Virtual science simulations: The new frontier in science instruction in the post-pandemic Caribbean

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Abstract

Many departments of science within Caribbean Higher Education Institutions were forced to provide science laboratory simulations because of the COVID-19 pandemic. This quantitative, comparative, retrospective study examined nursing students' science laboratory performance prior to and during the COVID-19 pandemic. It utilized 2975 laboratory science scores from four lab courses completed by five cohorts of first year undergraduate nursing students across each academic year for the period 2017 to 2021 at a Caribbean university. Data were analysed using SPSS version 29. The study revealed that the students' mean laboratory scores appear to be higher for the period 2020/2021 to 2021/2022 in comparison to the years 2017/2018 to 2019/2020. An ANOVA indicated that there was a significant difference in means for laboratory grades and years ($p < 0.05$). Tukey's HSD Post Hoc test revealed that the mean laboratory grades were all significantly different from each other except for 2020 and 2021. Based on this evidence, it can be concluded that there has been successful implementation of the science laboratory simulations during the pandemic and this can be incorporated as a best practice in digitally-enabled science instruction in the post COVID-19 era.

Keywords: Higher education; COVID-19; science laboratory simulations

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Introduction

The traditional method for the teaching of science involves a blend of face-to-face classes for teaching theory with practical and experimental skills being conducted mostly in the exclusive domain of the laboratory space at schools, colleges and universities throughout the Caribbean. It is generally thought that the laboratory practice becomes the reinforcement of classroom theoretical science concepts (Fongkong-Mungal et al., 2021). As far back as 1992, it was highlighted by Ware (1992) that there was a need for a systematic and systemic change in secondary school science in developing countries so that there can be greater accessibility to all for science education. Fast forward to the 21st century Caribbean and several studies have shown that there have been very little deviations from the traditional method of teaching science where there is a heavy reliance on teacher-centred instruction and lab-work (Brewster, 2015; Cassie, 2022; George, 2013; Herbert & Rampersad, 2007; Herbert et al., 2009; Mohammed, 2013). Therefore, due to the onset of the COVID-19 pandemic in March 2020, there was a need for Departments of Sciences across the Caribbean and globally to adopt teaching and learning strategies to facilitate students' understanding of science concepts despite their inability to meet face-to-face. This had come about due to the nationwide lockdowns that were rampant at that time due to the health emergency. Many resorted to the use of laboratory science simulations to help supplement face-to-face laboratory experience due to the restrictions imposed by various governments. Internationally, the use of online and simulation laboratories incorporated as part of a blended approach has been shown to have a positive response by students to this type of intervention in the past and it has improved significantly their achievements academically (Eryilmaz, 2015; Harahap et al, 2019; Ocak & Topal, 2015).

There have been studies which examined the response of universities with respect to academic continuity during the pandemic (Bleeker & Crowder, 2022; Cockburn & Chami, 2022; De Four-Babb et al. 2022). However, there has been a paucity of Caribbean literature associated with the direct implementation of virtual science simulations and Caribbean students' experiences with them (Cassie & George, 2021). Even more so, there have been very few studies which conducted

any evaluation of the performance of students using virtual laboratory simulations when compared to face-to-face laboratory activities in any Caribbean territory prior to or during the pandemic. Therefore, it was necessary to examine Caribbean undergraduate science students' performance using virtual science laboratory simulations when compared to face-to-face laboratory activities prior to and during the pandemic. This could provide useful data that can guide decision-makers and policy-makers with regard to the continued use and effectiveness of this intervention in teaching and learning of science.

Literature Review

There has been limited use of virtual science laboratory activities prior to the pandemic in the Caribbean (Cassie, 2022). There is evidence in the literature that supports its use in blended and online approaches to learning science. A recent study showed that students' outcomes have significantly statistically increased after having been exposed to a blend of modern educational methods (Bernard et al., 2017). Some studies have shown that students can perform just as well in an online environment as much the same manner as that being done face-to-face (Gulacar et al., 2013; Nennig et al., 2020). The usefulness of blended laboratory courses has been shown by Brewer, Cinel, Harrison and Mohr (2013). These courses included, inter *alia*, home experimental kits and a combination of online and hands-on learning. Faulconer, Griffith, Wood, Acharyya and Roberts (2018) used a quantitative study to show online students' propensity to perform better than their traditional face-to-face counterparts in the lecture and lab components. Even among secondary school students it has been shown that simulation-based technologies are more engaging than traditional methods (Figueiredo, 2023). A comparative study done among students in a Lisbon secondary school showed that when exposed to the utilization of computer simulations as opposed to traditional teaching strategy, the achievement rate in the post lesson test was in the range of 96.4% to 100% for the experimental group compared to 70.8% to 83.3% of the control group (Figueiredo et al, 2023).

The improvement in academic achievements has been shown by the use of online and simulation laboratories incorporated within a blended approach (Eryilmaz, 2015; Harahap et al., 2019; Ocak & Topal, 2015). Additionally, a review of the literature conducted by Celik (2021) revealed that, despite the increased effectiveness of computer simulations in science teaching over traditional teaching, it is only with the incorporation of other teaching strategies can there be significant gains in science process skills (SPSs).

With the advent of the COVID-19 pandemic many universities across the world and in the Caribbean had to offer virtual laboratory experiences and simulations to ensure continuity of teaching and learning within their various science related programmes. In a retrospective, comparative study of the teaching of clinical biochemistry course, Chinese researchers evaluated

the effectiveness of using a combination of online Problem-based learning (PBL) teaching and virtual simulation laboratory teaching through DingTalk (a free communication and collaboration software platform with features similar to a learning management system) during the pandemic as opposed to the traditional lecture-based learning (LBL) prior to the pandemic. It was found that the combined method of DingTalk based PBL was effective and an acceptable alternative strategy during the pandemic rather than the traditional LBL (Xie et al., 2022).

Also, within nursing education programmes there were innovative changes in the delivery of nursing education on account of the pandemic. In a systematic review, Amankwaa et al. (2022) examined three electronic databases for studies published between December 2019 – December 2021 using the Arksey and O'Malley framework, refined by Joanna Briggs Institute seeking to identify faculty innovations in nursing education as a result of the global COVID-19 pandemic. 111 out of the 1339 retrieved published works met the eligibility criteria and it was found that the innovative practices found in the studies focused on online teaching as an alternative to face-to-face delivery; providing an alternative to clinical placement; and faculty development (Amankwaa et al., 2022). It was also found that 27 research studies highlighted the integration of virtual simulations as part and parcel of the educational experiences during the pandemic period that used various platforms including Zoom, a three-dimensional learning management system, Microsoft Teams and 360 images. These studies showed that these technologies facilitated several virtual skill development experiences such as vital sign recording, health assessment activities, discharge planning and intramuscular injection administration (Amankwaa et al., 2022). Most significantly, Amankwaa et al. (2022), recognizing that the nursing education and by extension science education would be transformed beyond the pandemic, called for the assessment of the long-term effectiveness of innovations previously described.

There has been very little, if at all, any studies into the effectiveness of the use of virtual science laboratory simulations when compared to face-to-face laboratory exercises in the Caribbean (Cassie, 2022). This study sought to explore the effectiveness of the use of virtual simulation laboratories when compared to face-to-face laboratory activities. This was done by comparing students' laboratory performances in science courses prior to and during the pandemic at a Caribbean university. It can provide useful data that can guide decision-makers with regard to its possible permanent future inclusion in science programmes offered by Caribbean universities.

Purpose of Study

This study was designed to achieve the following objectives:

1. Determine the science laboratory performance trends of nursing students at a Caribbean university over a five-year period, 2017-2021
2. Compare the effectiveness of face-to-face laboratory activities with use of virtual science simulations using laboratory performance grades of nursing students at a Caribbean university, prior to and during the COVID-19 pandemic
3. Compare the laboratory performance of nursing students at a Caribbean university in various science courses over a five-year period 2017-2021

The following research questions were formulated in order to achieve the objectives of the study: Research Question 1: What are the performance trends of nursing students in the laboratory components of science courses over a five-year period, 2017 to 2021?

Research Question 2: Is there a significant difference in the laboratory performance of nursing students at a Caribbean university in science courses prior to and during the COVID-19 pandemic? H_0: There is no significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic. H_1: There is a significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic.

Research Question 3: Is there a significant difference in the performance of nursing students in certain science courses compared to others prior to and during the COVID-19 pandemic at a Caribbean university? H_0: There is no significant difference in the laboratory performance of nursing students at a Caribbean university in certain science courses prior to and during the COVID-19 pandemic. H_1: There is a significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic.

Background and Context

Description of Courses

The first- year biology and chemistry courses under study formed part of the Bachelor of Science, Nursing Degree programme at a university in the island of Trinidad. These courses were taught concurrently during the first semester and second semester of each academic year and students were required to earn a passing grade in the semester I course before being allowed to register for the semester II course. The courses are usually completed in the following sequence: BIO1, Anatomy and Physiology I followed by BIO2, Anatomy and Physiology II; CHEM1, Introduction

to Inorganic and Organic Chemistry then CHEM2, Introduction to Biological Chemistry. In order to obtain a deeper insight into the content that is covered in these courses the following general course descriptions are being provided: BIO1 and BIO2 are a first part and second part course respectively that deals with the study of cell biology, functional anatomy and control of each organ system of the human being. CHEM1 is an introduction to the basic theories, principles and applications of inorganic and organic chemistry. CHEM2 covers the study of basic concepts in biochemistry, including the structures and functions of biological molecules, metabolic and biochemical pathways, to include their roles in energy generation and regulation. The laboratory courses provided the supporting practical components that would support the theoretical concepts being taught in the theory section of the courses and are designated CHEML1, CHEML2, BIOL1 and BIOL2.

Lab Sessions – Prior to and During COVID-19

Each laboratory course had a separate 3-hour laboratory session that was held face-to-face in the biology and chemistry labs prior to the pandemic (2017/2018 to 2019/2020). However, during the pandemic (2020/2021 to 2021/2022) the sessions were facilitated using Zoom and students were given access to the Labster virtual simulations in the Moodle platform. Prior to the pandemic students were provided laboratory manuals for them to read, review and prepare for the upcoming lab activities. Usually, pre-lab activities were completed and submitted for review on the day of the lab session. Students were given a lab talk which would include a small session about theory associated with the labs as well as guidance on safety, and submission of the lab report or write up. Feedback on their pre-labs were given before the end of the first hour of the session. Students were usually supervised and assessed as they conducted their experiments and collected data. Techniques were reinforced, practised and guidance given by laboratory assistants who would supervise a small group of students. Once the laboratory session was over, students were required to submit individual lab reports which were marked and contributed to their laboratory grade. The submission of these reports varied from same day submission to up to 1 week for submission usually at a designated area in the laboratory area on campus or via Moodle, the learning management system.

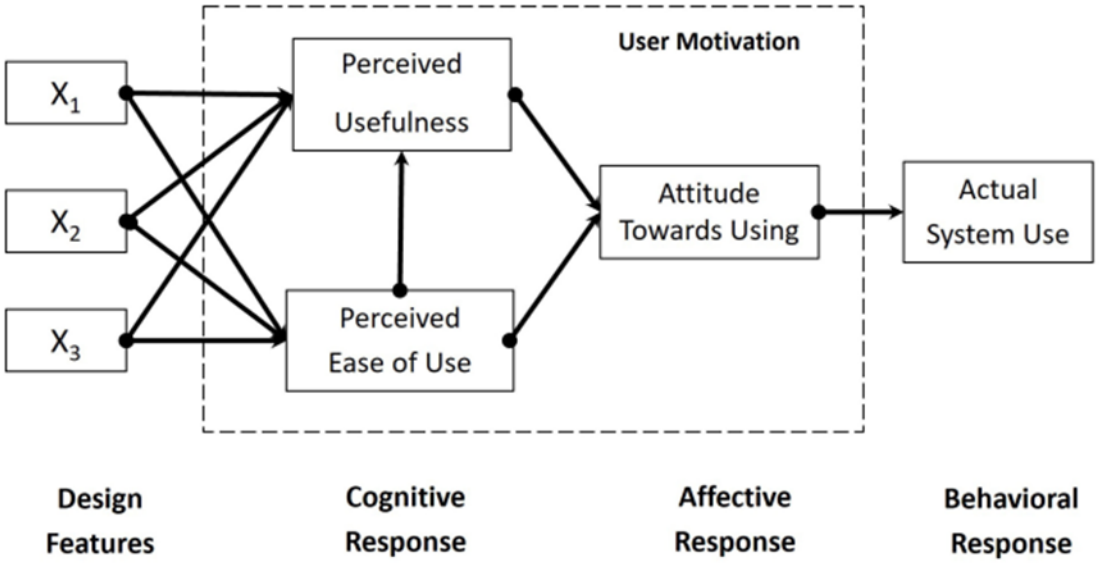
However, during the pandemic, virtual simulations were mainly incorporated for each of the laboratory courses as the Department of Science invested in the Labster software which was implemented in the beginning of the academic year 2020/2021 and its use was continued into 2021/2022. Labster (2023) describes virtual laboratories as interactive online science simulations that are used for teaching theory and lab techniques by immersing students in real world scenarios to apply knowledge to solve real world problems. The Department of Science invested in this commercial software for use with courses associated with the programmes offered by the department with students whose majors were in biology, nursing and consumer science. Additionally, it was also used in general science education courses which are part of the programmes of non-science majors of other departments of the university. Guidance was usually

provided by the laboratory technicians at the beginning of the lab session and students were allowed to either complete the simulations during the scheduled session or during a period of time when the access to the simulations were given. Students were expected to perform the virtual experiments individually and as they progressed through the lab session; they were required to answer questions based on the labs prompted by Dr. One, an A.I. drone lab assistant. The virtual labs from the Labster software were selected from those that were compatible with the learning outcomes that were expected in the face-to-face laboratory activities as far as possible.

Theoretical Framework

The infusion and use of technology within the educational setting is not a new phenomenon. However, due to the COVID-19 pandemic there was an exacerbation of its compulsory implementation and the examination of its relationship to teaching and learning has also been put high on many research agendas (Sadeck, 2022). Consequently, having been forced to use technology within the COVID- 19 pandemic period due to governmental and institutional policies many educators had to provide alternative means for education continuity. This was done via emergency online remote teaching within the tertiary education institutions of the Caribbean as well as the rest of the world. Naturally, in order to accomplish this implied the use of technologies for teaching and learning. Furthermore, administrators and faculty would have had to implement very drastic changes in teaching practices, such as the use of science simulations especially where science was concerned. In most cases administrators and faculty at tertiary institutions may not have been too familiar with this type of innovation (Cassie, 2022). As a result of this, there would have been further implications for behaviour changes towards the adoption and use of technology. These such behavioural changes would rest upon the individual's personal choices and which can range from basic survival to advanced personal needs and those of the learners (Sadeck, 2022). Therefore, this study is grounded upon the adaptation of the Technology Acceptance Model (TAM) (Davis, 1985) as shown in Figure 1.

Figure 1
Original TAM Model (Davis, 1985)



The TAM was developed by Davis (1985) with a focus initially on successful design and implementation of information systems. It was intended to provide greater understanding of the user acceptance processes as well as new theoretical insights. Additionally, it was intended to provide the theoretical underpinnings for a practical application of the user acceptance testing methodology (Davis, 1985). In fact, it was described as being able to determine the possibility of end users adopting particular technologies, understanding both influential external and internal factors that cause groups of users to either accept or reject technologies (Meerza, 2017).

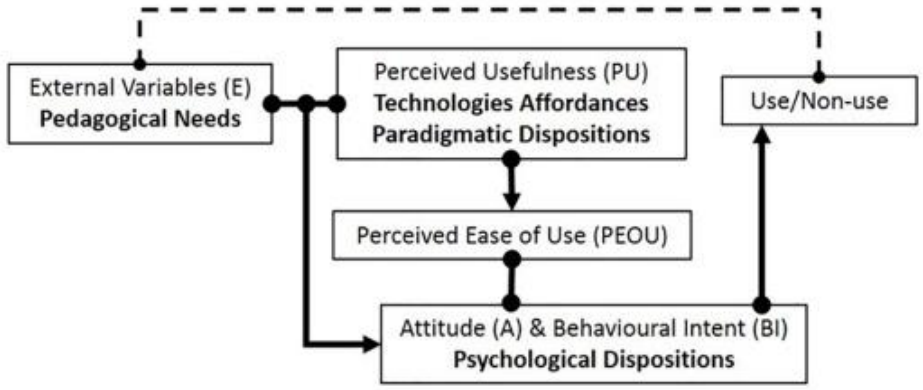
Two main belief constructs as shown in Figure 1 are Perceived Usefulness (PU) and Perceived Ease of Use (PEU). These are considered to be the main determinants of TAM and all the other iterations that have followed since its introduction. As shown in Figure 1, PU and PEU (cognitive response factors) can have implications for the attitude toward using (affective response) which further impacts the behavioural response (actual system use) (Go et al., 2020).

Since its first introduction in 1985, there have been several further modifications of the TAM (Davis et al., 1989, Venkatesh & Davis, 2000; Venkatesh et al., 2003; Venkatesh & Bala, 2008). However, the theoretical framework expounded by Sadeck (2022) which applies to this study made use of the original and the extended Technology Acceptance Model put forward by Davis et al. (1989). In this revised model, Sadeck (2022) suggested that

> The external variable (E) was taken as the contextual influence, i.e., the COVID-19 compulsion, which gave rise to a NEED—the need represents pedagogical reasoning. •

Perceived usefulness (PU) was taken to represent the technologies affordances. • The attitude (A) construct was taken as the disposition (p.6)

Figure 2
Representation of Adaptation of TAM (Sadeck, 2022)



Thus, in the context of this model as shown in Figure 2, Sadeck (2022) proposed that the use or non-use of technology is dependent on pedagogical needs, technological affordances and pedagogical reasoning or needs. Thus, the Faculty of the Department of Science's decision to implement virtual science simulations had its basis as satisfying the pedagogical need due to the pandemic since face-to-face labs were not possible. These science simulations provided all the technological affordances as it enabled learning of laboratory skills despite not having access to a physical lab. The psychological dispositions of the faculty would have supported the use of science simulations as the desired outcome of COVID-19 was educational and the use of these simulations would have been a means towards that goal. It was also a mandatory expectation by authorities that teachers should use technologies despite personal preferences. While this Sadeck (2022) model was intended initially to understand the depth to which technological affordances, disposition, and pedagogical reasoning at both primary and secondary school levels influence implementation (use/non-use) it can be also extended into the tertiary level too as shown in the previous discussion. The introduction of virtual science simulations can be clearly seen as an application of the adaptation of TAM within the constructs of the model.

Methodology

This study was designed as a comparative, retrospective, quantitative study. In order to conduct the study permission was sought and received from the university's ethical review board. This study made use of secondary data obtained from the undergraduate nursing students' scores in the laboratory components of science courses during the academic years 2017/2018; 2018/2019; 2019/2020; 2020/2021 and 2021/2022. A description of the science courses used in the study as

well as the conduct of laboratory exercises prior to and during the COVID-19 pandemic were outlined in the previous background and context section. The laboratory performance scores were obtained from faculty and staff who taught these courses over each academic year. Prior to the pandemic (2017/2018 to 2019/2020) the data included each students' individual performance on each of the lab reports submitted for each of the respective labs. During the pandemic (2020/ 2021 to 2021/2022) automatic scores generated during and upon completion of the virtual laboratory simulation exercises formed the basis of the grade for that particular lab. Data were analysed using descriptive and inferential statistics obtained using SPSS version 29.

Results

A total of 2975 laboratory scores from two chemistry courses, CHEML1 and CHEML2 and two biology courses, BIOL1 and BIOL2 that were completed by five cohorts of first year undergraduate nursing students across each academic year for the period 2017 to 2021 were analysed using SPSS version 29. Of the 2975 scores, 1585 were obtained for students exposed to face-to-face laboratory exercises whilst 1390 scores were obtained from students who used virtual laboratory exercises. There was a steady increase in the number of students doing all four courses per academic year except the 2018/2019 academic year as shown in Table 1 below.

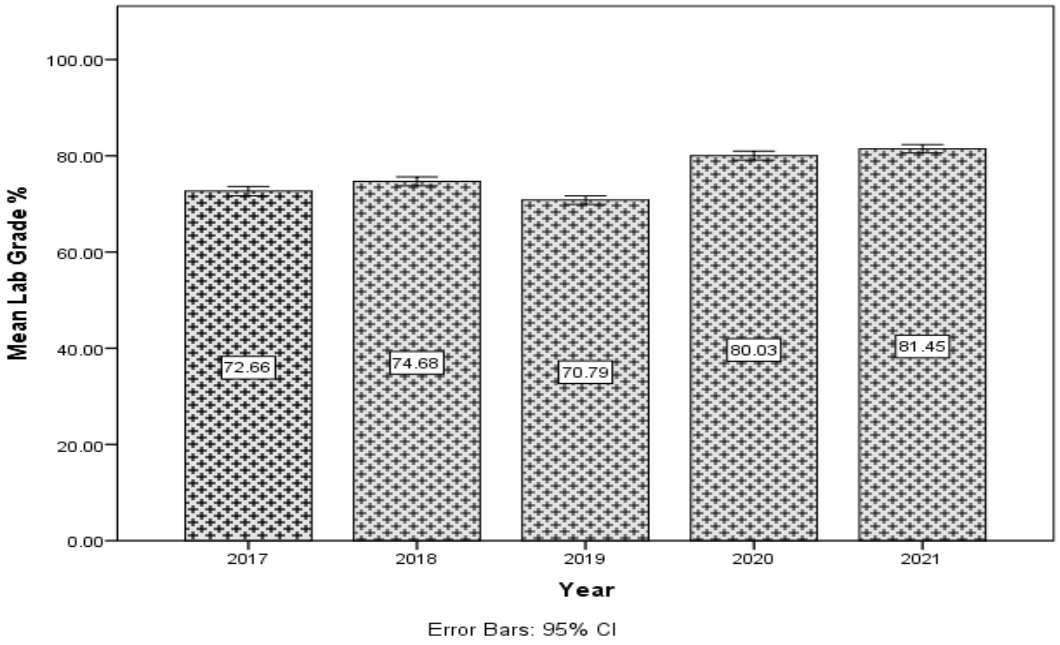
Table 1
Descriptive Statistics for scores by year for the period 2017 to 2021

Academic Year	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
2017/2018	517	72.66	11.13	0.49	71.69	73.62	36.00	100.00
2018/2019	505	74.68	10.64	0.47	73.75	75.61	33.00	100.00
2019/2020	563	70.79	10.73	0.45	69.90	71.68	40.00	99.00
2020/2021	660	80.03	12.19	0.47	79.10	80.96	11.10	100.00
2021/2022	730	81.45	11.88	0.44	80.59	82.31	15.00	100.00

It has been shown that the overall mean scores appear higher during the COVID-19 pandemic period (2020/2021 and 2021/2022) than the pre - COVID-19 period (2017/2018 to 2019/2020) as

shown in Figure 3 below. The academic years 2021/2022 and 2020/2021 also have the largest range in comparison to the years 2017/2018 to 2019/2020.

Figure 3
Mean laboratory scores by year for the period 2017 to 2021.



A one-way ANOVA was conducted to determine the effect of years (2017, 2018, 2019, 2020, 2021) on overall laboratory grades. The results indicate a significant effect, [$F(4, 2970) = 103.285$, $p < 0.05$]. Post Hoc tests were conducted using Tukey's HSD test. The comparison revealed significant differences between all years except 2020 and 2021, 2017 and 2019.

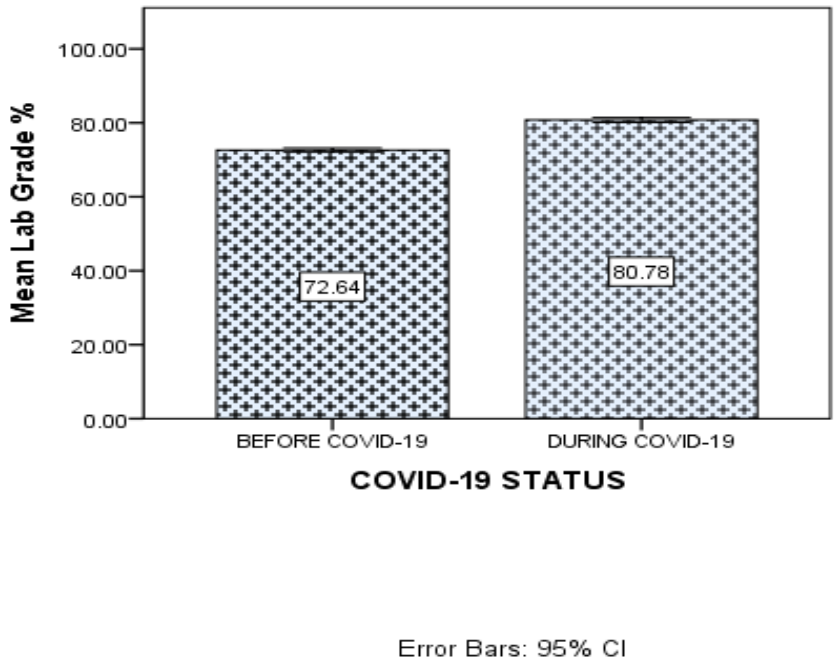
In order to compare the laboratory performance prior to and during the COVID-19 pandemic, the mean scores were calculated for the academic years from 2017/2018 to 2019/2020 (before COVID-19 period) whilst the mean scores were calculated for the academic years from 2020/2021 to 2021/2022 (during COVID-19 period).

Table 2 and Figure 4 show the overall mean lab grades were notably higher for students doing these courses during the COVID-19 pandemic than those who did the courses before the COVID-19 pandemic. However, there is a bigger range and standard deviation for student grades during COVID-19 as opposed to before.

Table 2
Descriptive Statistics for scores prior and during COVID-19

COVID-19 STATUS	N	Mean	Std. Deviation	Std. Error Mean	Minimum	Maximum
Lab Grade % BEFORE COVID-19	1585	72.64	10.94	0.27	33.00	100.00
Lab Grade % DURING COVID-19	1390	80.78	12.04	0.32	11.10	100.00

Figure 4
Overall Mean laboratory scores before and during COVID-19.



An independent samples t-test was conducted to assess for differences in the mean grades for laboratory courses before and during COVID-19. A significant difference ($p < 0.05$) was noted with mean laboratory scores being higher during COVID-19 than before.

Table 3 and Figure 5 below illustrate the mean scores for all individual courses. It can be seen that the mean scores were higher during the pandemic for all courses except BIOL 2 which was lower during the COVID-19 pandemic than the period before the COVID-19 pandemic.

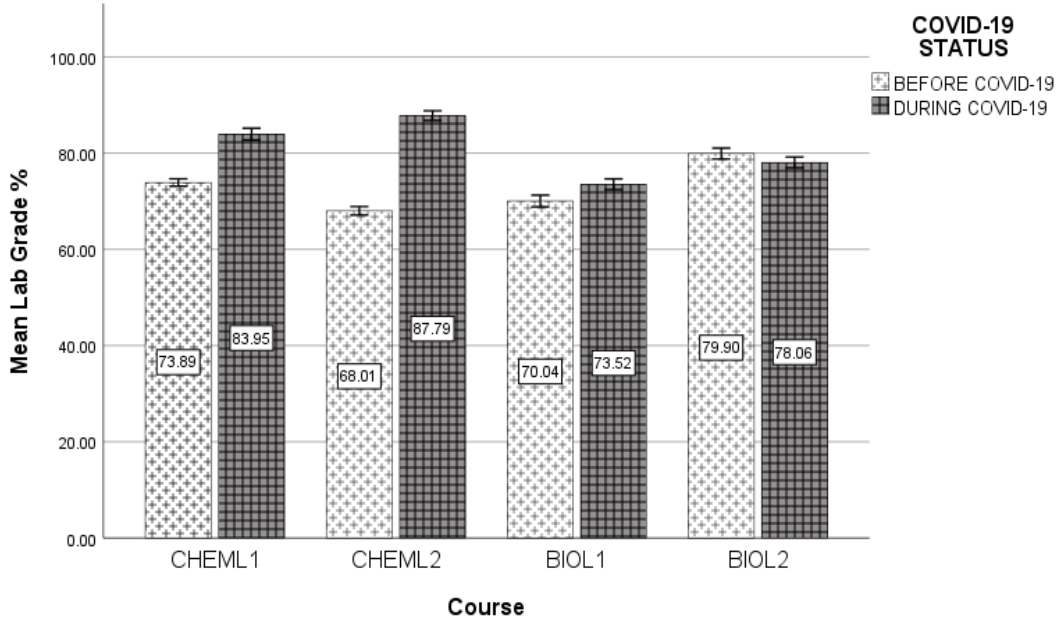
Table 3
Descriptive Statistics of scores for different courses Prior and During COVID-19

COVID-19 STATUS		Mean	N	Std. Deviation	Std. Error of Mean	Minimum	Maximum
BEFORE COVID-19	CHEML1	73.89	463.00	8.40	0.39	33.00	90.00
	CHEML2	68.01	404.00	9.02	0.45	36.00	88.00
	BIOL1	70.04	398.00	12.37	0.62	38.00	99.00
	BIOL2	79.90	320.00	10.43	0.58	54.00	100.00
DURING COVID-19	CHEML1	83.95	369.00	11.91	0.62	11.10	100.00
	CHEML2	87.79	336.00	9.47	0.52	45.00	100.00
	BIOL1	73.52	367.00	10.88	0.57	33.00	96.00
	BIOL2	78.06	318.00	10.36	0.58	15.00	99.00

A one-way ANOVA was conducted to determine whether there was a difference in overall mean laboratory scores by courses before COVID-19. The results indicate a significant effect, [$F(3, 1584) = 94.88$, $p < 0.05$]. Post Hoc tests were conducted using Tukey's HSD test and indicated all courses had significantly different means scores from each other before COVID-19.

A one-way ANOVA was conducted to determine whether there was a difference in overall mean laboratory scores by courses during COVID-19. The results indicate a significant effect, [$F(3, 1398) = 121.56$, $p < 0.05$]. Post Hoc tests were conducted using Tukey's HSD test and indicated all courses had significantly different means scores from each other during COVID-19.

Figure 5
Mean Lab grades by courses before and during COVID-19.



Discussion

With reference to the first research question: What are the performance trends of nursing students in the laboratory components of science courses over a five-year period, 2017 to 2021? It was seen that over the five-year period that the laboratory performance of the nursing students in the science courses steadily increased for all the years except 2019/2020 (see Table 1 and, Figure 3). The years 2021/2022 and 2020/2021 also have the largest range in comparison to the years 2017/18 to 2019/2020. This is noteworthy as it coincides with the academic year 2019/2020, marking the onset of the pandemic period in March 2020. It is possible that the science departments would have been in a period of transition from face-to-face laboratory to online laboratory experience and some adjustments may have been made to course and lab schedules. It has been shown that it was challenging for some educators at that point to source suitable alternatives. Some educators would have devised their own strategies at the time and there would have been challenges with those who were unfamiliar with online teaching tools (Díez-Pascual & Jurado-Sánchez, 2022; Huang, 2020; Makamure & Tsakenic, 2020). This therefore points to the need for exposing and strengthening pedagogical strategies for educators in the post-pandemic era (Deák et al. 2021; Paul & Jefferson, 2019).

The use of science virtual laboratories within the context of the COVID-19 pandemic by faculty, staff and students of the Department of Science at the university is supported by the revised theoretical framework of the TAM proposed by Sadeck (2022). The pedagogical need arose due

to the pandemic as there were restrictions in meeting face-to-face and this led the department faculty to acquire available technologies that could provide alternative and yet equivalent laboratory experiences. This decision to implement the use of this software would have been based on the technological affordances, perceived ease of use and the psychological dispositions of faculty at the time.

Having implemented these simulations, it was important to now examine the effectiveness of its use by investigating students' performance especially during this period and by comparing it to the students' performance prior to the pandemic and this now leads into the testing of the hypotheses: H_0: There is no significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic. H_1: There is a significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic. The study found that the mean lab grades were notably higher for students doing these courses during the COVID-19 pandemic than those who did the courses before the COVID-19 pandemic. Upon further analysis it was shown that a significant difference ($p < 0.05$) was noted with mean laboratory scores being higher during COVID-19 than before. This therefore supports the acceptance of the alternate hypothesis. This is supported in a systematic literature review completed by Chan et al., (2021) which indicated that virtual laboratories are more effective than passive teaching methods and show greater or equal effectiveness than hands-on laboratories. They go on further to report that studies have shown that the use of a blended combination of virtual labs and traditional methods yields even better results.

Additionally, Diwakar et al. (2023) in advocating for improved laboratory performance proposed that students can be given multiple attempts and longer duration to perform virtual laboratory experiments. This can auger well for improved proficiency in laboratory skills and competencies. Therefore, in the post-pandemic period, science laboratory exercises should include a blend of both face-to-face and virtual laboratories in order to broaden students' experiences and exposure to the best practices in 21st century pedagogy. This is important since there are many real - world applications of simulations in the training and professional development of students to become future career professionals. Cant et al., (2023) in their umbrella review of the use and effectiveness of virtual simulations in nursing education indicate that studies showed the students found that virtual simulations were easily accessible, fun, and engaging ways to learn. A qualitative study done among nursing students in South Korea by Kim et al. (2023) supports the notion that virtual simulations properly designed and implemented can improve student confidence and competence in the provision of patient-centred care.

The current study further investigated the performance of nursing students in certain courses compared to others prior to and during the COVID-19 pandemic by testing the hypotheses:

H_0: There is no significant difference in the laboratory performance of nursing students at a Caribbean university in certain science courses prior to and during the COVID-19 pandemic.
H_1: There is a significant difference in the laboratory performance of nursing students at a Caribbean university in a science course prior to and during the COVID-19 pandemic. It was found that there was a significant difference in the laboratory performance of the nursing students among each of the science courses prior to the pandemic and during the pandemic. Thus, this supports the acceptance of the alternate hypothesis. It was evident that there were improvements in students' laboratory performance prior to and during the pandemic. Of the four courses examined there was a steady increase in performance of three: CHEML1, CHEML2 and BIOL1. This is supported by the studies done by some researchers who found that virtual laboratories were equal or greater in effectiveness to hands-on laboratories and traditional methods of teaching (Celik, 2021; Chan et al., 2021; Reece & Butler, 2017; Xie et al., 2022).

Limitations

This study was a quantitative one and as such was unable to capture the full experience of the students' use of science simulations and their feelings and motivations towards them. This would have added a further balance and richness to the study if it was a part of a mixed methods study. The study was limited to first year nursing students and no other science majors across other year groups, such as those in biology and/or chemistry degree programmes.

Recommendations

Based on the study's findings it is being recommended that in the post-pandemic era that virtual laboratory and hands-on activities should be used in combination in the teaching and learning of science. Additionally, in order to enhance skill development activities and form a basis for evaluations, virtual laboratories can be implemented as pre-labs. These are some ways in which students' laboratory experience can be enhanced by the use of 21st century pedagogical best practices. This can generate interest and motivation for students who are desirous of pursuing Science, Technology, Engineering and Mathematics (STEM) education. Faculty should be encouraged to incorporate new and emerging teaching technologies in their classrooms. As a result of the findings of this study, this implies there is a need to review and develop instructional science curriculum for educators at tertiary level.

Additionally, a single laboratory experimental experience based on a specific topic should no longer be the only main method of assessment and evaluation of students' laboratory skills as has been the norm prior to the pandemic. In order to improve mastery, students should be afforded multiple attempts at the simulations after having been exposed to face-to-face equivalent

laboratory skill. This will be of benefit to students as it would afford more time for development of laboratory skills and competencies without the costly use of chemicals or need for physical supervision.

Future studies should include a comparison of laboratory performances among other science majors such as those students who do biology, chemistry and other science disciplines. This is being suggested because these students would have had more exposure and experience with the virtual science simulations across the various courses in their programmes and can provide a richer, fuller understanding and evaluation not only quantitatively but also qualitatively.

Conclusions

The results of the study supported the incorporation of virtual simulations in the teaching and learning process for the development of nursing students' knowledge, scientific and psychomotor skills. This was evident in this study which found that there was an increasing improvement of science laboratory performances of nursing students for the academic years 2017/2018 to 2021/2022 except during the academic year 2019/2020 when the pandemic started. This improved performance can also point to the increasing ease of accessibility, fun and engaging nature that virtual simulations have been proven to provide for students and this has been well documented in the literature.

There is no doubt that the inclusion of virtual simulations can provide opportunities for students to be given multiple attempts and longer duration to perform virtual laboratory experiments. This has cost benefits for the institutions since expensive chemicals used in face-to-face laboratories will no longer be required. In the case of nursing education students who are required to ensure the development of specific skills and competencies, the use of similar virtual simulations in specific real-world scenarios can assist in mastery of these skills with no risk to patients' lives. Thus, this would redound to the benefit of all those associated with the implementation of nursing programmes.

Based on this study, it has been shown that the laboratory performances of the nursing students were much more improved during the pandemic when they were exposed to the use of virtual science simulations rather than prior to the pandemic where they would have been exposed to traditional laboratory exercises. The study provides evidence for the inclusion of virtual science simulations as a part of the teaching and learning strategies within blended science programmes for nursing students across the Caribbean in the post-pandemic era. This now provides further opportunities for nursing curriculum designers to develop curriculum that incorporates real-world, patient-centred care in virtual simulations as well as bringing application of knowledge and skills in the virtual simulations to real world scenarios.

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