questions, 40 minutes, total = 40 marks; pass mark = 20) was administered to diagnose students' understanding of chemical bonding; items were drawn from WASSCE past questions and the SHS syllabus. The intervention then ran for five weeks using PhET computer simulations, a multimedia projector, and guided worksheets; weekly lessons covered (1) introduction to bonding, (2) ionic bonding, (3) covalent bonding, (4) metallic bonding, and (5) bonding–properties integration, with students manipulating simulations, predicting properties, and completing reflective tasks. Post-intervention assessment comprised two identical post-tests (four essay questions, 40 minutes each) administered in Week 7 and Week 9 to measure immediate gains and short-term retention. All tests were conducted under standard examination conditions to ensure independent work.

Data Analysis

Achievement test scores were summarised with means, standard deviations, and score distributions. Paired t-tests assessed statistically significant differences between pre- and post-test scores (and between post-tests). All quantitative analyses were performed in IBM SPSS Statistics v26, which provides reliable routines for descriptive statistics, paired t-tests, assumption checks, and effect-size calculations and is widely recommended for applied educational research (Field, 2018; Pallant, 2020). A frequency distribution and a t-test statistic were used to analyse the differential effects of CSIM on the academic performance of male and female students. Moreover, students' perceptions regarding the usage of CSIM were analysed and presented as frequencies, percentages, and means.

## RESULTS AND DISCUSSION

## RESULTS

This question explored whether CSIM impacts male and female students differently in their academic performance in chemical bonding. The result of the data collected and analysis compared the performance between male and female students across all three tests. These results are presented in Tables 1, 2, and 3.

4.2. 1 Comparable learning gains for male and female students in chemical bonding

Table 1: Frequency Distribution of Pre-test of Male and female Students

| Range of Marks | Female (N) | Female (%) | Male (N) | Male (%) |
|---|---|---|---|---|
| 0–19 | 10 | 34.5 | 12 | 33.3 |
| 20–24 | 7 | 24.1 | 8 | 22.2 |
| 25–30 | 6 | 20.7 | 9 | 25.0 |
| 31–35 | 4 | 13.8 | 4 | 11.1 |
| 36–40 | 2 | 6.9 | 3 | 8.3 |
| Total | 29 | 100 | 36 | 100 |

Mean (Females)= 21.45, SD= 9.70, Mean (Males)= 21.76 SD= 9.69

Table 1 presents the distribution of pre-test scores for male and female students. The results revealed that a significant proportion of students in both groups scored within the lower mark ranges, indicating limited prior conceptual understanding of chemical bonding before the intervention. 34.5 % of female and 33.3 % of male students scored marks between 0 and 19. This performance suggested that about one-third of both male and female students had very weak fundamental knowledge of the topic. Additionally, the 20–24 marks range that represented a relatively low performance had 24.1 % of female and 22.2 % of male students' performance within the range, which further emphasized the general trend of underachievement across both groups. As the scores increased, the proportion of students within each category gradually declined. For instance, 20.7 % of female and 25.0 % of male students scored marks within the 25–30 range, while only 13.8 % of female and 11.1 % of male students scored in the 31–35 range. The highest score range (36–40 marks) was achieved by just 6.9 % of female and 8.3 % of male students, showing that only a small fraction of the students had a better grasp of chemical bonding before the CSIM's intervention. The mean scores, 21.45 for females and 21.76 for males, were very close, indicating that both groups performed at a similar average level before the introduction of the CSIM. The comparable standard deviations (9.70 for females and 9.69 for males) also reflect similar spreads in performance, suggesting that the variability in understanding was consistent across both genders. The data clearly indicated a generally low level of academic readiness among students in both groups, underscoring the need for effective instructional strategies such as CSIM to improve conceptual understanding in chemistry.

From Table 2, a notable reduction in low scores was observed after the implementation of the CSIM pedagogy. Only 17.2% of female students and 8.3% of male students scored between 0–19, compared to 34.5% and 33.3% respectively, in the pre-test. This indicates that fewer students struggled with the basic concepts following the intervention. In the 20–24 marks range, 20.7% of females and 11.1 % of males fell into this category. Though this result is still relatively low-performing, these figures are lower than their corresponding pre-test percentages with a slight shift toward improvement. The 25–30 interval became the most populated range for both genders, with 34.5% of females and 27.8% of males scoring in this bracket. This shift implies that a large portion of students moved from low to mid-performance levels, which suggests better comprehension of the concept.

Higher performance was also seen in the 31–35 and 36–40 intervals. For example, 24.1% of females and 22.2% of males scored between 31 and 35, while 24.1% of females and 13.9% of males achieved the highest range of 36–40. These numbers reflect a substantial improvement in academic performance among both male and female students. The mean scores rose from 21.45 to 27.19 for females and from 21.76 to 28.18 for males, confirming the positive effect of CSIM on students' understanding of chemical bonding. The standard deviations, 8.90 for females and 7.91 for males, suggest that while the male scores were slightly more concentrated around the mean, both groups showed fairly consistent performance after the intervention.

Table 2: Frequency Distribution of Post-test 1 of Male and female Students

| Range of Marks | Female (N) | Female (%) | Males (N) | Males (%) |
|---|---|---|---|---|
| 0–19 | 5 | 17.2 | 3 | 8.3 |
| 20–24 | 6 | 20.7 | 4 | 11.1 |
| 25–30 | 10 | 34.5 | 10 | 27.8 |
| 31–35 | 7 | 24.1 | 8 | 22.2 |
| 36–40 | 7 | 24.1 | 5 | 13.9 |

Mean (Females): 27.19, SD: 8.90, Mean (Males): 28.18 SD: 7.91

Table 3 shows that the majority of both male and female students scored within the upper mark ranges after the second post-test, indicating sustained academic progress following continued exposure to the Computer Simulation Instructional Method (CSIM). A minimal number of students remained in the lowest performance category (0–19), comprising only 6.9 % of females (2 students) and 2.8 % of males (1 student). This marks a significant improvement from the pre-test, where 34.5 % of females and 33.3% of males had scores within this range. The reduction illustrates the success of CSIM in elevating students from basic to higher performance levels. In the 20–24 range, just 10.3 % of females and 5.6% of males were recorded, further supporting the trend that only a small fraction of students remained in the lower achievement bands.

The mid-range scores of 25–30 were occupied by 31.0% of females and 16.7 % of males. This group of students, although not at the top performance level, has proven to have continued improving from minimal to moderate understanding of chemical bonding concepts. Strong academic performance is further evident among those who scored between 31 and 35, with 34.5% of females and 27.8 % of males achieving this. Notably, the highest scoring range of 36–40 was attained by

31.0% of females and 36.1 % of males, the most populated interval for male students. This underscores the impact of CSIM not just in moving students out of failure zones, but also in pushing them toward excellence. The average score for females rose to 30.44, while males recorded an even higher mean of 32.58. Compared to pre-test scores of 21.45 (females) and 21.76 (males), and first post-test scores of 27.19 and 28.18, respectively, this growth reveals a consistent and significant improvement for both genders, with male students showing slightly more gains at this stage. The standard deviations of 7.28 for females and 6.35 for males suggest that students' scores were relatively clustered around the mean. The lower standard deviation for males also implies a more consistent performance pattern among them. Overall, these results demonstrate that the CSIM method not only improved understanding across the board but also reduced score variability, reflecting a more uniform mastery of chemical bonding among learners.

Table 3: Frequency Distribution of Post-test 2 of Male and female Students

| Range of Marks | Female (N) | Female (%) | Male (N) | Male (%) |
|---|---|---|---|---|
| 0–19 | 2 | 6.9 | 1 | 2.8 |
| 20–24 | 3 | 10.3 | 2 | 5.6 |
| 25–30 | 9 | 31.0 | 6 | 16.7 |
| 31–35 | 10 | 34.5 | 10 | 27.8 |
| 36–40 | 9 | 31.0 | 13 | 36.1 |

Mean (Females): 30.44 SD: 7.28 Mean (Males): 32.58 SD: 6.35

Null hypothesis: There is no statistically significant difference in the performance of male and female students taught chemical bonding using CSIM.

To test the null hypothesis, a t-test was used to examine potential gender differences in academic performance following the implementation of CSIM in learning chemical bonding. The results in Table 4 compare the performance of male and female students across the three tests.

In Table 4, female students (N = 29) had a mean score of 21.45 while male students (N = 36) recorded a slightly higher mean score of 21.76 in the pre-test. The closeness of these mean values suggests that both groups began at nearly the same level of understanding before the intervention. Importantly, the p-value associated with the difference in mean scores between females and males in the pre-test was 0.897. Since this p-value is significantly greater than the conventional threshold of 0.05, it indicated that there was no statistically significant difference in the prior knowledge of chemical bonding between the two groups. After the intervention, post-test 1 results showed improvement for both groups. Female students (N = 35) achieved a mean score of 27.19, while male students (N = 30) scored a slightly higher mean of 28.18. The observed increase in mean scores from the pre-test to post-test 1 for both genders suggests that the Computer Simulation Instructional Method had a positive effect on students' performance. The p-value for the difference between the female and male mean scores at this stage was 0.640, which is also greater than 0.05. This result confirms that the difference in performance between the genders remained statistically insignificant after the exposure to the intervention. Hence, the null hypothesis 2 was failed to be rejected. Therefore, it can be inferred that both female and male students benefited comparably from the computer simulation approach during the early post-intervention phase.

According to post-test 2, which assessed academic performance after two weeks of the implementation of the first post-test, further improvements were recorded. Female students (N = 33) attained a mean score of 30.44, while male students (N = 32) achieved a higher mean score of 32.58. The steady rise in mean scores across the three phases clearly illustrates an improvement in learning outcomes for both groups. The increase was more pronounced among male students, reflecting slightly greater improvement. However, the p-value for this test phase was 0.212, which exceeds the 0.05 threshold. This result shows there are no statistically significant differences among male and female students' performance in the three tests; therefore, the null hypothesis was failed to be rejected. Thus, while males performed somewhat better at that level, the difference cannot be considered significantly meaningful.

Table 4: t-test Analysis of Male and female students' Performance in the tests

| **Test Phase** | **Group** | **N** | **Mean** | **P-value** |
|---|---|---|---|---|
| Pre-test | Female | 29 | 21.45 | 0.897 |
| | Male | 36 | 21.76 | |
| Post-test 1 | Female | 35 | 27.19 | |
| | Male | 30 | 28.18 | 0.640 |
| Post-test 2 | Female | 33 | 30.44 | |
| | Male | 32 | 32.58 | 0.212 |

Not Significant at $p > 0.05$ level of significance

Students Perceive the Use of CSIM in Learning Chemical Bonding

The results in Table 5 indicate that students generally held highly positive perceptions of the CSIM in the chemistry classroom. The majority of respondents (above 80 % across most items) agreed that CSIM enhanced their understanding of abstract chemistry concepts (84.6 %, M = 2.78), improved their interest and motivation in learning chemistry (84.6 %, M = 2.78), and made lessons more engaging than traditional teaching methods (84.6 %, M = 2.77). Similarly, most students expressed a preference for using CSIM in collaborative group work (83.1 %, M = 2.77) and felt confident using the simulations even with limited teacher guidance (84.6 %, M = 2.78). Interestingly, while the majority of students recognised that CSIM has the potential to link chemistry theory to real-world applications, a small proportion (10.8 %) disagreed. Furthermore, technical challenges such as poor internet connectivity and limited access to devices were acknowledged by 84.6 % of the students as constraints that reduce the overall effectiveness of CSIM (M = 2.77). Taken together, these findings suggested that although learners overwhelmingly value CSIM for its pedagogical benefits, infrastructural limitations remain a critical barrier to its full integration in the chemistry classroom.

Table 5: Students' Perceptions of the use of CSIM in the Chemistry Classroom

| Statement | Agree (%) | Not Sure (%) | Disagree (%) | Mean |
|---|---|---|---|---|
| Computer simulations instructional approach (CSIM) helps me understand abstract chemistry concepts better. | 55 (84.6) | 6 (9.2) | 4 (6.2) | 2.78 |
| I find CSIM more engaging than traditional teaching methods. | 55 (4.6) | 5 (7.7)) | 5 (7.7) | 2.77 |
| CSIM improves my interest and motivation in learning chemistry. | 55 (84.6) | 6 (9.2) | 4 (6.2) | 2.78 |
| I prefer using CSIM in group work rather than working alone. | 54 (83.1) | 7 (10.8) | 4 (6.2) | 2.77 |
| I feel confident using CSIM without much teacher guidance. | 55 (84.6) | 6 (9.2) | 4 (6.2) | 2.78 |
| Technical issues (e.g., poor internet, limited access) reduce the effectiveness of CSIM | 55 (84.6) | 5 (7.7) | 5 (7.7) | 2.77 |
| CSIM helps me relate chemistry theory to real-world applications. | 52 (80.0) | 6 (9.2) | 7 (10.8) | 2.69 |
| I would prefer hands-on laboratory experiments to CSIM. | 10 (15.4) | 10 (15.4) | 45 (69.2) | 2.56 |
| Teacher support during CSIM lessons helps me understand the topic better. | 51 (78.5) | 6 (9.2) | 8 (12.3) | 2.66 |
| Using CSIM has increased my desire to pursue a science-related career. | 56 (86.2) | 4 (6.2) | 4 (6.2) | 2.77 |

## DISCUSSION

The findings from this study demonstrate that the CSIM improved the academic performance of both male and female students in chemical bonding, with gains sustained across two post-tests. Although male students consistently recorded slightly higher mean scores than their female counterparts (pre-test: 21.76 vs. 21.45; post-test 1: 28.18 vs. 27.19; post-test 2: 32.58 vs. 30.44), none of these differences were statistically significant ($p > 0.05$). This result indicates that CSIM produced comparable learning gains across genders, suggesting that the intervention functioned as an equitable instructional tool for the classes of learners. These results are strongly consistent with findings from previous international and African studies. For instance, Lamb (2025) in the United States and Gbeleyi (2021) in Nigeria both reported significant improvements in science learning outcomes with CSIM, but no statistically significant gender differences, echoing the pattern observed in the current Ghanaian context. Similarly, Dodoo (2023) found in Ghana that CSIM improved integrated science performance across Junior High School students irrespective of gender, supporting the idea that simulation-based approaches reduce gender disparities by engaging diverse cognitive styles and promoting active learning.

At the same time, the study's slight but consistent male advantage in mean scores aligns with the modest gender gap observed in Alabidi *et al.*'s (2023) study in the United Arab Emirates, where males recorded marginally higher conceptual gains than females. This also resonates with Wrigley-Asante *et al.*'s (2023) broader analysis of gender and STEM in Ghana, which noted that although males tend to outperform females in SHS-level science. The interventions such as CSIM may help narrow these gaps by creating more inclusive and interactive learning environments. Importantly, while Irakoze *et al.* (2021) highlighted persistent barriers for female students in Rwanda, such as lower confidence and limited role models, the current findings suggest that CSIM can mitigate these affective challenges by providing visualisation and interactivity that benefit both genders.

The evidence indicated that while gender-based disparities in science achievement remain a concern in many contexts, CSIM has the potential to act as a levelling pedagogical strategy to cater for the disparity. By engaging students in experiential learning through interactive models, CSIM helps both male and female learners overcome conceptual difficulties in chemistry topics such as bonding. However, the slightly stronger gains among males in the present study may reflect lingering sociocultural or confidence-related factors, as noted in regional literature (Irakoze *et al.*, 2021; Wrigley-Asante *et al.*, 2023). This finding highlights the need for complementing CSIM with targeted mentorship and teacher scaffolding to ensure equitable benefits for female learners in particular.

The results of this study also revealed that students overwhelmingly held positive perceptions of CSIM in chemistry learning, with more than 80 % of respondents agreeing across most items that it enhanced their conceptual understanding, motivation, and classroom engagement. This finding confirmed Srisawasdi and Kroothkeaw (2020) and de Jong and Lazonder (2019) reports that students valued simulations for making abstract molecular processes and chemical interactions more comprehensibly. Similarly, the evidence of 84.6 % respondents found CSIM more engaging than traditional teaching aligns with Owusu *et al.* (2021) in Ghana, where simulations were shown to increase interactivity and bridge the gap between theory and application. A particularly notable result was that 83.1 % of students preferred group work when using simulations. This finding is consistent with Asiedu and Nyarko (2022) outcome that female students are likely engaged more actively in collaborative simulation-based learning. The students felt confident using simulations with limited teacher guidance (84.6 %) was also in contrasts with Zacharia and Olympiou (2021) and Adjei and Kwarteng (2023) stressed of the importance of guided facilitation for deeper understanding. However, it may reflect growing digital familiarity among

Ghanaian students, as also observed by Lamptey and Agyemang (2023) in their study of blended ICT learning.

Interestingly, while 80 % of respondents agreed that CSIM helped them connect chemistry theory to real-world applications. This level of agreement was slightly lower than other items. This outcome aligns with Williamson and Abraham (2019), who reported that although simulations provided usefully exploratory experiences, students sometimes struggled to extend virtual models to real-world laboratory or industrial contexts. Moreover, nearly 70 % of students in this study disagreed with the preference for hands-on laboratory experiments over CSIM. The finding differs from Wainwright *et al.* (2020) and Mensah and Boateng (2021), who argued that many students still valued physical laboratory experiences. The difference may be due to the context of different locations; Kwahu Ridge Senior High Technical School had limited laboratory resources, which may have heightened appreciation for simulations as substitutes for practical.

The study also highlighted infrastructural and technical barriers: 84.6 % of students agreed that poor internet and limited access to devices. This responses from students could account for the reduced effectiveness of CSIM. The current finding confirmed reports of Owusu *et al.* (2021) and Akyeampong *et al.* (2022), who identified similar barriers in Ghanaian schools. Despite these challenges, 86.2 % of students in this study reported that CSIM increased their desire to pursue science-related careers, echoing Tüysüz (2020) finding that regular use of simulations stimulated long-term interest in STEM pathways. In all, the findings support the consensus across international and Ghanaian literature which indicate that CSIM is perceived positively for its pedagogical value, engagement, and motivational benefits. However, the results also provided contextual nuances: while global studies often note students' preference for hands-on labs (e.g., Wainwright *et al.*, 2020), the Ghanaian context shows stronger appreciation for CSIM due to resource constraints. Moreover, while teacher guidance is usually seen as critical (Zacharia & Olympiou, 2021), students in this study prefer to have high confidence in navigating simulations independently, possibly through reflection of the digital adaptation among Ghanaian SHS students.

## IMPLICATIONS OF THE STUDY

### *Theoretical Implications*

The findings of this study carry strong theoretical implications for experiential learning and technology-mediated instruction. They validate that Kolb Experiential Learning Theory, through computer simulations, allows students to engage in concrete experiences, reflect on interactions, form abstract concepts, and actively experiment with variables, thereby completing the full experiential cycle. This outcome confirmed that experiential tasks delivered through digital platforms can deepen conceptual understanding of abstract scientific ideas such as chemical bonding. Second, the absence of significant gender differences in performance demonstrates that technology-enhanced experiential environments can create a more equitable learning space, challenging theoretical assumptions that sociocultural and confidence-related factors inevitably lead to gendered disparities in science achievement. Third, the study extends ELT by highlighting the centrality of affective engagement. Student motivation, confidence and career interest were shown to be crucial in sustaining participation in the learning cycle. The result indicates that experiential learning must be reconceptualised to include perceptions and attitudes as integral rather than peripheral factors. Finally, by establishing the effectiveness of CSIM in a Ghanaian senior high school context marked by infrastructural limitations, the study broadens the applicability of ELT to low-resource educational settings. It shows that while the theoretical principles of experiential learning remain robust, contextual factors such as infrastructure and teacher facilitation must be embedded in those theoretical models to reflect their practical significance in real-world classrooms.

*Practical Implications*

The practical implications of this study are equally significant for classroom practice, school management, and education policy. For teachers, the results demonstrate that incorporating computer simulations into chemistry lessons is an effective pedagogical strategy for clarifying abstract topics such as chemical bonding, fostering deeper understanding, and sustaining student motivation. Teachers are therefore encouraged to integrate CSIM not as a supplementary add-on but as a core instructional tool, while also providing guided facilitation to maximise its benefits. For schools, the positive student perceptions have highlighted the need to invest in digital infrastructure, including reliable internet access, adequate computer facilities, and ongoing professional development for teachers to improve their competence in simulation-based teaching. For curriculum implementers such as Chemistry teachers, the findings provide literature on CSIM and similar experiential technologies within the national science curriculum to enhance equitable access for active learning by all learners. Furthermore, given that no significant gender differences were found, CSIM can be promoted as an inclusive strategy for narrowing traditional gaps in STEM participation. At the systemic level, addressing barriers such as limited infrastructure and technical challenges is crucial to ensuring that the benefits of simulation-based learning are not undermined.

*Contribution of the Study*

The study indicated several key contributions to research and practice in science education. The study provides empirical evidence from a Ghanaian senior high school context showing that computer simulations significantly enhance students' understanding of chemical bonding, thereby validating their effectiveness in low-resource educational settings. The study contributes to the discourse on gender equity in STEM education, suggesting that technology-mediated instruction can help neutralise traditional gender disparities. It also enriches Experiential Learning Theory by showing how digital simulations operationalise Kolb's learning cycle in ways that support both cognitive and affective dimensions of learning. Finally, it highlights students' overwhelmingly positive perceptions of CSIM, while also drawing attention to infrastructural barriers, thereby offering insights that can guide future integration of educational technologies in developing country contexts.

## CONCLUSION

This study demonstrated that the CSIM is an effective pedagogical tool for improving students' understanding of chemical bonding, a topic that has traditionally posed difficulties for Ghanaian learners. The findings revealed that CSIM significantly enhanced students' academic performance across pre-test and post-test phases, with no statistically significant gender differences observed. This underscores the approach's potential to promote gender equity in science learning. In addition, students expressed highly positive perceptions of CSIM, citing its ability to clarify abstract concepts, increase engagement and motivation, encourage collaboration, and even influence their aspirations toward science-related careers. However, infrastructural barriers such as limited access to computers, poor internet connectivity, and insufficient teacher guidance were identified as constraints that could limit its full effectiveness. In all, CSIM is a transformative instructional strategy that not only improves performance but also nurtures positive learner attitudes toward chemistry. When adequately supported with resources and teacher training, CSIM can catalyze equitable, engaging, and future-oriented science education in Ghana and beyond. Based on the findings, the study recommends that schools and policymakers should invest in ICT infrastructure, including reliable internet access and adequate computer laboratories, to reduce technical barriers that limit effective use of CSIM. Additionally, teacher professional development programs should emphasize training in simulation-based pedagogy to ensure that educators can effectively integrate these tools into lessons. Furthermore, simulations should be embedded alongside hands-on experiments where possible, creating a balanced instructional approach that combines virtual exploration with real laboratory practice.

AUTHOR CONTRIBUTIONS

Isaac Sarpong; Conceptualization, Design and implementation of CSIM intervention, writing the original draft, review and editing, visualization: Bawa Mbage; Conceptualization and methodology designing the study, review the investigation and data collection and analysis, review the draft and supervised every aspect of the study; and Robert Monto: data collection and analysis, and review the writing of draft.

Data availability

All data can be obtained using commonly accessed databases from journal websites. All the articles cited in the paper are provided in the references list.

Conflicts of interest

There are no conflicts to be declared.

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## REFERENCES

1. Adjei, K., & Kwarteng, R., (2023). Enhancing conceptual understanding through computer simulations in Ghanaian senior high schools. Afric.. J. Sci. Educ., 15(2), 123-135.
2. Adom, D., Mensah, J. A., & Dake, D. A. (2020). Test, measurement, and evaluation: Understanding and use of the concepts in education. Int. J. Eval. & Res Educ., 9(1), 109-119. DOI: 10.11591/ijere.v9i1.20457.
3. Akyeampong, J., Owusu, G., & Boakye, M. (2022). Challenges and prospects of integrating computer simulations in chemistry education: A Ghanaian perspective. J Sci & Techn Educ., 20(3), 45-67.
4. Alabidi, S., Alarabi, K., Tairab, H., Alamassi, S., & Alsalhi, N. R. (2023). The effect of computer simulations on students' conceptual and procedural understanding of Newton's second law of motion. EURASIA J Math Sci Tech Ed, 19(5),em2259.
5. Alhassn, I., Asiamah, . N., Opuni, F. F., & Alhassan, A. (2022). THE LIKERT SCALE: Exploring The Unknowns and Their Potential To Mislead The World. UDS Int. J Develop., 9(2), 867–880.
6. Asiamah, N., Mensah, H. K., & Oteng-Abayie, E. (2017). General, Target, and Accessible Population: Demystifying the Concepts for Effective Sampling. Qual. Rep., 22(6), 1607-1621. Retrieved from http://nsuworks.nova.edu/tqr/vol22/i ss6/9.
7. Asiedu, F., & Nyarko, E. (2022). Gender differences in students' perceptions of computer simulations in chemistry learning. Int J Sci Ped, 11(4), 210-225.
8. Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers & Education, 87, 218-237.
9. Brookhart, S. M. (2013). How to create and use rubrics for formative assessment and grading. ASCD.
10. Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). Sage Publications.
11. Dodoo, C. (2023). Effect of computer simulation on JHS 2 students' performance in integrated science. Glob Educ Res J, 11(8), 136–140. https://www.springjournals.net/articles/pdf/951201092023
12. Dolnicar, S. (2021). 5/7-point "Likert Scales" aren't always the best option: Their validity is undermined by lack of reliability, response style bias, long completion times and limitations to permissible statistical procedures. Ann. Tour Res, 91, 1–3. https://doi.org/10.1016/j.annals.2021.103297
13. Field, A. (2018). Discovering statistics using IBM SPSS Statistics (5th ed.). Sage Publications.
14. Ford, R., Daniels, K., & Mensah, T. (2022). Action research in education: Improving practice and addressing classroom challenges. Routledge. https://doi.org/10.4324/9781003156721
15. Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2019). How to design and evaluate research in education (10th ed.). McGraw-Hill Education

16. Gbeleyi, O. A. (2021). Gender difference in students' performance in chemistry – can computer simulation bridge the gap. Retrieved from https://www.academia.edu/83792101/Gender_difference_in_students_performance_in_chemistry_can_computer_simulation_bridge_the_gap
17. Ghana Statistical Service. (2020). Household survey on ICT in Ghana: Abridged report. Accra: GSS.
18. Hofstein, A. (2017). The role of laboratory in science teaching and learning. In Science education (pp. 355-368). Brill.
19. Hsu, Y. S., & Thomas, R. (2022). Computer simulations and scientific inquiry: Analyzing the impact on chemistry education. J Sci Educ & Techn, 31(2), 275-289.
20. Irakoze, E., Gakuba, E., & Karegeya, C. (2021). Effect of gender perspective towards performance of chemistry education in secondary school. J Res Innov & Implic Educ, 5(3), 11–21. https://jriiejournal.com/wp-content/uploads/2021/07/JRIIE-5-3-002.pdf
21. Khalid, M., Ahmad, T., & Hussain, S. (2023). Student attitudes toward computer simulations in science education: A meta-analysis. J Educ Techn & Soc, 26(1), 45–59.
22. Kolb, A. Y., & Kolb, D. A. (2017). Experiential learning theory as a model for learning in higher education. Educ Psych Rev, 29(2), 225-252.
23. Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ Prentice Hall.
24. Kristen K. B., Malinda, W. G., Monica, D., & Kendra, M. (2017). Pedagogical Methods and Technology Used in Chemistry Secondary Education. Mod Chem & Applc, 5(3), 223. https://doi.org/10.4172/2329-6798.1000223.
25. Kuit, V. K., & Osman, K. (2021). CHEMBOND3D e-module effectiveness in enhancing students' knowledge of chemical bonding concept and visual-spatial skills. Eur J Sci & Math Educ, 9(4), 252-264.
26. Kuphanga, D. (2024). Questionnaires in research: Their role, advantages, and main aspects. Preprint. https://doi.org/10.13140/RG, 2(15334.64325).
27. Lamb, R. (2025). Influences of gender on computer simulation outcomes. Retrieved from https://www.academia.edu/4177241/Influences_of_Gender_on_Computer_Simulation_Outcomes
28. Lamptey, P., & Agyemang, B. (2023). The impact of simulation-based learning on students' interest in chemistry: Evidence from Ghana. West African Journal of Chemistry Education, 18(1), 34-50.
29. Levy-Nahum, T., Mamlok-Naaman, R., Hofstein, A., & Taber, K. S. (2010). Teaching and learning the concept of chemical bonding. Stud Sci Educ, 46(2), 179–207. https://doi.org/10.1080/03057267.2010.504548
30. Mabweazara, R. (2018). The 21st century Academic Library. The case of three state universities in Zimbabwe. Unpublished Ph.D Thesis. University of the Western Cape Bellville, South Africa.
31. Mensah, A., & Boateng, K. (2021). Students' attitudes towards computer simulations versus hands-on experiments in Ghanaian chemistry classrooms. Ghana J Sci Educ, 25(1), 56-72.
32. Mihindo, W. J., Wachanga, S. W., & Anditi, Z. O. (2017). Effects of Computer-Based Simulations Teaching Approach on Students' Achievement in the Learning of Chemistry among Secondary School Students in Nakuru Sub County, Kenya. J Educ & prac, 8(5), 65-75.
33. Ministry of Education. (2010). Teaching syllabus for senior high school chemistry. Accra: Ghana. Curriculum Research and Development Division.

34. Owusu, K., Amankwah, E., & Asare, P. (2021). The role of computer simulations in enhancing students' academic performance in chemistry: A study of senior high schools in Ghana. J Sci Educ Africa, 16(3), 78-95.
35. Pallant, J. (2020). SPSS survival manual: A step by step guide to data analysis using IBM SPSS (7th ed.). Routledg
36. Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. Computers & Education, 58(1), 136-153.
37. Sadykov, T., & Ctrnactova, H. (2019). Interactive Lessons with ICT in Chemistry Education. International Conference on the Methods of Science Education Proceedings. https://doi.org/10.36007/eruedu.2020.1.095-110.
38. Sanger, M. J., Phelps, A. J., & Finkenstaedt-Quinn, S. A. (2019). Gender differences in the use and perception of technology in chemistry education. J Chem Educ, 96(7), 1385-1393.
39. Sapriati, A., Suhandoko, A. D. J., Yundayani, A., Karim, R. A., Kusmawan, U., Mohd Adnan, A. H., & Suhandoko, A. A. (2023). The Effect of Virtual Laboratories on Improving Students' SRL: An Umbrella Systematic Review. Education Sciences, 13, 222. https:// doi.org/10.3390/educsci13030222.
40. Shana, Z. J., & Abulibdeh, E. S. (2020). Science practical work and its impact on students' science achievement. Journal of Technology and Science Education, 10(2), 199-215. https://doi.org/10.3926/jotse.888.
41. Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. Int J Sci Educ, 34(9), 1337–1370. https://doi.org/10.1080/09500693.2011.605182
42. Smetana, L. K., & Bell, R. L. (2019). Computer simulations to support science instruction and learning: A critical review. Int J Sci Educ, 41(6), 682-706. https://doi.org/10.1080/09500693.2019.1586547
43. Srisawasdi, N., & Kroothkeaw, S. (2020). The impact of virtual laboratory simulations on students' understanding of chemical reactions. J Sci Educ & Techn, 29(4), 560-575.
44. Suleman, M., Sugiyarto, K. H., & Ikhsan, J. (2019). Development of Media Three-dimensional (3D) Visualization using Virtual Reality on Chemistry Education. J Phys: Conf Series, 1397, 012034. DOI: 10.1088/1742-6596/1397/1/012034.
45. Sun, Y., Lin, H., & Wang, J. (2021). Enhancing chemistry education through virtual simulations: A meta-analysis. J Chem Educ, 98(6), 1254-1263.
46. Tüysüz, C. (2020). The effect of virtual laboratory applications on students' achievement and motivation in chemistry education. Educ Techn & Soc, 23(2), 178-192.
47. Udo, M. E., & Etiubon, R. U. (2011). Computer-based science simulations, guided-discovery and students' performance in chemistry. Mod Appl Sci, 5(6), 34-42.
48. WAEC. (2021). Chief Examiner's Report: Elective Chemistry. Accra: West African Examinations Council. https://waecgh.org/chief-examiners-report/
49. Wainwright, C. L., Stewart, J. L., & McInerney, J. D. (2020). Comparing student learning outcomes using virtual versus physical laboratories in chemistry education. International Journal of Science Education, 42(5), 679-698.
50. Wieman, C. E., & Perkins, K. K. (2018). Transforming physics education with interactive simulations. Physics Today, 71(7), 38-45.

51. Williamson, V. M., & Abraham, M. R. (2019). Computer simulations and conceptual understanding in chemistry education. Journal of Chemical Education, 96(9), 1547-1559.
52. Wrigley-Asante, C., Ackah, C. G., & Frimpong, L. K. (2023). Gender differences in academic performance of students studying STEM subjects at the University of Ghana. Discover Education, 2, 1–14. https://link.springer.com/article/10.1007/s43545-023-00608-8
53. Wu, H. K., Krajcik, J. S., & Soloway, E. (2020). Promoting understanding of chemical bonding through computer-based modeling. Journal of Research in Science Teaching, 57(5), 591-617.
54. Yildizay, A., & Leman, T. (2017). Problem-based Learning in Teaching Chemistry: Enthalpy Changes in Systems. Research in Science & Technological Education, 36(1), 35–54. https://doi.org/10.1080/02635143.2017.1366898
55. Yuliati, L., Riantoni, C., & Mufti, N. (2018). Problem solving skills on direct current electricity through inquiry-based learning with PhET simulations. International Journal of Instruction, 11(4), 123-138. https://doi.org/10.12973/iji.2018.1149a.
56. Zacharia, Z. C. (2015). Comparing the effect of interactive simulations with physical manipulatives on students' understanding of chemical bonding. Educational Technology Research and Development, 63(3), 371-395.
57. Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. Learning and Instruction, 21(3), 317–331. https://doi.org/10.1016/j.learninstruc.2010.03.001
58. Zacharia, Z. C., & Olympiou, G. (2021). The role of teacher guidance in students' engagement with computer simulations. Science Education Research Journal, 17(2), 112-129.
59. Zhang, Y., Wang, C., & Li, L. (2020). Reforming science education in China: Integrating inquiry-based learning with modern technology. International Journal of Science Education, 42(5), 789–809. https://doi.org/10.1080/09500693.2020.1713590