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Teaching and learning innovations for distance learning in the digital era: a literature review

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This paper presents a review study on teaching and learning innovations (TLIs) for distance learning in higher education, which involves substantial use of technology in its practice. The study covers 247 publications that were published from 2017 to 2022 and collected from Scopus to analyze the patterns and trends of TLIs for distance learning in higher education. The results show four main types of TLIs: educational technologies, teaching and learning approaches and activities, teaching and learning programs, and assessment approaches and activities. They also reveal seven major pedagogical patterns in the TLIs, covering the learning of science through online laboratories, virtual and augmented reality, multimedia, gaming, collaboration, tasks/projects, and blended/hybrid/flipped learning. These findings suggest implications for distance learning, covering the use of online laboratories in science courses, promotion of virtual and augmented-based distance learning, encouragement of development, implementation, and the study of pedagogical approaches to distance learning, as well as the increase in interactivity in multimedia-based distance learning.

KEYWORDS
teaching and learning, innovation, distance learning, digital education, ODL

Introduction

Technological advances have promoted innovations in educational delivery. Distance learning, as one of the major education modes, has involved the substantial use of technology in its practice. The importance of technology has been reflected in its contemporary conceptualization. For example, Sangra et al. (2012) define distance learning as "an approach to teaching and learning… that is based on the use of electronic media and devices as tools for improving access to training, communication, and interaction" (p. 152). Pecori (2018) refers to it as "a scenario where instructors and students do not interact directly and often neither synchronously, and a virtualized learning process (e-learning) where students interact with various virtual learning environments (e.g., Moodle) that host all kinds of learning objects via their electronic communication devices" (p. 50). Nikolaevna et al. (2021) similarly describe it as "a teaching method based on the use of multimedia and Internet technologies to increase the availability and quality of education" (p. 5).

One of the technological contributions to the distance education community is the emergence of a wide range of teaching and learning innovations (TLIs). 'Innovation' has been extensively explained as "the introduction of a new idea, method, or devices" (Vasylyshyn and Vasylyshyn, 2017, p. 3) and "a novel, inventive, and usable solution… an end product, process, or method related to people's practical needs and purposes" (Lindfors and Hilmola, 2016, p. 373). In the context of education, TLI thus refers to a new principle, belief, plan, practice, method, and tool that is developed and used to help educators solve pedagogical problems and

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enhance and improve their students' learning and outcomes. Examples include educational apps designed specifically for students with autism (Somerton, 2022), augmented reality in chromatography learning (Merino et al., 2022), and online digital storytelling to develop argumentative writing skills (Salem, 2022), to name but a few. Muda and Yusof (2015) describe their significance as being able to help teachers in terms of new approaches in the teaching process and increase creativity in their teaching, thereby making the learning process easier for learners.

Recent years have witnessed a wide range of TLIs in distance learning (e.g., Eren and Oztug, 2020; Pulukuri and Abrams, 2020; Shakirova et al., 2020; Dickson-Karn and Orosz, 2021; Larriba et al., 2021; Pakinee and Puritat, 2021; Raharjo et al., 2021; Cheung et al., 2023). There is a need to systematically identify and classify these TLIs and analyze their pedagogical patterns. However, the existing literature has centered primarily on the effectiveness of distance learning, its pedagogical benefits, and its impacts on student learning outcomes and experiences (Berndt et al., 2017; Bashir and Warraich, 2020; Tibingana-Ahimbisibwe et al., 2020; Chen et al., 2021; Ødegaard et al., 2021; Martin et al., 2022). As such, this paper presents a systematic review study of TLIs in distance learning for higher education in recent years. In particular, the study focuses on the following research questions.

1. What types of TLIs have been implemented for distance learning in higher education in recent years?
2. What are the major pedagogical patterns among the most frequently implemented TLIs?
3. What are the implications for distance learning based on these pedagogical patterns in TLIs?

Related work

With technology becoming integral to distance learning, a wide range of research has been conducted in relevant areas. This body of work can be grouped into various strands. One concerns examining the quality of distance learning (Oduaran, 2017; Ramdass and Nemavhola, 2018; Kanwar et al., 2019; Sugilar, 2020; Toprak and Sakar, 2021). Another strand focuses on investigating specific teaching and learning issues, such as self-efficacy (Tladi, 2017), learner retention (Pinchbeck and Heaney, 2017), learner persistence (Au et al., 2018; Volk, 2020), learner motivation (Mahande and Akram, 2021; Capone and Lepore, 2022), learner satisfaction (Harsasi and Sutawijaya, 2018; Jarab et al., 2022), learner support and wellness (Wong and Li, 2020), and teaching and learning approaches (Hills et al., 2018; Bayyat, 2020). There have been analyzes of issues with respect to distance learning platforms, tools, and resources, such as design, implementation, and evaluation of materials (Sterling et al., 2017; England, 2018), as well as teacher and student perceptions and experiences of using them (Altunoglu, 2017; Padmo et al., 2019). There have also been studies of issues surrounding the nature, development, and management of distance education (De Langen, 2018; Cervantes-Perez et al., 2019; Kulikowski, 2021; Lischer et al., 2021; Kruse et al., 2022).

Various literature reviews on distance learning have been done in recent years. For example, Berndt et al. (2017) examined past literature regarding the range of distance learning strategies for providing continuing professional development to rural allied health practitioners. They identified a change in focus from reporting on technology use to reporting on user satisfaction, suggesting that future studies could be conducted to include more detailed information in order to "enable replications and further exploration of the complex relationships between instructional design, time use, and location" (p.12). Another study by Tibingana-Ahimbisibwe et al. (2020) analyzed past literature on the potential benefits of formalized peer-assisted learning for students enrolled in a fully online, distance learning program. Their findings show that online peer-assisted learning is useful in providing meaningful learning support because of the presence of online interactions between mentors and mentees.

In their study, Bashir and Warraich (2020) explored the scenario of distance learning using Semantic Web technology. The author identified eight major research themes such as e-learning system requirements/implementation, differences between training and learning, semantic web architecture, e-learning standards, ontology, framework of semantic web and e-learning, integration and interoperability, and future trends. Technological and socio-cultural challenges were also found to cause the hurdle for the implementation of e-learning via semantic web.

Similarly, He et al. (2020) studied publications on synchronous distance education in order to understand whether it is more effective than traditional classroom-based education for health science students. Their study found that synchronous distance education is not significantly different from traditional classroom-based education in learning outcomes, but has a higher overall satisfaction rating among the students. It was also found that there are significant differences in knowledge acquisition and knowledge gains between both the synchronous distance education and traditional classroom-based education groups with low and moderate heterogeneity, respectively.

Ødegaard et al. (2021) explored scholarship on digital learning designs in physiotherapy education. The authors observed the use of blended learning and distance learning designs in physiotherapy education with both modes of learning being more effective than traditional classroom teaching in terms of knowledge and skills acquisition and positive effects on student learning supported by the use of a flipped learning approach, interactive websites/apps, and self-made videos.

The study by Martin et al. (2022) investigated publications on distance and online learning to determine the extent to which its instructional setting moderated the influences on students' cognitive, affective, and behavioral outcomes. The results of their study revealed a significant positive effect of distance learning on overall learning outcomes. It was also found that distance learning seems to have a greater impact on cognitive outcomes than on affective and behavioral ones. These findings suggest the importance of enhancing students' cognitive skills in distance education.

As can be seen, despite the many systematic reviews on distance learning, they have not paid particular attention to studying the types of TLI that have been developed and implemented and their pedagogical patterns. As such, this paper reports a systematic review study of research in relation to TLIs in distance learning. The results will advance our understanding of the pedagogical patterns that prevail in distance learning and provide implications for the field.

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Methodology

Data collection

For this review study, relevant literature was collected through Scopus. This publication database was chosen because of its wide application in prior systematic reviews (Charef et al., 2019; Sweileh, 2019; Derah et al., 2022; Karasneh et al., 2022). An initial search of literature from the database was done using the keyword '*distance learning*', which returned more than 76,000 results. To narrow down the focus on TLIs in recent years, the literature search was further restricted to research articles published between 2017 and 2022 in the discipline of education. This restriction yielded a total of 2,170 potential articles.

This article collection was further screened based on the following selection criteria. Each of the articles must report an empirical study focusing on the development, implementation, and evaluation of TLIs (such as learning apps, course programs, and pedagogical approaches) for distance learning in higher education. TLI was identified as a method, plan, practice, or tool presented in an article to solve pedagogical problems and enhance student learning. Moreover, the article must be written in English language and be available in full text. Those articles which failed to meet any of these criteria were excluded from the present study. A total of 247 articles were eventually selected for review and analysis. Figure 1 illustrates the procedures for searching and selecting the articles.

Data analysis

A content analysis approach was adopted to analyze the selected articles. Each article was checked to identify three categories of information for analysis, including the contexts on countries/regions, educational levels, and subject disciplines where the TLI was implemented; the type of TLI implemented by examining their nature (covering teaching and learning approaches and activities, teaching and learning programs/courses/projects, educational technologies, and assessment approaches/ activities); and the pedagogical patterns in distance learning by studying the ways in which the TLI was used. To analyze the trends of TLIs, the articles were divided into two groups for comparison according to their publication year, i.e., 2017–2019 and 2020–2022.

The article selection process, as well as information identification and categorization, involved two researchers. One of them focused on article screening and information coding from the selected articles according to the procedures illustrated above, and another one on checking. Discordant cases were discussed until a consensus was reached.

Results

Overview of publications

Publication year

Figure 2 shows the distribution of the TLI-related publications in the periods of 2017–2019 and 2020–2022. These two time spans were chosen to analyze the changes in TLI applications as reported in the publications. There is a marked difference in the total number of publications between the two periods, with only 56 articles identified in the former period and 191 ones in the latter. This result is due to the outbreak of COVID-19, where a significant amount of attention was placed on the development and implementation of TLIs to lessen the impact of the pandemic for teaching and learning.

Country/region of TLI

Figure 3 presents the distribution of the countries/regions of the TLIs from the two periods. The TLIs cover a total of 53 countries/ regions. For both periods, the United States had the largest proportion of TLIs, followed by the United Kingdom. Many more countries/ regions were covered in the second period (a total of 47) than those in

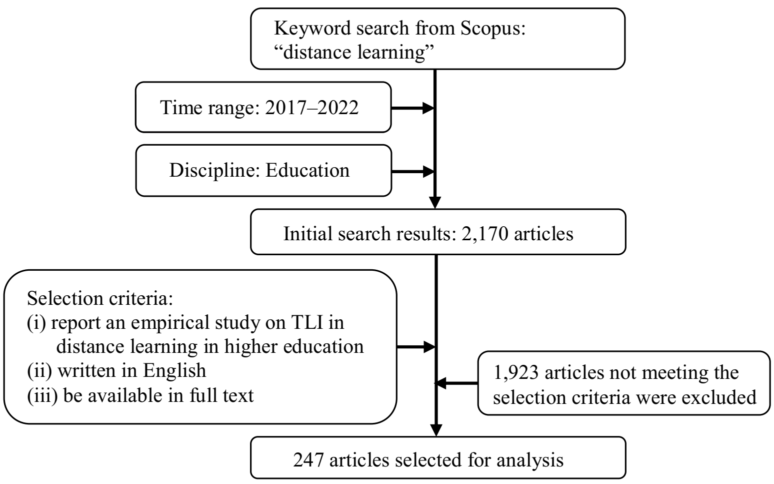

FIGURE 1
Procedures for search and selection of articles.

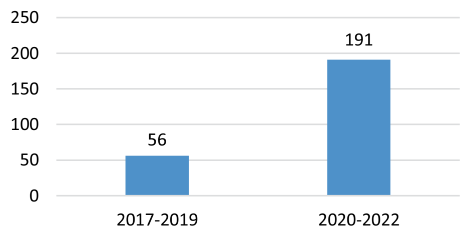

FIGURE 2
The distribution of TLI-related publications in the two periods.

the first period (a total of 23). These results suggest that TLIs in distance learning have received attention in a broader range of countries/regions.

Education level

Figure 4 shows the distribution of education levels involved in the TLIs. Most TLIs belong to the undergraduate level in both periods. There is a greater difference in the proportion of TLIs between the undergraduate and postgraduate levels for the second period when compared with the first one–above 80% of the TLIs for the second period belong to the undergraduate level.

Subject discipline

A total of 30 subject disciplines were found in the TLI-related publications, as listed in Table 1. This result reveals that the development and implementation of TLIs have been widely emphasized in distance education across various subject disciplines. Figure 5 illustrates the distribution of the top five most frequently addressed subject disciplines. Medicine and nursing is the most frequently addressed subject discipline in the first period, but its proportion dropped significantly in the second period. A majority of TLIs in the second period focused on chemistry, suggesting that this subject discipline has attracted particular attention to innovate its teaching and learning practices.

Types of TLIs

After examining the publications collected for the current study, four main types of TLIs were identified: (1) teaching and learning approaches and activities, (2) teaching and learning programs, (3) educational technologies, and (4) assessment approaches and activities.

Figure 6 shows the distribution of the four types of TLIs that were identified in the publications. The overall patterns are similar in both periods, with TLIs in educational technologies being the most frequent ones followed by teaching and learning approaches and activities. The proportion of these two types of TLIs even increased in the second period. These results suggest the growing importance of technology for innovating distance learning practice.

Types of educational technologies

Educational technologies are the most common types of TLIs identified from the publications. Table 2 shows the types of educational technologies involved in the relevant TLIs.

Figure 7 shows the distribution of the top five types of most commonly used educational technologies in TLIs across the two periods. For the first period, video and audio materials, virtual and augmented reality, and learning management systems were used relevantly more frequently. For the second period, laboratory-based software and hardware became the largest proportion, and video-conferencing tools were also used relatively more frequently. These results indicate a pedagogical change in the use of educational technologies between the two periods, which would be driven by the influences of the pandemic on the mode of lesson delivery and interaction that conventional types of laboratory-based activities which are conducted physically in laboratories needed to be changed.

Types of teaching and learning approaches and activities

There are 10 types of teaching and learning approaches and six types of teaching and learning activities identified from the TLIs, as shown in Table 3. Blended, hybrid, and flipped learning approaches were categorized into the same type based on the classification of Tonbuloğlu and Tonbuloğlu (2023). Figure 8 reports the distribution of the teaching and learning approaches across the two periods. Overall, the top three are the blended/hybrid/flipped learning approach, gamification approach, and collaborative learning approach. Comparing the two periods, there have been new approaches which existed in the second period, including the task/project-based approach, visual approach, e-service learning approach, questioning technique, and group formative technique. Furthermore, the accelerated learning approach, which contributed 10% of TLIs in the first period, did not exist in the second period.

Figure 9 shows the distribution of the teaching and learning activities in the TLIs across the two periods. For the second period, laboratory-based activities contributed a majority of TLIs (67%), followed by discussion-based (15%), and writing-based ones (7%). This result suggests a marked instructional change in the use of laboratory-based activities, and aligns with the relatively large proportion of TLIs involving the use of laboratory-based software and hardware in the field of natural sciences (e.g., chemistry) as illustrated above where experiments are common.

Types of teaching and learning programs

There are six types of teaching and learning programs identified in the TLIs (Table 4). Figure 10 shows the distribution of them across the two periods. On-the-job related programs and academic support-related programs were the most frequent overall. For the second period, there was a greater proportion of language-related programs and new types of programs related to specifically laboratory work and medical and healthcare training in a distance learning mode. Also, cross-institution-related programs contributed 30% of TLIs in the first period, but 0% in the second period.

Assessment approaches and activities

A total of 11 assessment approaches and activities were identified in the TLIs, as shown in Table 5. Their frequency is relatively small, i.e., covering only a total of 14 TLIs. They could be categorized into the summative and formative types in general. E-portfolio, quiz, and writing assignment were found in both periods ($N = 1$ for each period), and the others occurred once only in the first or second period. Technologies were involved in the assessment activities, such as the

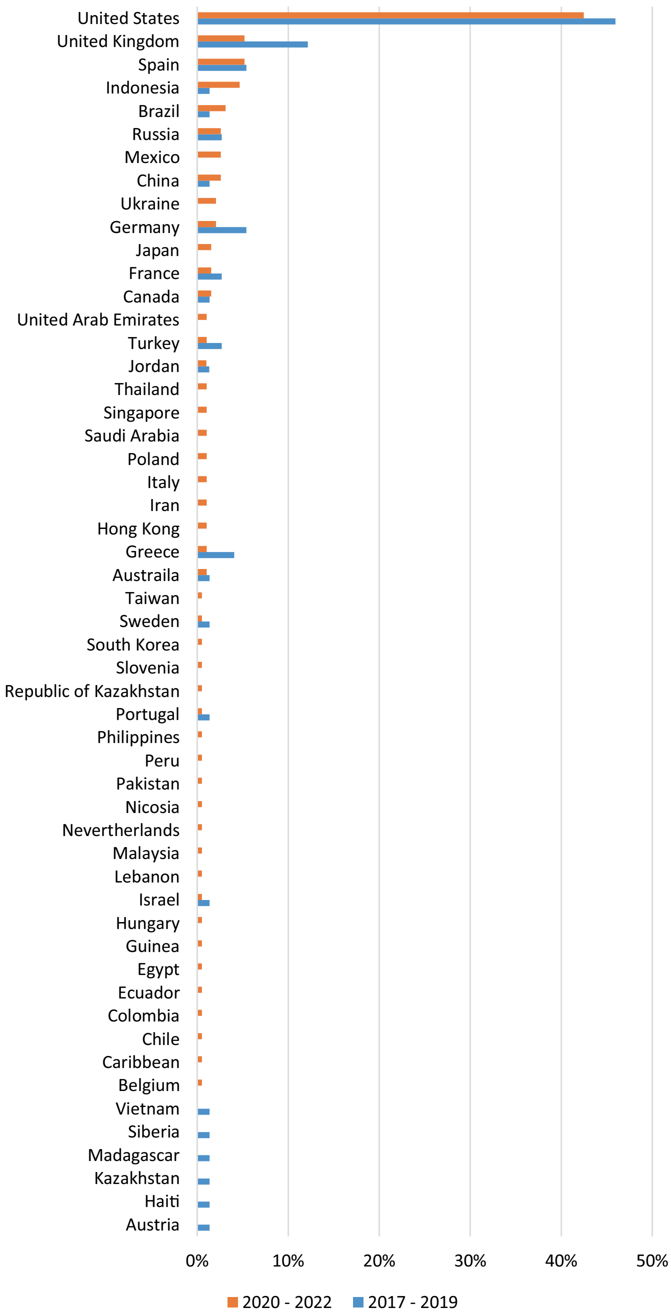

FIGURE 3
The distribution of the countries/regions of the publications across the two periods.

use of 3D virtual technology for a tooth identification test, and personalized screencasts for a writing assignment.

Pedagogical patterns among the most frequently implemented TLIs

The major pedagogical patterns were identified from the most frequently implemented TLIs. Table 6 shows the seven pedagogical patterns corresponding to the nine TLIs most frequently implemented.

Figure 11 presents the distribution of the pedagogical patterns which are sorted in a descending order according to the frequency counts of the relevant TLIs. For the first period, the most frequent pedagogical pattern was learning through multimedia followed by learning through virtual/augmented reality, learning through collaboration, blended/hybrid/flipped learning, learning through gaming, and learning of science through online laboratories. This is in sharp contrast to the second period where the most frequent pattern was learning of science through online laboratories followed by learning through gaming, blended/hybrid/flipped learning, learning

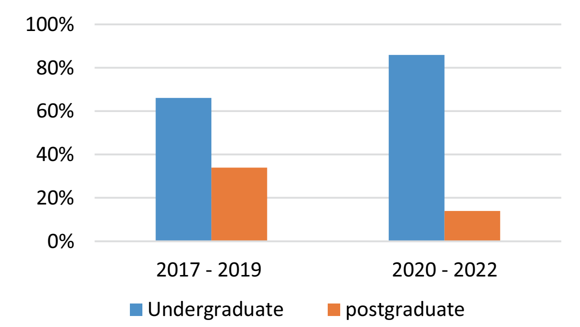

FIGURE 4
The education-level distribution of the TLIs across the two periods.

TABLE 1 The subject disciplines of TLIs in the publications.

Subject disciplines		
1. Agriculture	11. Geography	21. Medicine and nursing
2. Architecture	12. Geology	22. Music
3. Biology	13. Humanities	23. Physics
4. Business and business administration	14. Information systems	24. Political science
	15. Language	25. Psychology
5. Chemistry	16. Law	26. Public affairs
6. Computer science	17. Management	27. Religious studies
7. Cultural studies	18. Marketing	28. Social work
8. Economics	19. Mathematics	29. Sports and sport management
9. Education	20. Media and communication	
10. Engineering		30. Translation

through collaboration, learning through virtual/augmented reality, and learning through multimedia. These results suggest differences in pedagogical focus between the two periods. In particular, the greater pedagogical focus on learning of science through online laboratories in the second period may be accounted for the impact of the pandemic on science learning that restricted teachers' and students' access to physical laboratories.

Learning of science through online laboratories

Online laboratory-based innovations such as software and hardware, activities, and programs were found to be most common in the TLIs. This also reveals the prominent pedagogical pattern in distance learning of science through online laboratories. Conducting experiments in laboratories is an essential part of the learning experience in science disciplines such as chemistry, engineering, and physics (Sharpe and Abrahams, 2019). They allow students to apply the knowledge they have learnt to develop important experimental skills. However, there are circumstances in which doing experiments in a physical laboratory is not possible or feasible, such as when students are unable to access a laboratory or when they need to perform high-risk experiments that may endanger their lives (Weicht et al., 2012). In these cases, using an online laboratory is a viable alternative.

An online laboratory may exist in the form of a totally online environment in which students create and conduct virtual experiments over the Internet via a computer program in either the classroom or at home (Hlescu et al., 2020), or a remote environment where students conduct real experiments in a physical laboratory by remote access over the Internet (Orduña et al., 2018). Both forms aim to help students experience the process of carrying out experiments and obtaining experimental results. Examples of relevant TLIs include a virtual sampling activity to help chemistry students understand the concept of sampling through a guided learning exercise on the effects of sample size and the number of replicate samples on sampling errors (Dickson-Karn and Orosz, 2021), and an instructional tool called ROXI (Research Opportunity through eXperimental Instruction) to assist chemistry students to run experimental analysis using low-cost data through electronic sensors and command and control software (Larriba et al., 2021).

Learning through virtual and augmented reality

Another pedagogical pattern pertains to learning through advanced digital technologies, as shown in the findings about the common use of virtual and augmented reality. Virtual reality refers to "a computer-generated 3-D experience in which a user can navigate around, interact with, and be immersed in another world in real time, or at the speed of life" (Briggs, 2002, p.35), whereas augmented reality "combines two dimensional or three-dimensional virtual objects into the real-world environment in real time" (Bhatti et al., 2020, p.3).

As pointed out by Kukulska-Hulme et al. (2021), virtual and augmented reality technologies allow teachers to provide students with exciting learning experiences that include: remote participation (e.g., for field trips to places which would be difficult, dangerous, or impossible to visit for students such as the inside of a volcano), remote presence (e.g., people who cannot be in the physical world are able to interact and work together in a virtual reality environment, manipulating virtual objects and moving around the setting together), simultaneous engagement with the physical world (e.g., learners are able to interact with both the real world and augmented reality elements simultaneously), and a time machine (e.g., students can go on trips through time and engage with historic events or watch landscapes change over the centuries).

Examples of relevant TLIs include the use of virtual reality to assist geo-education students in studying the geography of tourist destinations (Shakirova et al., 2020), and augmented reality to train students in using instructional software authoring tools (Eldokhny and Drwish, 2021).

Blended/hybrid/flipped learning

The pedagogical pattern on blended/hybrid/flipped learning is shown in the findings about the high occurrence of the blended/hybrid/flipped learning approach used in relevant studies in recent years to solve pedagogical problems and enhance student learning. Tonbuloğlu and Tonbuloğlu (2023) classifies blended, hybrid, and flipped learning into the same category with a common feature to combine the presentation environments and teaching methods in various modes. This approach is common in distance education, which emphasizes expanding and maximizing student learning outside the classroom by making best use of the benefits of online and face-to-face teaching (Heinerichs et al., 2016).

This pedagogical pattern features both online instruction and face-to-face instruction. The former is conducted on an online platform where only online materials such as videos, textbooks, and software are made available to students, and the latter takes place in a physical classroom

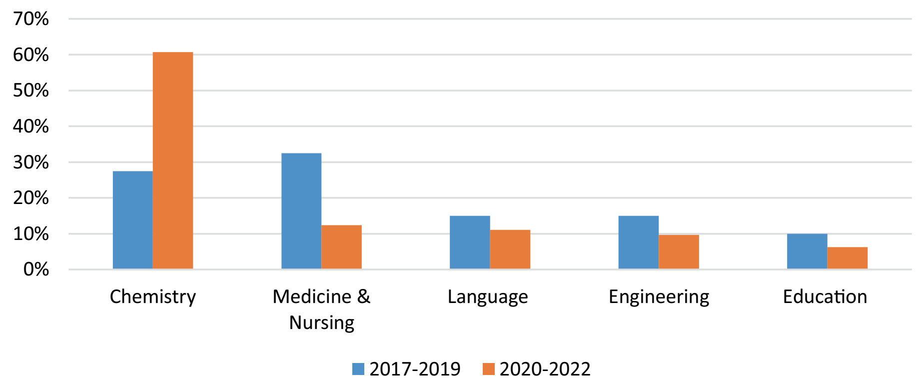

FIGURE 5
The distribution of the top five frequently covered subject disciplines in the TLI-related publications across the two periods.

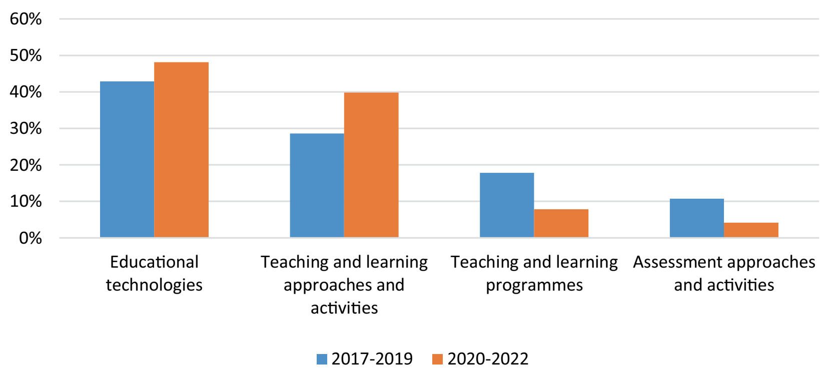

FIGURE 6
The distribution of the types of TLIs across the two periods.

where the teacher is present to guide students and provide them with immediate feedback (Nugroho and Wahyono, 2019). Blended/hybrid/flipped learning provides teachers with opportunities to create a flexible environment where the physical space can be used to enable group work. Teachers and students can make best use of their own devices to enhance their teaching and learning.

Examples of relevant TLIs include the use of a flipped learning approach to increase teacher–student interactions in a general chemistry course (Christiansen et al., 2017) and the use of a scaffolded inverse blended learning approach to help students engage with learning activities at higher cognitive levels (Ang, 2020).

Learning through multimedia

Technological advances have facilitated the development of computer-based multimedia materials such as videos and recordings. This not only creates a multimedia-rich environment in which students are able to interact with different audio–visual resources, but also provides students with an active learning experience that has an impact on their engagement (Tugetkin and Dursun, 2022). Computer-based multimedia materials can be either animated or interactive in nature (Kukulska-Hulme et al., 2020; Tugetkin and Dursun, 2022).

Animated multimedia such as animated videos is used to reveal processes that are too fast for learners to follow or too small to see. It also shows the ways in which difficult problems are tackled by an expert, and explain abstract issues in the real world such as an animated weather map showing changes in air pressure. Interactive multimedia such as interactive videos or audio is used to increase students' motivation and make their learning process more enjoyable.

TABLE 2 The types of educational technologies involved in TLIs.

Types of educational technologies	
1. Virtual and augmented reality (e.g., augmented reality tutor, Google Earth)	10. Assignment grading systems
2. Video and audio materials	11. Laboratory-based software and devices (e.g., lab tool kits, electronic sensors)
3. Learning management systems (e.g., Moodle and Blackboard)	12. Electronic communication systems (e.g., emails)
4. Videoconferencing tools (e.g., Skype)	13. Office suites (e.g., Excel)
5. E-textbooks	14. Websites
6. Blogs	15. Online whiteboards
7. Mobile apps	16. Barcodes (e.g., QR codes)
8. Social networking sites (e.g., Facebook)	17. Data collection and management systems (e.g., Google Form)
9. Video editing and annotation tools	18. Mobile devices (e.g., smartphones, tablets)

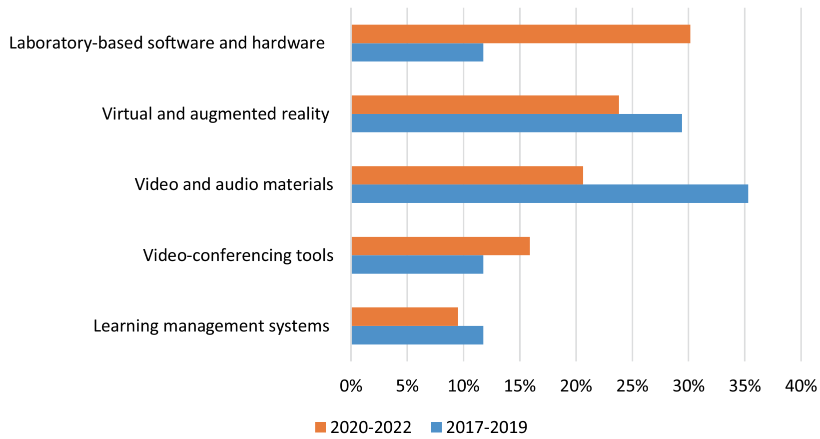

FIGURE 7
Distribution of the top five most frequently used educational technologies across the two periods.

Examples of relevant TLIs include the use of interactive online videos to promote active learning and help students remain on-task and accountable for their work (Pulukuri and Abrams, 2020), and the application of virtual choir recordings to help students practice duets (e.g., soprano-alto and tenor-bass; Eren and Oztug, 2020).

Learning through gaming

This pedagogical pattern involves the application of a game and its design elements in a non-gaming context (Khaleel et al., 2015). A game refers to "a rule-based formal system with a variable and quantifiable outcome, where different outcomes are assigned different values, the player exerts effort in order to influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable" (Juul, 2003, p.53).

A gamification approach to teaching and learning can take various forms (Sharples et al., 2013). In its simplest form, teachers may use games that cover ordinary educational tasks and give rewards to students who successfully complete them. Another way is to make use of the trappings of games, such as badges, scores, and timed challenges, to make drill-and-practice work more appealing. A more sophisticated way is to situate learning within a game environment or virtual world.

Instances of relevant TLIs can be seen in the studies of Barbieri et al. (2021), Pakinee and Puritat (2021) and Raharjo et al. (2021), in which the use of a gamification approach was adopted to improve engagement with students and promote active learning and increase student engagement in the class, respectively.

Learning through tasks/projects

Learning through tasks/projects involves a group of students completing a task or project, thereby achieving a deeper understanding and obtaining different learning outcomes. For it to be effective, the approach must be (1) problem-based, meaning that the project/task should involve a question or problem that drives students to encounter or struggle with the central concepts and principles of a discipline; (2) realistic, meaning that the project/task should involve a question or problem that is relevant and meaningful to students' own interests and daily lives; (3) student-driven, meaning that the project/task should be student-led, involving more student autonomy, choice, unsupervised work time, and responsibility; and (4) focused on knowledge transformation and construction, meaning that the project/task should involve learning processes which involve inquiry, knowledge building, and resolution such as decision-making, problem-finding, problem-solving, or model-building (Thomas, 2000).

Examples of relevant TLIs can be seen in the research studies of Kato et al. (2020) and Panova et al. (2021), in which a project-based learning approach was implemented to increase student motivation and willingness to communication and to stimulate the development of various types of thinking among students, respectively.

TABLE 3 The types of teaching and learning approaches and activities for the TLIs.

Types of teaching and learning approaches
1. Accelerated learning approach
2. Visual learning approach (e.g., 3D figures)
3. Questioning technique (e.g., use of bridging questions)
4. Group formation technique
5. Blended/hybrid/flipped learning approach
6. Gamification approach
7. Problem-solving approach
8. Task/project-based approach
9. Collaborative learning approach
10. E-service-learning approach
Types of teaching and learning activities
1. Writing-based activities (e.g., digital storytelling)
2. Quiz-based activities (e.g., self-generated presentation quizzes)
3. Feedback-based activities (e.g., peer feedback exchange)
4. Laboratory-based activities (e.g., at-home/remote lab exercises)
5. Medical training activities (e.g., intensive therapy-related activities)
6. Discussion-based activities (e.g., online peer discussion)

Learning through collaboration

The use of a collaborative learning approach was found to occur commonly in the TLIs. Collaborative learning involves "any of the variety of strategies employed by an instructor to promote students working together to advance their understanding of a subject matter" and these strategies are capable of "prompting students to interact

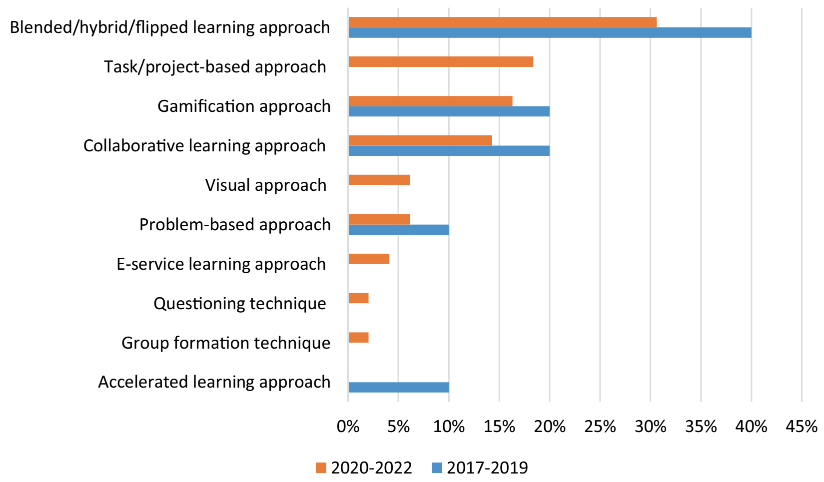

FIGURE 8
The distribution of the teaching and learning approaches across the two periods.

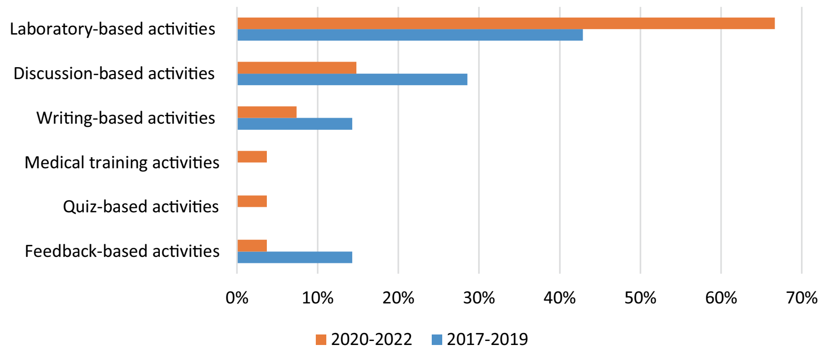

FIGURE 9
The distribution of teaching and learning activities across the two periods.

with one another, encouraging them to articulate their perspectives and to resolve differences in understanding" (Osman et al., 2011, p. 547). Collaborative learning also helps to develop a social support system for learners, increase students' self-esteem, reduce students' anxiety, promote critical thinking skills, personalize large lectures, and promote active learning (Laal and Ghodsi, 2012).

Instances of relevant TLIs include the research by Raymond et al. (2016) in which a collaborative peer learning approach was implemented in a medical course offered for nursing students in order to foster collaboration among them and prepare them for their future careers, and that of Wenzel (2020) in which a collaborative group learning approach was implemented in analytical chemistry to facilitate the teaching of a large online class.

Implications of the pedagogical patterns in TLIs for distance learning

The pedagogical patterns identified from the TLIs provide important implications for distance learning, as discussed below.

TABLE 4 Types of teaching and learning programs identified in the TLIs.

Types of teaching and learning programs
1. Laboratory-based (e.g., distance learning experimental project)
2. On-the-job related (e.g., distance learning firefighter training program)
3. Academic support-related (e.g., online induction program)
4. Cross-institution-related (e.g., international collaborative distance learning program)
5. Language-related (e.g., online Japanese course)
6. Medical and healthcare training-related (e.g., online medical course on the use of antimicrobial agents and the prevention of antimicrobial resistance)

Use of online laboratories in distance learning science courses

A wide variety of TLIs that facilitate students to conduct laboratory experiments outside the classroom (e.g., online laboratory programs, activities, software, and hardware) have been implemented in distance learning courses in science subjects such as chemistry and biology. This finding has an implication

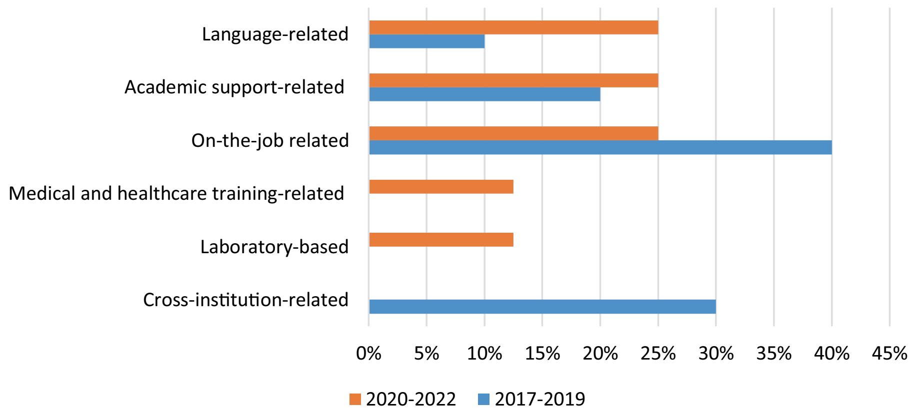

FIGURE 10
Distribution of teaching and learning programs in the TLIs across the two periods.

TABLE 5 The assessment approaches and activities identified in the TLIs.

Summative	Formative
• Demonstration • E-portfolio • Essay with audio presentation • Project • Virtual oral examination • Take-home examination • Writing assignment	• Think aloud activity • Multi-rule quality control • Quiz • Web-based self-assessment

TABLE 6 The pedagogical patterns corresponding to the most frequently implemented TLIs.

The most frequently implemented TLIs	Major pedagogical patterns shown
• Laboratory-based software and hardware • Laboratory-based activities • Laboratory-based distance learning programs	Learning of science through online laboratories
• Blended/hybrid/flipped learning approach	Blended/hybrid/flipped learning
• Gamification approach	Learning through gaming
• Virtual/augmented reality technologies	Learning through virtual/ augmented reality
• Video and audio materials	Learning through multimedia
• Task/project-based approach	Learning through tasks/projects
• Collaborative approach	Learning through collaboration

regarding the use of online laboratories as a substitute for physical ones in distance learning science courses. Conducting laboratory experiments is an integral part of the learning experience in various science disciplines. However, there are circumstances where students are unable to attend physical laboratories; for instance, because of full-time work commitments or experiments being too dangerous. This makes online laboratories a possible and feasible option. Prior studies have consistently revealed the benefits of online laboratories on students' learning, ranging from enhancing their soft skills (e.g., creativity, problem-solving skills, and critical thinking skills) to their hard skills (e.g., experimental skills and knowledge of science subjects; Destino and Cunningham, 2020; Seaton et al., 2021; Vargas-Oviedo et al., 2021). Management of distance learning institutions should consider the use of online laboratories as an alternative to physical ones, particularly in the post-COVID-19 period, and, if so, the extent to which they could be integrated into laboratory-based distance learning courses.

Promotion of virtual and augmented-based distance learning

Virtual and augmented reality, among the technology-based TLIs identified, was found to be the second most frequently used in distance learning. Virtual and augmented reality technologies have been applied in distance learning in various subject disciplines, such as chemistry (Levonis et al., 2021), English language (Urueta and Ogi, 2021), architecture (Kowalski et al., 2020), and geology (Jeffery et al., 2021). Studies focusing on their applications in distance learning have found positive outcomes on teaching and learning, such as promoting active learning (Broyer et al., 2021), improving acquisition of subject knowledge (Kowalski et al., 2020), and enhancing digital literacy (Eldokhny and Drwish, 2021). However, a major drawback of virtual and augmented reality has been its cost and complexity. As such, not all distance learning institutions are able to afford relevant equipment, and not all distance learning teachers are familiar with this type of technology. Thus, management should consider not only allocating funding for the purchase of technologies to promote virtual and augmented reality-based distance learning, but also providing distance learning teachers with professional training on ways to apply virtual and augmented reality to their teaching disciplines.

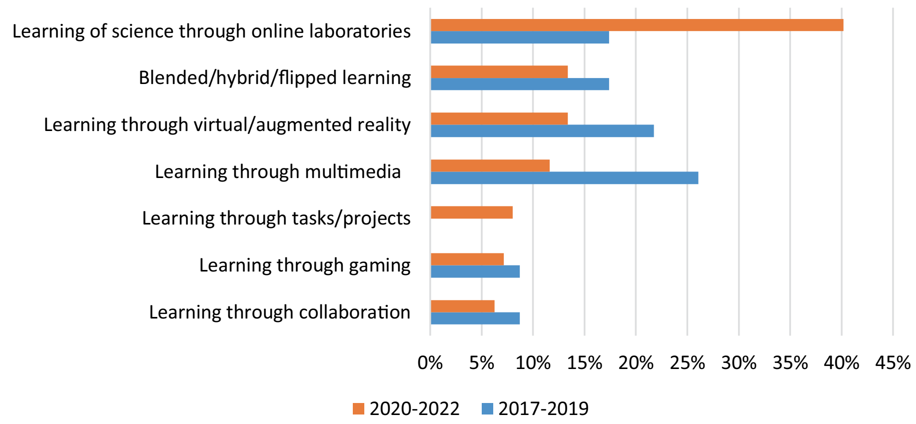

FIGURE 11
Distribution of the pedagogical patterns among the TLIs in the two periods.

Encouragement of development, implementation, and study of pedagogical approaches to distance learning

Pedagogy-based TLIs such as the gamification approach, task/project-based learning approach, and collaborative learning approach have been implemented in distance learning courses in subject disciplines such as nursing (Raymond et al., 2016), Japanese language (Kato et al., 2020), and media communication (Pakinee and Puritat, 2021). This finding offers an implication in relation to pedagogical approaches to distance learning. Distance learning teachers may have a tendency to focus on using pedagogical approaches with which they are familiar, thereby constraining themselves from diversifying their pedagogies. In this regard, management should consider providing incentives such as teaching development grants to encourage teachers to design, implement, and examine pedagogical approaches to distance learning specific to their own disciplines. Doing so would help in not only transforming pedagogy-based innovations into research studies, but also enhancing the quality of teaching for students.

Increase in interactivity in multimedia-based distance learning

Multimedia is one of the most frequent types of TLIs in distance learning. Distance education has been evolving from relying on hard-copy printed learning materials to audio–visual learning and technology-based learning (Yan and Batako, 2020). This evolution has allowed distance learning teachers to experiment with various educational technologies that best suit their own teaching practices. It has also enriched distance learning students' learning experiences by providing a wide range of multimedia resources that best facilitate their learning outcomes. The extent to which multimedia resources can be effectively exploited depends largely on the interactivity of the multimedia teaching and learning materials used; that is, the inclusion of different multimedia elements in the teaching and learning materials (Prasetya et al., 2018). In order to optimize multimedia-based distance learning, distance learning teachers must augment interactivity by supplementing their lessons with smart classroom technologies such as interactive whiteboards, interactive mobile devices (e.g., tablets and smartphones), and interactive learning platforms (e.g., learning apps), while at the same time incorporating into the design of instructional materials both interactive elements (e.g., quizzes, multiple choice questions, discussions, and hotspots) and multimodal elements (e.g., images, sounds, videos, and animations). This would not only help the creation of an interactive and fun learning environment, but also to engagement of students' attention and interest in the lessons (Kusuma et al., 2021).

Conclusion

The findings of this study contribute to highlighting the patterns and trends of TLIs in distance learning in recent years. Concerning the types of TLIs implemented, the results reveal four main types of TLIs, namely educational technologies, teaching and learning approaches and activities, teaching and learning programs, and assessment approaches and activities. Pertaining to the major pedagogical patterns in the most frequently implemented TLIs, the results found a total of seven pedagogical patterns, covering the learning of science through online laboratories, learning through virtual and augmented reality, blended/hybrid/flipped learning, learning through multimedia, learning through gaming, learning through collaboration, and learning through tasks/projects. Regarding the implications for distance learning based on the major pedagogical patterns, the results provided four important implications, covering the use of online laboratories in science courses, promotion of virtual and augmented-based distance learning, encouragement of development, implementation, and the study of pedagogical approaches to distance learning, and increase in interactivity in multimedia-based distance learning.

Limitations and future work

There are limitations of the present study. One is that the study was limited to the examination of the types of TLIs in distance learning and their major pedagogical patterns. Future studies could investigate other relevant areas such as the perceptions of the TLIs among distance learning teachers and students, their positive and negative impacts on teaching and learning, and the experiences and challenges of distance learning for teachers and students using the TLIs in order to give a clear description of their effectiveness. Another limitation is that the study focused primarily on the TLIs in the context of distance learning. Future studies could also investigate TLIs implemented in conventional face-to-face learning in order to identify their similarities or variations. Finally, the study was restricted to the analysis of TLI-related publications from the past 6 years. Future work could include a larger sample size of publications to identify their features, evolutions, and trends along the years.

Author contributions

KL, BW, and HC contributed to conception and design of the study and analysis of data. HC performed the data collection and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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