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Software and Tools in Online Chemistry Class and Experimental Activities During Covid-19 Pandemic: A Systematic Literature Review

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Abstract: The COVID-19 outbreak had transformed the chemistry learning from physical class to online class. The alteration in class method could be challenging for several instructors, particularly those who were not aided with technological advancements and adequate training. One of the challenges was the selection of software and tools used in online lectures as well as online experiments class. Herein, we present a systematic literature review with the PRISMA model from two databases regarding the software and tools many researchers used in chemistry learning during COVID-19 pandemic. The particular steps of laboratory activities and students' perspectives towards these learning tools were also incorporated in the results and discussion. At the end of the review, we provide the promising directions of learning tools for future chemistry learning too.

Keywords: Chemistry class; COVID-19 pandemic; Experimental activities; Software

Introduction

The COVID-19 pandemic posed a global disruption to humanity in many fields including education, economy, public health and employment stabilization. In the field of education, there was a huge challenge for educators to be able to deliver the learning materials due to the closure of educational institutions. In addition, students also faced the challenge of not being able to meet in class in order to avoid the spread of coronavirus among people. The only way to overcome this problem was migration from face-to-face (F2F) learning to online learning. Consequently, many academia, from primary level to higher education level, needed to redesign their classes to be continued with online learning in an extremely short time. Although online learning has been used for decades Singh & Thurman (2019), the study related to it significantly increased in these last two years (2020 - 2022).

In chemistry education, it was highly important to conduct hands-on activities like laboratory experiments because the graduates expected to have the ability to conduct experiments, analyze the experimental data, and interpret the results (Yeerum et al., 2022). One biggest challenge for educators is determining the method to give students' experience in the laboratory in the safest and the most affordable way possible. Several studies stated that many teachers decided to give the pre-recorded experiments to students instead of any physical activities, like teachers in Africa continents (Okebukola et al., 2020), Brazil (Soares et al., 2020), and India (Giri & Dutta, 2021). The reasons were nearly the same, namely lack of infrastructure, lack of access to appropriate internet connection, and lack of funding. However, in developed countries, these cases were rarely reported, as they already had a proper method to conduct laboratory class. Despite the difficulties that arose, many educators tried to apply virtual lab experiments and at-home experiments. These other forms of experiments can achieve better learning outcomes than pre-recorded experiments in the aspects of developing decision-making skills, developing an

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understanding on how to design the experiments, and experiencing the hands-on activities (Warning & Kobylianskii, 2021).

The increased number of published original articles in COVID-19 pandemic era learning had motivated many authors to write literature review papers. Many papers had raised the issue regarding challenges and opportunities (Abdulkareem & Eidan, 2020; Adedoyin & Soykan, 2020; Ahmadon et al., 2020; Mielgo-Conde et al., 2021; Mseleku, 2020; Pokhrel & Chhetri, 2021; Tadesse & Muluye, 2020; Yusuf, 2021). Advantages, constraints, and solutions Fatoni et al. (2020), online platforms Camargo et al. (2020), and student engagements (Salas-Pilco et al., 2022). Although there are many reviews reported, the reviews about online platforms used in specifically chemistry learning have never been published elsewhere. Moreover, chemistry learning had some differences with other subjects in terms of hands-on activities, which notably resulted in different platforms to carry out the learning activities. Therefore, it was important to address this issue particularly in chemistry learning.

Herein, the software, tools, and platform for supporting the chemistry online learning have been reviewed and discussed. The students, instructors and teaching assistants (TAs) experience are also reviewed for each respective platform they used, hence providing valuable insights for readers to select the best platform.

Method

This scoping review aimed to analyze the scientific literature on software, tools, or platforms used in online chemistry learning during COVID-19 pandemic. To accommodate this purpose, Systematic Literature Review (SLR) and the PRISMA model were used as the references and guidance. The requirements of bibliographic sources used were written in English, only article document type (not conference proceeding, book chapter, or book), the articles were in the final publication stage, and related to chemistry learning during pandemic in all educational levels. For the third requirement, we used human exclusion by skim-reading the title and abstract. The following databases were used to obtain the bibliographic sources.

The first database is ERIC (Figure 1a). The initial keyword was “online learning COVID-19 chemistry”, 6639 articles were found, and using the parameters such as “journal article”, “online courses”, “pandemics”, and “distance education”, 803 articles were found. From 803 articles, we only reviewed if there was “chemistry” in the title, written in English, and not aimed at pre-service teachers, which only 32 articles.

The second database is Scopus (Figure 1b). The initial keyword was “online learning COVID-19 chemistry”, 208 articles were found, and using the parameter of “document type: article”, 176 articles were found. We used additional parameters such as “distance learning/self-instruction”, “COVID-19”, “chemistry”, “pandemic”, “distance learning”, “teaching”, and “online teaching”, and only English articles, 12 articles were found. From 12 articles, we only reviewed the open-access articles, close-access articles but we can access them, which only 6 articles.

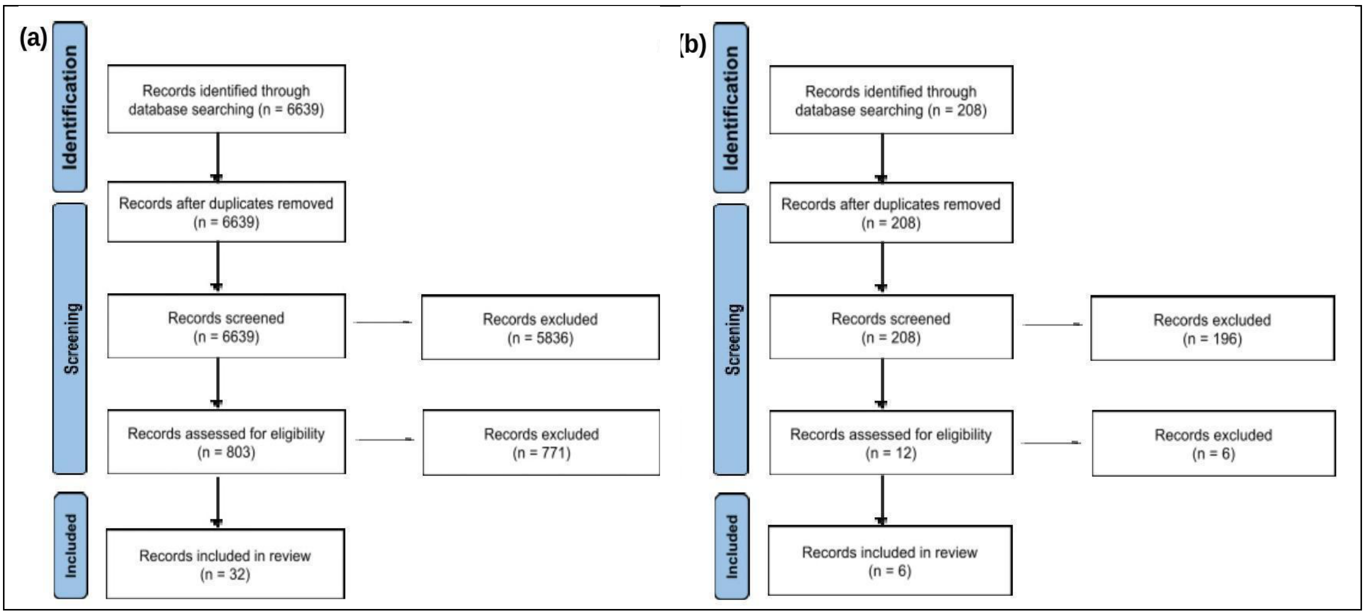

Figure 1. PRISMA diagram (inspired by Ref. (Moher et al., 2009) of (a) ERIC database and (b) Scopus database

Result and Discussion

The original articles presenting the chemistry online learning mostly originated from Journal of Chemical Education, published by American Chemical Society and Sustainability, published by Multidisciplinary Digital Publishing Institute (MDPI). Most of the articles have the online learning reported for undergraduate students instead of middle school students. In this section, we separated the tools or software based on the activities involved in online lecture and discussion and experimental activities.

Online Lecture and Discussion

There were several tools to conduct the synchronous online lecture, including Blackboard Collaborate, Zoom, Google Meet, and Microsoft Teams (Figure 2a). Zoom was the most widely used software compared to others due to many advantages, such as breakout rooms, on-screen annotation, and private and public chat (Gemmel et al., 2020). Breakout rooms were helpful for conducting discussion in a small group, in which instructors/TAs could enter each room to supervise students' discussion (Bopegedera, 2020; Liberman-Martin & Ogba, 2020; Ramachandran & Rodriguez, 2020). On-screen annotation, especially in chemistry education was notably important to encourage students solving the problem like real-whiteboard. Instructors and students annotated the powerpoint being presented by writing chemical reactions and drawing chemical structures in the general chemistry or organic chemistry class (Chiu, 2020).

Besides synchronous learning, the instructors also utilized Learning Management System (LMS) to conduct asynchronous learning to easily collect the tasks and uploaded students' learning sources such as Moodle, Canvas and Google Classroom (Figure 2b). In addition, students in China also used LMS like Rain Classroom Guo et al. (2020), CCTALK (Chen et al., 2020), and Tencent (Meng et al., 2020). Canvas was the most widely used by many studies due to its superiority in attendance tracking, question bank creation, various format assignment-submission, easy feedback giving and many more (El-Batanouny et al., 2018). Moreover, YouTube has become the most popular learning resource for instructors who did not have their own LMSs or did not prepare the instructional videos, which are widely utilized in chemistry learning (Aguirre & Selampinar, 2020; Hwang, 2020; Kollalpitiya et al., 2020; Lee, 2020; Reynders & Ruder, 2020). In addition, instructors tend to use other software for making the materials, enhancing students' collaboration and facilitating file organization, such as Microsoft Office e.g. Powerpoint (Rodríguez Núñez & Leeuwner, 2020; Sunoqrot et al., 2020), Google products (Deveau et al., 2020; Holton, 2020), Explain Everything (Ranga, 2020), and many more.

For online learning to go well, many studies revealed that they applied both synchronous and asynchronous learning (Kollalpitiya et al., 2020). This was also suggested by It was rare for instructors to only use one software or platform, as they are giving their best efforts to increase students' learning outcomes. According to Holton (2020), there were mixed responses of students in synchronous and asynchronous learning. Synchronous learning could keep students motivated and engage more interactions. On the contrary, Hwang (2020), revealed that synchronous learning was not suitable for large classes due to decreased attendance trends. In addition, synchronous learning in larger classes can collapse the discussion (Al Soub et al., 2021). On the other hand, too little synchronous learning could eliminate the possibility of direct question-answer sessions and lower the students-instructors' interactions. In addition, asynchronous learning benefited students because of their ability to study at their own pace Wijenayaka & Iqbal, (2021), but had huge shortcomings in motivated students due to self-directing learning (Rodríguez Núñez & Leeuwner, 2020).

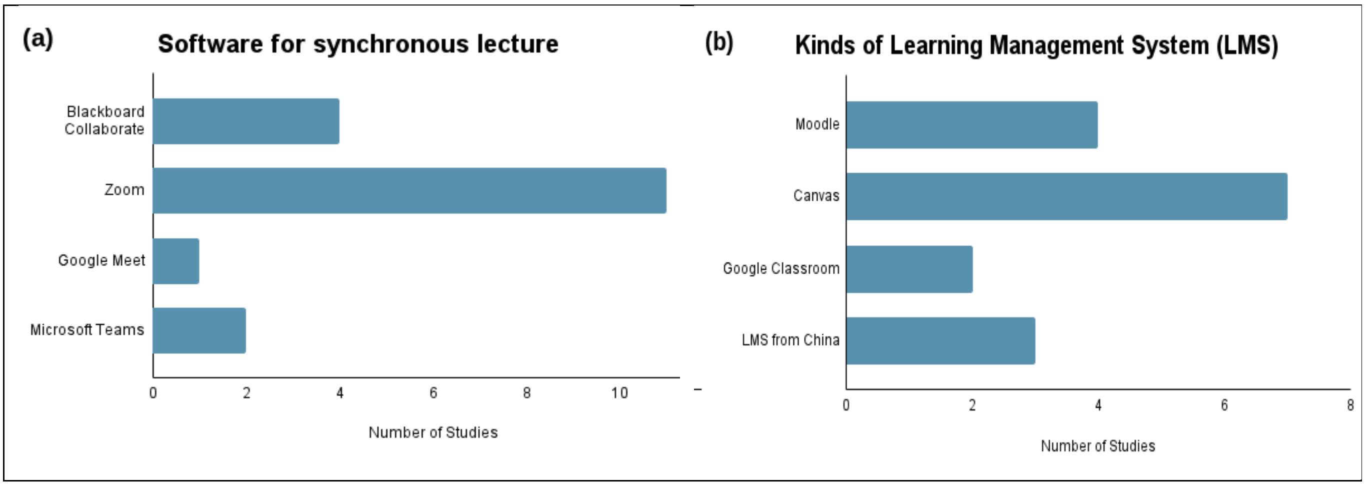

Figure 2. (a) Software for synchronous learning and (b) kinds of LMSs used by many instructors in chemistry learning

Besides these tools, instructors or TAs had to ensure that students kept connected to them and did not miss any learning activities. Kollalpitiya et al. (2020), employed email communication for all assignments, contents, and exams delivery. The email frequently sent to students could reduce their anxiety towards the uncertain situation and did not leave them out. This method was also used by Simon et al. (2020) and Dunnagan & Gallardo-Williams (2020), which highlighted the importance of communication for successful online learning. Significantly, many authors specified the usage of chatting applications such as WhatsApp, Facebook, LINE, WeChat, etc. for maintaining persistent communications (Chen et al., 2020; Guo et al., 2020; Yeerum et al., 2022).

Specifically, for chemistry learning, there was some additional software integrated in the learning process to establish the improvement of students' conceptual understanding. Lipin (2020), utilized ChemTube 3D for students aims to self-assess their understanding in group theory. Based on their survey, most students found ChemTube 3D giving them better clarity and help in better comprehension. Sunoqrot et al. (2020), suggested the usage of a mobile application called Chirality-2 for students to improve their mastery in some concepts such as isomerism, intermolecular forces in pharmaceutical organic chemistry course. Besides, students can use this application to practice compound naming and functional group identification. Regardless of the existence of pandemic or not, specific tools in chemistry education were necessarily important to be integrated in learning. Prior to pandemic, some authors had developed some mobile applications and emphasized their usefulness e.g. Chairs! designated for learning the ring flip of cyclohexane Winter et al. (2016), Mmacutp for analytical chemistry learning Guerrero et al. (2016), Green Tycoon for learning green chemistry in the aspect of biorefining (Lees et al., 2020). Moreover, Naik (2017) has summarized a lot of iOS- and Android-based mobile applications for chemistry learning, which are significantly helpful to aid instructional process and could be gradually integrated with the coursework. On top of that, minimal expertise in technology was the main advantage for using these applications.

Experimental Activities

Many authors had reported the complement of physical laboratory activities, including: watching the pre-recorded experiments, online simulations, virtual laboratories, and at-home laboratories. These techniques can assist students to obtain hands-on experience despite not being able to physically do the activities. Costabile (2020) used an online simulation to teach the biochemistry laboratory. There were five simulations in total, which covered the basic laboratory skills including mathematical skills, usage of pipette, basic biochemistry assays, kinetics of enzymes and protein quantification. However, the author still opened the opportunity for students who can attend the laboratory once the restrictions were relaxed. Still, the usage of online simulations can help the students to understand biochemistry when the F2F was not possible to be conducted.

Meanwhile, Deveau et al. (2020), conducted the at-home laboratories and asked students to watch the pre-recorded experiments done by the instructor for Organic Chemistry Laboratory course and Fundamentals of Biochemistry Laboratory course, respectively. The author stated that at-home laboratories were possible to be performed due to availability of local stockrooms to choose the chemicals. Prior to the experiments, students had the instructor's guidance to build the project. However, for the Fundamentals of Biochemistry course, students cannot do the experiments by themselves due to inability to perform complex experiments at home like polymerase chain reaction (PCR) and gel electrophoresis experiments. Recordings of an actual experiment was also used by many researchers (Lee, 2020; Sunoqrot et al., 2020; Tran et al., 2020), where TAs did the experiments and the recordings were disseminated to students. Students only wrote the lab reports according to the data provided. Similar to Costabile (2020), Lee (2020) provided the time at the end of semester for willing-students to perform the actual experiments.

Dunnagan & Gallardo-Williams (2020), supplied virtual reality (VR) laboratories for students in organic chemistry courses. Students are offered many kinds of unknowns and identified them using infrared spectroscopy. According to their survey, most students have reported a high degree of satisfaction towards VR. In addition, students reported there is no remarkable obstacle, and found the VR to be useful and a good resource. Moreover, Huang (2020) also reported the virtual experiments strategy to conduct chemistry class. The author used MLabs for students, which offers on-screen experiments and many interactional simulations. Prior to experiments, students had to preview the experiments via massive open-access courses (MOOCs), then instructors delivered online teaching to explain the fundamental concepts of experiments. Some instructors preferred recording the laboratory and its instruments, but some other instructors preferred doing the experiments right away in the laboratory. For self-learning experiments via MLabs, students could repeat their experiments as much as they like and can vary the parameters by themselves. These systematic strategies were considered excellent by most students, as they reported they can learn the key skills of experiments. Wijeyanaka & Iqbal (2021) also proposed a similar virtual lab under the name of "virtual chemistry lab space". These methods were nearly the same as the one proposed by (Warning & Kobylianskii, 2021). They called their own experimental method with "Choose-Your-Own-Adventure" (CYOA)-style activity, as students can decide how they built the electrochemical cells by varying the experimental parameters. Unfortunately, this activity was virtually held and students did not gain the hands-on experiments. At the same time, CYOA-style could facilitate students receiving immediate feedback and was notably easy to conduct. In contrast with the former three studies, Lipin (2020) only used a concept-based learning approach by conducting inorganic chemistry virtual laboratory classes via Google Classroom. The instructors only provided the hypotheses of inorganic complex preparation. Subsequently, students were asked to calculate the theoretical data based on the hypotheses. The learning activities also had the converse sequence, in which students built the hypotheses according to the theoretical data supplied.

In addition to many variations of online laboratory classes that have been described, Nguyen & Keuseman (2020) employed an uncommon method to teach chemistry laboratory to their students. Kitchen can be used as laboratory media, with so-called "Chemistry in the Kitchen" course. Students were required to perform the laboratory experiments by themselves with the determined curriculum made by instructors and write the laboratory write-up of every experiment. To ensure that students did their experiments, they must provide photographic evidence. The variety of experiments focused on making food to establish the cost-effective strategy by using students' own kitchen kits. According to students' perception, they admitted that they enjoyed the activities, mostly on how their experiments can benefit them and their families. Their only challenge is how they write the write-ups since they have to convey it with scientifically-written languages. Another group of researchers, Chans et al. (2022) reported that students preferred the experiments with simple materials at home, besides real-time demonstration and videos held in laboratories, hence reinforcing the idea of at-home experiments to facilitate students in getting hands-on experience.

Two studies suggested the method to run the experiments of analytical chemistry courses. Soong et al. (2021) innovated the open-source remote titration unit to substitute the physical titration experiment. Their titration unit had the ability to control the titration parameter using a remote, allowing students to titrate everywhere as long as they connected to the internet. The open-source computer they used is Raspberry Pi, which requires the user to log in first. Students can set the volume of the titrant by turning the stopcock via servo. For the process of titration, students can observe it via a camera module integrated with Raspberry Pi (Figure 3a). Yeerum et al. (2022) developed hands-on analytical chemistry experiments that can be done at home, called "Lab-at-home" (LAH). The experiment was focused on colorimetric methods. The LAH experiments were conducted according to Figure 3b. The LAH set box was sent to students' homes prior to the experiments. Authors revealed the usage of non-toxic chemicals e.g. guava leaf extract as natural reagent for Fe(III) ion complexation. Moreover, all other kits were disposable due to the availability and low-cost. Before doing the experiments, students joined the online lab briefing session and pre-quiz. Subsequently, students did the experiments and attended virtual meetings simultaneously in order to receive advice and answer from instructors and TAs. After they conducted the experiments, students submitted the data and reports virtually with Google Docs/Spreadsheet. Students admitted that they were satisfied with these LAH experiments due to the harmlessness of chemicals and reusability of equipment.

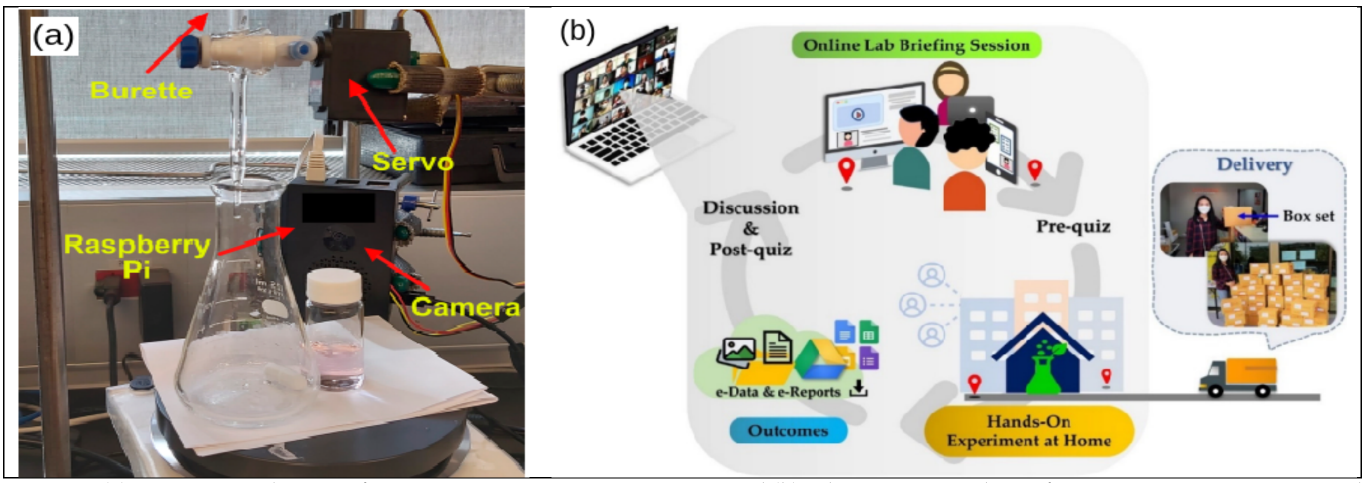

Figure 3. (a) Experimental setup of open-source remote titration unit and (b) schematic procedure of LAH experiments. Reprinted with permission from Soong et al. (2021) and Yeerum et al. (2022), Copyright ©2021 American Chemical Society and 2022 MDPI

Conclusion

The transition from F2F learning to online learning indeed had major challenges, especially when the instructors and TAs had to redesign their learning method in a short time due to COVID-19 pandemic. Since March 2020, a number of research associated with online chemistry learning has significantly escalated. Most of them reported the tools or software they used, including the online lecture class as well as online experimental activities. Various synchronous methods using the video conference software, mostly Zoom, and asynchronous methods using the LMSs software, mostly Canvas. YouTube was one major platform to disseminate learning videos for students. For online experimental activities, several attempts have been made, including pre-recorded experiments, virtual laboratories, at-home laboratories, and online simulations. Pre-recorded experiments were the most common method for many institutions who did not have enough resources or facilities to conduct the virtual experiments. Other methods, like at-home laboratories and virtual laboratories can facilitate students to gain hands-on experience. Meanwhile, some researchers have proposed their own method in conducting experiments, for instance, "Chemistry in the Kitchen" and CYOA-style activities. Practically, we offer plenty opportunities to be considered in the future regarding the tools for online chemistry learning, such as (1) combine the synchronous and asynchronous learning to achieve better learning outcomes, (2) use MOOCs to provide varieties of learning videos, (3) analyze deeply about students' conditions and ask about their capability to manage such learning instructions due to differences in students' and school's economic ability, and (4) develop frequent communication and clear instruction for students. Regardless of what kinds of software or tools the instructors used, the noble purpose of each instructor in every learning class is how they can improve their students' outcomes. It clearly depended on many situations and ability of faculty to provide the tools for instructors and students.

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