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Perceptions of Virtual Laboratories and Attitudes Towards Chemistry Among Jamaican Grade 10 Students

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Abstract

Virtual laboratories have been proposed as an alternative approach to support student learning and foster positive attitudes towards science. This sequential multimethod study aimed to investigate students' perceptions of virtual laboratories and their attitudes towards chemistry. In Phase 1 of the study, 153 Grade 10 chemistry students completed the Perceptions of Virtual Laboratories (PVL) and Attitudes Towards Chemistry (ATC) surveys. The results indicated that students held moderate perceptions of virtual laboratories and moderate attitudes towards chemistry. Spearman's rho test revealed a statistically significant positive correlation between these two variables ($r = .18$, $p = -.024$). In Phase 2, a subgroup of 20 students from the main sample conducted virtual chemistry laboratory exercises and completed the two surveys again. Students' perceptions of virtual laboratories and attitudes towards chemistry remained moderate. Overall, the sustained moderate perceptions and attitudes following students' use of the virtual laboratories indicate their potential for supplementing chemistry teaching.

Keywords: attitudes towards chemistry, chemistry experiments, perceptions of virtual laboratories

Introduction

The attitudes of students towards science play a crucial role in their achievement in the discipline. However, there is a steady decline in students' interest in science (especially as they progress through school) for various reasons including, perceived difficulty in understanding key concepts, teachers' use of traditional teaching methods, lack of laboratory exposure, and poor achievement (Mahdi, 2014; Musengimana et al., 2021; OECD, 2018). As a result, assisting students to develop positive attitudes towards science is critical (AlAli & Al-Barakat, 2024). Experimental work is integral to learning scientific concepts. One way to enhance students' interest and engagement in subjects such as chemistry, physics, and biology is to use more interactive experiments that incorporate real-world examples (Boesdorfer, 2019; Shana & Abulibdeh, 2020).

However, integrating experimental work in science instruction can be hindered by various factors in schools, including inadequate infrastructure, facilities and resources; large class sizes; teachers lacking practical skills or certification to teach a particular subject; and examination systems that focus more on theory than practical application (Abdallah et al., 2022; Ado et al., 2022; Ali & Ullah, 2020; Islam, 2010; Sibomana et al., 2021). The COVID-19 pandemic presented additional challenges as schools were forced into emergency remote teaching and learning, which required an urgent and

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innovative response for conducting laboratory work (Hu-Au & Okita, 2021). During COVID-19, chemistry students in Jamaica and the wider Caribbean region were faced with completing laboratory assessments required by examining bodies, such as the Caribbean Examinations Council (CXC), within a shortened timeline, in classes held online. Given the challenges that could affect the ability to effectively conduct physical laboratory activities, it is essential to explore alternative solutions. Virtual laboratories offer another approach to addressing these issues.

Virtual laboratories consist of digital materials such as glassware (e.g., thermometers, beakers, pipettes, test tubes), Bunsen burners, and chemicals similar to real school laboratories. They are interactive environments where experiments and activities can be conducted that simulate the processes of physical laboratories (Chan et al., 2021; El Kharki et al., 2021; Stahre Wästberg et al., 2019). In virtual laboratories, students can read instruments, observe unobservable phenomena such as chemical reactions, and repeat experiments to deepen their learning experiences (Alhashem & Alfailakawi, 2023; Kapici et al., 2019). Integrating virtual lab exercises in science subjects such as chemistry could stimulate and deepen students' interest and engagement in the subject. In addition, they offer a possible solution for inadequate infrastructure, resource constraints, and large class sizes which also threaten effective science instruction (Faour & Ayoubi, 2018; Olympiou & Zacharia, 2012; Tuysuz, 2010). Researchers suggest there may be some relationship between types of instructional strategies and students' attitudes towards chemistry (e.g., Hofstein & Mamlok-Naaman, 2021; Kubiatko et al., 2017). Virtual laboratories could be used innovatively to influence students' attitudes and change the scope of science education (Zhang et al., 2024).

While virtual laboratories have been proposed to offer promise in overcoming challenges in conducting hands-on lab activities, their implementation lags behind in Global South countries (Shambare & Jita, 2025). In addition to the challenges outlined previously, Jamaica's science education is vulnerable to natural hazards (such as hurricanes) which damage infrastructure and disrupt schooling (Huesler, 2025; Murphy, 2025; Spencer et al., 2016). Understanding the potential of virtual laboratories is crucial for providing quality learning experiences in such contexts. Therefore, the current study aimed to investigate Grade 10 students' perceptions of virtual laboratories, their attitudes towards chemistry, and whether the two were related.

The following research questions were posed to guide the study:

1. How do Grade 10 students' perceptions of virtual laboratories relate to their attitudes towards chemistry?
2. What is the impact of an intervention involving the use of virtual laboratories on students' i) perceptions of virtual laboratories, and ii) attitudes towards chemistry?

Some researchers propose that virtual laboratories are under-utilized in chemistry classrooms (Gambari et al., 2018; Jensen, 2019). Further, Hofstein and Mamlok-Naaman (2021) emphasize the need to understand the relationship between the types of laboratory tasks that students engage in during chemistry instruction, and their actual acquired content knowledge and skills. The authors are not aware of any studies to date that have specifically examined the use of virtual laboratories in chemistry within the Jamaican context. This study is significant as it contributes to the literature on integrating virtual laboratories in science education, particularly in less-studied regions. The study may provide guidance for educators seeking to implement innovative teaching approaches for enhancing students' laboratory experiences and preparing them for conducting face-to-face laboratory exercises. Additionally, the findings may provide information on the potential role that virtual lab exercises could play in fulfilling specific curricular needs of Jamaican schools such as the experimental component of the CXC chemistry examination.

Literature Review

Virtual Laboratories

Science education researchers recognize that laboratories enhance students' learning by improving visualization, conceptual understanding, and attitudes (Gambari et al., 2018; Kapici et al., 2020). Laboratory work in science is grounded in constructivism, experiential learning, and the principle of learning by doing (Kolb & Kolb, 2017; Manyilizu, 2023). These frameworks support the idea of students actively engaging with equipment and other resources, while constructing their own understanding based on the experiences gained. Traditionally these experiences are situated in physical laboratories. However, virtual laboratories deliver these experiences through digital devices using computer software, online platforms, or mobile laboratory applications including Core Sciences (https://www.coresciences.co.uk/), Amrita (https://vlab.amrita.edu/), ChemCollective (https://chem.libretexts.org/Ancillary_Materials/Interactive_Applications/ChemCollective_Virtual_Labs), Labster (https://www.labster.com/), Gizmos (https://gizmos.explorelearning.com/), LabXChange (https://www.labxchange.org/), and The Royal Society of Chemistry (https://virtual.edu.rsc.org/), which may or may not require licenses or subscription fees (Shambare & Jita, 2025; Urek, 2024). Using virtual laboratories as an alternative to physical laboratories involves an approach to teaching that aligns with the Technological Pedagogical Content Knowledge (TPACK) framework, which highlights the need for teachers to aim for synergy among technology, pedagogy, and content to ensure meaningful learning experiences (Koehler et al., 2014). When properly applied the TPACK framework can unlock the potential benefits of virtual laboratories. Virtual laboratories provide many of the same benefits of physical laboratories, such as the opportunity to explore scientific concepts through immersion, interaction, and engagement (Gambari et al., 2018; Herga et al., 2016). Additionally, they offer unique advantages such as accessibility, individualized pacing, and immediate feedback (Alhashem & Alfailakawi, 2023).

Several studies have examined students' perceptions of virtual laboratories. These studies indicate that students generally have positive perceptions likely shaped by prior exposure to technology, and expectations of accessibility, flexibility, and support for learning. For instance, a study by Kareem (2022) showed that secondary school students in Nigeria who used virtual laboratories in biology expressed greater interest in laboratory activities, indicating a positive perception. Similarly, in a study by Penn and Mavuru (2020) in South Africa, pre-service teachers' attitudes towards virtual laboratories increased after using them. When focus groups in the study were asked about virtual experiments, most of the participants said they were previously unaware of their effectiveness. However, the experience with the lab activities stimulated their curiosity, and on completing the experiments they perceived virtual laboratories as useful and relevant.

Other studies have explored the implementation of virtual laboratories in science instruction. Castro's (2025) meta-analysis involving 17 studies provides evidence that virtual chemistry laboratories significantly enhance academic achievement among secondary-level chemistry students. Similar studies have concluded that students demonstrate significant achievement gains when using virtual laboratories individually or collaboratively (Gambari et al., 2018); outperform students who are in traditional laboratory settings; and increase in confidence (Latifah et al., 2019; Watson et al., 2020). Among the reasons for these results were that students valued having access to laboratory equipment at any time, and appreciated the opportunity to explore collaboratively. In addition, the ability to conduct a greater number of experiments, combined with the visual models provided by the virtual laboratories, helped students clarify abstract scientific concepts and enhance their procedural understanding.

Although the usefulness of virtual laboratories has been acknowledged, caution is expressed about their limitations. Effective technology integration can be hindered by factors such as limited access to reliable electronic devices and internet service, increased demands on teachers' time, and a lack of institutional support (Chudaeva, 2021). In some contexts, lack of infrastructure to support virtual learning also presents a challenge. For instance, during the COVID-19 pandemic, limited device availability and inadequate internet connectivity negatively affected class attendance and engagement across Caribbean countries (Blackman, 2022; Caribbean Policy Research Institute [CAPRI], 2021).

In addition to access and infrastructure challenges, other pedagogical limitations have been identified in the use of virtual laboratories. Gnesdilow and Puntambekar (2025), and Hunegnaw et al. (2025) found that while virtual laboratories can support conceptual understanding, they may fall short in fostering students' ability to handle laboratory equipment safely and accurately, carry out physical manipulations, and make real-time observations of unpredictable phenomena. Avwiri and Odiri (2025) also cautioned that over-reliance on simulations could lead to improvements in learning resulting from repeatedly performing virtual experiments, an option that is not typically available in physical laboratory sessions. Dependence on and overuse of virtual laboratories could also limit students' understanding of experimentation and affect their perceptions of physical laboratories (Griffin et al., 2025). These views are supported by Asare et al. (2023) who pointed out that students could end up with poor error analysis skills by overlooking or ignoring measurement errors in a virtual environment.

Some studies have indicated that hands-on laboratory exercises may offer advantages over virtual laboratories. For instance, hands-on exercises can assist in developing troubleshooting skills, identifying natural measurement errors, and honing psychomotor skills through real-world manipulation of materials (Hofstein & Mamlok-Naaman, 2021; Zacharia et al., 2019). Findings in another study showed that hands-on experimentation resulted in better academic performance (Serrano-Perez et al., 2023). However, other studies have highlighted the challenges experienced in executing hands-on laboratory activities, such as students' poor confidence, safety concerns, and differences between expected outcomes and actual observations (Gambari et al., 2018; Nicol et al., 2022). Virtual laboratories have been proposed as having the greater advantage and affordances to overcome the challenges highlighted for hands-on lab activities. They also offer the advantage of being useful if schools do not have adequate physical laboratories and related resources (Byukusenge et al., 2023; Faour & Ayoubi, 2018).

Overall, the literature has yielded inconclusive results on the comparative effectiveness of virtual laboratories and traditional hands-on laboratories. In a study among Greek high school students, Papalazarou et al. (2024) revealed no statistically significant learning gains when virtual and hands-on laboratories were used for the topics "electricity" and "magnetism". Similarly, Hunegnaw et al. (2025) found that virtual experiments were as effective as physical ones in improving Grade 11 Ethiopian students' understanding of chemical kinetics. While findings appear inconclusive overall, many studies highlight the greater advantages of virtual laboratories over traditional hands-on approaches (Alneyadi, 2019). These findings therefore indicate that the effectiveness of virtual laboratories when compared to traditional laboratory activities justifies further research into their use in subjects like chemistry, particularly in the Caribbean context.

Given the variability in the findings, it is crucial to note the suggestion of Jensen (2019) and Toth (2016) that teachers should be cautious when considering replacing traditional lab activities with virtual ones for a number of reasons. These include the possibility of students' inability to develop inquiry skills; difficulties in relating virtual technology to the real world; and the risk of being distracted or misunderstanding scientific content knowledge. In a quasi-experimental study involving 53 biology students in Rwanda, physical and virtual laboratory exercises were used to teach the students. In the survey administered, the majority of students did not agree that virtual laboratories should replace physical laboratories, as physical lab activities better helped them to understand the content (Byukusenge et al., 2023). In another review study it was reported that virtual laboratories can yield positive learning outcomes in certain domains, but they cannot replace the hands-on laboratory experience. It is recommended that better learning outcomes can be achieved when both virtual and physical laboratories are used in combination (Sypsas & Kalles, 2018). Papalazarou et al. (2024) suggest that when deciding which mode to use, factors such as the required learning goals, skills, and depth of conceptual understanding should be considered. By drawing on the strengths of both methods, science teachers may be able to create a more holistic learning environment for students, and improve learning outcomes (Sarabando et al., 2014).

Students' Attitudes towards Chemistry

Studies investigating students' attitudes towards chemistry have produced mixed results. Research conducted in Malaysia reported generally positive student attitudes towards chemistry. For instance, Heng and Karpudewan (2015) found marginally positive attitudes, while Ibrahim and Iksan (2018) observed moderate to highly positive attitudes. Mahdi (2014) and Surya and Arty (2021), also found that students had positive attitudes towards chemistry, although they perceived it as challenging. In addition, Mahdi (2014) found that students perceived chemistry as interesting and useful in their everyday lives but did not view it as a preferred career choice. However, Arniezca and Ikhsan (2021) reported that students had neutral attitudes towards chemistry, finding it neither easy nor difficult. These findings highlight a potential disconnect between students' recognition of chemistry's value in daily life and its perceived relevance to their future professional goals. This disconnect is possibly compounded by students' mixed perceptions of chemistry as being both interesting and challenging. Hofstein and Mamlok-Naaman (2011), and Musengimana et al. (2021) suggested that if students hold negative attitudes towards chemistry, it can inhibit their engagement and learning. These varying findings highlight the importance of addressing negative attitudes and fostering positive attitudes to enhance students' success in chemistry.

Virtual Laboratories and Students' Science Attitudes

Addressing the affective domain is important in the laboratory setting where, if properly implemented, the experiences provided have the potential to shape science students' perceptions and attitudes. Associations have been proposed among students' preference for instructional strategies, their attitudes towards science, and achievement in science (Fulmer et al., 2019). For instance, Correia et al. (2019) found that using PhET simulations positively impacted high school students' learning experiences in selected chemistry topics. In another study, Grade 9 students in Turkey expressed positive attitudes towards virtual laboratories, stating that they made learning easy and interesting (Ambusaidi et al., 2018; Tuysuz, 2010). Similarly, biology students in Rwanda perceived virtual lab activities as easier, more motivating, and more interesting than physical lab activities — even though their content understanding was not enhanced (Byukusenge et al., 2023).

On the other hand, conflicting results have been reported. For instance, Ratamun and Osman (2018) found no significant effects of both virtual and physical laboratories on upper secondary Malaysian students' attitudes to chemistry. In other studies at the undergraduate level in Greece, students conducting hands-on physics activities outperformed students engaged in virtual activities (Tokatlidis et al., 2024). In addition, undergraduate health science students in Spain who conducted both traditional and virtual lab activities during one semester expressed preference for hands-on experimentation. They also reported a perceived increase in motivation towards their discipline when using traditional laboratories (Serrano-Perez et al., 2023). In another study by Ambusaidi et al. (2018), while students had positive attitudes towards virtual laboratories, there was no statistically significant impact on their attitudes towards science.

The research findings regarding the use and effect of virtual laboratories on students are inconclusive. Further research is therefore needed to explore the appropriateness of virtual laboratories in educational contexts including their role in pedagogy; investigation in real world situations; and their relationship to cognition, attitude and process skills. The current study aims to contribute to the existing body of research by providing insights into the potential role of virtual laboratories in enhancing high school students' chemistry attitudes.

Methodology

This study used a sequential, multimethod design which involved two quantitative methods: online surveys and a one group pre-test/post-test intervention in which virtual laboratories were used (Mills et al., 2010; Morse, 2003). This design was considered appropriate for optimizing data collection in light of constraints imposed by the COVID-19 pandemic, which made it difficult to recruit participants. To address the research questions a descriptive survey phase was first implemented, followed by an intervention phase.

Two survey instruments were used in the study. The Perceptions of Virtual Laboratories (PVL) instrument had Likert-type items that were adapted from selected items on Dalgarno et al.'s (2009) and Reimer and Moyer's (2005) questionnaires. The Attitudes Towards Chemistry (ATC) instrument was adapted from selected items on Mahdi's (2014) chemistry questionnaire and Bramwell-Lalor's (2010) Attitudes Towards Biology questionnaire in which the word "biology" was replaced with "chemistry" in the items. In addition to replacement of terms, other items were reworded for clarity and relevance to the research context. The items on the ATC were related to the themes "interest in chemistry", "interest in learning chemistry", and "the value of chemistry".

One secondary school teacher and two university lecturers with expertise in the content area reviewed the instruments to ensure content validity. Their review focused on assessing the alignment of the items with the intended constructs, and on the relevance, clarity, and appropriateness of the items for high school students. Based on their feedback, revisions were made to improve the clarity of the items. The instruments were piloted on 24 Grade 10 students in two high schools that were not a part of the main study. After further adjustments to the items and instructions, the final version of the PVL consisted of 13 items, and the ATC consisted of 15 items. The Cronbach alpha reliability was calculated to determine the internal consistency of the items. A value of 0.90 was obtained for the PVL and 0.79 for the ATC, both of which were acceptable, according to Bryman and Cramer (2012).

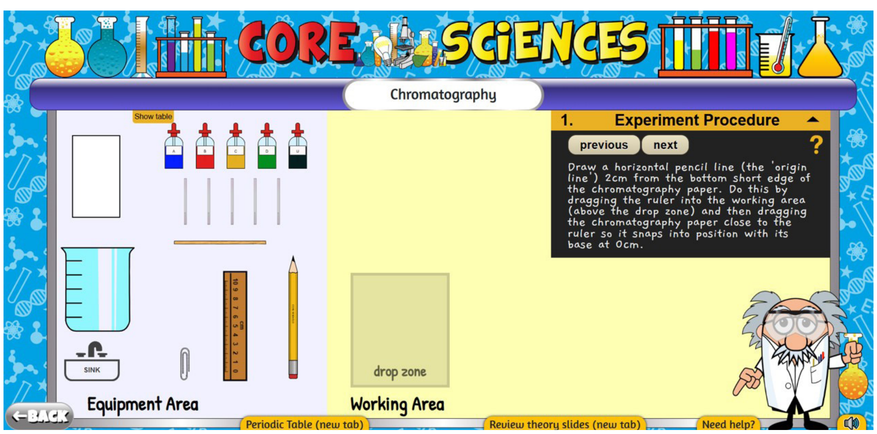
Permission was obtained from the director of CORE Data Systems Ltd. to access virtual laboratory experiments (https://www.coresciences.co.uk). The platform offers practical exercises aligned with the General Certificate of Secondary Education (GCSE) curriculum in the United Kingdom. One university chemistry lecturer and two high school chemistry teachers reviewed the virtual laboratory application to evaluate its content validity; its usefulness for the School Based Assessment (SBA) component of the CXC examinations; its appeal to students; and whether it would be enjoyable (Yusoff, 2019).

The study was originally designed to utilise multi-stage, stratified, purposive sampling to include representation of all school types (all boys, all girls, co-educational, rural, urban). However, due to disruptions caused by COVID-19 such as school closures, convenience sampling was also employed. Fifteen schools were included in the sample selected from across Jamaica based on willingness to participate. Written informed consent and assent were obtained from participants prior to the study. In Phase 1 of the study, classroom teachers were relied on to distribute the surveys online within these schools. A total of 153 Grade 10 students (52 male; 101 female) responded to the survey. However, challenges related to access to digital devices, and internet connectivity experienced at the time of data collection introduced uncertainty regarding whether all intended participants received the survey. In addition, the class size for each teacher was not recorded during the initial data collection period. To address this limitation, class size data were obtained in a subsequent follow-up with participating schools. However, information was not received from all schools due to the time elapsed since the original data collection, difficulties in making contact, and changes in teachers and other school personnel. Ten schools reported a total of 735 students, representing an average class size of approximately 30 students. The calculated response rate based on these 10 schools was 16.9% which falls within the range reported for online surveys (e.g., Rousset et al., 2025). According to Nair et al. (2008) and Saleh and Bista (2017), online surveys normally yield lower return rates than other survey modes. The response rate could have been further impacted by COVID-19-related factors (Krieger et al., 2023; Possamai et al., 2022).

From the group of respondents, a subsample of 20 students (5 male, 15 female) and their teachers (selected based on their willingness to participate) took part in Phase 2. In this phase, the teachers were trained by the first author on how to use the virtual laboratories on the CORE Data Systems Ltd. platform. The students were also trained by the first author in the use of virtual labs, and completed four virtual laboratory exercises on the topics: "Chromatography" (see Figure 1), "Simple Distillation", "Making salts", and "Titration", in 1-hour sessions under the supervision of their teacher. Having completed the surveys before the intervention, these 20 students completed the same two survey instruments (PVL and ATC) at the end of the intervention. The entire study was conducted over a period of 8 weeks.

Figure 1

Image of Virtual Laboratory Experiment



Items on both instruments were scored on a scale of 1—5, where Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, and Strongly Agree = 5. Negatively-worded items were reverse coded where Strongly Agree = 1, and Strongly Disagree = 5. The data were analysed using the IBM SPSS Statistics programme (Version 26). Total scores were calculated for each respondent on both instruments and then used to compute the mean score for each instrument. The mean scores were further categorised into distinct levels reflecting students' perceptions and attitudes. The score ranges for both instruments were divided into three intervals, representing low, moderate, and high levels (Alkharusi, 2022). For the PVL (with a possible score range of 13–65, the division resulted in categories of 13–30.4 (low), 30.5–47.4 (moderate), and 47.5–65 (high). Similarly, the ATC score range of 15–75 produced the categories of 15–34.4 (low), 34.5–54.4 (moderate), 54.5–75 (high). In addition, percentages were calculated for each item on both instruments to further describe the data.

The Shapiro-Wilk test indicated significant departures from normality for both the PVL ($W = 0.95$, $p = 0.001$) and the ATC ($W = 0.98$, $p = 0.011$) questionnaires. Due to these violations, the non-parametric Spearman's rho was calculated to determine the relationship between students' PVL and ATC scores before the intervention. In addition, the Wilcoxon matched-pairs signed-ranks test was conducted to compare the experimental students' pre-test and post-test scores on the PVL and ATC scales. These tests were deemed appropriate given the small sample size and the lack of conformity to the assumption of normality (Pett, 2016). Effect sizes were also calculated to determine the strength of any significant differences identified.

Results

Research Question 1. How do Grade 10 students' perceptions of virtual laboratories relate to their attitudes towards chemistry?

Perceptions of Virtual Laboratories

Students' mean PVL score was 40.6 out of a maximum possible score of 75, indicating moderately positive perceptions of virtual laboratories (see Table 1). A closer examination of the items indicated that the highest agreement was noted for those that probed students' perceptions of virtual laboratories and their ability to help with real lab activities (56.2%); lab instructions (56.9%); recognizing lab equipment (56.8%); and developing confidence with doing real lab activities (56.9%) (see Table 2). It is important to note that 60.1% of the students agreed or strongly agreed that virtual laboratories experiments could replace real lab experiments.

Table 1

Table Showing Descriptive Statistics for the Perceptions of Virtual Laboratories and Attitudes Towards Chemistry Survey Instruments

	PVL	ATC
Mean	40.56	43.94
Std. Error of Mean	.746	.470
Std. Deviation	9.23	5.81
Minimum	13	23

A large number of students selected the neutral option for many of the items. For example, while 54 students (35.3%) disagreed or strongly disagreed with the statement "I like using virtual labs", 67 students (43.8%) selected "neutral". Similarly, while 45 students (29.4%) disagreed or strongly disagreed that virtual labs were easy to use, 66 students (43.1%) selected "neutral" for this statement.

Table 2

Frequency and Percentage Responses to Selected Statements on the Perceptions of Virtual Laboratories Survey

Statement	SA	A	N	D	SD
I like using virtual labs.	5 (3.3)	27 (17.6)	67 (43.8)	29 (19.0)	25 (16.3)
Virtual labs are easy to use.	8 (5.2)	34 (22.2)	66 (43.1)	28 (18.3)	17 (11.1)
Virtual labs will help me with real experiments.	15 (9.8)	71 (46.4)	51 (33.3)	12 (7.8)	4 (2.6)
I can recognize laboratory apparatus using virtual labs.	21 (13.7)	66 (43.1)	49 (32.0)	11 (7.2)	6 (3.9)
I think virtual labs can replace real experiments.	51 (33.3)	41 (26.8)	41 (26.8)	16 (10.5)	4 (2.6)
Virtual labs will help me with instructions in the real lab.	16 (10.5)	71 (46.4)	49 (32.0)	11 (7.2)	6 (3.9)
Virtual labs will help me to develop my confidence in doing real labs.	16 (10.5)	71 (46.4)	44 (28.7)	11 (7.2)	11 (7.2)

Attitudes Towards Chemistry

The overall mean score on the ATC was calculated as 43.9, indicating moderate attitudes towards chemistry (see Table 1). Approximately 119 students (77.7%) agreed or strongly agreed that skills learnt in chemistry will be important for their future career, and 108 students (70.6%) mainly agreed that chemistry would make them more confident when seeking a job in the future (see Table 3). However, a larger percentage of students indicated that they did not know why they were doing chemistry (132 or 86.2%).

Additionally, while 64.0% of the students agreed or strongly agreed that chemistry classes were interesting, and 59.5% said that chemistry was exciting; 55.6% indicated that chemistry was boring; and 110 students (71.9%) responded that they did not look forward to going to chemistry classes — indicating some inconsistency in their perceptions of the subject. As with the AVL, for many of the items such as "I like chemistry" and "I work harder in chemistry than any other subject", a large number of students selected the "neutral" option (41.2% and 42.5% respectively). This could have contributed to the overall moderate attitudes towards chemistry reflected in the mean.

Table 3

Frequency and Percentage Responses to Selected Statements on the Attitudes Towards Chemistry Survey

Statement	SA	A	N	D	SD
I like chemistry.	15 (9.8)	59 (38.6)	63 (41.2)	12 (7.8)	4 (2.6)
Chemistry is exciting.	30 (19.6)	61 (39.9)	46 (30.0)	11 (7.2)	5 (3.3)
I work harder in chemistry than any other subject.	15 (9.8)	24 (15.7)	65 (42.5)	43 (28.1)	6 (3.9)
The skills I learn in chemistry will be applicable in my future career.	64 (41.8)	55 (35.9)	19 (12.4)	11 (7.2)	4 (2.6)
I do not look forward to going to chemistry classes.	52 (34.0)	58 (37.9)	24 (15.7)	13 (8.5)	6 (3.9)
I do not know why I am doing chemistry.	66 (43.1)	66 (43.1)	15 (9.8)	6 (3.9)	0 (0.0)
Chemistry skills will make me more confident when I'm seeking a job in the future.	51 (33.3)	57 (37.3)	30 (19.6)	8 (5.2)	7 (4.6)
Chemistry is a girl's subject.	84 (54.9)	48 (31.4)	17 (11.1)	3 (2.0)	1 (0.6)
Chemistry classes are boring.	37 (24.2)	48 (31.4)	52 (34.0)	10 (6.5)	6 (3.9)
Chemistry classes are interesting.	27 (17.6)	71 (46.4)	39 (25.5)	7 (4.6)	9 (5.9)

Overall, students reported moderate perceptions towards virtual laboratories and moderate attitudes towards chemistry. A Spearman's rho correlation was conducted to assess the association between students' PVL and ATC scores. The results revealed a weak, positive association, which was statistically significant ($r = 0.18$, $p < 0.05$). This indicates that students with more positive perceptions of virtual laboratories are associated with having more positive attitudes towards chemistry.

Research Question 2. What is the impact of an intervention involving the use of virtual laboratories on students' i) perceptions of virtual laboratories and ii) attitudes towards chemistry?

The group of students who completed virtual laboratory exercises increased in their mean perceptions towards virtual laboratories (see Table 4), suggesting apparent improvement. However, the Wilcoxon matched-pairs signed-ranks test results indicated no statistically significant change (Z = -0.078, $p > 0.05$). Although no statistically significant difference was found, the effect size was still calculated to assess the practical importance of the findings, as recommended by Fritz et al. (2012). The effect size was calculated to be r = -0.019, which is very small (Cohen & Holliday, 1982, as cited in Bryman & Cramer, 2012). This indicates that the intervention had little or no impact on students' perceptions of virtual laboratories. The negative sign on the effect size suggests that a few participants showed large pre-/ post-test gains in their perceptions of virtual laboratories, while the majority had small or no improvements, and some perceptions declined.

This interpretation is further supported by the item-level analysis of the PVL. For instance, students' percentage scores in response to the item "I think virtual labs can replace real experiments" increased greatly after the intervention, moving from 30% (6 students) to 60% (12 students) either agreeing or strongly agreeing. Additionally, students' agreement with four of the items increased slightly after the intervention; for example, "I like using virtual labs" and "I think virtual labs help me to understand chemistry (topics)". Conversely, their agreement with five items declined, including "I understand experimental results from a virtual lab", and "Virtual labs will help me with instructions in the real lab". It was also noted that there was no change in agreement for three items, including "Virtual labs will help me with real experiments".

Students had a mean score of 43.9 on the ATC before the intervention, and 43.5 afterwards (see Table 4). This result indicates that students showed almost no change in their attitudes towards chemistry following the virtual lab exercises. A Wilcoxon matched-pairs signed-ranks test confirmed that there was no statistically significant difference between the two scores (Z = -0.141, $p > .05$), and the effect size was very small (=-0.032). The results suggest that the virtual lab exercises had little or no effect on influencing students' attitudes towards chemistry.

Discussion

Students' Perception of Virtual Laboratories

In the first phase of this study, more students reported positive perceptions of virtual laboratories than negative ones. Notably, students believed that they would be able to confidently recognize laboratory equipment and develop the skills for real laboratories once they used virtual laboratories. The majority of students also perceived that virtual laboratories would assist with understanding science concepts. This finding is in line with studies done by Castro (2025) and Correia et al. (2019), who reported that virtual laboratory exercises can provide positive learning experiences, enhance conceptual understanding, and are an effective tool for gaining familiarity

Table 4

Table Showing Descriptive Statistics for the Pre- and Post-PVL and ATC Survey Instruments

	PRE-PVL	POST-PVL	PRE-ATC	POST-ATC
Mean	40.56	44.55	43.94	43.50
Std. Error of Mean	.746	2.489	.470	1.202
Std. Deviation	9.229	11.133	5.810	5.375
Minimum	13	13	23	24
Maximum	60	62	57	49

with laboratory apparatus. The majority of students in the current study also perceived that virtual laboratories would be able to replace real laboratories, which contrasts with the findings of Byukusenge et al. (2023) where the majority of students did not agree that virtual laboratories should replace physical laboratories.

Students' positive perceptions of virtual laboratories prior to using them might have been influenced by their expectations of accessibility, and their comfort with technology (Penn & Mavuru, 2020), both of which were likely reinforced by the shift to emergency remote learning during the COVID-19 pandemic. Students' favourable outlook on virtual laboratories can be interpreted as successful synergy of components of the TPACK framework. This framework emphasises alignment among technology, instructional strategies, and the subject content for meaningful learning to occur. Students' likely familiarity with digital technologies reflects technological knowledge, and the anticipated flexibility and belief in the labs' ability to support chemistry learning point to integration of technological pedagogical knowledge.

The large number of students who selected the neutral option for many of the items could have been due to unfamiliarity with virtual laboratories, where students might not have had sufficient exposure to form definitive opinions. This finding is in line with Penn and Mavuru's (2020) study in which pre-service teachers expressed initial curiosity about virtual laboratories before actually using them, and had doubts about their usefulness. It is important to give students opportunities to engage with new technology over time to allow them to form more definite opinions.

Overall, researchers have highlighted several advantages of using virtual laboratories over physical laboratories (e.g., Alhashem & Alfailakawi, 2023; Alneyadi, 2019; Gambari et al., 2018; Kapici et al., 2020). The positive affordances offered by the virtual laboratory are good for teachers, especially in situations where schools lack the resources for experiments that require specific equipment; in situations where students are not able to access the resources for conducting in-person laboratory work; or when students require additional practice to develop their skills (Faour & Ayoubi, 2018; Olympiou & Zacharia, 2012; Ratamun & Osman, 2018). The incorporation of virtual laboratories would aid teaching and learning in chemistry because of the knowledge that can be gained from being virtually exposed to various types of laboratory equipment and chemicals, and students' potential increase in confidence — all important factors in the study of chemistry. The lab exercises used in the study were in line with the CXC CSEC syllabus (Caribbean Examinations Council, 2017). Therefore, the positive attitudes expressed by students towards virtual laboratories are especially important for helping with supporting them in completing the laboratory activities required for the SBA component of the CXC examinations.

Students' Attitudes Towards Chemistry

Chemistry is an optional subject at Grade 10 in Jamaica, therefore students in the study likely chose to study it. The survey results indicated that students expressed interest in chemistry, and appreciated the usefulness of learning it. They also acknowledged that skills gained from chemistry would be valuable to their future careers, contrasting somewhat with the findings of Mahdi (2014). Despite this, and based on the survey results, which were similar to the findings of Heng and Karpudewan (2015) and Ibrahim and Iksan (2018), Grade 10 students' attitudes towards chemistry were modest overall. In addition, many reported that they did not enjoy chemistry classes, finding them to be boring. These findings are concerning, especially since the study was conducted near the end of the academic year, when students had already experienced a large portion of the curriculum. Musengimana et al. (2021) pointed out a decline in chemistry interest as students progressed to higher grades, which could have been applicable to the Grade 10 students in the current study.

The modest attitudes and lack of enjoyment toward chemistry reported in this study may be partly linked to the COVID-19 pandemic, but also suggests that current teaching approaches may not be adequately fostering positive learning experiences. The findings imply that the onus is on teachers to plan interesting classes to capitalise on students' recognition of the importance of chemistry to everyday life. As students seem to be easily disengaged in chemistry classes, teachers must carefully select instructional materials that foster interest and assist with promoting more positive attitudes towards the subject, especially in challenging contexts. Teachers are central to improving chemistry education by finding ways to implement strategies that support meaningful and engaging student learning (Boesdorfer, 2019; Shana & Abulibdeh, 2020).

Results from the Spearman's rho test showed a significant but weak positive association between students' PVL and ATC scores ($r = 0.18$, $p < 0.05$). This result indicates that students with more positive perceptions of virtual laboratories were more likely to have positive attitudes towards chemistry. This finding is also supported by Fulmer et al. (2019) who reported positive relationships between students' science attitude and instructional materials used for learning. The statistically significant relationship between students' PVL and ATC scores provides promise that relevant instructional methods can positively impact their subject-specific attitudes. Although the correlation is statistically significant, the weak strength indicates that there may be other factors beyond students' PVL that play a greater role in influencing their ATC. This highlights the complexity of the nature of students' attitudes and the need to consider other influences beyond PVL in interventions.

Students' Perceptions and Attitudes after using Virtual Laboratories

A comparison of pre-test/post-test means on the PVL showed that students' perceptions of virtual laboratories marginally improved after the intervention. However, the Wilcoxon matched-pairs signed-ranks test revealed that the change was not statistically significant. Although the change in perceptions was minimal, it was also positive, indicating the potential of the virtual laboratory tool to influence students' perceptions. The interactive and immersive nature of digital tools such as virtual laboratories aligns with constructivist principles which emphasize active, student-centred approaches to learning (Manyilizu, 2023). By engaging students in experimentation not normally encountered in physical laboratories, these tools may help to shift students' perceptions more substantially.

There was no statistically significant increase in the students' scores on the ATC instrument after the intervention based on the Wilcoxon matched-pairs signed-rank test. Ratamun and Osman (2018) found a similar trend, where the chemistry attitudes of students measured after they used virtual laboratories were not significantly different from those students who were in physical laboratories. Stahre Wästberg et al. (2019) reported that virtual laboratories can assist in increasing students' interest in and engagement with learning chemistry. Students' perceptions of virtual laboratories improved over time in the current study, and it was anticipated that this would translate into more positive attitudes towards chemistry. However, this was not the case, thus contrasting with the findings of Stahre Wästberg et al. (2019). Additionally, the increase in the number of students who selected the neutral option for certain questionnaire items suggests that students may have mixed feelings about chemistry. The findings also suggest that students' attitudes towards chemistry were possibly stable and therefore hard to change within the study's short duration. It is also possible that students' attitudes towards chemistry were viewed as distinct from their experiences gained from conducting virtual laboratory exercises. It is noted that the correlation reported in Stahre Wästberg et al.'s (2019) study was weak, suggesting that other factors can influence students' attitudes towards chemistry and their perceptions of virtual laboratories. This might also have been the case in the present study, and warrants further exploration.

As suggested by Conlin et al. (2019), the absence of statistically significant differences in studies can still offer insights. For example, the findings may be reflecting complexity of students' attitudes and point to opportunities for more research in the area. While virtual lab exercises did not significantly affect students' overall attitudes towards chemistry, they were generally viewed positively. Based on these findings, virtual laboratories appear to be viable tools that can be used to introduce and assist students to develop scientific skills.

The findings of this study have additional implications for classroom teachers. Since students have preconceived and perhaps ingrained attitudes about chemistry, teachers need to use a variety of strategies to aid in teaching laboratory activities, while simultaneously nurturing positive attitudes (Ratamun & Osman, 2018). Teachers also need to use experiments that demonstrate chemistry concepts relating to everyday life (such as Redox, energetics, and acid-base or neutralization reactions) to influence their perceptions positively. For instance, Redox reactions involve oxidation and reduction, and can be observed in the bleaching of clothes or hair, and the corrosion of metals. Energetics, the study of energy changes in chemical reactions explains how fuels burn, how food changes during cooking, and how batteries work. Neutralisation is the reaction between acids and bases, and is applicable to indigestion treatment with antacids, and environmental contamination testing using titration techniques. These and other everyday situations can be explored using virtual lab activities. It is recommended that when planning a unit of chemistry and introducing a new educational tool such as virtual laboratories, students are given enough time to acclimatize to the tool. Even if there is initially no substantial change in students' attitudes or perceptions; if students are observed to be maintaining a steady positive attitude towards the subject, this should not be deemed a loss. Teachers need to be mindful that students' perceptions and their attitudes to educational material can change over an extended period of time, particularly as they work towards preparation for high-stakes examinations such as those of the CXC. More research is still needed to identify other factors that may interfere with the effectiveness of virtual laboratories among high school chemistry students.

Limitations

This study has several limitations that should be considered when interpreting the findings. Firstly, the study was conducted during the COVID-19 pandemic, which disrupted students' access to lessons due to factors such as poor internet connectivity and lack of devices (Blackman, 2022; Caribbean Policy Research Institute [CAPRI], 2021). These challenges constrained researcher access to participants and reduced the available teaching time for the study, and likely also contributed to the small sample size, particularly in the intervention phase. Additionally, instrument validation, assent and consent procedures, and data collection were all conducted under the restrictive conditions of COVID-19 that may have impacted the methodological rigor of the study. The small sub-sample employed could have introduced sampling and gender bias. For example, a high percentage of the respondents were female, which might have influenced the overall perception that chemistry is a "girls' subject". Given the sampling strategy, caution should be exercised when interpreting the findings of the study which are specific to the participating schools and their respondents.

Another limitation is that the study focused on only four experiments, each from a different chemistry topic. The unique nature of each experiment, and the timing of when these topics were taught in the curriculum might have influenced the results. For example, if too much time had passed since the relevant topics were done in class, students might have forgotten key concepts needed to fully engage with the corresponding virtual lab experiment. A final limitation was that the study was based on a pre/post-test design without a control group. In light of the absence of a control group, instruments were carefully designed to enhance both reliability and validity by using clear, relevant statements and standardised scales on the instruments, ensuring alignment of the items with the intended constructs, and determining internal consistency through calculating Cronbach's alpha. The instruments were reviewed by content experts and piloted before use. Despite these factors, the findings offer helpful insights and should be interpreted as preliminary evidence of the potential for using virtual laboratories in Jamaican and Caribbean classrooms.

Conclusions and Recommendations

Students had moderate perceptions of virtual laboratories and moderate attitudes towards chemistry. Although there was a significant relationship between perceptions of virtual laboratories and attitudes towards chemistry, this association was weak. More research is therefore needed to identify the factors affecting the relationship between these two variables.

Students' perceptions of virtual laboratories increased marginally after being trained in their use. The incorporation of virtual laboratories could therefore aid teaching and learning in chemistry education, as improved perceptions of virtual laboratories can affect confidence in their use, resulting in increased knowledge and skills. Students who used virtual laboratories did not register a significant change in their attitudes towards chemistry after the intervention. Other factors such as gender and grade level can be explored for their effects on students' chemistry attitudes using both qualitative and quantitative methods. As traditional laboratories remain a core component of science education in Jamaica, and this study revealed only moderate improvements in students' perceptions of virtual laboratories, it is recommended that virtual laboratories be integrated alongside traditional ones. Further studies could then explore the potential benefits of this blended approach.

This study adds to the foundational knowledge base arising from the Global South. While highlighting the potential benefits of virtual laboratories, the need for further investigation into the various factors that could be influencing students' attitudes towards chemistry is also underscored. Conducting additional research that addresses these factors and incorporates a larger sample size could allow for a more comprehensive and widely applicable understanding of the topic. With this deeper understanding educators will be better able to tailor their instructional approaches to enhance student learning in chemistry.

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