United International Journal for Research & Technology

Volume 05, Issue 09, 2024 | Open Access | ISSN: 2582-6832

Delivery of Remote Laboratory Work During the COVID-19 Pandemic: A Literature Review

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Abstract— The strict lockdowns implemented around the world consequently result in the quick transition to emergency remote learning in most Universities. Vulnerable professors in the higher education community are puzzled about how to continue the delivery of laboratory work in their science courses. Published studies are available online that can share the fusion of technology and strategies to make the delivery of remote laboratory work possible. These studies can serve as a guide and basis for designing a remote laboratory work model to be employed in the field of emergency remote learning. This need has led the researchers to do a narrative review on delivering remote laboratory work in the universities. Following the set of inclusion and exclusion criteria, 7 studies in Europe, 6 in America, and 3 in Asia conducted from March 2020 to March 2022 have qualified for this study. Studies were obtained from the databases of ERIC, ScienceDirect, and JSTOR. Remote laboratory work was made possible through online and home-based delivery modes. The integration of social, cognitive, and teaching presences in the pre-laboratory phase, laboratory phase, and post-laboratory phase provided support to distant students for them to feel that they belong to a learning community leading to quality interaction with peers and their instructor.

Keywords— Remote laboratory, virtual laboratory, home-based laboratory, online laboratory, narrative overview, simulations.

I. INTRODUCTION

The operation of the higher education community was significantly challenged by the Covid-19 pandemic. The urgent and unexpected switch from previously onsite university courses to online was the most felt among these challenges [1]. Even before the crippling effect of the pandemic was felt, universities are already challenged to ensure accessible and affordable learning opportunities for all, adapting themselves to the needs of individuals and providing education in a variety of settings and forms, even beyond the boundaries of the university walls. This clearly shows that the emergence of distance learning is the direct consequence of digitalization, enabling higher learning communities to construct new opportunities to expand, progress, and transform themselves [2,3].

Published literature shows the wide range of availability of technologies to make distance learning possible. Still, distance learning remains complex with no standard model for planning, executing, and evaluating it. This issue resonates with the delivery of remote laboratory work.

Remote laboratory work may operate synchronously online, asynchronously online, or home-based. Synchronous online laboratory work commonly requires simultaneous log-in to an online learning platform and performing experiments in real-time using a simulation. Asynchronous online laboratory work still uses simulations as an alternative to real lab materials and equipment, but students have the freedom to work on the experiment in their available time as long as it was still covered by the assigned schedule to finish the laboratory work. Home-based experiments are also done asynchronously, its distinguishing feature is the use of common household materials and equipment as substitutes for real lab materials and equipment.

Moreover, in any type of remote laboratory work, the instructors may choose a fusion of technologies to complement the objective of the experiment. They may integrate recorded demonstration videos [4,5], simulation-based experiments [6,7], databases [8], or use physical programmable circuit boards (e.g., Arduino) [9].

Educational models were available for review to make the delivery of remote laboratory work more coordinated. Out of these educational models, our interest was focused on the Community of Inquiry (CoI) framework. CoI shows a design for online learning environments to fully support critical thinking, critical inquiry, and discourse between students and teachers [10]. A productive online learning environment can

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manifest through the skillful use and integration of the three key presences (Social Presence, Cognitive Presence, and Teaching Presence).

Social presence is revealed when participants present themselves socially and emotionally as real people in the online learning environment. Indicators of social presence include risk-free expressions and encouraging collaborations [10].

Cognitive Presence is the event to which the student can build meaning through a sustained process of communication, reflection, and discourse [11]. Likewise, through collaboration and reflection in a community of inquiry, it's the exploration, integration, resolution, and confirmation of understanding [12]. Indicators of cognitive presence include the sense of puzzlement for the triggering event, information exchange for exploration, connecting ideas for integration, and applying new ideas for resolution [10].

Teaching Presence binds social presence and cognitive presence. Efficient cognitive and social presence is dependent upon the presence of a teacher. Instructional management and direct instruction are some of the indicators that the teacher manifests in the community of inquiry [10].

The need for online and remote teaching in the universities were accelerated during the strict lockdowns due to the Covid-19 pandemic. New strategies for working remotely were intentionally explored. The full potential of digital technologies was exhausted to still meet the demand of quality education while catering to the need of both educators and students that are separated by geographical and technological gap. These endeavors might result in fusion of teaching strategies and technology that can lead to new models for remote delivery of laboratory work.

This study generates a narrative review of the remote delivery of laboratory works in universities during the covid-19 pandemic. This review summarized implemented strategies, materials, equipment, and computer software in delivering laboratory work in Physics, Chemistry and Biology courses. Likewise, the indicators of each facet of Community of Inquiry framework (Social Presence, Cognitive Presence and Teaching Presence) were observed to provide a basis for a theoretical model for crafting laboratory worksheets and teaching guide that can guide teachers in online and home-based laboratory work.

II. METHODOLOGY

A. Research Design

The narrative overview research design was employed by the researcher. A narrative overview summarizes the contents of each article and reports the author's findings in a condensed format [13].

B. Study Search Procedure

The researchers set first the criteria for inclusion and exclusion of articles before searching the online databases for peer-reviewed journal articles. Education Resources Information Center (ERIC), ScienceDirect, and Journal Storage (JSTOR) were used to search for qualified journal articles. The search was purposely delimited from March 2020 to March 2022. Further, the search terms entered in the search engines were as follows: remote laboratory, distance laboratory, and online laboratory. These words were put in the search engine with the Boolean search operator "AND" followed by the required subjects Physics, Biology or Chemistry until studies were exhausted.

C. Inclusion and Exclusion Criteria

Research articles published from March 2020 up to March 2022 were included in the screening process. The screening of the articles was delimited to these dates since COVID-19 was declared a pandemic by the World Health Organization (WHO) on the 11th of March 2020, leading to some form of lockdown across almost all countries of the world [14]. After two years countries worldwide started to lift the restrictions. Specifically, the inclusion criteria protocol has set in selecting journal articles, to wit: (a) must be a research article from a peer-reviewed journal; (b) must include an explicit reference to deliver remote laboratory work in its title or abstract; (c) must present actual operation of remote laboratory work during the highlight of the lockdowns in its full text; (d) must be at the higher education level; (e) must focus on scientific disciplines of Physics, Biology, and Chemistry (f) Revealed covered topic specific-contents. Collected journal articles were filtered with the given inclusion criteria.

In Physics, 3,217 studies about remote laboratory work were screened but only 8 articles qualified. In Biology, there were 3,772 screened studies, and only 4 articles qualified. In Chemistry, there were 3,233 screened studies, and only 4 articles qualified. The major reasons

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Volume 05, Issue 09, 2024 | Open Access | ISSN: 2582-6832

for the minuscule number of qualified articles were that some of the gathered articles were just replicates and did not meet the set inclusion criteria.

D. Coding Procedures

Collected data from the qualified journal articles were coded using the following: (a) study identification (author's last name and year of publication); (b) experiment type; (c) types of technology applied; (d) pre-laboratory activities; (e) laboratory proper activities; (f) post-laboratory activities (g) cognitive presence manifestations; (h) social presence manifestations; (i) teaching presence manifestations.

III. RESULTS AND DISCUSSION

Experiment type and technologies applied to facilitate remote laboratory work

Three types of remote laboratories were identified for Physics: home-based laboratory, online laboratory and online laboratory combined with real lab (See Table 1).

Table 1. *Experiment type and technology requirements to facilitate remote laboratory work in Physics*

Type of Experiment	Technology Requirements													
	Mobile Apps and Sensors	Arduino Board	Online Meeting Platform	Sims	File Hosting Service	MS Office	Videos	Webpage	Moodle	Home and Office Supplies	Lab Kits	LMS	3D Printing	Online Repository
Home-based	/									/				
	/		/							/				/
	/	/								/				
			/	/							/			
											/		/	
Online Laboratory			/	/	/	/	/					/		
Online Laboratory Combined with Real Lab				/		/	/	/	/		/			

The home-based laboratory was diverse in terms of using technology to facilitate the remote operation of laboratory work. Typically, students use only standard tools available at home and proceed to investigation using sensors and software that smart phones are equipped with [15, 16].

Use of materials commonly available at home and office supplies was upgraded by integrating an online meeting platform to promote peer-to-peer interaction and use of mobile phones to gather data and facilitate analysis. These features are additionally supported by an online repository where needed instructional materials were stored as well as the experimental data that can be retrieved by the students if ever, they cannot set-up the experiment to still proceed with data analysis [17]. Additionally, a low-cost alternative to smartphones was presented using a microcontroller (Arduino Board) equipped with a large variety of sensors that transmits data to a smartphone using Bluetooth Low-Energy protocol [18]. Moreover, if there was a required set of materials and equipment for an experiment, an institution even sends or ships inexpensive laboratory kits to each student which is previously made for specific homework assignments during the previous in-person offerings of labs to facilitate independent laboratory work [19]. Furthermore, expensive equipment found in laboratory facilities was replaced by 3D-designed and printed equipment that was small, portable, lightweight, and low-cost which can be mailed also to the students [20].

Significant efforts into redesigning the labs in Physics for online delivery were also observed in the reviewed articles. Koenig and Bake presented the use of Zoom, a video communications platform, for supporting collaborative group work where students worked in breakout rooms in groups of three to four [21]. Each group worked through the lab instructions, collected data through videos or simulations and analyzed data in

Excel, and documented all work in a Word file. Through Zoom, students can share their screens if needed. When help was needed, groups may contact their instructor, who then dropped into the breakout room to address the questions. Although the instructor can periodically drop into a breakout room, their appearance can be distracting. The use of Microsoft OneDrive provided the instructors the ability to view each group's work as it was being generated and provide feedback in real-time. Hamed and Aljanazrah showed the efficiency of remote virtual labs used in combination with a real hands-on lab that is offered in reduced presence hours at a university [22]. In this study, the virtual lab was designed to encourage students' active participation and engagement in constructing their knowledge and acquiring mind and practical skills. This was done by developing interactive simulations that allowed students to perform the experiment online and practice inquiry skills. Together with the virtual labs are explainer videos aimed at introducing the equipment, how to construct the experiments as well as how to gather and analyze data. These simulations and explainer videos prepare the students to carry out real experiments on their own. The virtual experiments were delivered online by a dynamic webpage and integrated within Moodle.

Table 2. *Experiment type and technology requirements to facilitate remote laboratory work in Biology*

Experiment Type	Technology Requirements								
	Online Meeting Platform	Simulations	Videos	Webpage	Independent Plant Observation	Learning Management System	Database and Software	Google Spreadsheets and Slides	Twitter
Full Independent Lab & Hybrid Laboratory	✓		✓		✓	✓			
Online Biology Laboratory (Type 1)	✓	✓							
Online Biology Laboratory (Type 2)	✓	✓		✓					
Online Biology Laboratory (Type 3)	✓		✓			✓	✓	✓	✓

Reviewed articles show that remote laboratories in Biology are more inclined to online access than the use of improvisation or lab kits (See Table 2).

Sindelar and Witkowski presented in their study a hybrid remote laboratory work where students experienced a fully independent asynchronous model as well as an online laboratory [23]. For a fully independent asynchronous model, students observe plants in their surroundings and conduct simple experiments independently with readily available items to do lab work. The lab was supported by textbook reading assignments, short video from the instructor, and reporting of findings via discussion board posts. For the hybrid model, the general structure of text reading, independent plant observations, and reporting of findings via discussion board posts remained the same, the key difference was that discussions were conducted synchronously via Zoom breakout rooms.

Çıngıl showed that students can perform their experiments in a real laboratory by following the instructions given to them or the instructions in the experiment sheets [24]. Specifically, it utilized a "Gizmos" program, an interactive laboratory program developed by Explore Learning. This program includes experiment simulation, theories, worksheets, and procedures. The teacher can write the process steps and theory about the experiment to be designed, and the students can follow these process steps, perform the experiment in an interactive way, and note their observations. The laboratory work was carried out synchronously with the video conferencing platform Zoom.

Quesada used a simulator that was coded as a web page where it was publicly available under the MIT license at https://github.com/vqf/kinetics [25]. An example of use is also included, along with instructions for customization. When the system was already customized or programmed by the professor, the user presses a button, and the simulation starts. There was a separate web page for each session containing the corresponding model. Students were provided a script detailing the procedure for each lesson in advance. Sessions were conducted using the meeting feature of Microsoft Teams. The design of the simulator as a web page allowed all students to run the mechanisms with their computers and tablets including the browsers. However, in this remote setting professors need to adapt to uneven computer and network resources. For instance, if the students had problems running an

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application on their computers the professor share his desktop and the student can take control of Microsoft Teams features.

The instructors in the study of Delgado, Bhark, and Donahue researched possible virtual lab options in an attempt to provide their students with the best substitutes for in-person learning [26]. The instructors also hired senior undergraduates as teaching assistants (TAs), who helped with online cell biology lab creation, lab grading, and during online synchronous lab sessions. All cell biology lab materials were posted on the Canvas learning management system in weekly modules for easy navigation. Lab resources, announcements, and assignments were also posted in Canvas in specific modules. Virtual class sessions were held synchronously on Zoom where meeting links are integrated into Canvas. For virtual lab experiments, the instructor purchased a 5-simulation package for their 32 students from Labster, which highlighted cellular and molecular biology techniques. The instructor also used various online videos and websites to create or supplement their virtual labs. Students learned to use different types of scientific software and databases during this course, including freeware software or sources available for purchase after 30-day free trial. Google sheets and slides were used as cloud-based tools for online learning. The social media twitter account of Dr. Elisabeth Bik @MicrobiomDigest provided resources for an image forensics group game. During this lab, online google slides were embedded with real data published in peer-reviewed journal articles. Student groups were then asked to identify and mark images that were manipulated in the google slides. Online google spreadsheets were also used in the "Stages of Mitosis" lab to tally up the total class results before graphing individual data and total class data in student lab reports.

Table 3. *Experiment type and technology requirements to facilitate remote laboratory work in Chemistry*

Experiment Type	Technology Requirements										
	Mobile App & Sensors	Web Applications	Online Meeting Platform	Simulations	Spreadsheets	Videos	Computer	Home & Office Supplies	Lab Kits	Learning Management System	Database
Virtual Laboratory			✓	✓							
Synchronous Online Delivery			✓	✓		✓					
Home-Based Labortory with support from LMS								✓		✓	
Home-Based Labortory with support from Smart Phones, PC, Web App, Database and Online Meeting Platform	✓	✓	✓		✓		✓	✓			✓

Remote laboratory work in Chemistry as observed from included articles was made possible by home-based laboratory and online-laboratory formats (See Table 3).

Avcı used together synchronous and asynchronous platforms in the application process [27]. First, students were asked to read the article about the topic and discuss the details with the group members in synchronization over the Zoom video conference platform. Then, links to simulations were added to the Google Classroom platform by the instructor which is the main equipment for the virtual hands-on investigation of the students.

Andrews, de Los Rios, Rayaluru, Lee, Mai, Schusser and Mak utilized the efficiency of Slack for members of the formed teams to coordinate their work as they plan to produce an experiment protocol that will be followed by each student in their home-based experiment [28]. Their experiment follows the important element in home lab design which is to use no special equipment.

Jones, Shepler and Evans presented a synchronous online model for the remote delivery of laboratory work [29]. In the SOD model, students worked collaboratively in small groups (via the breakout room feature of the video conferencing platform) during a scheduled time to collect data via simulations. The simulation platforms were also supplemented by videos from additional sources to provide introductory discussions.

Al-Soufi, Carrazana-Garcia and Novo efficiently combined different technologies to provide a worthwhile experience of hands-on experiments at their homes [30]. In the presented experiment, the students are required to produce an improvised photometer. The cameras of mobile phones detect light intensity through red, green, and blue color filters and cover thus two important design components. As cuvettes, any cylindrical plastic cup or glass tumbler can be used. As a light source, the instructors initially proposed indirect lighting by a table lamp, or a flashlight directed on or through a sheet of white paper. However, the students themselves later came up with the idea to use a PC monitor or a tablet as a much more homogeneous light source. Once the photo is taken it can be uploaded to a PC and analyzed by free color picker web applications. Looking back to the prelab part, the instructor conducts an online group meeting of about 30 minutes to introduce the concepts relevant to the tasks and experiments of the day. In case the students did not obtain valid experimental results, they can analyze and discuss "fallback" data from spreadsheets prepared by the instructor with numerical data from the laboratory experiments.

Instructional approaches in delivering remote laboratory work in Physics

Laboratory work presents professional science in practice. It will become meaningless if students just proceed immediately to laboratory procedures without understanding their significance. A well-designed pre-laboratory activity can prepare the students for the actual laboratory whether real or virtual. In reviewed models of delivering remote laboratory in Physics, if the laboratory work will require to use a mobile application, it will be essential to direct first the students on how to use the downloaded mobile application [16]. Kaps, Splith, and Stallmach present a general introduction to the experimental exercises already using their technology (smart physics lab), provide discourse into data analysis of the digitally recorded physical quantities, and show demonstration experiments visualizing the physical content of the topic before sending the package to the students containing the material for the experimental set-ups or lend suitable smartphones and tablets to the students upon request [15]. Aside from giving a list of the required items, Campari et.al also show videos presenting the experiment by providing a link with a written description [17]. If the students can't gather all the items needed to accomplish one or more of the proposed laboratories, they could retrieve experimental data related to the various experiments from the online repository, which instructors collected previously in the laboratory. Before sending the Arduino board to the students, Bouquet, Creutzer, Dorsel, Vince & Bobroff developed a program in Arduino nano board that installs all the libraries for wireless communication (Bluetooth Low Energy or BLE) and sensor utilization [18]. Dark provides safety training to the students and sends an assignment related to the training [19]. It was followed by a quiz about the training where they need to obtain a minimum score of 85% to continue in the course. After students received the experiment kit, the teacher conducts synchronous sessions showing live demonstrations of the experiment setup, and simulations. Students were also required to read about concepts in the textbook, listen to shared slides with recorded audio, and explore web-based simulations in advance of synchronous sessions. Similarly, Larriba et.al begins with a teaching activity that discusses a brief description of the experiment using video conferencing tools provided by the university [20]. Specifically, the professor explains the materials provided, the safety measures required of the students, and the methodology to be followed to obtain experimental data. Koenig and Bake deliver pre-lab instruction through Canvas that introduces key concepts or skills while providing deliberate practice in hypothetical situations [21]. They showcase a laboratory class that began in the main room (Zoom), where a single teaching assistant (TA) provided up to 32 students an overview of the activities before they were directed to freely available simulations for some online labs. For some experiments, instructors made a collection of videos showcasing related tests that students could select to be used in their data collection. Hamed and Aljanazrah also present watching videos before the actual laboratory work that explain the theoretical background and the physical concepts related to the experiment [22]. It was followed by watching videos showing demonstrations of experiments' procedures as well as how to gather data as mentioned in the manual. Before the real lab, students are also scheduled to communicate with the instructor and collaborate with peers through open forums in Moodle before coming to the hands-on lab. It is important to note that the students perform online drills and practice before being given a permit to proceed to the on-site real laboratory.

At the actual laboratory sessions, students proceed with their investigations which can be structured, guided, or open inquiry. At this stage, it is remarkable how instructors made possibilities to assist their students in distance learning mode. Kaps, Splith, and Stallmach present in their study that students may attend an additional tutorial, during which the topic of the experiment is explained and discussed with the students. Restrictions in the set-up and devices are also discussed in the tutorial to find workarounds [15]. Similarly, Campari et.al, Larriba et.al and Koenig and Bake support the students in their course of laboratory work but through online communicating platforms [17, 20, 21]. Additionally, Koenig and Bake can alternatively provide immediate feedback during laboratory work as students and teachers could type directly onto the shared document made possible by the file hosting service [21]. Dark showcases the use of discussion forums to troubleshoot experiments and give feedback to students [19].

At post-laboratory sessions, we commonly expect discussions between students in a large group or instructor initiated to provide explanations or correct student misconceptions to the findings of their investigations. Variations of post-laboratory activities were presented in the reviewed articles. Dark required the students to submit a written report and gave a presentation during the synchronous meeting as part of the requirements for the project [19]. Similarly, Larriba et.al presented in their study the conduct of reasoned discussion of the results obtained to guarantee the acquisition of transversal competencies [20]. Also, the professor may ask questions to the students to assess the acquisition of skills and learning outcomes, evaluating each student based on the answers. Koenig and Bake creatively used a table created in MSWord that was posted in the Class Folder on OneDrive by the TAs for groups to share outcomes of the experiment, monitor the added detail in the table and use the table for a wrap-up discussion, allowing students to resolve inconsistencies [21]. Other than the presentation of results online, the instructors assure that they can evaluate the logbooks and give feedback to the students' laboratory reports [16, 22] or make students solve problems or answer conceptual questions for each experiment [22].

Instructional approaches in delivering remote laboratory work in Biology

Included articles in Biology show significant effort from the instructors to prepare their students before the actual laboratory work. In a design of an online-independent laboratory, Sindelar and Witkowski reported in their study the use of textbook reading assignments and a short video from the instructor followed by a quiz to gauge the students before they proceed to actual laboratory work [23]. In the design of the hybrid model, Sindelar and Witkowski reported in their study that the general structure of text reading and literature reading remained the same except that those discussions were conducted synchronously via Zoom breakout rooms. Likewise, Çıngıl Barış gives a reading assignment of a research article about the topic to empower the students about the topic and partially prepare them for the related simulation by matching the variables required to the simulation features [24]. In the study of Quesada, the instructor prepared a separate web page for each session containing the corresponding model to simulate [25]. Additionally, students were provided a script detailing the procedure for each lesson in advance. At the beginning of each session administered in Microsoft Teams, the instructor offered a brief explanation and answered questions about the work, using the share screen feature to show examples of use. Likewise, Delgado, Bhark, and Donahue allot time to conduct virtual class sessions held synchronously on Zoom before the laboratory work [26]. Additionally, all biology lab materials were posted on the Canvas learning management system in weekly modules for easy navigation which includes prelab questions, lab worksheets, post-lab questions, syllabus, videos, data files, and web links.

Various techniques in actual remote laboratory operations in biology were observed. Sindelar and Witkowski stated in their study that students were asked to observe plants and report their findings via discussion board posts where others could see and review for both online-independent laboratory and hybrid model [23]. Pre-service teachers in the study of Çıngıl Barış carried out synchronously the laboratory via the video conferencing platform Zoom [24]. This virtual laboratory application was completed in eight lesson hours in a period of 2 weeks where pre-service science teachers tested a hypothesis by designing a laboratory procedure and recording their data and observations. Prior to the virtual laboratory application, the students performed first 3 structured experimental activities. The students in the study of Quesada worked individually in their lab work setting and running each simulated experiment then prepare a report with results, analysis, and conclusions and uploaded it to a maintained web platform [25]. Delgado, Bhark, and Donahue utilized and combined more technology to make it possible to perform complex laboratory remotely [26]. For some topics requiring virtual laboratory, the instructor purchased a 5-simulation package. For topics where hands-on student learning in the lab was not possible, both JoVE and YouTube provided students with a visual of real molecular/cellular biology experiments and methods with the use of advanced scientific equipment.

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There was a topic where students use DNA sequencing chromatograph software, flow cytometry imaging software, and a web-imbedded fluorescent 3D cell viewer software. Students also analyzed real laboratory data files saved in a database or published in peer-reviewed journals. Students calculate live and dead cell numbers using a hemocytometer and perform calculations to determine how to seed cells for experiments.

Post-laboratory sessions in included remote laboratories in Biology majority focused on correcting misconceptions and providing assessments to the students. Sindelar and Witkowski provided rich activities in the post-lab part [23]. In both independent lab and hybrid lab, students were required to comment and provide feedback on each other's lab work submissions as part of the discussion goal. For hybrid lab only, students logged in to Zoom at a set time every other week to discuss the posts of the prior week. For both labs also students were asked to read and review scientific literature related to the course topic. Lastly, to end the course the instructors administer one exam, worth about 10% of the course grade. Çıngıl Barış asked the pre-service teachers to predict the possible outcomes before performing the virtual laboratory applications [24]. After the application, they corrected their wrong predictions with the correct ones. Oral and written presentation of information, their biological importance, and their practical applications were highlighted in the study of Quesada [25]. Delgado, Bhark, and Donahue used the post-lab part to give questions to assess deeper student learning of the lab material [26]. Also, each simulation contained graded quiz questions embedded throughout the simulated lab tasks.

Instructional approaches in delivering remote laboratory work in Chemistry

Reviewed models in the online remote laboratory in Chemistry incorporate reading related articles [27] and conducting an introductory discussion of highlighted concepts in their pre-laboratory sessions [29]. Commonly, preparations for the successful conduct of the laboratory proper was administered such as providing detailed protocol to the students to visualize the experiment flow [29] and proving the necessary materials for the experiment which is now virtually oriented such as adding links of the simulation to the learning management system. Similarly, Andrews, de Los Rios, Rayaluru, Lee, Mai, Schusser and Mak reported the delivery of protocol to the students but in a unique way since the protocols are prepared by group of students as part of their laboratory work which is then performed individually by the students at their homes [28]. Likewise, Al-Soufi, Carrazana-Garcia and Novo provided introductory discussion online to teach to the students the relevant concepts they need for the task [30]. After the introductory discussion, the instructor gives an online quiz to provide avenue for feedback assuring that the students understand the concepts from the discussion prior to the experiment. Additionally, the instructor provides another online meeting to discuss the practical aspect of the experiments. Also, the instructor provides critical documents to support completion of laboratory works and reports such as teaching guide, learning sheets, and fallback data spreadsheets.

During laboratory proper Avcı reflected in his article the authentic inquiry experience of the students which was stretched in a span of 2 weeks [27]. Along the inquiry journey the lecturer provided guidance when the students needed it through the Google Classroom platform. Similarly, Andrews, de Los Rios, Rayaluru, Lee, Mai, Schusser and Mak offered an open inquiry laboratory experience after the students perform individually at home the experiment protocol they prepared they offered [28]. The open laboratory challenge requires to combine the skills and concepts learned from the initially guided experiments. Jones, Shepler and Evans continued to use the available features of the online meeting platform by sending the students from main room introductory discussion to their assigned breakout rooms to start working in pairs on the simulation-based activity [29]. Then, the students were requested to return to the main room for another discussion in preparation for an enhanced group experiment where students are engaged in a more challenging experiment. After the support given by the instructors from learning sheets, online group meetings and feedback from online quiz, Al-Soufi, Carrazana-Garcia and Novo reported that each student already work on their own, solving the defined tasks [30]. They are continuously supported by their teachers, who were available through chat and videoconferencing.

The included articles in Chemistry reported familiar activities during post-laboratory sessions that we usually see in on-site laboratory. This includes checking and presenting of lab reports [27, 28], online wrap-up and answering post-lab assignments [29].

UIJRT ISSN: 2582-6832

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Manifestations of cognitive presence in the remote Physics experiments

Cognitive presence is one of the critical elements that compose the Community of Inquiry Framework. This element manifests in cycles starting from the triggering event which can be questions, problems or dilemmas which stimulate the inquiry process. After the inquiry process was triggered, students may explore to seek new insights into the problem. This new information can be integrated into a new idea or concept that consequently led to a resolution that provides the solution to the investigated problem or may produce new problems that can lead to a new cycle of inquiry.

There are variations in the triggering event for the inquiry process as observed in the included Physics articles. There are experiments that present already the structure of the experiment [17, 22, 20]. Pols almost presented a structured experiment and only becomes distinct due to the method of providing partial procedures leading to an "incomplete model" where completion of the model was presented as a task or research question by the facilitator [16]. Koenig and Bake and Kaps, Splith, and Stallmach guided their students in triggering the inquiry process by providing research questions to the students [15,21]. Dark presented a more authentic level in triggering the inquiry process where the students proposed their own topics and carried them out independently once they received the instructor's feedback and approval [19].

The gathering of empirical data through investigation appears as if the students are doing the experiment in the laboratory even though they are in the comfort of their homes. This was made possible due to the significant assistance from the instructors. Kaps, Splith, and Stallmach conduct tutorial where the students obtain the possibility to discuss their experimental problem, physical assumptions of the experiment and possible limitations of their set-up and their measuring devices [15]. The students in the study of Dark applied what they learned from the pre-lab synchronous sessions and homework assignments facilitated by their teachers [19]. Larriba et.al reported that in the data collection period, the professor was at the students' disposal through the videoconference software [20]. Hamed and Aljanazrah reported that before the students interact with online simulations to gather data, they allot time to watch videos online that explain the theoretical background and the physical concepts, demonstrations of experiments' procedures, and how to find the required variables using the collected data [22]. The online experience of the students through simulations and videos scaffolds their way to successfully conduct on-site hands-on experiment.

The integration of new information that led to the resolution was evidently observed in the included articles. In the study of Pols, the students prepared reports where they assessed the reliability of their measurements and compared the empirical data with the theoretical model [16]. Similarly, Kaps, Splith, and Stallmach required the students to write a short report for each experimental exercise, consisting of a description of the experiment with the relevant equations, the experimental setup and the procedure, the representation of the measured data including their analysis and the estimation of the of measurement [15]. Dark also asked the students to submit a written report but also require them to give a presentation during the synchronous meeting as part of the requirements for the project [19]. Although the data collection stage and analysis were done individually by the students in the study of Larriba et.al, the students will then discuss in groups the results of their analysis and write a laboratory report [20]. Lab report writing is also heavily emphasized in the study of Koenig and Bake, but uniquely used a shared drive allowing all students to simultaneously contribute to the completion of the Lab report which is then summarized and shared in MSWord table and use by the instructor for a wrap-up discussion [21]. Hamed and Aljanazrah and Campari et.al highlighted the answering of assigned research questions as a significant part of the report [17, 22]. Additionally, Hamed and Aljanazrah with the goal of combining online lab and real lab, facilitated communication through open forums in Moodle before the schedule of on-site hands-on lab [22]. Likewise, after conducting the real lab students must write their own report outside the lab.

Manifestations of cognitive presence in the remote Biology experiments

Textbook reading assignment and literature readings were common as triggering event in the study of Sindelar & Witkowski including concepts learned from discussions which is offered in short video in full-independent laboratory model or scheduled thru online meeting for hybrid model [23]. Both the hybrid model and the full-independent model use plant observations from the student's location and posting of the report of their findings via discussion board posts where students are required to comment and provide feedback or log-in to Zoom at a set time every other week to discuss the posts of the prior week. Likewise, Çıngıl Barış gives a reading assignment of a research article about the topic to empower the students about the topic and partially prepare them to the related simulation by matching the variables required to the simulation features [24]. After carrying out the guided activities in the virtual laboratory according to the instructions given in the worksheets the students then answer the guide questions in the worksheets and engage in practical experiments where they design a laboratory procedure and recorded their data and observations. Quesada provided a script to the students detailing the procedure for each lesson in advance then set the students to work individually, setting and running each simulated experiment [25]. They were asked to submit a report showing the results, analysis, and conclusions of their experiment. The majority of the offered virtual laboratory in the study of Delgado, Bhark, and Donahue reflects the process of cognitive presence due to its feature of including most or all the steps in the scientific method [26]. The labs provide more than just a data interpretation exercise since students could virtually manipulate their experiments, from start to finish, in the simulations and almost sense what it is like being in a lab doing the experiments and providing conclusions based on observed and integrated patterns in their collected data leading to a resolution.

Manifestations of cognitive presence in the remote Chemistry experiments

For the remote online laboratory work in Chemistry, the activities that trigger the inquiry journey of the student can be traced from article reading with group discussion [27] and delivered protocol from the instructor which contains links to simulations and videos, background information and detailed procedures for each activity [29]. For the home-based laboratory work in Chemistry, the task presented on learning sheets [30] and "open-ended" protocol prepared by the students are the triggering event that started the inquiry process of the students.

The exploration stage of the students as presented by included articles was focused on working on the experiment either by group or solo. The remote online experiments highlight the use of simulations to test their hypothesis based on the created set-up and procedure by the students [27] or a protocol delivered by the instructor [29]. Similarly, the home-based laboratory work highlights the improvisation and creativity of the students as they perform the home experiments in open inquiry level [28] or guided inquiry level [30]

Integration of concepts learned from their investigation leading to a resolution can be traced along the process of preparation and presentation of laboratory reports by the students [27, 30]. This last phase in cognitive presences, was uniquely shown in a home-based laboratory work by Andrews, de Los Rios, Rayaluru, Lee, Mai, Schusser and Mak where they give a lab challenge that requires the student to utilize the experience, knowledge, and skills they had learned from previous guided experiments [28].

Manifestations of social presence in the remote Physics experiments

Students can experience a sense of aloneness when performing laboratory work in distance learning mode. It is vital that each student feels that they are part of the class or part of a community of learners. Review of the included articles shows various quality interactions where learners feel secure to openly communicate with each other and with their instructor to develop a sense of community.

Pols use the evaluation of logbooks to provide feedback to students' methods in the experiment and assess the quality of inquiry [16]. When help was needed, the experiment groups in the study of Koenig and Bake used the "contact your instructor" feature that alerts the TA, who then dropped into the breakout room to address questions or engage students in Socratic dialogue to check the reasoning behind their work [21]. Alternatively, TAs can provide immediate feedback during laboratory work as they could type directly onto the shared document of the student's lab report made possible by the file hosting service. Likewise, Larriba et.al assists the lone students during the data collection stage through video conference software [20]. Instructors in the study of Hamed and Aljanazrah managed to provide prompt feedback thru the Moodle LMS on their submitted answers about the questions or problems in the online experiments [22]. Additionally, due to the goal of administering a real laboratory after the online laboratory, open forums were scheduled in Moodle LMS before students visit the university where the students and facilitators collaborate and communicate about the experiments. Consequently, after the real laboratory session, each student must still write her or his own report outside the lab which will be

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reviewed later and given written feedback by the instructor. Campari et. al emphasized in their study the use of online resources by teachers or tutors to support the students in their experiments [17]. Also, students can collaborate with their team members thru TEAMS and WhatsUp. Similarly, Dark mentioned the use of discussion forums where a student could post challenges and difficulties about the experiment, and the instructor would respond with suggestions, or another student would share how they dealt with a similar challenge [19]. The use of discussion forum was already applicable at the beginning of the semester where it was utilized to connect and get to know the students' research interests. The use of feedback system was immediately used even at the time the students were proposing their own topics for the independent project.

Manifestations of social presence in the remote Biology experiments

Three out of four included articles in Biology clearly showcased manifestations of social presence during the conduct of remote laboratory work. Sindelar and Witkowski applied the system of giving peer comments and feedback on either fully independent asynchronous model on each other's lab work through a discussion board [23]. Additionally, for the hybrid model students logged in to Zoom at a set time every other week to discuss the posts of the prior week. Instructors use this additional opportunity from provided Zoom sessions to correct common errors on prior work and connect with students. Similarly, Quesada harnesses the efficiency of online learning platforms to answer questions of the students about their laboratory work [25]. If this common online problem arises which is equity issues in computer and network resources, instructors made it possible to share their desktop and allow students to take control. This way, students could use the instructor's computer to run programs not supported on their own devices. Delgado, Bhark, and Donahue shifted the highlight to use of Canvas messaging system to message their instructor for immediate queries and clarifications that require assistance from their instructor [26]. The messaging system was linked to the instructor's email.

Manifestations of social presence in the remote Chemistry experiments

Instructors in the included articles in Chemistry relied on communication features of online media to reach their students in need. Managing the activities and providing guidance was made possible by the instructors through Learning Management Systems [27, 28]. Synchronous discussions with peers or with instructors as well as answering the questions of the students were made possible through video conference platforms [27, 29, 30].

Manifestations of teaching presence in the remote Physics experiments

Aside from technology the teacher's presence is equally important to the success of remote laboratory work. Teachers have a critical role to design, organize, facilitate discourse, and give direct instruction for students to achieve a deep approach to their learning and create meaningful and purposeful interactions with their instructor or with peers.

Teaching presence observed in the included articles in Physics may happen before the laboratory work of the students. Kaps, Splith, and Stallmach presented that before the laboratory proper teachers provide a demonstration of the smartphones as experimental tools and provided lectures on analysis of the digitally recorded physical quantities [15]. Similarly, Hamed and Aljanazrah reported that teachers create videos that discuss the theories and concepts as well as introducing the equipment, how to construct the experiments as well as how to gather and analyze data as mentioned in the manual [22]. Likewise, Campari et.al showed how instructors immediately guide the students by providing a written description and a link to videos presenting the experiment and list of the required items [17]. Also, Dark revealed teachers supporting scientific process at home by presenting information in synchronous session showing live demonstrations of experiment setups, and simulations related to the highlighted Physics concept [19]. Additionally, Dark presented shared responsibility from the learners where they are tasked by teachers to read about concepts in the textbook, listen to shared slides, and use web-based simulations in advance of synchronous sessions. Then, a week before the experiment students were given homework where they answered questions based on readings from the textbook, and sometimes related to simulations. Instructors in the study of Larriba et.al begins each activity with a brief description of the experiment to be carried out through online learning platform which specifically includes explanations of the materials provided, the safety measures required of the students, and the methodology to be followed to obtain experimental data [22].

UIJRT ISSN: 2582-6832

United International Journal for Research & Technology

Volume 05, Issue 09, 2024 | Open Access | ISSN: 2582-6832

During the laboratory work, the observed teaching presence extends more to support the students in accomplishing their remote investigation. The teachers in the study of Kaps, Splith, and Stallmach provide additional tutorials, during which the topic of the experiment is explained and discussed with the students [20]. Also, during the tutorial, the students obtain the possibility to discuss their experimental problems, physical assumptions of the experiment and possible limitations of their set-up and their measuring devices to find workarounds. To further guide the students to the solution of each task, teachers provide support with detailed hints aside from giving direct link to the related articles or references. Koenig and Bake presented that Teaching Assistants facilitate the online laboratory work using Zoom thru its main room and break-out rooms. Additionally, teaching Assistants oversee the process and details of drafting the laboratory report thru shared folders in Microsoft OneDrive and provide immediate feedback and compliments to the work of experiment teams in real-time [21]. Larriba et.al reported that if the students need assistance, they may contact the professor through video conference software [20]. Through this moment the professor may also ask students individual or group questions to assess the acquisition of skills and learning outcomes, evaluating each student based on the answers.

Manifestations of teaching presence in the remote Biology experiments

To guide the students to a quality inquiry journey, instructors in the included Biology remote experiments provide various instructions to their students Sindelar and Witkowski present instructors' use of textbook readings and videos to provide guidance to the students in terms of concept and probably laboratory techniques especially since they are going to work independently in their location away from their instructor [23]. Additionally, the instructor provides directions, rubrics and examples to guide students in the submission of reports and facilitate a peer-to-peer feedback system in the discussion board posts. For the Hybrid model, aside from retaining the delivered textbook readings and literature readings, the instructors set Zoom sessions every other week to discuss the posted reports of the students from independent plant observation of the prior week. Specifically, students were encouraged to screen share and take notes so that the instructor could see their thought process and make suggestions as needed in a fashion very similar to looking over students' shoulders during group discussions in a lab classroom. Instructors also use the Zoom sessions to make announcements, correct common errors on prior work and connect with students. Similarly, Çıngıl Barış presents the instructor's practice of giving article reading assignments to the students before proceeding to the guided experiment [24]. Additionally, instructors provide worksheets to administer both structured and guided experiments to the students. Quesada presented the effort and talent of the instructor to prepare a separate web page for each laboratory session containing the corresponding simulation model for the experiment [25]. Additionally, instructors provided a script detailing the procedure for each lesson in advance. Delgado, Bhark and Donahue provided collections of technologies and techniques that was well supported by teaching presences [26]. The use of Canvas gives way for the instructor to organize and post prelab questions, lab worksheets, post-lab questions, videos, data files, and web links. Frequent reminders and announcements were also made thru Canvas's "Announcement" feature. The instructor guides the students in their inquiry journey through different ways such as conducting learning sessions in Virtual Classrooms via Zoom, live video and audio streaming of experiment methods and materials, screen sharing of lectures and other materials, utilization of chat boxes for class discussions, live annotation using a virtual whiteboard, and break out rooms for smaller group work or one-on-one meetings with the instructor/TA.

Manifestations of teaching presence in the remote Chemistry experiments

The instructors in the included articles of remote laboratory work in Chemistry provide various ways to assure quality interaction among students and to complete their inquiry journey. Using an online meeting platform, the instructors led discussions about the concepts relevant to completing the task of the experiment [29, 30]. Specifically, at some experiments that requires use of simulation the instructors shared their screens and led the entire class through a video or simulation [29]. Al-Soufi, Carrazana-Garcia and Novo even provided online quiz to assess the student's attention and understanding of the discussed concepts [30]. Prior to the experiment proper, a detailed protocol was provided to students for visualization of the experiment flow [29, 30]. During the experiment proper the instructors continuously provide guidance when the students needed it through the selected Learning Management System [27, 28]. Also, even if the students fail to collect reasonable data due to material and

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internet constraints, fallback data arranged in spreadsheets are prepared by the instructors for the students to still respond to the problems and tasks assigned in the experiment [30].

IV. CONCLUSION

Research papers on remote delivery of laboratory works in the university was majorly abundant in the peer-reviewed journals. Whereas, this can be interpreted as a good indicator, it can also be concerning as some of the peer-reviewed journal publications lacks sufficient reflection of actual operation of remote laboratory work in the field. That alone can hinder the progression of the literature on remote delivery of laboratory work.

All reviewed articles generated substantial data to discuss the operation of distance laboratory work in the universities. These are the experiment type, technologies applied, instructional approaches, and manifestations of the key presences of community of inquiry framework.

V. RECOMMENDATIONS

Concerning the promises of online and home-based laboratory in making delivery of remote laboratory work more accessible in science, it is suggested for the science instructors to focus on the use of affordable technologies and free database and software. Consequently, software developers must intensify the drive to provide free or at least limited access to widely used applications or software of their companies. This is to provide a chance for instructors and students to experience the promising features of their software even at its restricted state. Also, to ensure the fruitful interventions and practices to emerge in delivering remote laboratory work in the universities, it is suggested that the conferences and symposiums specifically on the use of innovative technologies in science education should be established. Lastly, there is no doubt that incorporating remote laboratory work in the methods of science teaching is not only crucial for learners but also vital for science educators. Therefore, the incorporation of innovative technologies in the science courses should be integrated more in the training practices, not only for the sake of the research but also for the professional practice.

Moreover, the three key presences of community of inquiry framework must be given extra emphasis in every lesson that will utilize remote laboratory work, if possible, must be highlighted in the lesson exemplar to be noticed and become part of any evaluation process.

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