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A Systematic Literature Review on Trends in the Use of Science Experiments in Online Learning Environments

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Abstract

Experiments are considered to be essential components of science learning. This research aimed to investigate trends in the use of science experiments in online learning. A systematic literature review was carried out, with data sourced from the Scopus and Google Scholar databases. The reviewed documents were journal articles published between 2015 and 2022, with the keywords "science practicum," "science experiments," "distance learning," "online learning," and "hands-on science." Using Harzing's Publish or Perish software, 970 articles were found but only 32 were reviewed. The literature review followed a procedure adapted from the preferred reporting items for systematic reviews and meta-analyses (PRISMA), with articles reviewed based on predetermined criteria such as the year of publication, article source, practicum topics, research subjects, assessment methods, technology, and experiment design in online learning. In the results, various designs for online learning models, the technology used in science experiments, topics addressed, and appropriate assessment methods were identified. Trends included the extensive use of interactive simulation models in online science experiments, the use of virtual laboratories as a crucial technology, and the use of experiment reports to assess students. The analysis showed a sharp increase in the number of publications since the pandemic (2020) and that online science experiments might be carried out effectively by considering the characteristics of the material, matching the science curriculum, and using assessments that fulfill the objectives of science experiments.

Keywords: experiment report, online learning, science experiment, simulation, virtual laboratory

Introduction

COVID-19 has changed the learning paradigm from face-to-face to online formats (Andrews et al., 2020; Manca et al., 2021; Salta et al., 2022). Research has shown that the pandemic has presented substantial challenges for students in accessing science laboratories at various universities (Marinoni et al., 2020). The challenges include designing science laboratory experiments, maintaining students' motivation, and making efficient use of online learning platforms (Müssig et al., 2020) and technology (Gya & Bjune, 2021). This transition from traditional face-to-face to online formats has required significant adaptation from teachers, particularly in conducting laboratory experiments and engaging students in a virtual environment (Kier & Johnson, 2022).

Experiments are considered to be essential components of science learning (Ha & Kim, 2020; Hofstein & Lunetta, 2004; Mamlok-Naaman & Barnea, 2012). They improve students' confidence, scientific reasoning (Beck & Blumer, 2012), conceptual understanding (Srisawasdi & Kroothkeaw, 2014), scientific argumentation writing (Kapici et al., 2022), experimental design skills (Baker & Cavinato, 2020; Blumer & Beck, 2019), critical thinking, creativity (Malik & Ubaidillah, 2020), collaboration, and communication skills (Malik & Ubaidillah, 2021). Given their importance in developing these skills, science experiments remain a vital aspect of science education.

During COVID-19, science experiments carried out at home improved students' conceptual understanding and laboratory skills, as well as provided meaningful laboratory experiences. Students also showed greater interest in experimental procedure design (Andrews et al., 2020) and problem-solving (Mistry & Shahid, 2021). Home-based experimental activities prioritize inquiry-based learning, allowing students to develop practical skills (Baker & Cavinato, 2020). However, these studies contradict Foo et al., (2021) whose work suggested that the proficiency level of students who engaged in problem-based distance learning was lower than those who participated in problem-based face-to-face learning. While home-based science experiments during the pandemic have shown potential to improve a variety of educational outcomes, the results validate the ongoing debate about the effectiveness of online learning compared to traditional face-to-face learning.

Research related to online learning has explored the use of virtual experiments using augmented reality (AR) within an inquiry and discovery method, which has been proven to increase students' motivation to conduct experiments (Müssig et al., 2020). Virtual laboratory experiments also improve problem-solving skills (Prahani et al., 2020) and can be as effective as face-to-face activities (Hamed & Aljanazrah, 2020). Furthermore, virtual laboratories enable online practicum sessions, improve multiple representation skills, and assist the process of receiving information by students (Widarti et al., 2021). As a result, virtual laboratory activities offer a viable alternative to learning science at home (Gya & Bjune, 2021).

Previous reviews related to online learning have examined a variety of topics, including online teaching and learning (Martin et al., 2020), meaningful learning about e-learning environments (Tsai, Shen, & Chiang, 2013), problem-based learning in e-learning contexts (Tsai & Chiang, 2013), game-based learning in online settings (Tsai & Fan, 2013), and self-regulated learning in online environments (Tsai, Shen, & Fan, 2013). Furthermore, research has examined the use of tools and strategies in online learning (Vijayan, 2021) and the trend in using of platforms such as Google Classroom and WhatsApp in online learning (Nasution, 2022). However, further investigations are needed to examine the design of science experimental learning, subject matter, technology, and practical assessments in online learning in order to determine best practices in conducting experiments in online learning.

Literature review research has been conducted by Faulconer and Gruss (2018) by analyzing articles from 1999–2017 that discuss aspects of non-traditional laboratory terminology, non-traditional laboratory learning outcomes, and the benefits of traditional and non-traditional laboratories. However, there is a pressing need for systematic review research to provide comprehensive information on the variety of technology, instructional designs offered in non-traditional laboratories, the science materials taught, and the types of non-traditional science laboratory assessments. Our systematic literature review is crucial in filling these gaps and advancing our understanding of science education.

Theoretical Framework

Science Experiments in Online Learning

The COVID-19 pandemic and the development of information technology have changed the learning paradigm from face-to-face to online formats (Hasani et al., 2022). During the pandemic, some laboratory activities were carried out at home by using available materials without special equipment (Andrews et al., 2020). Alternative remote laboratory learning, such as hands-on activities at home, might be beneficial for students when carefully designed (Accettone, 2022). Students could conduct science experiments at a low cost, with the majority choosing hands-on activities over simulators or using experimental data from previous years (Larriba et al., 2021). During the pandemic, students remotely carried out science practicum activities through authentic and inclusive hands-on experiences that could improve scientific research skills (Schnell et al., 2021). Inquiry-based home experiments provided an authentic learning experience, increased practical student engagement, motivated learning, and enhanced curiosity (Gya & Bjune, 2021).

Online science experiments had been implemented before the COVID-19 pandemic as an alternative method for education. One of the important reasons for online learning is to provide flexibility and accessibility for students who cannot attend face-to-face learning. For example, Nandana and de Mel's (2016) study showed that an integrated laboratory experiment setting could strengthen engineering education in the distance mode. Domínguez et al. (2018) found that a virtual experiment setting could complement a traditional laboratory effectively. Through a randomized control study, DeBoer et al. (2019) found that using home laboratory kits in online courses could improve students' attitudes and achievements. At the same time, Seifan et al. (2019) found that virtual visits could be an effective introductory tool before actual visits in chemical engineering education. In addition, Donkin et al. (2019) stated that video feedback and e-learning improved laboratory skills and student engagement in medical laboratories. Based on this evidence, online science learning before the pandemic had shown potential to improve the quality of education by using digital technology. However, implementation challenges and the need for adequate infrastructure remain.

Online learning uses Internet technology that connects teachers and students, enabling learning without being limited to a physical location. Online or digital learning aims to support learning (Mayer, 2019). Teachers and students interact through online learning platforms, including the learning management system (LMS), video conferences, and discussion forums. Technologies used in online learning include multimedia on the Internet, streaming video, streaming audio, push technologies and data channels, Web whiteboarding, audio chat and voice-over-Internet protocol, and instant messaging (McGreal & Elliott, 2008). Meanwhile, online experimental learning technology can be categorized as augmented reality and virtual reality (Mayer, 2019; Sajka & Rosiek, 2021), remote laboratory (Ma & Nickerson, 2006), virtual laboratory (Ma & Nickerson, 2006; Potkonjak et al., 2016; Wieman et al., 2008), and computer simulation (Oliveira et al., 2019).

Several criteria were important for conducting experiments, including the quality of the experimental results, laboratory logistics, and feasibility, as well as students' learning and achievement (Andrews et al., 2020). Technological integration was required for online practicum activities. For instance, science practicum activities used smartphones (Schmuck et al., 2022) in conjunction with a Google Meet video conference, and assessments based on reports that included headings such as introduction, experimental procedures, results and discussions, conclusions, as well as literature references (Larriba et al., 2021). Online learning of science experiments was carried out through video tutorials and live virtual sessions (Schnell et al., 2021). Research indicated that online experiments might be used efficiently to teach physics (Setiaji & Santoso, 2023). However, students believed that distance practicum learning through videotapes and online simulations was less valuable than direct laboratory experiences (Accettone, 2022).

Assessment is one of the important elements in online experiments since it serves as a benchmark for students' success. The instruments used in online practicums have included practicum reports (Gya & Bjune, 2021), concept-understanding tests (Müssig et al., 2020), pre-laboratory assignments (Brevik et al., 2021), feedback (Donkin et al., 2019), quizzes, and performance assessments (Hamed & Aljanazrah, 2020). A key challenge for teachers has been to develop the right instrument to assess students' abilities in practicums.

Methodology

This research aimed to conduct a systematic review to synthesize the use of online experiments in science learning. The review examined the design of online experimental learning, the technology adopted, and the materials and assessments used in online experiments. The purpose of the literature review was to answer the questions that follow.

1. How were science experiments designed for online learning?
2. What technologies were used in science experiments in online learning?
3. What subject matter is practiced in science experiments in online learning?
4. What was the form of assessment in science experiment activities during online learning?

Inclusion and Exclusion Criteria

The inclusion criteria for the eligible articles included: (a) articles discussing online science experiments; (b) empirical articles using quantitative, mixed, and qualitative methods; (c) articles written in English; (d) articles published in peer-reviewed journals; and (e) articles published between 2015 and 2022. The exclusion criteria were: (a) non-empirical articles such as meta-analyses, literature reviews, and conceptual papers; (b) conference papers, books, book chapters, technical reports, editorials, and commentaries; and (c) articles not written in English.

Search Databases, Strategies, and Process

The research used data obtained from the Scopus and Google Scholar journal indexing engines. Articles on the indexed database were published between 2015 and 2022, with keywords including “science practicum,” “science experiments,” “distance learning,” “online learning,” and “hands-on science.” Using the Publish or Perish software (https://harzing.com/resources/publish-or-perish), 970 articles were found, and only 32 were selected for analysis. Data meeting the inclusion criteria were coded for further analysis. The data analysis focused on the design criteria of the science practicum, the technology used, practicum assessment, and practical topics/materials in online learning. Table 1 provides details about the various sources used in our analysis.

Table 1

Distribution of Analyzed Articles by Source and Journal Ranking

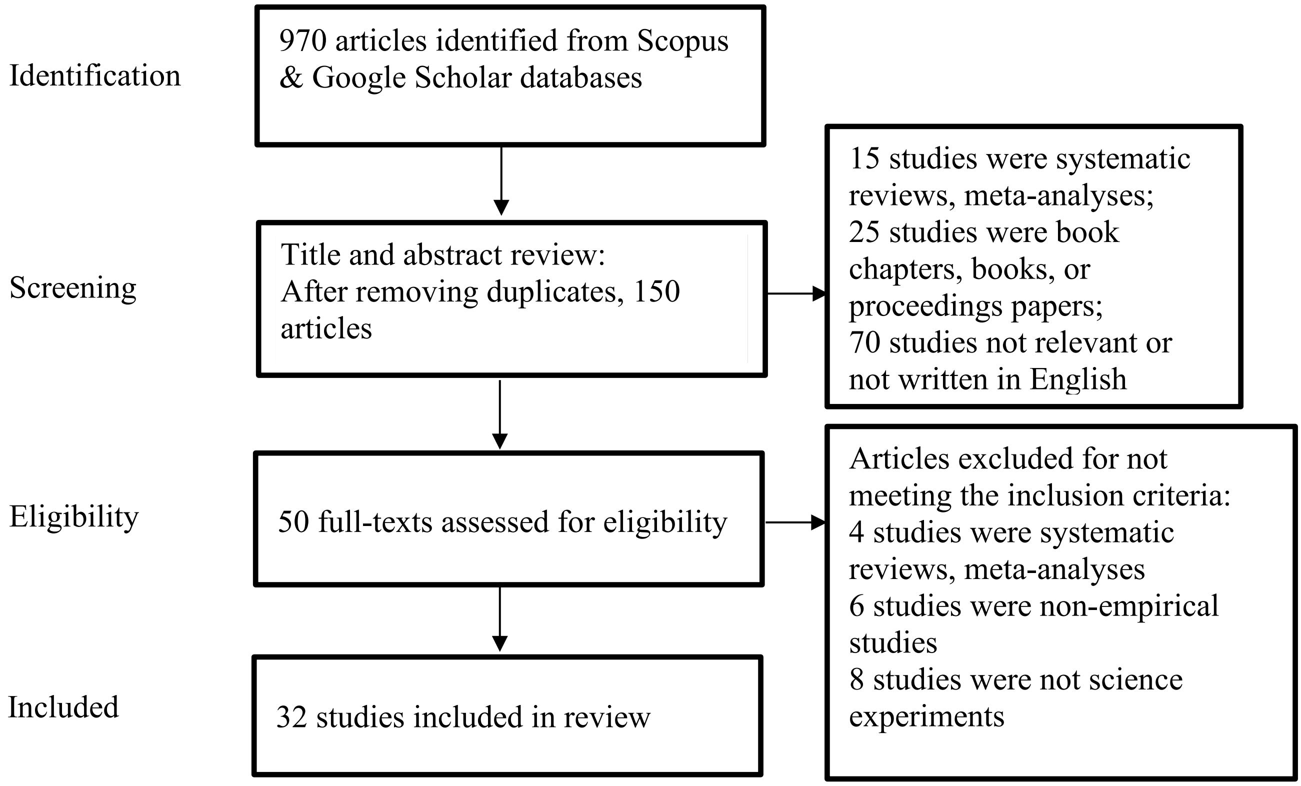
Journal	Quartile (SJR 2023)	*n*
Journal of Chemical Education	Q2 (0.51)	10
Physics Education	Q2 (0.39)	4
Biochemistry and Molecular Biology Education	Q3 (0.38)	3
Education for Chemical Engineers	Q1 (0.93)	3
TEM Journal	Q3 (0.24)	2
Ecology and Evolution	Q1 (0.86)	2
Natural Sciences Education	Q2 (0.39)	1
Journal of Research on Technology in Education	Q1 (0.87)	1
Journal of Information Technology Education: Research	Q1 (0.72)	1
International Journal of Science and Mathematics Education	Q1 (1.04)	1
Education and Information Technologies	Q1 (1.30)	1
European Journal of Engineering Education	Q1 (0.77)	1
BMC Medical Education	Q1 (0.74)	1
Asian Association of Open Universities Journal	Q1 (0.62)	1

Note. SJR = scientific journal ranking.

For our research method, we adopted a literature review combined with a modified systematic review and meta-analysis, following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Page et al., 2021). The procedure consisted of identification, screening, eligibility, and inclusion, as shown in Figure 1.

Figure 1

Research Procedure for a Systematic Literature Review on Science Experiments in Online Learning Environments Using PRISMA Guidelines



Note. PRISMA = preferred reporting items for systematic reviews and meta-analyses.

Results and Discussion

Trends in the Approach to Science Experiments

The analysis of the reviewed articles showed a variety of practicum models. Science practicum that combines hands-on activities with cognitive engagement could still be effectively conducted in online learning. These science experiments activities prioritized the development of scientific knowledge, skills, and attitudes. Students were assigned independent tasks to conduct experiments in their respective homes, and the model for the online learning experiments is presented in Table 2.

Table 2

Pedagogical Approaches to Science Experiments in Online Learning Environments

Study	Pedagogical approach
Ali et al. (2022); Brevik et al. (2021); Damopolii et al. (2022); Domínguez et al. (2018); Hamed & Aljanazrah	Simulations

Study	Pedagogical approach
(2020); Kader et al. (2020); Kapici et al. (2020)	
Baldock et al. (2021)	Problem-solving
Andrews et al. (2020)	Inquiry-based learning, discovery learning at home
Larriba et al. (2021)	Autonomous learning, cooperative learning
Gya & Bjune (2021)	Do-it-yourself (DIY) experiments, inquiry-based laboratories
Nandana & de Mel (2016)	Integrated laboratories experiment setup (ILES)
Schnell et al. (2021)	Course-based research
Müssig et al. (2020)	Inquiry-based learning, discovery learning
Vasiliadou (2020)	Inquiry-based virtual laboratories
Papaneophytou (2020)	Straightforward approach-online delivery
Sherrer (2020)	Discussion, experiments design lab, hybrid learning
Ishafit, Indratno, et al. (2019); Ishafit, Mundilarto, et al. (2020)	Online experiments in remote laboratories
Ametepe & Khan (2020)	Online live demonstration
Accettone (2022)	Chemistry laboratory delivery models
Pratidhina et al. (2022); Schmidt et al. (2021); Schultz et al. (2020); Selco (2020)	Hands-on experiments, video recorded and reported in the LMS
Koretsky (2020)	Re-flipping in the remote classroom, computer-based learning
Seifan et al. (2019)	Virtual field trip
Cesin-AbouAtme et al. (2021)	Demonstration, hands-on practicum at home video recorded
Kapici et al. (2022)	Inquiry-based virtual experiments
Casaburo (2021)	Physics experiments
Donkin et al. (2019)	Blended learning (face-to-face and e-learning)
DeBoer et al. (2019)	DIY “do-it-yourself” remote lab
Schmidt et al. (2021)	Hands-on experiment with remote learning modules

Note. LMS = learning management system.

Online experiments are practical activities carried out through digital platforms to facilitate the distance learning of science. Selco (2020) emphasized direct experiments in online chemistry teaching to improve the fundamental understanding of concepts. Hand-on experiments involved technology; students recorded practical activities in video and reported video recordings on the LMS (Selco, 2020). Schultz et al. (2020) developed a kitchen practicum as a valuable solution for online science learning involving LMS devices and video recordings.

Individual online and traditional laboratory experiments differ significantly in methods, resources, and interactions. The individual online experiment approach is usually conducted at home or through virtual simulations, while traditional laboratory experiments involve complete laboratory facilities and direct interaction with instruments and chemicals. Selco (2020) stated that chemistry experiments conducted from home allow students to gain practical experience even though they are not in the laboratory. Students use materials that are readily available at home to conduct experiments. Schultz et al. (2020) stated that hands-on experiments from home provide practical experience despite limited tools and materials. Meanwhile, Herer (2020) stated that individual practicums using the virtual photosynthesis laboratory module cannot replace more in-depth expertise and the use of actual laboratory equipment. Online individual experiments offer greater flexibility and accessibility in emergencies such as pandemics but have limitations regarding depth of knowledge and interaction with laboratory equipment. In contrast, traditional laboratory experiments provide a more in-depth and comprehensive experience, although they require extensive facilities and resources. The combination of both approaches can provide more holistic and adaptive learning.

Do-it-yourself (DIY) experiments could increase students' interaction with experimental items and systems, develop practical skills, increase motivation and theoretical knowledge, as well as provide authentic experiences (Gya & Bjune, 2021). At-home experiments improved learning results, motivation, and interest in science, as well as provided opportunities for students to develop at their own pace (Zulirfan et al., 2018). The germination experiment with a DIY approach was designed using simple equipment at home and locally accessible plants (Gya & Bjune, 2021). Students completed the modules provided by teachers, submitted hypotheses for testing, designed and carried out experiments, as well as recorded the results on the provided observation sheet. Additionally, they collected and shared observation data online for the benefit of the entire class and wrote a practical report. Students also attached the observational data to the report and discussed the results of the practicum online.

Inquiry-based virtual laboratories learning included conducting virtual experiments using various platforms, particularly Go-Lab (https://premium.golabz.eu/about/projects/go-lab-project.html). Prospective science teachers designed and used experimental activities as well as wrote arguments on an online platform, guided by teachers through online worksheets. Teachers were responsible for carrying out the main task of guiding students on using virtual learning technology. At the end of the activity, students submitted their written results, which were analyzed by teachers (Kapici et al., 2022).

During COVID-19, inquiry-based experiments could be designed and adapted for home settings. Home laboratory designs focused on four main elements, including: (a) avoiding security problems, (b) not requiring special equipment, (c) providing a genuine chemical laboratory experience, and (d) directly interacting with the concepts of pH, acid-base titrations, buffers, solubility, phase equilibria, and thermodynamics (Andrews et al., 2020). Autonomous and cooperative learning was adopted in science practicum activities, with students independently conducting experiments at home (Larriba et al., 2021) and collaboratively writing the practicum report in small groups.

Inquiry-based learning enhanced by AR technology was used to teach chemistry. Students could carry out the learning using this particular technology from home. There were six steps. First, students completed an online test with 10 multiple-choice questions to determine their prior knowledge, with a time limit of 20 minutes. Second, teachers provided multiple-choice test questions related to chemistry. Third, students watched videos provided by the teachers online, which showed step-by-step laboratory activities and how to use AR. Fourth, students were given a brief explanation before experimenting.

Fifth, students downloaded and installed an AR app on an Android or Apple device, conducted experiments, and took pictures of the results. The experimental activities were carried out for a maximum of 2 hours. Finally, students uploaded their experimental reports and accompanying photos to the available platforms (Andrews et al., 2020).

Subject Matter Trends in Science Experiments

The subject matter of practical experiments was quite diverse, covering the fields of physics, chemistry, and biology. In order for any experiment to be conducted in a student's home, suitable materials would have to be easily found around the home or through a virtual laboratory. For instance, in the articles we reviewed, photosynthesis was taught in a virtual laboratory, Ohm's law was practiced through simulation, and acid-base chemistry experiments were easily conducted at home. The trends we discovered in our study are shown in Table 3.

Table 3

Subject Matter of Science Experiments

Subject area	Study	Subject matter
Physics	Kapici et al. (2022)	Electric circuits, Archimedes' principle
	Kapici et al. (2020)	Electric circuits
	Pratidhina et al. (2022)	Ohm's law
	Hamed & Aljanazrah (2020)	Measures the acceleration of gravity (g), the half-life of a draining water column, RC circuit
	Ishafit, Mundilarto, et al. (2020)	Malus law
	Ametepe & Khan (2020)	Principles of physics
	Ishafit, Indratno, et al. (2019)	Magnetic field
	Casaburo (2021)	Gravitational acceleration
	Nandana & de Mel (2016)	Mechanics
Biology	Gya & Bjune (2021); Schnell et al. (2021)	Plant biology
	Damopolii et al. (2022)	Coordination systems
	Brevik et al. (2021)	Microbiology, soil chemistry
	Sherrer (2020)	Photosynthesis
	Baldock et al. (2021)	Biochemistry
	DeBoer et al. (2019)	Neuroscience
	Donkin et al. (2019)	Tissue morphology
Chemistry	Larriba et al. (2021)	Thermal engineering chemistry, separation process
	Andrews et al. (2020)	pH, acid-base titration, buffers, solubility, phase equilibrium, and thermodynamics

	Kapici et al. (2022)	Mole, molarity, acid-base, pH
	Papaneophytou (2020)	Enzyme test, kinetics laboratories
	Müssig et al. (2020)	Crystal structure
	Schultz et al. (2020)	Acid-base materials
	Kader et al. (2020)	Forensic chemistry
	Cesin-AbouAtme et al. (2021); Domínguez et al. (2018)	Electrochemistry
	Selco (2020)	Acid–base chemistry, exothermic processes, endothermic
	Koretsky (2020)	Chemometrics
	Schmidt et al. (2021)	Polymer synthesis, intermolecular interactions, thermomechanical properties, structure-function relationships, and molecular design
	Ali et al. (2022)	Oxalic acid solution
	Accettone (2022)	Chemical reactions

Note. RC = remote control.

The topics of science experiments had different characteristics and levels of difficulty. In virtual laboratory experiments, the chemical topics explored consisted of mole, molarity, acid-base, pH (Kapici et al., 2022), enzyme tests, kinetics laboratories (Papaneophytou, 2020), and photosynthesis (Sherrer, 2020). Meanwhile, chemical topics related to pH, acid-base titration, buffers, solubility, phase equilibrium, thermodynamics, and electrochemistry were carried out through hands-on experiments (Andrews et al., 2020; Cesin-AbouAtme et al., 2021). Physics topics such as electric circuits, Ohm's law, acceleration of gravity, and Archimedes' law could be simulated using virtual laboratories (Hamed & Aljanazrah, 2020; Kapici et al., 2020, 2022). Biological experiments, including plant biology (Gya & Bjune, 2021) and microbiological materials (Brevik et al., 2021), were conducted using both hands-on activities and virtual laboratories.

Trends of Technology Used in Science Experiments

Technology has played an essential role in the learning process and has been fundamental to online learning. Trends in the articles we analyzed showed that there were various technologies used by teachers to achieve the effectiveness and efficiency of practical learning. Table 4 presents the technologies found in the publications we examined.

Table 4

Technologies Used in Science Experiments in Online Learning Environments

Study	Technology
Domínguez et al. (2018); Kapici et al. (2020, 2022); Papaneophytou (2020); Vasiliadou (2020)	Virtual laboratory

Study	Technology
Ametepe & Khan (2020)	Virtual laboratory, video recording, online live demonstration
Baldock et al. (2021)	iPads apps, video recording, Zoom, quizzes
Damopolii et al. (2022)	Augmented reality
Müssig et al. (2020)	Augmented reality, video tutorial
Accettone (2022); Andrews et al. (2020); Koretsky (2020); Schultz et al. (2020)	Video record
Larriba et al. (2021)	3D printed, Google Meet
Gya & Bjune (2021)	Video conference
Sherrer (2020)	Virtual laboratories, Zoom
Nandana & de Mel (2016)	Multimedia demonstration
Ishafit, Indratno, et al. (2019); Ishafit, Mundilarto, et al. (2020)	Remote laboratory
Selco (2020)	LMS, video
Kader et al. (2020)	Web virtual reality
Seifan et al. (2019)	Virtual field trip
Cesin-AbouAtme et al. (2021)	Real laboratory-kit laboratories
Hamed & Aljanazrah (2020)	Virtual laboratories, online video integrated within Moodle
Pratidhina et al. (2022)	Arduino and block programming language
Casaburo (2021)	Arduino
Brevik et al. (2021)	Video, virtual laboratories
Ali et al. (2022)	Virtual chemistry laboratories
Schmidt et al. (2021)	Remote learning module
Schnell et al. (2021)	Video tutorial, live virtual
Donkin et al. (2019)	LMS, video recording of the practicum
DeBoer et al. (2019)	MOOC conducted RCT

Note. LMS = learning management system; MOOC = massive open online course; RCT = randomized control trial.

AR technology was a trend seen in many science experiments activities. To use the technology, students would first download and install an application on a smartphone. Students would then need to print the available markers and use the AR app to scan the markers with their devices (Müssig et al., 2020). Using the virtual laboratory in a science practicum, learners performed simulations independently according to the instructions on the worksheet (Ametepe & Khan, 2020). Remote laboratory technology, also known as virtual reality, allowed students to perform real, practical work remotely by using Web technology with real practicum equipment (Ishafit et al., 2019; Kader et al., 2020). In practical activities, including video recordings, students watched tutorial videos provided by teachers and then carried out the experiments independently at home (Andrews et al., 2020). However, distance practicum learning using video recordings and online simulations failed to provide meaningful experiences (Accettone, 2022). The use of practicum activities was followed up by presenting the experimental results through online discussion platforms, particularly on Zoom (Gya & Bjune, 2021). Combining hands-on and virtual laboratories was more effective in increasing students' knowledge and developing inquiry skills (Kapici et al., 2019). The research has not yet shown trends toward integrating artificial intelligence (AI) in online science experiments learning.

AI technology is currently experiencing rapid development and has been used in various levels of education and disciplines. In online science practicum learning, there are AI applications such as ChatGPT with AI Chatbots. Research has shown that AI could be integrated into blended learning environments (Park & Doo, 2024). The technology has the potential to facilitate communication between teachers and students (van Leeuwen, 2019), change learning processes, improve performance (Huang et al., 2023), and develop positive affective results (Troussas et al., 2020).

Trends of Assessment Used in Science Experiments Conducted in Online Learning

Teachers use assessment in science experiments to evaluate the effectiveness of experiments. This assessment assesses aspects of cognition, skills, and attitudes. The literature review identified several assessment methods, including performance assessment, comprehension tests through quizzes, experimental reports, pre-experiment tests, and research papers. Trends in the assessment of science experiments in online learning environments are shown in Table 5.

Table 5

Trends of Assessment in Science Experiments in Online Learning Environments

Study	Assessment method
Andrews et al. (2020); Gya & Bjune (2021); Kader et al. (2020); Larriba et al. (2021); Papaneophytou (2020); Sherrer (2020); Vasiliadou (2020)	Experiment reports assessment
Hamed & Aljanazrah (2020)	Performance assessment, experiment reports, achievement test
Selco (2020)	Performance assessment
Schnell et al. (2021)	Research paper
Brevik et al. (2021)	Online homework assignments (pre-labs)
Müssig et al. (2020)	Concept understanding test
DeBoer et al. (2019)	Survey self-efficacy, self-concept
Kapici et al. (2022)	Scientific argument
Baldock et al. (2021)	Online quiz, homework
Koretsky (2020)	Homework
Ametepe & Khan (2020)	Quiz

Study	Assessment method
Donkin et al. (2019)	Practical examination, feedback from a peer, video feedback
Nandana & de Mel (2016)	Assignments marked by tutors, continuous assessment tests, daily school, and final exams.

The assessment of science experiments generally evaluated cognitive aspects, skills, and attitudes. Cognitive aspects were assessed through multiple-choice questions and essay tests, while skills were assessed using observation sheets. On the other hand, attitude aspects were evaluated using observation sheets and questionnaires. Performance assessment was carried out by recording practicum activities, with video footage submitted through the LMS (Hamed & Aljanazrah, 2020). Furthermore, assessments were carried out before and after the practicum, as evidenced by Baldock et al. (2021) and Brevik et al. (2021). Experiment reports, which were considered a form of product research, were submitted through the LMS platform provided by the institution (Andrews et al., 2020). Specifically, assessment through research papers included students preparing papers based on the results of their experiments. The research paper would consist of an abstract, introduction, methods, results and discussion, conclusion, as well as references (Schnell et al., 2021).

Experiment reports were prepared similarly, adopting a structure containing an introduction, experimental procedure, results and discussion, conclusions, and literature references. Reports were collected 10 days after the completion of the practicum and were weighted at 60% of the assessment (Larriba et al., 2021). Students collaborated on writing these reports, thereby reaching a consensus on the results and conclusions. This group activity in working on experiment reports was intended to enhance students' transversal competence.

Conclusion and Implication

Learning design trends in science experiments was varied, using both hands-on and minds-on methods. Interactive simulations have arisen as a popular trend, and virtual laboratories have become an essential technology in science learning. The topics addressed in science practicums were varied, including a wide range of experimental methods. In terms of assessment, experiment reports were the most common method used in online learning.

The implications of this research suggest that virtual laboratories and interactive simulations could be effectively used and adapted for both online and face-to-face experiments. Online experiments enhance interaction between teachers and students, which tends to improve students' analytical and practical skills while fostering critical and creative skills. Virtual laboratories have significant potential to expand access to conducting science experiments, especially for those with limited opportunities to conduct direct experiments. The use of technology, including AI, could improve the effectiveness and efficiency of science learning.

The variety of practicum materials covered several topics and experimental methods. The predominance of practicum report assessments signifies the importance of teachers designing comprehensive rubrics in accordance with learning objectives. These assessments could provide in-depth information on students' mastery of science concepts and their use of knowledge.

Online science labs cannot wholly replace traditional laboratory-based labs. Online hands-on experiments at home can be an alternative to traditional labs in school laboratories. Traditional science labs in the laboratory provide meaningful learning experiences for students and improve their technical skills while applying theories learned in class. Meanwhile, online science labs do not always provide enough training in essential laboratory skills. Carefully designed online science labs can be an alternative to science lab activities.

The research results for learning theory imply that online science practicums can support constructivist theory, which emphasizes the importance of hands-on experience and minds-on thinking. Curricula that cover various topics and experimental methods must be continuously updated to ensure relevance to the latest developments in science and technology. Research recommendations for policymakers include providing policy support that enables and encourages educational institutions to adopt online science learning by providing adequate funding, teacher training, and infrastructure.

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