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# Efficiency of Web-Based, Computer and Mobile Software Applications in Facilitating Teaching and Learning of Chemical Concepts

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**Abstract**

Some of the most commonly used technologies for chemistry education are web-based, mobile, and computer software applications. Thus, this study investigated the teachers' perceptions of the efficiency of web-based, mobile, and computer software applications in facilitating the teaching and learning of chemical concepts. The study adopted a survey research design to cover a large, scattered population in the shortest possible time. The survey was developed from the literature of related studies. About 266 responses were retrieved from an estimated population of 700 chemistry teachers in both public and private secondary schools, polytechnics and monotechnics, colleges of education, and universities across the Sokoto metropolis. The obtained data was computed and analysed using the Statistical Package for Social Sciences (SPSS) version 25. The result of the study reveals that chemistry teachers considered web-based, mobile, and computer software applications efficient in delivering effective classroom and laboratory instructions.

**Keywords:** Chemistry, Web-Based Tools, Mobile Software Application, Computer Software Application, Teaching and Learning

**Introduction**

The learning process has to be interactive, challenging, and motivating with tasks that stimulate and maintain the interest of the students. With the rapid development of information education, the application of high-tech has become the direction of the education field to help learners develop self-learning abilities and knowledge renewal abilities (Geng & Wu, 2021).

Chemistry instruction in secondary and high schools, colleges, and universities is frequently divided into direct instruction and laboratory experiment. During direct instruction (traditional or active learning), students learn fundamental knowledge of chemistry, whereas in the laboratory, they are introduced to chemicals, science process skills, practical skills, and various apparatus and instruments. The recurring challenges in education forced this practise to change. Technology has found a way to relieve chemistry teachers of the burden of developing models of representation for students to visualise the most invisible chemical concepts. Thus, web-based resources and computer software applications for simulations and distance learning have been utilised to facilitate chemistry education.

For example, students' attitudes towards the chemistry instrumentation of general chemistry laboratories using Augmented Reality in Educational Laboratory (ARiEL) were investigated by An et al., (2020) and An & Holme, (2021), where learners downloaded and used the software on their phones or tablets while working on experiments. This software application provides students with direct and immediate information about laboratory instruments. The results suggest that the availability of ARiEL helps to reduce the anxiety associated with using instruments and improve intellectual accessibility.

As virtual reality (VR) in educational settings grows more and more popular, Dunnagan et al. (2019) assessed the viability of substituting an instrumentation-based organic chemistry lab with a VR experience. The authors claim that low-cost peripheral devices combined with virtual reality (VR) technology enable users to access immersive, three-dimensional (3-D) information from any location. The outcome suggests that this method might be used to deliver this organic chemistry lab experiment via distant learning. According to the authors, students who are unable to visit the lab owing to a disability, attendance issues like pregnancy, or safety concerns may benefit from these virtual reality experiences.

Within a decade, traditional face-to-face teaching and learning channels gave way to remote online and offline learning via web and computer applications. Although not all teachers received instruction via these learning resources during their training, they must be willing to accept them as supplementary channels for instructional delivery. Web, mobile, and computer software applications provide instructional materials that make invisible scientific concepts visible. Chemistry has been described as having multiple levels of representation, including macroscopic, submacroscopic, and symbolic. The abstract nature of the subject, which makes it difficult to understand for both teachers and students, has been simplified by the visual effects provided by web resources.

With the help of Technology Driven Pedagogy (TDP), a study titled "Effects of Technology Driven Pedagogy Application on the Comprehension of Complex and Abstract Concepts of Chemical Equilibrium" sought to understand how students improved their understanding of complex chemistry topics by using animation, simulation, and video integrated with student-centered learning to visualise complex and abstract chemistry concepts. For 30 first-year college students, the researchers used a sequential embedded mixed case study method (15 male and 15 female). The findings indicated that TDP significantly increased students' capacity for comprehension and academic performance.

In a study titled "ConfChem conference on interactive visualisations for chemistry teaching and learning: accessibility for PhET interactive simulations: advances, challenges, and possibilities," Moore (2016) highlighted the challenges and potential with PhET interactive simulations. The researcher discussed the integration of 3D models with simulations, as well as the advantages and possible fields of study for graphical representations in simulations.

One of the captivating studies titled "Using a cooperative hands-on general chemistry laboratory framework for a virtual general chemistry laboratory" was conducted by Chabra (2020) to find out the effectiveness of a virtual general chemistry laboratory. The author emphasises that the break-out of the COVID-19 pandemic forces the transition of an in-person cooperative learning advanced general chemistry laboratory course into an online or remote cooperative learning experience. Although many of the elements of open inquiry, process-oriented guided inquiry learning, project-based laboratory learning, and argument-driven inquiry are similar and have all been demonstrated to be effective, St. John's University chose to adopt cooperative learning because of its methodical approach to reorganising the laboratory experience. The cooperative learning labs were created to highlight the critical abilities of problem solving, data analysis and interpretation, experimental design, communication skills, and manipulative skills. The authors followed all the suggested procedures from the published laboratory manual. The findings of the study show that while virtual experiments can be used to satisfy laboratory learning outcomes when complemented with a proper framework, they cannot completely replace the hands-on laboratory experience.

Based on this outcome, the current study sought to investigate the efficiency of those web-based, mobile, and computer software applications in facilitating the learning and teaching of chemical concepts.

**Objectives of the Study**

The study intends to find out the chemistry teachers' judgements on the efficiency of

i. Web-based learning resources facilitate the teaching and learning of chemical concepts
ii. Mobile and computer software applications facilitate the teaching and learning of chemical concepts

**Methodology**

A survey research design was used for this study to assess teachers' perceptions and beliefs on how efficiently technological resources facilitate chemistry education in the 21st century. The study is conducted in the Sokoto metropolis, where an estimation of 700 chemistry teachers is spread across secondary and tertiary educational institutions, including public and private ones. Since the research involves web, mobile, and computer software applications, an online survey was more relevant than a conventionally printed questionnaire. Similarly, convenient sampling is adopted to scout for data from the respondents.

The questionnaire titled "web, mobile, and computer software applications for chemistry education" was designed to comprise three sections, A, B, and C. Section "A," titled "demographic information," seeks personal data from the respondents. Moreover, section "B," titled "Teachers' Perception of Efficiency of Web-Based Resources for Chemistry Education," comprises five items designed in the form of a four-point Likert scale of agreements. Finally, Section "C," titled "Teachers' Perception of Efficiency of Mobile and Computer Software Applications for Chemistry Education," contains five items designed on a four-point Likert scale of agreements.

**Table 1:** List of test items and the literature it was adopted

| **Section B: teachers' perception of efficiency of web-based resources for chemistry education** | | |
|---|---|---|
| **SN** | **Items** | **Researchers** |
| 1 | Items 1 & 2 | Pearson (2020) |
| 2 | Item 3 | Karayilan, McDonald, et al. (2021) |
| 3 | Item 4 | Marincean & Scribner (2020) |
| 4 | Item 5 | Dunnagan et al. (2019); Dunnagan et al., (2020) |
| **Section C: teachers' perception of efficiency of mobile and computer software applications for chemistry education** | | |
| **SN** | **Items** | **Researchers** |
| 1 | Items 2 & 3 | Toscanini et al. (2021) |
| 2 | Item 1 | Yang et al. (2018) |
| 3 | Item 4 | Demissie et al., (2013) |
| 4 | Item 5 | Seritan et al. (2021) |

The online survey was shared on the WhatsApp groups of chemistry teachers from various institutions. Moreover, the survey was also shared on the social media handles of educational institutions within the geographical circle of Sokoto metropolis. About 313 responses are retrieved after sharing the instrument for a period of six months. Consequently, about 47 responses are found invalid because some of the respondents are not part of the population. A total of 266 valid responses are used for data analysis.

The internal consistency of the instrument was determined using Cronbach's alpha coefficient of reliability since the obtained data is ordinal. Internal consistency is measured on a scale of 0 to 1; the closer the coefficient of reliability is to 1, the more reliable the instrument. Table 2 represents the test for the reliability of the instrument.

**Table 2:** Cronbach's alpha coefficient of reliability of the instrument

| Cronbach's alpha coefficient of reliability | No of items |
|---|---|
| 0.68 | 10 |

It can be observed from Table 2 that the Cronbach's alpha coefficient of reliability, 0.68, is closer to 1 than 0.68, which indicates that the instrument is reliable. This means that the items of the instrument are measuring similar constructs.

**Result**

The presentation of the results of this study starts with the demographic information of the respondents. This information includes the gender, qualifications, and school of the respondents.

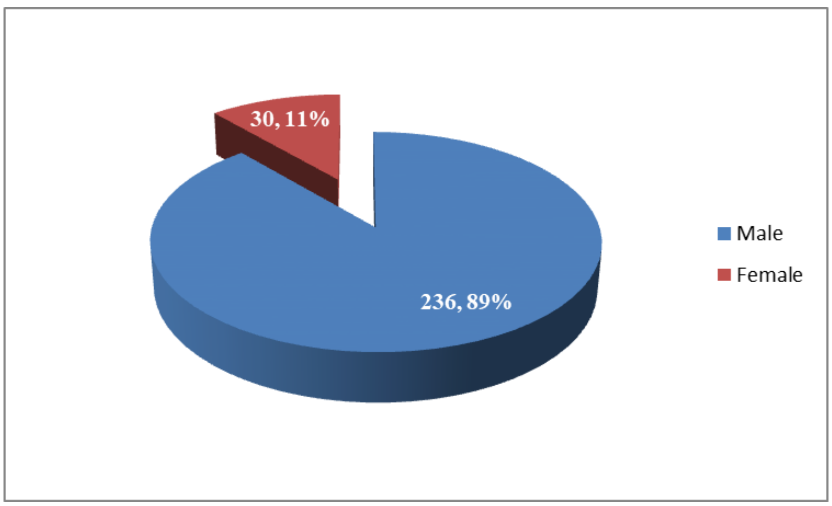


**Figure 1:** Gender distribution of the respondents

It can be observed from Figure 1 that while there are 236 males, there are 30 female respondents in the study. This means that about 89% of the respondents are males while 11% are females, showing that there are more males than female counterparts.

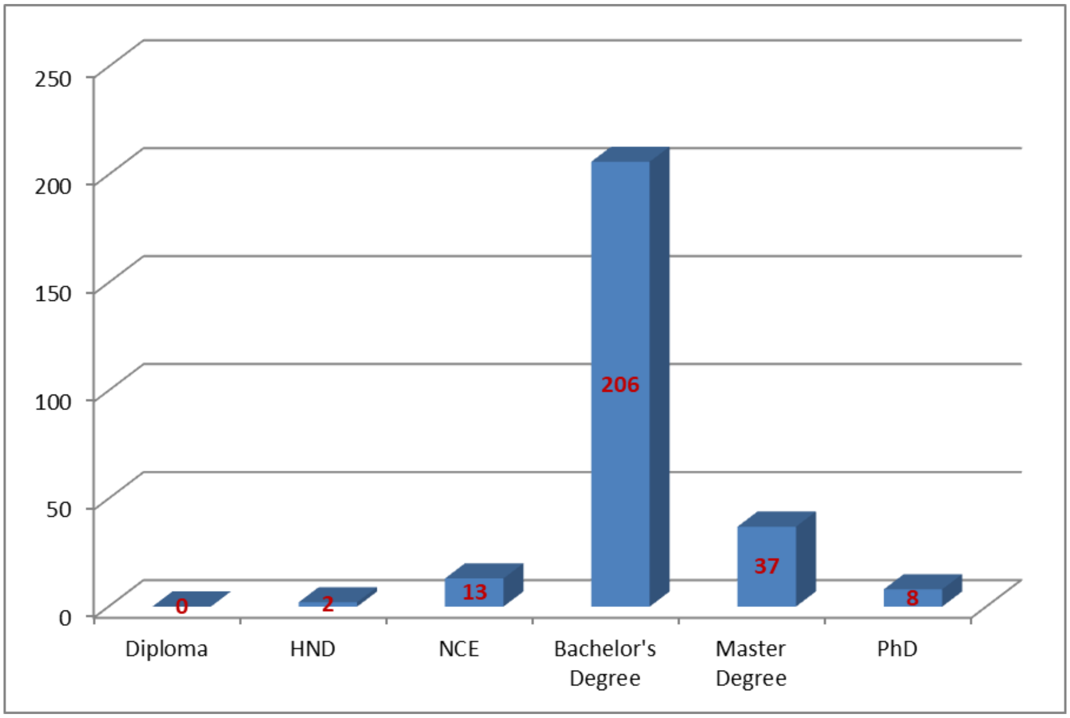


**Figure 2:** Qualification of the respondents

As observed in Figure 2, there are 206 bachelor's degree holders, 37 master's degree holders, 13 NCE holders, 8 PhD holders, and HND holders, and no respondents found with a diploma. Chemistry is taught at Senior Secondary 1 (SS1), which is equivalent to Form 4 and K10 in the United Kingdom and the United States of America. The minimum qualification for teaching at the level chemistry is taught is a bachelor's degree or its equivalent (that is, HND).

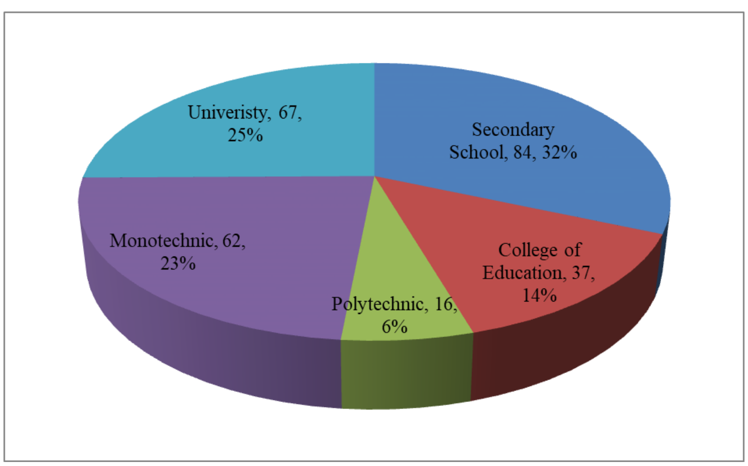


**Figure 3:** Schools distribution of the respondents

It can be observed from Figure 3 that about 84 respondents are secondary school chemistry teachers, 67 university lecturers, 62 lecturers from monotechnic institutions (including public and private colleges of health and agriculture), 37 lecturers from colleges of education, and 16 from polytechnic institutions. In other words, there are 32% secondary school teachers, 25% university lecturers, 23% monotechnic teachers, 14% lecturers from colleges of education, and 100% polytechnic lecturers. This means that there is more participation by secondary school students than by those in educational institutions other than secondary schools.

The second section of the instrument seeks to measure the teachers' perceptions of web-based resources for chemistry education through five items represented in Table 3 below. Statistical tools like the mean and standard deviation are used for the analysis of the obtained data.

**Table 3:** teachers' perception of efficiency of web-based resources for chemistry education

| SN | Item | Option | Freq(%) | Mean | StnDev |
|---|---|---|---|---|---|
| 1 | With the help of web resources, more interactive formats of online and offline electronic media facilitate the learning of chemical concepts. | SD | 0.0 (0.0%) | 3.7 | 0.4 |
| | | D | 0.0 (0.0%) | | |
| | | A | 77 (29%) | | |
| | | SA | 189 (71%) | | |
| | | **Total** | | | |
| 2 | During an assessment, web resources can provide instant feedback on a child's learning development. | SD | 0.0 (0.0%) | 3.9 | 0.2 |
| | | D | 0.0 (0.0%) | | |
| | | A | 23 (8.6%) | | |
| | | SA | 243 (91.4%) | | |
| | | **Total** | | | |
| 3 | Web-based virtual lab experiments can effectively complement face-to-face lab experiments. | SD | 0.0 (0.0%) | 3.9 | 0.2 |
| | | D | 0.0 (0.0%) | | |
| | | A | 14 (5.3%) | | |
| | | SA | 252 (94.7%) | | |

| | | | | | |
|---|---|---|---|---|---|
| | | **Total** | | | |
| 4 | The concept knowledge gained when using web-based resources is similar to that gained from the face-to-face version. | SD | 0.0 (0.0%) | 3.8 | 0.4 |
| | | D | 2 (0.8%) | | |
| | | A | 57 (21.4%) | | |
| | | SA | 2.7 (77.8%) | | |
| | | **Total** | | | |
| 5 | Through a web-based virtual lab, it is possible to offer organic chemistry lab experiments via distance education. | SD | 0.0 (0.0%) | 3.9 | 0.2 |
| | | D | 0.0 (0.0%) | | |
| | | A | 26 (9.8%) | | |
| | | SA | 240 (90.2%) | | |
| | | **Total** | | | |

[88]SN=Serial Number; SD= Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; Freq=Frequency; %=Percentage; StnDev=Standard Deviation

As observed from Table 3, the mean values of items 1, 2, 3, 4, and 5 are 3.7, 3.9, 3.8, and 3.9, respectively, which indicated that the respondents strongly agreed on the test items measuring teachers' perceptions of the efficiency of web-based resources for chemistry education. This implies that the respondents strongly agreed that web-based resources are efficient tools for facilitating the teaching and learning of chemical concepts, online or offline, near or far, direct or virtual. Consequently, the standard deviation of 0.2 for items 2, 3, and 5 indicates that the data is concentrated around the mean value of 3.9, while items 1 and 4 have a standard deviation of 0.4 each, indicating that the data is fairly spread around the mean value of 3.8.

**Table 4:** Teachers' perception of mobile and computer software applications for chemistry education

| SN | Item | Option | Freq(%) | Mean | StnDev |
|---|---|---|---|---|---|
| 1 | Immersive chemistry learning provided by the software applications enhances students' interest. | SD | 0.0 (0.0%) | 3.9 | 0.3 |
| | | D | 0.0 (0.0%) | | |
| | | A | 31 (11.7%) | | |
| | | SA | 235 (88.3%) | | |
| | | **Total** | | | |
| 2 | Software applications are useful for helping students comprehend complex molecular structures in chemistry. | SD | 0.0 (0.0%) | 4 | 0.1 |
| | | D | 0.0 (0.0%) | | |
| | | A | 2 (0.8%) | | |
| | | SA | 264 (99.2%) | | |
| | | **Total** | | | |
| 3 | Software applications offer meaningful learning and motivation. | SD | 0.0 (0.0%) | 4 | 0.0 |
| | | D | 0.0 (0.0%) | | |
| | | A | 0.0 (0.0%) | | |
| | | SA | 266 (100%) | | |
| | | **Total** | | | |
| 4 | Software applications are promising tools for simplifying and clarifying complex and abstract concepts in chemistry. | SD | 0.0 (0.0%) | 4 | 0.2 |
| | | D | 0.0 (0.0%) | | |
| | | A | 11 (4.1%) | | |
| | | SA | 255 (95.9%) | | |
| | | **Total** | | | |
| 5 | Software applications provide visual effects for invisible abstract concepts like molecular geometry and structure, molecular bonding and orbitals, etc. | SD | 0.0 (0.0%) | 4 | 0.1 |
| | | D | 0.0 (0.0%) | | |
| | | A | 1 (0.4%) | | |
| | | SA | 265 (99.6%) | | |
| | | **Total** | | | |

[88]SN=Serial Number; SD= Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; Freq=Frequency; %=Percentage; StnDev=Standard Deviation

It can be observed from Table 4 that the mean values of items 1, 2, 3, 4, and 5 are 3.9, 4.4, 4.4, and 4.4, respectively, which reveal that the respondents strongly agreed that mobile and computer software applications are efficient in facilitating the teaching and learning of chemical concepts. This means that software applications provide an immersive chemistry experience that makes remote learning effective and efficient. However, the standard deviation of item 1 is 0.3 higher than that of other items on the same scale. This means that when compared to other items on the same scale, the data for item 1 is fairly spread around the mean value. Item 4 has its data clustered around the mean value, indicating that the respondents voted for the same opinion.

**Discussion**

The study investigated teachers' judgements on the efficiency of web-based, mobile, and computer software applications to facilitate the learning and teaching of chemical concepts. The result reveals that both web-based and mobile as well as computer software applications are efficient in facilitating the teaching and learning of chemical processes. This finding is supported by the results of many studies conducted by chemistry researchers (Demissie et al., 2013; Dunnagan et al., 2019, 2020; Karayilan et al., 2021; Marincean & Scribner, 2020; Pearson, 2020; Toscanini et al., 2021; Yang et al., 2018) over the past decade. For example, Toscanini et al. (2021) report that iMolview Lite offers meaningful learning that enhances students' motivation. iMolview Lite is a free molecular visualisation software programme that is available for both iOS and Android devices. It offers a full set of features for the visual analysis of molecules with an easy-to-use interface. With the help of iMolview Lite, students can learn a set of molecular representations of different structural features of organic substances. According to the authors, iMolview Lite is preferred among other applications due to its availability for Android and iOS devices and because it combines visualisation with a wide range of manipulating actions within a user-friendly interface.

In the article "Mobile augmented reality assisted chemical education: elements 4D insights," Yang et al. (2018) reported that participants generally had a positive attitude toward the immersive chemistry learning experience. This study was conducted to investigate how preservice chemistry teachers feel about MAR-assisted mobile chemical education. A free Mobile Augmented Reality (MAR) product called Elements 4D offers a cutting-edge method for learning actual chemistry. The item comes with a set of six paper blocks made up of the 36 naturally occurring elements from the Periodic Table plus educational software. In the study, roughly 15 students were given access to Elements 4D, a mobile app for learning MAR chemistry, and were given instructions to do certain self-paced, practical activities. Semi-structured interviews and classroom observations were used to gather the data.

Students have the chance to hone their critical thinking and problem-solving abilities by performing the identification of organic chemical compounds from a collection of spectroscopic data. In fact, analysing spectroscopic data requires students to understand how to organise and extract pertinent data from a variety of analytical techniques in order to determine a chemical structure based on evidence. Agnello et al. (2020) therefore undertook a study to evaluate the growth of students' critical thinking and problem-solving skills when learning chemical spectroscopy. Using a multiplatform Web-based application (ULg Spectra), the researchers created a student-centred methodology for teaching molecular structural analysis to first-year undergraduate students. Mass, infrared, and nuclear magnetic resonance spectra are used in the fully interactive instructional and drill materials provided by ULg Spectra (i.e., one-dimensional 1H NMR and 13C NMR spectra and two-dimensional 1H13C HSQC spectra). It is a spectral database with workouts of varying degrees of difficulty. Therefore, they are a valuable resource for students to develop critical-thinking skills through relevant problem-solving strategies. The findings of the study reveal that the vast majority of students valued the ULg Spectra application combined with guided inquiries, especially in terms of usability and usefulness. According to the researchers, the approach prompted them to actively engage in problem solving, and student autonomy improved. Interestingly, a statistically significant increase in final grades and success rates was also observed compared to previous years.

Marchak et al. (2021) did a study named "Teaching Chemistry by a Creative Approach: Adapting a Teachers' Course for Active Remote Learning" to explain how the course structure and contents changed from a planned face-to-face format to a successful online learning environment. The authors focused on giving teachers practical tools so they could rethink and create their own lesson plans that would work for remote teaching by including supportive neuropedagogical elements. By using innovative, active learning techniques, teachers are given the theoretical and practical foundations they need to internalise the arts-integration strategy. The findings of the study show that the original course's essence and primary goals were effectively kept in the online version, that the course was helpful for remote teaching, and that it appears to have had an impact on teachers' practises.

Wright and Oliver-Hoyo (2021) did a study titled "Development and evaluation of the Hydrogen Nuclear Magnetic Resonance MoleculAR Application" to promote conceptual problem-solving and discourage memorising by doing away with chemical shift tables. This research looks into the concept of spectroscopy. The idea introduces students to the techniques used in chemistry research and gives them useful information on energy levels, symmetry, molecular geometry, chemical bonding, reaction mechanisms, resonance, and connections between energy and matter. Students can visualise 3D structures, molecular orbitals, and maps of electrostatic potential with the use of the AR resource. The study's conclusions showed that students enjoyed using the application and thought its novelty was its finest feature. The article also explains how the H NMR MoleculAR app, which is now free to download from the Android and iOS app stores, was integrated as in-lab software for the 1H NMR laboratory at our institution.

Aguirre & Selampinar's study, "Teaching Chemistry in the Time of COVID-19: Memories and the Classroom," compared the challenges of teaching approaches between laboratory and discussion methods. In order to simulate the laboratory and experimental experience for students, the researchers used virtual laboratories made available by Hayden-McNeil while using Blackboard Learning System (BLS) for synchronous regular classroom instruction. In order to aid students in understanding the idea before to the session, they recorded mini-lectures as PowerPoint presentations with supplementary audio and published them to BLS. Prior to the lecture, the students were expected to watch the videos. At the appointed time, class discussion is conducted using a collaborative ultra-program and a blackboard. Additionally, students had four days to complete the tasks and submit their final solutions. The BLS online quiz feature was used to inform the students of the accuracy of their response.

Buchberger et al. (2020) conducted a study titled "Analytical Chemistry Online: Lessons Learned from Transitioning a Project Lab Online Due to COVID-19" to assess the key successes and challenges identified in the staff and student feedback from Lessons Learned after Transition to a Project Lab Online. The outcome showed that the customization of the course material and the tools created for student achievement were responsible for the success documented with reference to the online lab project.

**Conclusion**

The study investigated the teachers' perceptions of the efficiency of web-based, mobile, and computer software applications in facilitating the teaching and learning of chemical concepts. We adopted a survey research design to cover a large, scattered population in the shortest possible time. The survey was developed from the literature of related studies. The result of the study reveals that chemistry teachers considered web-based, mobile, and computer software applications efficient in delivering effective classroom and laboratory instructions. Many of these web tools and software applications are intended to provide students with visualisation of invisible components of the chemistry curriculum. Some of these resources include iMolview Lite, Elements 4D, H NMR MoleculAR, ULg Spectra, ChemSense, CHEMTrans, AutoChrom, Katalyst D2D, Luminata, Method Selection Suite, MS Fragmenter & NMR Predictors, Spectrus JS, ChemOffice (the new version includes ChemDraw Ultra, Chem3D Ultra, E-Notebook Ultra, ChemFinder, CombiChem, Inventory, BioAssay, and The Merck Index), Spectrus Processor, Gaussian, Structure Elucidator Suite, ChemSketch, Hyperchem, Betwixt, Odyssey, ChemBuddy, Monte Carlo Gas Simulator, SAVANT Laboratory Training, Atomic orbitals CD-ROM, Chemical Thesaurus, CHEM-IT, Newbyte, WinTorg, CHEMIX School, Kintecus.

**Recommendation**

This study presented many software applications for learning chemistry that have never been circulated in research databases across the globe. Chemistry teachers should use relevant apps to deliver instructions that facilitate learning of concepts teachers and students perceive as difficult. Moreover, teachers should also test those software applications for their effectiveness in facilitating chemistry education in this century.

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