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# Open education for sustainable development: Contributions from emerging technologies and educational innovation

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# Open education for sustainable development: Contributions from emerging technologies and educational innovation

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# Editorial: Open education for sustainable development: Contributions from emerging technologies and educational innovation

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Editorial on the Research Topic
Open education for sustainable development: Contributions from emerging technologies and educational innovation

## 1. Introduction

The difficulties in carrying out formal educational processes are not a novelty; historically, some examples, such as the cuneiform pictograms dating back to 3000 B.C., speak of the problems that the Sumerian people had in educating, disseminating the knowledge to reach future generations, and finding ways to translate the representations into productive processes. It has been 5000 years since those Mesopotamian schools tried to establish a systematization of knowledge through educational institutions. From this perspective, we must understand that educational institutions must constantly be moving, pending social dynamics, adapting, and in many cases, anticipating the transformations that human beings undergo in their daily lives. We must understand excellence as Galeano commented, "Utopia is on the horizon. I walk two steps, it moves two steps away, and the horizon moves ten more steps away. So, what is a utopia for? That's what it's for, to walk.

When we think of trying to find solutions in education, the starting point is the observer's perspective in evaluating the process because it is vital to visualize the whole panorama. We must have a macro view, but without neglecting the micro instances that make up the whole social phenomenon; that is, the tree does not prevent us from seeing the forest, and the forest does not prevent us from examining the particularities of each tree. Bibliometric analyses of complexity identify challenges for education (Baena-Rojas et al., 2022; Ramírez-Montoya et al., 2022a; Suárez-Brito et al., 2022; Vázquez-Parra et al., 2022), where the habits of mind of systems thinking are fostered, with educational interventions that build and enhance the complex system with constituent subsystems (Kastens and Manduca, 2017). In particular, Morin (2019, 2020) invites us to think of complexity as "interwoven," where the parts are analyzed in the whole and the whole in correspondence with its parts. How are the parts linked in educational processes?

These words, close to a metaphor, do no more than try to show that to analyze educational phenomena, it is necessary to consider the political, economic, and cultural characteristics peculiar to each student in the scenarios where the act of teaching takes place. The pandemic that devastated the world in 2020 showed us the uncertainty of the future and left some lessons to be learned, ranging from the rational use of technologies to the economic and social differences in various sectors of the population around the world that impacts education. Ramírez-Montoya et al. (2022b) speak of the future of education as imprinted by open education that interweaves purposes, challenges, and complex scenarios. Similarly, Sanabria-Zepeda et al. (2022) put into perspective the importance of promoting open science to respond to the challenges of the Sustainable Development Goals. Global and local requirements spotlight the need for educational institutions to provide answers.

One of the most significant aspects of the transformation generated by the COVID-19 pandemic was its direct effect on using technologies to overcome distance barriers. Stracke et al. (2022) exposed COVID contextual actions with open education practices. Likewise, Vicario et al. (2021) presented a diagnosis of Mexican institutions facing the crisis; also, García-González et al. (2022) analyzed how Spanish institutions faced the crisis. In many cases, these technology implementations were carried out exclusively for communicative interactions between teachers and students, not designed for an educational project with a precise foundation. Thus, it is now imperative, understanding the importance of using technology, to design and establish concrete strategies in the assessment, use, and implementation of specific tools, according to the context of the intended practice. The educational institution should not evaluate itself, excluding its community. A better knowledge of the population that is part of the educational community leads to more effective problem solutions.

When we think of "the context," we must bear in mind that societal characteristics at the beginning of the 21st century present us with a panorama of the future that is difficult to predict. The new forms of interactions between people, the characteristics of consumption, new jobs, the massification of technological supports, and almost unlimited access to information have created new types of relationships. They have built parallel imaginaries between the tangible and the intangible, spaces in which it is difficult to differentiate what is real from what is not. Considering the context of these characteristics, educational institutions must undergo a fundamental transformation that provides new generations with learning spaces and transmit a culture that allows understanding our condition and favors open and free thinking. In this sense, this paper presents articles from a call for papers that aimed to share open education practices and educational innovation from socio-cultural, political, psychological, historical, economic, legal, and political perspectives, where emerging technologies and educational innovation have played a vital role in sustainable development.

## 1.1. Open education for sustainable development

Sustainability and education share an intertwined and complex path. On the one hand, sustainability depends to a large extent on quality education, as stated in the UNESCO Sustainable Development Goals (UNESCO, 2014). On the other hand, education has to be sustainable. Thus, there seems to be a cycle of interdependence that can be virtuous or vicious, depending on the context. Some authors state that there are greater sustainability challenges according to geography, because they consider that, in the so-called Global South, the minimum conditions for quality education are often non-existent. These authors also indicate that open education seems to have great potential for development in these contexts, offering the possibility of leveling the scope of training in comparison to developed economies. Kanwar et al. (2010) focus on the potential of open educational resources (OER) to provide access to quality content and guidelines for sustainable OER. Yuan and Powell (2013) are concerned with the sustainability of massive open online courses (MOOCs) and their relationship with OER. They focus primarily on the funding model and the intrinsic value of providing non-credit, no-cost materials. This sustainability is particularly important given the great potential of these educational tools under budget-constrained conditions. McGreal (2017) reinforces this notion of the potential of OER and MOOCs to achieve UNESCO's Sustainable Development Goal 4 (SDG4), particularly for developing countries, but recognizes that they are also useful for underserved communities in the Global North.

There are some common characteristics identified in the literature for open education to be effective and sustainable. Two of the most commonly named are reflection and transformation. The use of inquiry-based learning (Pretorius et al., 2016) adds value to learning experiences and supports transformative learning. Bell (2016) adds that most discussions of twenty-first century education focus on service, rather than focusing on transforming the global economy. Bell amplifies his idea and asserts that connecting education to sustainability can result in a shift from conventional to transformative educational styles. However, Wamsler (2020) does not seem to agree that the focus has not been on the global economy. Instead, she argues that sustainability science and education have focused on ecosystems, broader economic structures, technology, and governance, an approach that hinders the impact of sustainability education, as there is limited capacity to produce reflection due to the neglect of internal dimensions or capacities. However, she agrees that educational transformation is needed in order to be successfully sustainable.

Finally, the role of teaching has a definite effect on the relationship between sustainability and open education. This is even more critical when it comes to open education, where teacher involvement may be considered hidden, but never absent. Moreover, engagement with sustainability issues may be less than desired, despite having adequate policies in place, both at institutional and national levels (Tamrat, 2021). Laurillard (2008) states that teachers need to adopt an open teaching approach by becoming technology experts, sharing knowledge and materials, innovating pedagogical strategies, and taking advantage of digital technologies. This is how sustainable open education can be achieved. However, it is important that teachers share a common understanding of what open education

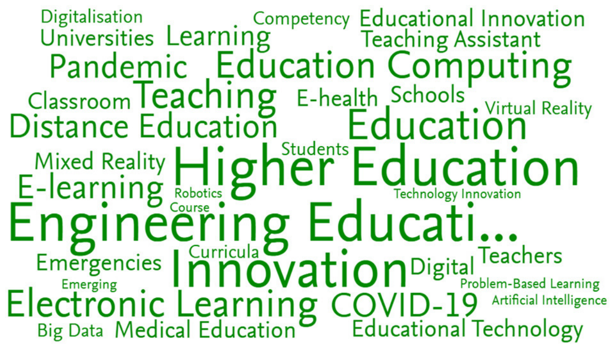


FIGURE 1
Keyphrases analysis from Scopus (2022a,b).

means. Shephard and Furnari (2013) observed that teachers have four different interpretations of education for sustainability, but only one is positive toward its development.

In summary, open education has enormous potential to promote sustainability, but it also has to be sustainable in itself. The effectiveness of any effort to educate for sustainability with open education tools will depend on adherence to a model that seeks to promote reflection and transformation. In addition, the role of the many stakeholders in the process, such as teachers, students, and policymakers, can greatly promote or inhibit its performance.

### 1.2. Emergent technologies for educational innovation in complex environments

The solution to scenarios with complex problems requires multidisciplinary collaboration, and it is necessary to emphasize aspects such as good decisions and effective communication. The presence of vanguard Information and Communication Technologies in current work environments requires a revolution of the current educational model. Therefore, today's universities must develop strategies for students to improve many skills and generate the necessary competencies to resolve the complex problems in these scenarios (Cortés et al., 2022). It is crucial to use emerging technologies in university education, with open innovation characteristics and educational strategies, to promote innovative and collaborative active learning techniques to develop skills to meet societal challenges within the context of Education 4.0. In Kanstens (2012), an example of using an appropriate technological program called InTeGrate is exposed where an educational intervention is generated for students to visualize themselves as builders and designers of a complex system with modular subsystems in the area of geosciences. This complex scenario first comprises an essential set of subsystems, then how they interact and generate parallel semi-autonomous subsystems replicating and adapting as experience accumulates. In this way, complex thinking capabilities are developed through their systemic, innovative, creative, and scientific components.

From Scopus, we can observe the key phrases to know what topics are most prominent about combining emergent technologies, educational innovation, and complex scenarios (Figure 1).

Besides broadening their disciplinary perspectives, optimizing their strategies to approach the objects of knowledge, and increasing their interrelations with various organizations (educational, business, political, and social), educational institutions must not fail to direct their objectives toward the welfare of the population. To achieve this, open education is a valid option.

Society requires new options for its welfare, where education, especially open education, offers new opportunities for sustainable development. In 2015, UNESCO identified sustainable development goals for social well-being and, in 2019, defined new recommendations for open education, calling on member states to promote actions for building open and inclusive knowledge societies and achieving the UN Sustainable Development Goals. It is vital to attract practices and research that can bring practical and scientific knowledge in support of the cutting edge of society, with social media studies underpinning open education and its implications for the sustainable development of society. In the face of dynamic changes, crises, and challenges, opportunities arise for education, science, media, and technology. Open education converges in design and practical applications with visionary, operational, and legal openness to improve opportunities for all people and contribute to the sustainable development of society.

These analyses generated the idea of creating this research monograph to continue building inter-institutional relationships to learn and share and disseminate practices of open education and educational innovation from socio-cultural, political, psychological, historical, economic, legal, and political perspectives, where emerging technologies and educational innovation play significant roles for sustainable development and the welfare of the population.

## 2. Presentation of the monographic articles

Of the total number of articles received for this Research Topic, 10 papers, consisting of two reviews and eight original investigations, were accepted. We organized the accepted contributions according to the areas of practice and research covered.

Five papers are concerned with how the COVID-19 pandemic forced teachers to implement digital tools and materials to continue their students' education. Ponce et al. proposed an undergraduate course called "Digital Control of Electric Machines" (electric drives) which implemented the Tec-21 Educational Model of Tecnológico de Monterrey, V Model, MATLAB/Simulink, low-cost hardware, and complex thinking. This course used simulations as a virtual strategy, allowing students to acquire hard and soft skills in their education. Martínez-Pérez et al. analyzed the educational possibilities of T-MOOCs for the development of digital competencies in teachers as a strategy for open education and the development of sustainable goals. The results of this study, conducted using 313 students of the Primary Education Degree at the University of Seville (Spain), revealed that training in educational technology is needed to acquire digital competencies. Pasquel-López et al. described how the COVID-19 pandemic urged educational institutions to use resources contained in public repositories, such as YouTube, turning teachers into "EduTubers." Thus, the study used social network analysis to explore the dynamics of EduTubers to understand the motivations for their interactions. Ruiz Loza et al. described how, during the pandemic, it was possible to develop mathematical

TABLE 1 Papers accepted for this Research Topic.

| The 10 papers accepted in this Research Topic | Technologies and educational innovation | Open education for sustainable development | Complex environment, robotics, and educational innovation | COVID-19 |
|---|---|---|---|---|
| Type: Original article | | | | |
| 1. Ponce et al. | X | | X | X |
| 2. Cox el al. | | X | | |
| 3. Otto and Kerres | | X | X | |
| 4. Santos-Hermosa and Atenas | | X | | |
| 5. Martínez-Pérez et al. | X | X | | X |
| 6. Class | | X | | |
| 7. Pasquel-López et al. | X | | | X |
| 8. Ruiz-Loza et al. | X | X | X | X |
| Type: Review | | | | |
| 9. Chaka | | X | | |
| 10. Montiel and Gómez | X | | | X |

competencies in undergraduate students through virtual learning environments. They used 3D visualization tools and a project-based strategy and measured the spatial skill of more than 200 students. They proved that virtual environments are useful for developing skills through active learning. Finally, the review conducted by Montiel and Gomez-Zermeño about teachers' competencies in ICT identified 23 studies related to using ICT tools during the COVID-19 pandemic. The results suggest a rise in using ICT tools in learning environments, encouraging organizations to implement UNESCO's "Information and Communications Technology Competency Framework for Teachers."

The other five papers are focused on the topic of sustainable open education. Cox et al. presented a model of open textbooks to address social justice in the classroom and to promote inclusion. The study applied Bovill's framework of inclusion in the analysis of the degrees of inclusiveness of 11 open textbook initiatives, focusing on student participation. Otto and Kerres argued that it is necessary to increase the discoverability of available OERs in different locations and platforms, adding intelligence and promoting interconnectivity. They used the learning ecosystem approach to illustrate their proposal. Santos-Hermosa and Atenas conducted an exploratory study about how openness to knowledge is being taught in Library and Information Science schools (LIS). They concluded that LIS schools are not providing formal training to gain skills and competencies in openness, and this instruction is now given by librarians. Furthermore, Class conducted a reflective report with thoughts and praxis on Open Education and Open Science as a public good. The author provided some theoretical framework with conceptual tools and suggestions for researchers on openness. Finally, Chaka reviewed published journal articles on Education 4.0 in higher education aimed to promote and develop sustainable development goals (SDGs). The author found that real-world Education 4.0 is confined to certain countries and certain higher-education institutions. Moreover, related technologies are classified as disruptive, scalable, and sustainable, and the soft skills cited are not exclusive to Education 4.0.

Table 1 presents the 10 accepted papers organized by the three Research Topics of the call, as well as the articles related to COVID-19:

The compilation of papers for this Research Topic aims to inspire and promote the research around sustainable open education, improving knowledge of technologies, and educational innovation strategies in this post pandemic time.

## 3. Conclusion and new avenues

The objective of this work was based on the understanding of the need for a shared effort to bring together as many voices and perspectives as possible to help design the paths toward the most democratic educational forms possible, with a scope never seen before, by taking advantage of the possibilities offered by new technologies and supported by the tools provided by open education.

We do not expect unique solutions, but rather that the result of the interactions of each of the contributions will allow us to take elements adjusted to the realities of each context and put them into practice in specific scenarios. Furthermore, these new ideas will be useful to establish lines of research that can show the impact of new practices. Such documentation will allow for evaluation that can serve to make precise decisions in the search for results that will benefit communities.

It is difficult to speak of the future of education when the problems of society must be solved in the present with posterity in mind. Thus, future studies must take into account that the complexities and dynamics of society mediated by information and communication technologies require short-, medium-, and long-term answers. The threats to humanity are not only epidemics, but also include the degradation of the biosphere that threatens the disappearance of species, social inequalities, and the proliferation of weapons and wars: in short, dangers to the survival of the human species. Education must become the axis that helps the development of a spirit of solidarity and responsibility centered on planetary awareness. This is a humanistic perspective with the hope of achieving a better world for all.

## Author contributions

MR-M and DH-M: conceptualization. MR-M: methodology, writing—review and editing, supervision, and funding acquisition. MR-M, GR-A, DH-M, EL-C, and CG-G: investigation. GR-A, EL-C, and CG-G: writing—original draft preparation. DH-M: visualization. All authors have read and agreed to the published version of the manuscript.

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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.

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# Rock the Boat! Shaken by the COVID-19 Crisis: A Review on Teachers' Competencies in ICT

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The COVID-19 pandemic suddenly brought great challenges to the continuation of education. Institutions had to elect between pre-maturely ending their current school cycles or shifting to an online, flexible environment that had to deal with the digital divide in internet access. As part of its Sustainable Development Agenda, UNESCO developed the "Information and Communications Technology Competency Framework for Teachers" in 2018 to help institutions achieve digital literacy and reduce the digital divide. A systematic literature review (SLR) was conducted, identifying 23 studies on the use of ICT tools during COVID-19 educational disruptions in the database ProQuest Central and Google Scholar from August 2019 to August 2020. The results of this SLR showed that frameworks such as that of UNESCO could guide institutions to fast-track the development of educational strategies for post-crisis, COVID-19 implementation. Also, findings suggest an increase in the use of ICTs in learning environments, which will encourage organizations like UNESCO to develop plans and projects, such as the ICT framework further. Coping with the challenges of today's learning environments is urgent; it is already time to "Rock the boat!" Introduction.

**Keywords: ICT competency, COVID—19, educational innovation, educational disruption, frameworks, higher education**

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## INTRODUCTION

COVID-19 is rapidly spreading around the world. Many scientists and researchers have been investigating the nature of this novel coronavirus to evaluate its short- and long-term impacts (Akram 2020). Research results show the COVID-19 pandemic has brought socio-economic disruptions and technological changes worldwide. This virus also adversely affects all educational systems around the world, forcing institutions to either pre-maturely end their ongoing school terms or adapt their operations to the requirements necessitated by COVID-19. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) estimates that 1.3 billion learners across the globe are severely affected by the shutdown of schools, colleges, and universities (McCarthy 2020). As the virus spreads daily, there is great uncertainty about when and how institutions will reopen. Within this context, educational stakeholders are preparing for post-crisis. They focus on the transition of teachers and students to online learning environments to ensure continuity of the learning process (Gudmundsdottir and Hathaway, 2020). UNESCO launched The Global Education Coalition (GEA) as a platform for collaboration, leading the movement toward innovative and flexible instruction to minimize disruption to education. GEA calls for coordinated and creative actions, applying solutions that will support not only learners and teachers, but also governments. Throughout the recovery process, the principal focus has been on inclusion, equity, digital divide and gender equality (d'Orville 2020). UNESCO has given fair warning about the need to implement

Information and Communication Technologies (ICTs) in the efforts to accelerate progress and diminish the digital divide. COVID-19 has made these issues more evident to everyone. Through the development of the Information and Communications Technology Competency Framework for Teachers (ICTCFT), UNESCO has collaborated with institutions globally to assess the use of ICTs in the educational setting. The framework also serves as a guide toward digital literacy. The internet has enabled the proliferation of online content and digital resources that support teaching and learning, albeit these vary widely in quality. However, digital education media and resources, if carefully designed and implemented, have significant potential to transform learning to support the building of sustainable, flourishing societies ("UNESCO MGIEP" 2020).

As seen through literature, ICT has the potential to stimulate growth and variability, while providing new opportunities in developing countries. However, it requires educators to develop the skills and competencies to perform tasks and solve problems. Digital Literacy (DL) summarizes these aforementioned skills, while also providing the foundation of various measuring scales to rely on while evaluating an educator as digitally literate (Reddy et al., 2020; Reddy et al., 2021). Developing DL among educators will contribute towards the achievement of UNESCO´s GEA mission.

This SLR explores and summarizes the literature written about the UNESCO ICT framework and how these works tie to the current educational environment amid the COVID-19 pandemic. While conducting our review related work, such as Yun et al., shed some light on home-based learning, particularly in K-12 education where the impact technology had on the educational landscape was reviewed (Wen et al., 2021). Abiky (2021) work addresses the challenges faced by pre-service teachers while COVID-19 restrictions were in place, and how they managed to incorporate technology into the curricula to avoid disruption in the continuation of education. Zambrano (2020) research discerns the emotional intelligence of educators and its correlation to ICT skills and technology usage in virtual environments.

Studies concerning Emergency Remote Teaching (ERT) were identified and analyzed to spot similarities with our study and converging research questions. ERT, as stated by Shamir-Inbal and Blau, offers an alternative way to preserve the teaching-learning processes Shamir-Inbal and Blau (2021). ERT is not to be confused for Distance Education (DE). As suggested by Toquero C. M (2020), DE constitutes a planned activity, and its implementation is grounded in theoretical and practical knowledge, while ERT deals with surviving a time of crisis with all resources available, both offline and/or online. Regardless of the tools, techniques or strategies selected as ERT, it will help deliver educational contents and organize communication within classes (Anthony Jnr and Noel 2021). Authors of these studies seem to coincide with the magnitude of the emergency. They also examine the unstructured manner of most responses taken by educational institutions to prevent educational disruption (Toquero C. M. D, 2020; Trust and Whalen 2020; Shim and Lee 2020; Iglesias-Pradas et al., 2021).

The results of this review show what measures countries worldwide have taken during the epidemic and what they have done to address the digital divide. Identifying the features technological tools must have to enable the continuation of education is critical; this is one of the aspects covered by the framework. Also, this review provides information about the changing role of educators and teachers in the online educational environment. How is the acquisition of new skills linked to the new roles of educators is also part of this review.

To give direction to this SLR, we proposed the following research question: Amid the educational disruption caused by COVID-19 and the consequent shift in teachers' roles, what are the technical skills and competencies that educators need to acquire to adapt to current learning environments? This served as our main objective, however we divided our review into three sub-objectives to help guide our study. These sub-objectives are later addressed in the methods and materials section.

The answers to these questions will help know whether the UNESCO-ICTCFT can serve as a guide that helps educational institutions overcome the learning disruptions caused by COVID-19 and achieve post-pandemic progress and continuity of education.

## The UNESCO Information and Communications Technology Competency Framework for Teachers (UNESCO-ICTCFT)

The Sustainable Development Goals are a universal call to action to end poverty, protect the planet, and improve the lives and prospects of everyone everywhere (Perdana et al., 2020). All United Nations (UN) member states adopted several goals in 2015 as part of the 2030 Agenda for Sustainable Development. Within this agenda, UNESCO recognizes that the prevalence of ICTs has a significant potential to accelerate progress, bridge the digital divide, and help develop inclusive knowledge societies based on human rights, gender equality and empowerment (Fallis 2013). To achieve this, UNESCO has developed the UNESCO-ICTCFT as a tool to guide pre- and in-service teacher training on using ICTs throughout education systems. This competency framework for teachers is intended to support national and institutional goals by providing a foundation for up-to-date policy development and capacity building in the dynamic area of ICT (Fallis 2013).

The UNESCO-ICTCFT version 3 responds to the 2030 Agenda for Sustainable Development adopted by the UN General Assembly, which underscores a prevalent global shift toward inclusive knowledge societies. It addresses recent technological and pedagogical developments in the fields of ICT and Education. It incorporates inclusive principles of non-discrimination, open and equitable information accessibility, and gender equality in the delivery of technology-supported education. Used by countries around the world, the UNESCO-ICTCFT highlights the role technology can play in supporting six major education focus areas across three phases of knowledge acquisition, as illustrated in **Figure 1** below (Fallis 2013):

Through its ICT competency framework for teachers, UNESCO underscores the importance of educators to foster

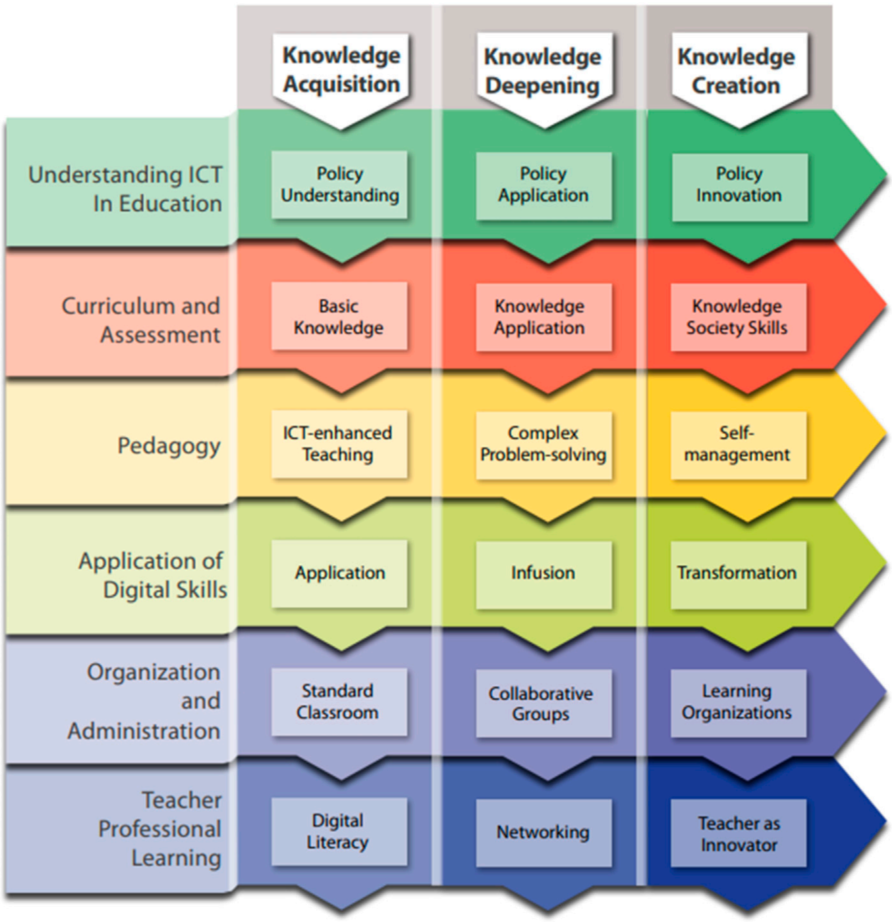


**FIGURE 1 |** The UNESCO ICT competency framework for teachers (Fallis 2013).

students' skills in collaboration, problem-solving, and creativity in the use of digital technologies. Teachers must also be equipped to manage digital technologies, allowing them to transfer these managing skills back to their students. In our digital age, these skills become part of citizenship training to participate fully in society. This digital role requires the use of ICTs for organization, communication, and research in the classroom and home, regardless of the subject taught. It facilitates access to documents and the development and modification of written, audio, and audiovisual materials, among others. This implies learners must acquire technical skills and be part of a culture that uses these technologies safely, effectively, and responsively (Saini 2020).

## Rethinking Pedagogy to Explore the Potential of Digital Technology

The Mahatma Gandhi Institute of Education for Peace and Sustainable Development (MGIEP) is UNESCO's Category one educational institution in the Asia-Pacific region dedicated to education for peace and sustainable development, as enshrined in SDG Target 4.7. UNESCO-MGIEP promotes the use of digital learning platforms where teachers and students co-create and share highly interactive learning experiences. When considering its contribution to SDG Target 4.7, which focuses on education for peace, sustainable development, and global citizenship, UNESCO-MGIEP explored digital pedagogies as a means to scale transformative learning, connecting millions of learners across the world. The global review of digital textbooks, media, and other educational resources highlighted the potential of digital technology to support and improve pedagogical methods. The focus was to bring to the fore what we do and do not know about digital education, and the gaps in research and practices that must be addressed, drawing from a body of knowledge about the role that digital technology plays in inclusive education (UNESCO MGIEP 2020).

The COVID-19 pandemic has demonstrated that it is essential to provide teachers with software that integrates pedagogical theories. However, for a decade, there have been neither enough digital tools nor the accommodating culture to develop teachers' skills, specifically in active pedagogy (Bruillard and Baron 1998; Bruillard and Baron 2018). Within this context, the UNESCO-MGIEP report emphasizes that education challenges are not only technical issues, but also


**FIGURE 2 |** SLR phases, as suggested by Brereton et al. (2007).

demand that we envision the kind of world in which we want to live. To understand what is at stake and support transformative education, we need to adopt a historical and contextualized approach. We must avoid technological determinism and uninformed advocacy to shift from anachronistic, "analog" pedagogy to innovative, "digital" pedagogy. Technological determinism refers to the theory of how a society ´s technology can determine its values, structure and history. Depending on how they are designed and used, digital educational media and resources can either promote or undermine opportunities for "learning to learn" and "learning to think." These capabilities are essential foundations for educational innovation. Also, our ethical discernment and sense of responsibility are needed if we harness machines to shape a peaceful and sustainable society (Hosmana et al., 2020).

# MATERIALS AND METHODS

We conducted a systematic literature review to identify the skills and competencies educators must acquire due to the academic disruption caused by COVID-19, which has forced a change in teachers' roles. We also wanted to know if UNESCO's ICT CFT could serve as a guide for institutions to follow to promote the use of ICT in educational settings, overcoming the disruption and ensuring academic continuity. Following the principles stated by Brereton et al. (2007), we intended this review to evaluate and interpret all available research relevant to a particular research question, topic, or phenomenon of interest. We grouped the SLR activities into three main phases (see **Figure 2**).

## Plan Review

The first phase of the SLR methodology described by Kitchenham et al. (2010) involves developing and validating a strategy around specific research questions. These questions should be based on the knowledge gaps identified in the field of study (Ramírez-Montoya and García-Peñalvo 2018).

### Research Questions and SLR Protocol

To generate the relevant information about which technical skills and competencies educators need in current learning environments, we established three sub-questions for this SLR to provide insight into whether UNESCO-ICTCFT can be a guide to help institutions deal with the academic disruption caused by COVID-19. Some aspects covered by UNESCO's framework were analyzed within the studies to know the impact they have on the current educational status due to COVID-19. **Table 1** shows the proposed SLR research questions.

### Database and Search Terms

We selected *Google Scholar* and *ProQuest Central* for our review to include academic publications. Although there is criticism for the use of Google Scholar as a source of scientific information, as seen in Beel and Gipp (2010), Jacsó (2012), Mayr and Walter (2008), and Boeker et al. (2013), there is also evidence presented in Halevi et al. (2017) of its advantages over controlled databases. The decision to include both Google Scholar and a controlled database in *ProQuest Central* may be perceived as biased selection, which is presented as a limitation of this study. We created search strings for each of the research questions (see **Table 2**). Keywords such as "Education," "UNESCO," "COVID-19" and "Technology" were used to construct our search terms, while using a Boolean "AND" to join the main terms, and "OR" to include synonyms (Brereton et al., 2007).

### Inclusion and Exclusion Criteria

A set of detailed inclusion and exclusion criteria was designed to identify whether a study could help answer the specified research questions (Brereton et al., 2007). Many studies found that the economic and social repercussions of the pandemic were not of interest to this investigation. The scope of this review considered academic publications covering the period of the COVID-19 pandemic, thus limiting the publication date to 2019 forward. **Table 3** shows the full list of inclusion and exclusion criteria.

**TABLE 1 |** Research questions of the SLR.

| No | Research question |
|---|---|
| RQ1 | What measures have countries, regions, or districts taken to address the digital divide the pandemic has brought to light in their territories? |
| RQ2 | What features must digital tools possess to be seen by teachers as possible support to overcome the academic disruption brought about by COVID-19? |
| RQ3 | How was the role of teachers affected in the learning environments after the educational disruption brought about by COVID-19? |

**TABLE 2 |** Search strings in ProQuest Central and Google Scholar.

| Research question | Database | Results |
|---|---|---|
| (education AND technology AND teachers AND UNESCO AND skills AND digital AND (coronavirus OR COVID-19)) AND (stype.exact("Scholarly Journals") AND pd(20190705-20200,705)) | Google Scholar | 402 |
| (education AND technology AND teachers AND digital AND (coronavirus OR COVID-19)) AND (stype.exact("Scholarly Journals") AND pd(20190705-20200,705)) | Proquest | 89 |
| (education AND technology AND teachers AND UNESCO AND skills AND digital AND (coronavirus OR COVID-19) AND ("digital divide")) AND (stype.exact("Scholarly Journals") AND pd(20190705-20200,705)) | Google Scholar | 146 |

**TABLE 3 |** Inclusion and exclusion criteria.

| Inclusion criteria | Exclusion criteria |
|---|---|
| Academic publications | Non-academic publications |
| Publishing date no older than 2019 | Studies that focus on COVID-19 disruptions outside of Education |
| Studies that focus on COVID-19 educational impacts | |
| Studies that mention UNESCO-ICTCFT | |

### Limitations of the Study

Possible limitations of this study include the use of Google Scholar and ProQuest Central as primary sources used to conduct this study. There is an ongoing debate among SLR authors whether multiple databases should be used in a review (Zhao and Guo, 2014; Bramer et al., 2017) leading to conclude that it depends on the reader´s point of view, however this is a potential critique to this study. Another potential limitation could be the publication dates of the articles selected for the study. Given the COVID-19 pandemic started in 2019, we decided to limit the scope of the review to publications no older than 2 years (2019-presenet). It is pertinent to acknowledge that this review presents some findings of initiatives and measures taken around the globe to avoid disruption of education. The fact that the review contemplates projects of only some countries could bias the study towards generalizing results. Future work could dwell in the complete list of articles listed in the review, and a more comprehensive search as the topic develops, to perhaps offer a more conclusive perspective towards the issue. COVID-19 educational initiatives and projects are still being developed and implemented at the time of this study, enticing future research to be done.

## Conduct Review

During this phase, the studies that fulfilled the search terms for each research question were input into a spreadsheet (Link: https://figshare.com/s/10db772cfffcfae091c9). The search produced 637 results, which were then filtered to eliminate duplicates. Once the duplicates were removed, a detailed review was conducted to assess the relevance of the studies to the proposed research questions. This review discarded 602 studies either as duplicates or not relevant to the research questions for this review, rendering 23 studies (see **Table 4**), that met the protocol developed in the first phase of the methodology. **Figure 3** illustrates the process that took place for the selection of the studies.

## Document Review

The final phase of the proposed methodology involved creating and validating the results of the study.

# SLR RESULTS

## RQ1 what Measures Have Countries, Regions, or Districts Taken to Address the Digital Divide the Pandemic has Brought to Light in Their Territories?

One of the six aspects covered by the UNESCO-ICTCFT framework, "Organization and Administration," suggests ways to manage the digital assets of schools and provide safeguards for

**TABLE 4** | Studies selected for the review.

| No | Authors | Item type | Title |
|---|---|---|---|
| 1 | Adzovie et al | Conference Proceedings | E-Learning resulting from COVID-19 pandemic: A conceptual study from a developing country perspective |
| 2 | Akram, Waqar | Journal Article | Scenario Analysis and Proposed Plan for Pakistani Universities COVID-19: Application of Design Thinking Model |
| 3 | Ali, Wahab | Journal Article | Online and Remote Learning in Higher Education Institutes: A Necessity in light of COVID-19 Pandemic |
| 4 | Bhaumik, Rikisha; Priyadarshini, Anita | Journal Article | E-readiness of senior secondary school learners to online learning transition amid COVID-19 lockdown |
| 5 | Bozkurt et al | Journal Article | A global outlook to the interruption of education due to COVID-19 Pandemic: Navigating in a time of uncertainty and crisis |
| 6 | Chabbott, Colette; Sinclair, Margaret | Journal Article | SDG 4 and the COVID-19 emergency: Textbooks, tutoring, and teachers |
| 7 | CoSN | Journal Article | COVID-19 Response: Preparing to Take School Online |
| 8 | Dawadi, Saraswati; Giri, Ram; Simkhada, Padam | Journal Article | Impact of COVID-19 on the Education Sector in Nepal - Challenges and Coping Strategies |
| 9 | Flack et al | Miscellaneous | Educator perspectives on the impact of COVID-19 on teaching and learning in Australia and New Zealand |
| 10 | Huang et al | Journal Article | Guidance on flexible learning during campus closures: Ensuring course quality of higher education in COVID-19 outbreak |
| 11 | Kaden, Ute | Journal Article | COVID-19 school closure-related changes to the professional life of a k-12 teacher |
| 12 | Kaur, Naginder; Bhatt, Manroshan Singh | Journal Article | The Face of Education and the Faceless Teacher Post COVID-19 |
| 13 | Keefe, Elizabeth Stringer | Journal Article | Learning to Practice Digitally: Advancing Preservice Teachers' Preparation via Virtual Teaching and Coaching |
| 14 | Onyema et al | Journal Article | Impact of Coronavirus Pandemic on Education |
| 15 | Reich et al | Report | Remote Learning Guidance From State Education Agencies During the COVID-19 Pandemic: A First Look |
| 16 | Santiago et al | Journal Article | Learning management system-based evaluation to determine academic efficiency performance |
| 17 | Sherrard, Daniel | Report | RUFORUM THOUGHT PIECE ON COVID-19 The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), www.ruforum.org |
| 18 | Szente, Judit | Journal Article | Live Virtual Sessions with Toddlers and Preschoolers amid COVID-19: Implications for Early Childhood Teacher Education |
| 19 | Toquero, Cathy Mae Dabi | Journal Article | Inclusion of people with disabilities amid COVID-19: Laws, interventions, recommendations |
| 20 | d'Orville, Hans | Journal Article | COVID-19 causes unprecedented educational disruption: Is there a road towards a new normal? |
| 21 | Krönke, Matthias | Journal Article | Africa's digital divide and the promise of e-learning |
| 22 | Romero-Tena et al | Journal Article | The challenge of initial training for early childhood teachers. A cross sectional study of their digital competences |
| 23 | MagalhÃes et al | Journal Article | Online vs traditional homework: A systematic review on the benefits to students performance |

the people who use them. The suggestions depend entirely on the extent to which ICTs are integrated into the country, district, or school in question (Fallis 2013; CoSN 2020). The academic disruptions brought about by COVID-19 varied among countries, regions, and districts, making evident the digital divide globally, and that constrains the suggestions from UNESCO-ICTCFT (Reich et al., 2020; United Nations Educational Scientific and Cultural Organization, 2020). The purpose of this research question was to analyze the different measures taken by institutions or governments to limit the interruption of education while acknowledging their limitations and capabilities.

The first study was found in Italy, where the University of Bologna extended deadlines for tuition fees and distributed free SIM cards to students without access to internet (Ali 2020). These measures depend on internet access, in addition to data and devices, to provide continuity of teaching and learning (Bozkurt et al., 2020). Another study took place in Saudi Arabia, where schools and universities were ordered to close down by the Ministry of Education because of COVID-19. The government, however, directed that "Virtual schools and distance education be activated to ensure that the educational process continues in an effective and quality manner" (Onyema et al., 2020). The Philippines enacted alternative delivery plans as one of the government responses to address the educational needs of learners. However, educational and legislative emergency preparedness plans must include provisions for students with disabilities throughout this pandemic (Toquero C. M. D. 2020). These plans deal with continuity, but, most importantly, they must offer inclusiveness by respecting UDL and principles of non-discrimination, equal access to information, and gender equality in education (Fallis 2013).

One example where ICT in education has been explored is in Ghana. This country faces numerous challenges, including access to internet and data, support and guidance for students for easy navigation of courses online, the quality of technology being deployed, and access to the technology. These problems are particularly relevant to developing and underdeveloped countries (Adzovie et al., 2020). The shift to online education has highlighted the stark digital divide between those who have access to electricity, internet infrastructure, data, and devices, and those who do not. As of 2019, only 39.6% of Africans have internet access, compared to 87.7% of Europeans and 95% of North Americans (Bozkurt et al., 2020). These statistics provide

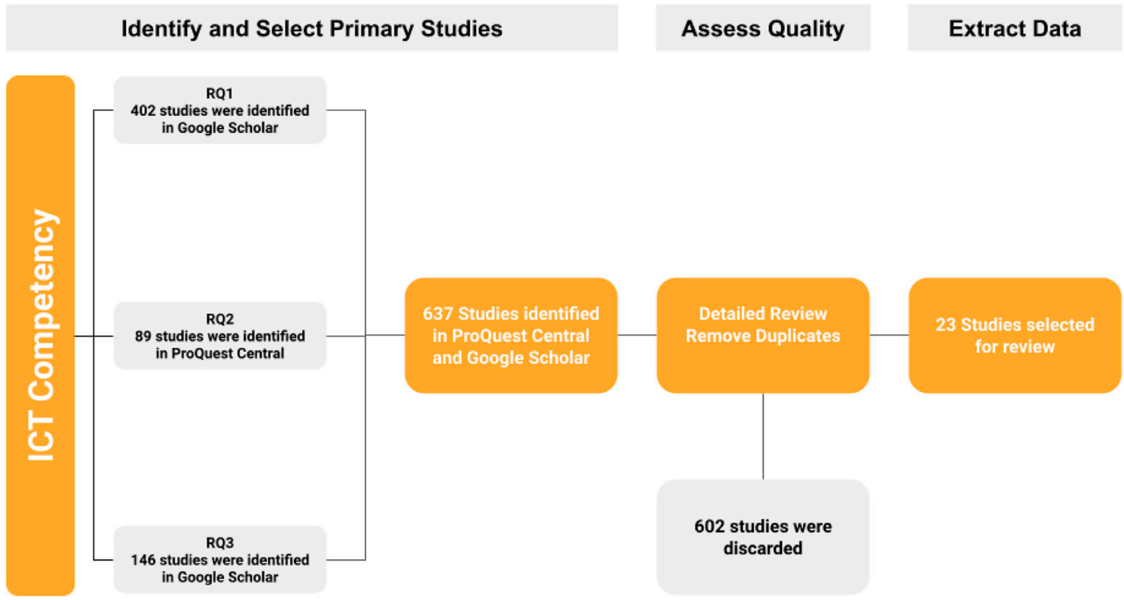


**FIGURE 3 |** The review phase.

some context as to how context affects DD, but it does not account for effective use of digital tools. It is one thing to have access to digital resources, it is another to use them effectively. While there are several collaborative platforms for remote learning that do not require an internet connection, the access to the internet vastly increases the range of tools that schools, educators, and students can use to study and share knowledge (Krönke 2020). Pakistan has acknowledged the importance of technology, and thus has allocated the budget of 77.3 billion PKR for educational affairs and services during the fiscal year 2019—20. Of this, 28.64 billion PKR has been allocated for HEI, 2.83 billion PKR for the primary education section, and 6.72 billion PKR for the secondary education sector (Akram 2020).

Unless scholarships and other educational opportunities are maintained and hopefully increased, fewer economically disadvantaged students will have the chance to access higher education (Sherrard 2020). Given this circumstance, access to digital assets in an institution is crucial to the delivery of education throughout the pandemic.

## RQ2 what Features Must Digital Tools Possess to be Seen by Teachers as Possible Support to Overcome the Academic Disruption Brought About by COVID-19?

The application of digital skills in the learning environment is another aspect covered by UNESCO-ICTCFT. Either a simple word processor or a more complex networking app plays a role in strengthening and enhancing learning. UNESCO suggests the learning community should determine the tools appropriate to the task at hand (Fallis 2013), which is the continuation of education. We aimed to recognize what features the learning community identified as favorable for digital tools to serve as possible solutions to the academic disruption brought about by COVID-19.

Santiago et al. (2020) identify innovative teaching-learning processes using ICTs in Personal Learning Environments (PLEs), which allows students to study off-campus without the need for a teacher-student encounter. This e-learning model also serves as a way to expedite the learning process (d'Orville 2020). The COVID-19 pandemic has led to physical distancing, but the use of digital tools means school activities do not have to stop (Magalhães et al., 2020).

Heidi Gautschi (Schwartz et al., 2020), an Associate Professor of Media Literacy at Haute Ecole Pédagogique de Vaud (Switzerland), used "learnflow.ch" to design an online course providing the necessary skills and knowledge for students during the pandemic. She suggested the essential content and features an online course should have: it should deliver course content in easy-to-digest pieces, provide simple and effective activities, offer students mechanisms to evaluate other students' work, have clear boundaries for student communication, avoid teacher overextension, and remind students, colleagues, and parents to be compassionate (Schwartz et al., 2020).

Dawadi et al. (2020) identified four types of students in terms of their access to digital services and internet: 1) Students without access to any form of digital means and internet, 2) students whose parents have access to mobile devices) students whose parents have adequate access to mobile phones, but limited access to the internet and other digital devices, and d) students whose family members have access to several digital devices, internet and sufficient digital literacy to use. Recognizing which group is being attended should be a factor to consider when evaluating digital tools (Santiago et al., 2020). Flack et al. (2020) recommend institutions identify what good distance learning looks like and what innovations are occurring in schools across their region. This promotes an accessible multi-platform approach that combines the right features, including support for learning in even their under-resourced institutions.

Any form of digital learning resource should be assessed and selected with the following criteria in mind, as stated by Huang et al. (2020): *licensing*, whether it is open or agreed that the resource could be disseminated and adapted legally; *accuracy and quality,* meaning educators should consider reliable resources and platforms with known publishers or content; *interactivity* referring to resources with interactive elements that help increase the learning engagement and motivation of students; *adaptable resources* that allow contents to be modified and mixed to fit a specific learning context; and finally, *culturally relevant and sensible resources* that do not offend any given race or culture.

## RQ3 How was the Role of Teachers Affected in the Learning Environments After the Educational Disruption Brought About by Covid-19?

Our last research question details the pedagogical and teacher professional learning aspects of UNESCO-ICTCFT. We decided to analyze any information pertaining to the change in roles for teachers and the skills associated with these changes that support effective teaching and learning methods. We wanted to know the repercussions that the new skills have on the learning objectives specified in a defined curriculum. Most importantly, how does a role/skill shift allow teachers to reinterpret the curriculum to function effectively within knowledge societies, and how are authentic assessment strategies devised to monitor development, progress, and outcomes (Fallis 2013)?

Some studies addressed the sudden shift of roles COVID-19 brought to teachers and educators (Chabbott and Sinclair 2020). As Bozkurt et al. (2020) mention, learners had to suddenly regulate their own learning and become digitally savvy. Educators have had to switch to online teaching overnight regardless of their comfort level, familiarity, and training in digital technologies. Children's lives also got turned upside down, substituting on-screen contacts for teachers and friends, while parents, caregivers, and older siblings suddenly found themselves in emergency homeschooling roles (Szente 2020). Some authors, like d'Orville (2020), state that this change in roles due to disruption and uncertainty led to digital technology being used to create personalized solutions for each student based on his/her knowledge and learning style.

It is important to recognize the different settings of institutions and stances they took toward this change in learning dynamics. As Chabbott and Sinclair (2020) state, mobilizing households in densely populated and fragmented urban neighborhoods requires different skills and approaches than in smaller, stable towns or sparsely populated rural areas. The role parents play in distance learning as supports was mentioned throughout the studies. For example, Flack et al. (2020) state that guardians need time and resources to help their students, which means they must master the preferred digital learning platforms promptly. Having to deal with learning platforms on short notice adds pressure on teachers and parents, especially those with limited digital skills and limited resources for continued education (Onyema et al., 2020).

The acquisition of skills by educators and teachers needs to be flexible and mobile as learners move from a traditional system to online learning (Bhaumik and Priyadarshini 2020). This may cause some teachers to struggle, as their roles are changed from a primary input provider to a facilitator of learning who "rocks the boat" drastically, often outside of their comfort zones (Kaur and Singh Bhatt 2020). No longer are teachers viewed as knowledge transmitters who merely prepare lesson plans and deliver them in class. Now they need to continually adapt, change, and shift to meet the changing needs of their students (Keefe 2020). One global trend is the inclusion of sustainability in education, which is why teachers and students are increasingly focused on the acquisition of skills or attributes that lead to academic success (Santiago et al., 2020).

While some studies focused on the multiple and complex factors that influence the integration of ICT in educational settings, others focused on the ways teachers integrate them in teaching and learning. Whether technologies are used or integrated into the classroom depends on the intentions and capacities of teachers to learn and integrate them, more than whether the technology is available or not (Romero-Tena et al., 2020). The shift toward distance learning and virtual settings was not new, but the sudden shift in role to many teachers during the crisis was new (Kaden 2020).

# DISCUSSION

Following UNESCO-ICTCFT, our review identified how institutions could address COVID's academic disruption by focusing on some aspects covered by the UNESCO framework. The results of this review aim to show what measures countries worldwide have taken during the pandemic and how they are dealing with the digital divide.

This SLR was helped mainly by the Organization and Administration section of the framework, which acknowledges the digital divide and encourages educators and institutions to find innovative ways to address it using educational assets. The digital gap between the "haves and have nots" was even more present when students and teachers were confined to work from "home," heavily relying on technology to overcome the interruption to education. Bozkurt et al. (2020) mention that those privileged to have data, devices, and digital literacy can shift to emergency remote education far more easily than those who do not have such affordances. Examples of how COVID-19 accelerated ICT implementation plans worldwide include Belgium moving all their lectures online, Pakistan shifting to virtual learning environments, and governmental dependencies in Africa provisioning smartphones and computers to students (Akram 2020; Krönke 2020).

At the basic level of Organization and Administration in the UNESCO framework, teachers are encouraged to physically arrange the classrooms and labs to accommodate the integration of ICT into their lessons. In the current situation, the classrooms and labs suddenly moved to online environments, potentially limiting educators' leeway in this matter. Nevertheless, the framework advises teachers to devise implementation strategies to identify and set up technological tools that enhance teaching and learning, regardless of the medium. Identifying the features that these tools need to have to facilitate the continuation of education is a critical detail covered by the framework.

Although different technologies were implemented to address the educational disruption caused by the pandemic, they all revolved around simplicity and effectiveness. That being said, it is also true that technologies must facilitate social distancing to prevent the virus from spreading. In our review, we saw that institutions and organizations tailored ICTs to their infrastructure. They ranged from robust online course platforms to more traditional technologies like radio and television (Dawadi, Giri, and Simkhada 2020; Schwartz et al., 2020). Studies agreed that it was important to identify the level of access to technology at the institution in question, as this would help determine equitable educational resources.

Therefore, the framework requires educators to identify the hardware and software solutions that could be integrated into digital learning environments. Moreover, it looks to an environment of blending and coexistence where students learn to self-regulate and collaborate. Also, it provides information about the change in the role that educators and teachers undergo in the online environment, and suggests the skills linked to the new role that they must acquire.

The abrupt and rapid change to dynamic distance learning brought teachers a sense of being replaceable. However, as Wright (2013) states, with or without technology, teachers will remain inherently indispensable, but will endure qualitative evolution in the education of students. As more and more ICTs are implemented in the learning process, institutions must prepare candidates with the digital competencies they need and examine how regulatory teacher preparation can be met in a virtual environment (Keefe 2020). This preparation will never cope with the students' rate at which they gain access to knowledge, or even how they learn a technical skill through a few clicks. Therefore, a re-evaluation of the responsibilities and duties of an educator needs to happen (Kaur and Singh Bhatt 2020).

Needless to say, new pedagogical skills play a role just as important as technology in engaging future digital teaching and learning methodologies. As discussed, UNESCO encourages educators to take up alternative student-centered pedagogies, ideally favoring problem resolution, collaboration, and cooperation. Teachers should design and support ICT learning activities, which can help students achieve self-management. Students could potentially determine their own learning parameters, which will be monitored and supported by their teachers.

Educators will shift from knowledge transmitters and input providers into facilitators of content. Consequently, institutions will place a greater focus on students' engagement and motivation to learning. This in turn will require teachers to develop interpersonal skills and values to sympathize with students' needs while effectively managing their groups (Kaur and Singh Bhatt 2020). Openness for educators will be key to supporting innovative learning methodologies, as ICT by itself will not suffice, as Bozkurt et al. (2020) state that "teachers should demonstrate their emotional presence, build a sense of community, support and care for students," allowing them to show empathy for their students.

It is important to acknowledge this shift in educators' roles, but it is even more important for institutions to support teachers in achieving digital literacy through professional development. Furthermore, the framework suggests educators should develop a personal learning network, allowing them to share expertise and resources and interact with peers who share their interests. Given the current situation, being able to connect with other educators and share experiences on how they or their institutions handle educational disruption is paramount. Lave and Wenger (1991) work states the importance of situated learning in communities of practice, specifically on how old-timers (experienced tenured teachers) could influence newcomers (recently promoted teachers) into growing and carrying on the community, thus preserving knowledge and skills shared among the community. These interactions will, in turn, foster innovation throughout the institution, promote continuous learning among colleagues, and finally, as intended by the framework, support the ICT strategy developed by the organization.

## CONCLUSION

There is no assurance when and how the pandemic will end, and, more importantly, what effects it will have on educational settings. COVID-19's disruption brought many challenges to teachers, as existing lesson plans were no longer adequate. Teachers were challenged to learn new technologies quickly, while suddenly removed from their students. Many teachers will consider this the most traumatic and transformative event of the modern era. Any post-pandemic changes that prevail will surely depend on frameworks like UNESCO's to monitor and evaluate an institution's use of ICTs, but most importantly, to prepare organizations to respond adequately to future disruptions to education.

To orientate this SLR, we had proposed the initial research question that, given the shift in educators' roles due to the educational disruption brought about by COVID-19, which technical skills and competencies do educators need to adapt to current learning environments? We can conclude by the studies that the skills and competencies acquired depend on the organization's access to ICT and the level of competency of educators and teachers. Surely, UNESCO's intention with its ICT CFT was not to offer a short-term solution to organizations for the educational disruptions of COVID-19, but rather to serve as a framework to determine the level of ICT implementation needed within an educational organization, as part of UNESCO MGIEP, 2020 Agenda for Sustainable Development. Projects and plans in different domains, not just education, have been fast-tracked around the globe. The institutions rely heavily on technology to achieve their goals, while also observing the social distancing imposed by the COVID-19 pandemic. Organizations committed to UNESCO-ICTCFT have had advantages because they became familiar with the framework and how the different aspects of ICTs impacted their institutions.

Our SLR results showed that frameworks such as UNESCO's could serve as guides for institutions to fast-track the development of educational strategies post-crisis COVID-19 to cope with the new learning environments.

## RECOMMENDATIONS FOR FUTURE RESEARCH

These times of uncertainty allow no predictable outcome for the educational disruption caused by COVID-19. Institutions are cautious about reaching for what could be considered disruptive solutions, reluctant to break traditional and successful educational models. When the pandemic ends and schools return to traditional settings, we can see better what measures and dynamics will remain and become part of the everyday educational settings. One thing for sure, regardless of the outcome, there will be an increase in the use of ICTs in learning environments, which will encourage organizations like UNESCO to develop plans and projects, such as the ICT framework further. COVID-19 has brought great challenges to the educational setting, prompting organizations, students, researchers, and educators to find innovative solutions to overcome the disruption of educational continuity. The field of education has suffered losses, but we must not allow ourselves to be empty-handed once the pandemic is over. There is a need to disrupt the current educational setting. It is time to "Rock the boat!"

## AUTHOR CONTRIBUTIONS

HM and M-ZG contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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# Is Education 4.0 a Sufficient Innovative, and Disruptive Educational Trend to Promote Sustainable Open Education for Higher Education Institutions? A Review of Literature Trends

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The paper explored whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for higher education institutions (HEIs). To investigate whether this is the case, the paper reviewed published journal articles that provide real-world, empirical applications of Education 4.0 in the higher education (HE) sector that are intended to promote and realize the United Nations' (UN) sustainable development goals (SDGs). In particular, the paper focused on aspects of SDGs related to education (or to sustainable open education), and which had relevance to the HE sector. Three of the findings of this review study are worth mentioning. First, real-world Education 4.0 is confined to certain countries, and is more concentrated to a few countries and to a few HEIs. Second, ten sets of Education 4.0 technologies were classified as disruptive, scalable, and sustainable, and as holding the prospect to promote sustainable open higher education in accord with the UN's SDGs. Thirdly, most of the soft-skill affordances cited (especially the twenty-first century skills cited), lend themselves well as *stylized facts* as they predate Education 4.0 and are, thus, not exclusive to it.

**Keywords: higher education, Education 4.0, fourth industrial revolution, Industry 4.0, sustainable open higher education, innovation**

## INTRODUCTION

During crises and human pandemics, new changes and unexpected challenges emerge, necessitating new ways of doing things. This seems to have been the case with the current novel coronavirus disease-2019 (COVID-19) pandemic. The pandemic has not only caused major sudden changes, but it has also put a halt to the old ways of doing things in different spheres of life. Education in general and, particularly, higher education (HE) has not been immune to such pandemic-induced abrupt changes and their associated challenges. Elsewhere, Chaka (2020a) refers to this rapid change scenario as episodic outbursts and massive disruptions accompanied by a series of punctuated changes. And, these punctuated changes appear to continue unabated, given the flowing and ebbing of the viral infections and the on- and off-lockdown measures across the globe. Prior to the pandemic, and more so during and post-pandemic, certain digital innovations were already being touted as possible solutions for, especially, the HE sector.

One such digital innovation is Education 4.0. Since its pre-pandemic days, Education 4.0 was already being seen as holding the prospects of being a game-changer within the HE sector. Indeed, Sharma (2019) points out that Education 4.0 will enable students to remotely access courses and register for them based on diverse open online courses, voice calling, and video chatting. In this particular setup, data will be leveraged to extrapolate courses in which students will likely to enroll in large numbers and to predict their likely future employability based on the knowledge and skill sets they possess (Salomon, 2019). As such, Education 4.0 is seen as a disruptive educational innovation capable of unbundling the HE system in favor of repackaged, personalized, and peer-to-peer learning offerings (Fisk, 2017). In this instance, the disruptive nature of Education 4.0 and its game-changing capability serve as one of its main differentiators. This relates, primarily, to reconfiguring the HE system, disaggregating its course offerings, and the kinds of technologies through which students are to access its course offerings and interact with those course offerings. This means that Education 4.0 also represents an educational and innovative disruptor. At one point, information technology (IT) was touted as a game-changer (Oblinger, 2012) and as an educational and innovative disruptor, too.

Against this background, a case can be made that Education 4.0 is what open and inclusive higher education needs in order for different nations to be able to achieve the United Nations' sustainable development goals (SDGs). But not only that, rather, the rupturing effects of the COVID-19 pandemic require a rethinking of how HE is offered. Therefore, this paper set out to explore whether Education 4.0 is a sufficient innovative, and disruptive educational development to promote sustainable open education for higher education institutions (HEIs). To do so, it reviewed published journal articles that provided real-world, empirical applications of instances of Education 4.0 in the HE sector that were intended to promote and realize the UN's SDGs (Ally and Wark, 2020; Bai et al., 2020; Zizka and Varga, 2020). The review took into account that Education 4.0 is a broad, overarching concept that is informed by the Fourth Industrial Revolution (4IR) (Chaka, 2020b). It also considered its variation such as Higher Education 4.0 and cognate technologies related to 4IR such as artificial intelligence (AI), automation, robotics, blockchain, big data, cloud computing, augmented reality (AR), virtual reality (VR), and the Internet of Things (IoT) (Ally and Wark, 2020; Chaka, 2020b), as long as they had a specific relation and a direct application to Education 4.0 and sustainable open education, or SDGs.

## SITUATING EDUCATION 4.0 AND INNOVATION

There are different types of HEIs. Conventionally, the two main types of HEIs are traditional universities (either research-intensive or non-research-intensive universities) and universities of applied sciences (cf. Andreadakis and Maassen, 2019a). Mostly, the typology of HEIs varies according to countries in which HEIs are situated. For instance, some countries have a more nuanced differentiation between their HEIs. Classic examples are technical/technological HEIs, medical universities, business and management sciences HEIs, pedagogical HEIs, and theological HEIs (see Eurydice, 2021). So, this HE landscape typology is important to note.

Since this paper's main focus is on HE, its use of Education 4.0 is solely restricted to this sector, notwithstanding the fact that this term often has a generic application. That is, Education 4.0 is used to embody the same meaning as Higher Education 4.0 or University 4.0. The paper posits that Education 4.0 is an educational derivative of the Fourth Industrial Revolution (4IR). In this sense, it is informed and underpinned by the same cognate and flagship technologies as those attributed to 4IR. Some of these technologies are: autonomous robots; artificial intelligence (AI); cloud computing; quantum computing; big data; smart sensors; virtual reality (VR); augmented reality (AR); the Internet of Things (IoT); or Industrial Internet of Things (IIoT); simulation; additive manufacturing; 3D printing; holograms; and drones (Keser and Semerci, 2019; Reaves, 2019; Salomon, 2019; Sharma, 2019; Bongomin et al., 2020; Butt et al., 2020; Chaka, 2020b, 2021). A digital fusion and embedding of these cluster technologies within a cyber-physical system (CPS) is a key differentiating factor of this 4.0 technological development. Two of Education 4.0's variants, or two of its equivalents within the HE landscape are Higher Education 4.0 (Chea and Huan, 2019; Sharma, 2019; Goh and Abdul-Wahab, 2020; Adnan et al., 2021) and University 4.0 (Gueye and Exposito, 2020). In addition, on a comparative basis, Education 4.0 is an advanced version of its preceding iterations such as Education 1.0, Education 2.0, and Education 3.0 in the same way as 4IR is an advanced iteration of its predecessor technologies in the form of Industrial Revolution 1.0, Industrial Revolution 2.0 and Industrial Revolution 3.0, and Industry 1.0, Industry 2.0 and Industry 3.0, respectively (Chea and Huan, 2019; Sharma, 2019; Butt et al., 2020; Chaka, 2020b; Miranda et al., 2021). Another similarity is that of Web 4.0 when it is compared to Web 1.0, Web 2.0, and Web 3.0 (Keser and Semerci, 2019; Salomon, 2019).

In this context, Education 1.0, 2.0, 3.0, and 4.0 can each be seen as a download education, an open-access education, a knowledge-producing education, and an innovation-producing education (Himmetoglu et al., 2020)., respectively. For her part, Sharma (2019) points out that these four versions of education each represents: the era of memorization; the dawn of Internet-powered education; the era of education as consumption; and the advent of a change-driven education. Butt et al. (2020) characterize each of these four iterations as corresponding to: a one-way, passive educational process (Education 1.0); a collaborative education with passive and active learning (Education 2.0); an open, collaborative, flexible, and creative education (Education 3.0); and an education marked by a dynamic, independent, active, innovative, and self-directed learning (Education 4.0).

Notwithstanding the differing definitions attached to these four codes of education, what is clear is that the last iteration (Education 4.0) is conceptually, radically different from its three other counterparts. In light of the preceding characterization of Education 4.0, for this paper, Education 4.0 is, especially in the HE sector, an education that leverages and is powered by all of the currently available 4IR technologies including the relevant future technologies as long as they are classified under the 4IR code name. In this instance, the paper proposes three types of Education 4.0: a fully integrated Education 4.0, a near-fully integrated Education 4.0, and a partial Education 4.0. The first is as described in the preceding sentence; the second entails the use of a number of different Education 4.0 technologies, but not all of them; and the third incorporates the use of one to three different Education 4.0 technologies. This distinction is critical as Education 4.0 is, at times, like 4IR, vaguely constructed. Overall, whatever type it is and whatever permutation it assumes, Education 4.0 is about integrating and leveraging these technologies for educational purposes (Gueye and Exposito, 2020).

## Core Features of Education 4.0

Education 4.0 comprise certain core features. These features include:

- Integration and fusion of various digital technologies (e.g., the 4IR technologies mentioned above and others not cited above) and mobile technologies
- Flipped classrooms, massive open online courses (MOOCs), social network-based learning, smart campuses, seamless learning environments, and open educational resources (OERs)
- Open and distance learning, open access, lifelong learning, application-oriented learning, adaptive learning, individualized learning, and self-paced learning (Himmetoglu et al., 2020).

Most of these features such as those listed in the last two bullets, bar smart campuses, are not new, though. That is, they do not owe their origin to 4IR/Industry 4.0 nor did they come into existence due to 4IR/Industry 4.0. It is their incorporation into the 4IR/Industry 4.0 paradigm that makes them eligible features for Education 4.0. Importantly, it is the digitization and automation, and the integration and harnessing of human and technological capabilities within the physical, digital, and biological spaces of education that spawn Education 4.0. Concerning the HE sector, this development results in Higher Education 4.0 or University 4.0.

## Innovation

As a concept, innovation predates the advent of Education 4.0. For example, throughout human history, innovation has permeated different spheres of life in sector-specific ways. The same is true of education as a sector with multiple layers. Elsewhere, Serdyukov (2017) maintains that innovation entails developing a novel idea, a change, and a disruption. To this effect and narrowly, there is educational innovation or technological innovation. Serdyukov (2017) also argues that innovation is revolutionary or evolutionary (also see Osolind, 2012), and disruptive or sustaining (also see Yu and Hang, 2010; Christensen et al., 2018; Kylliäinen, 2019). Revolutionary innovation leads to a wholesale change, resulting in a complete replacement of the old system with the new one; evolutionary innovation is about incremental improvements, and ensures continuity. Disruptive innovation leads to a radical change of the whole system, while sustaining innovation preserves the current *status quo* (Serdyukov, 2017). The paper contends that Education 4.0 can assume any of these four permutations in terms of its innovativeness. Moreover, the innovative form that Education 4. 0 assumes is likely to determine whether it is sustainable, disruptive, and scalable or not, and whether it can lead to sustainable open higher education in line with the UN's SDGs or not.

# PURPOSE OF THE STUDY

The purpose of this study was to explore whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for HEIs. To investigate whether this was the case, the paper reviewed sixteen published journal articles that documented real-world, empirical applications of Education 4.0 in the HE sector that were intended to promote and realize the UN's sustainable development goals (SDGs) (Ally and Wark, 2020; Zizka and Varga, 2020; de S Oliveira and de Souza, 2022). In particular, the study focused on elements related to either education for sustainable development (ESD) (Cebrián and Junyent, 2015; Andreadakis and Maassen, 2019b) or education or sustainable open HE, and which had relevance to the HE sector. Based on this, the study had the following research questions (RQs):

- RQ1: Which HEIs are reported to apply Education 4.0, in which countries are they situated, and who are the reported participants?
- Which types of Education 4.0 technologies do these HEIs apply as reported by the reviewed articles?
- RQ2: What are the affordances offered by the utilized Education 4.0 technologies?
- RQ3: What innovation classification does this Education 4.0 fall under?
- RQ4: What academic disciplines or subject areas is it applied to?
- RQ5: Does the reported Education 4.0 have a sustainable open higher education element and focus on the UN's sustainable development goals (SDGs)?

# METHODS

## Search Strategy and Full-Text Downloading

A literature search strategy for eligible and relevant articles was carried out online from June 2021 to October 2021. It entailed determining and locating suitable bibliographic databases. Thirteen online databases, which included two search engines, were identified. These were: Google; Bing; Education Resource Information Center (ERIC); IEEE Xplore; ScienceDirect; Scopus; SpringerLink; Taylor & Francis Online; Wiley Online Library; Emerald Insight; Sematic Scholar; Google Scholar; and Microsoft

Academic (**Figure 1**). Keywords, in search string combinations, were developed and iteratively queried into these databases according to their bespoke requirements. Some of these search string combinations were as follows:

- "Education 4.0" AND "technologies for sustainable development in higher education"
- "Education 4.0 technologies" AND "sustainable development goals in higher education"
- "Education 4.0" AND "technologies for sustainable open education in higher education"
- "Education 4.0" AND "sustainable development goals" AND sustainable open education AND technologies
- "Education 4.0" AND "sustainable* open education" in higher education

Education 4.0 was varied or swapped with Industry 4.0 and Higher Education 4.0, and with any of the 4IR technologies. Quotation marks were employed to ensure that entire phrases are located within a document; *AND* was used to identify groups of keyword phrases available in a document; and the asterisk (*) was employed to ensure that all possible suffixes for a word were locatable within a document

All qualifying full-text articles that were located in the above-mentioned databases and search engines were downloaded. They were, then, saved in thirteen separate folders named according to

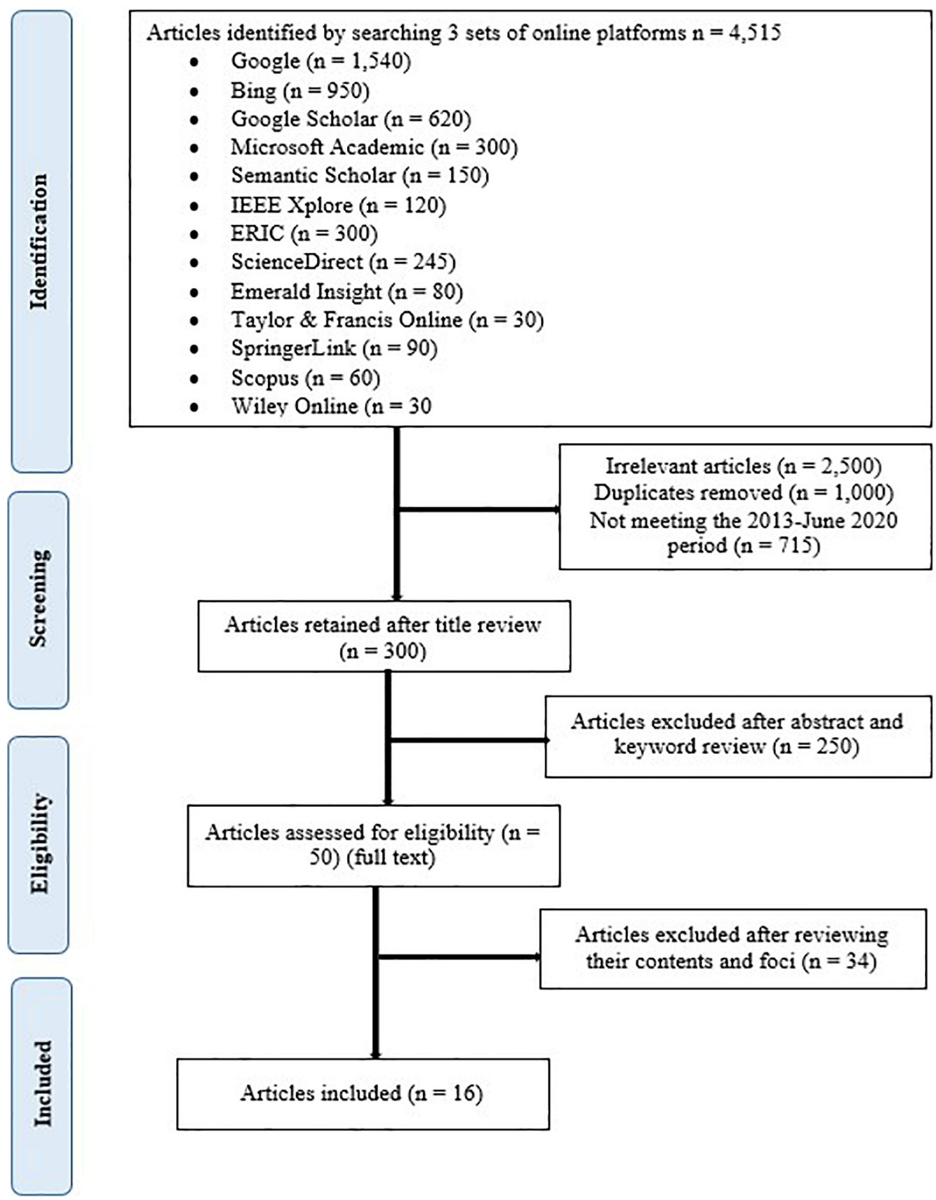


**FIGURE 1 |** The PRISMA flow chart and the online search platforms.

the names of the databases and search engines from which they were downloaded. These folders were archived in File Explorer. The total number of the full-text articles saved in these folders was 300 (see **Figure 1**).

If there are journal articles that focus on real-world, empirical applications of Education 4.0 together with its related technologies in the HE sector and that deal with an element of sustainable open higher education or with UN's SDGs as highlighted in this paper, but which do not explicitly mention Education 4.0 as one of their keywords as indicated in the search string combinations provided above, then, they could have been missed by the search strategy employed here. However, the possibility of this happening and of the *bubble effect*—a selection bias—(see Piasecki et al., 2018) is mitigated by the fact that most of the aggregating algorithms used by the thirteen online databases are intelligent enough to locate such journal articles. Additionally, the use of these different online databases compensates for one another's weaknesses. This is particularly the case when different search engines and different online bibliographic databases are employed together for search purposes. For example, Piasecki et al. (2018) point out that even though Google Search and Google Scholar have drawbacks, they, nevertheless, are appropriate for certain forms of qualitative systematic reviews when used together.

## Eligibility Criteria and Selection of Studies

Even though this was a literature review paper, it employed aspects of a systematic literature review (SLR) in its research design, or what Snyder (2019) calls semi-systematic review. It also utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) in its search strategies. Based on this, the study had eligibility (inclusion) criteria, examples of which included the following:

- Articles published between 2015 and October 2021
- Articles published in peer-reviewed journals and published in internationally accredited conference proceedings (e.g., IEEE and Procedia)
- Articles that simultaneously focused on Education 4.0 (and its variations, e.g., Industiry4.0 or/Industrie 4.0) and elements of sustainable open education in higher education/elements of SDGs in higher education
- Articles that provided real-world instances/cases of the implementation of Education 4.0 in given higher education institutions involving students
- Articles that did not report pure prototypes or pure prototype implementations
- Articles that were not pure reviews/not pure theoretical or conceptual reflections of Education 4.0
- Articles published in English

The year 2015 was used as a starting point because it is the year in which the UN declared its SDGs (Ally and Wark, 2020; Zizka and Varga, 2020). A four-phase selection process was conducted for identifying, choosing, and screening qualifying articles. This process was based on the PRISMA flowchart (**Figure 1**). The RISMA approach has transparency and clarity as one of key features (Liberati et al., 2009; Moher et al., 2009). In the first phase, articles were searched and identified each time search string combinations had been queried in each of the 13 online bibliographic databases. Collectively, 4,515 articles were returned by this phase. This phase was followed by the second one in which the 4,515 returned articles were screened. The screening involved reviewing the titles and abstracts of these articles. After conducting this process, 300 articles were retained, while 4,215 were eliminated for irrelevance and for being duplicates. During the third phase, the remaining 300 articles were reviewed in terms of their abstracts. This process resulted in 250 articles being excluded due to duplicates and irrelevance. In the fourth phase, only 16 articles were retained as their contents and foci satisfied the eligibility criteria mentioned above. These 16 articles were the major data source from which the data sets of the current study were extracted.

## Data Extraction, Coding and Inter-Rater Reliability

Data sets, which were informed by twelve article characteristics, were extracted from the 42 full-text articles mentioned earlier. These characteristics were: author(s); country; year of publication; name of HEI; participants; a fully integrated Education 4.0, a near-fully integrated Education4.0, or a partially integrated Education 4.0; types of Education 4.0 technologies used; affordances offered by Education 4.0 technologies used; innovation classification; academic disciple(s)/subject area(s); a sustainable open HE element; and SDGs (also see the RQs of this study). A coding scheme based on these twelve characteristics was developed. The researcher and two independent coders extracted the data sets from the 16 articles using this coding scheme. To maintain data extraction and data coding consistency, interrater reliability (IRR) as recommended by Landis and Koch (1977) and Belur et al. (2018) was used. For instance, Landis and Koch (1977) offer the following range of the kappa (κ) scores and their interpretation for IRR: 0.81–1.00 = near perfect; 0.61–0.80 = substantial; 0.41–0.60 = moderate; 0.21–0.40 = fair; 0.00–0.20 = slight; < 0 = poor. The IRR of the three coders was 0.80, which was substantial.

## Data Analysis

Data sets were analyzed using quantitative content analysis and qualitative content analysis (Vaismoradi et al., 2013; Vaismoradi and Snelgrove, 2019). First, quantitative content analysis involved calculating frequencies of occurrence of the twelve article characteristics mentioned above. Second, qualitative content analysis entailed analyzing themes formulated from the twelve article characteristics. Thereafter, themes emerging from these characteristics were iteratively compared with a view to synthesizing them. This means that for each full-text article, firstly, the author(s), the country of origin of the author(s), the year of publication, the name of an HEI involved, and the participants mentioned were identified. Secondly, each full-text article was evaluated on whether the type of Education 4.0 it mentioned was fully, near-fully, or partially integrated as

**TABLE 1** | Authors' countries of origin, years of publication, HEIs, participants, and academic disciplines/subjects.

| Article number | References | Country of origin | HEIs | No. of participants | Academic disciplines/subjects |
|---|---|---|---|---|---|
| Art. 1: | Elbestawi et al., 2018 | Canada | McMaster University | N/M | Engineering and technology |
| Art. 2: | Adnan et al., 2019 | Malaysia | Three Malaysian public universities | 19 English language educators | English language |
| Art. 3 | Adnan et al., 2020 | Malaysia | Universiti Teknologi MARA Perak Branch | 560 undergraduate students | English as a second language, Mandarin & Arabic |
| Art. 4 | Prieto et al., 2019 | Spain | Universitat Politècnica de Catalunya | Undergraduate and graduate students | Industrial, aerospace and audiovisual engineering |
| Art. 5 | Bonfield et al., 2020 | Australia, Singapore, UK, and Ireland | Deakin University, Nanyang Technological University (NTU) & University of Bath | Deakin = Campus users; NTU = Singaporeans of all ages; Bath = N/M | NTU: aerospace, data analytics, robotics and predictive analysis |
| Art. 6 | Bushmeleva et al., 2020 | Russian Federation | Vyatka State University | 79 third-year students | Informatics, mathematics and physics |
| Art. 7 | Ciolacu et al., 2020 | Germany | Deggendorf Institute of Technology | 4 computer science students | Mathematics and knowledge management |
| Art. 8 | dos Silva et al., 2020 | Brazil | Federal University of Paraná | 32 undergraduate and graduate students | Mobile robotics |
| Art. 9 | Silva et al., 2020 | Brazil | Federal University of Paraná | 6 education professionals | Teacher education |
| Art. 10 | Yoshino et al., 2020 | Brazil | Universidade Tecnológica Federal do Paraná | 111 university students | Science, technology, engineering, and math; computer science; and teaching courses |
| Art. 11 | Marcial, 2020 | Philippines | Silliman University | Students and community | Technology business |
| Art. 12 | Porubčinová et al., 2020 | Slovakia | Slovak University of Technology in Bratislava | P.hD. Students and teachers | Civil engineering and materials science and technology |
| Art. 13 | Benis et al., 2020 | Israel | Holon Institute of Technology | N/M | Industrial engineering and technology management |
| Art. 14 | López et al., 2021 | Mexico | Tecnologico de Monterrey | Undergraduate mechanical engineering students | Mechanical engineering |
| Art. 15 | Miranda et al., 2021 | Mexico | Tecnologico de Monterrey | 40 to 60 undergraduate students | Computer science |
| Art. 16 | de S Oliveira and de Souza, 2022* | Brazil | Federal Rural University of Pernambuco | 13 undergraduate students | Computer science |

*HEIs, higher education institutions; N/M, not mentioned. *Even though this article's indicated publication date is 2022, its journal copyright date is 2021.*

explained earlier. Thirdly, each full-text article was evaluated in terms of the types of Education 4.0 technologies used in it, the affordances provided by those technologies, and the innovation classification of those technologies. The innovation classification related to revolutionary, evolutionary, or disruptive innovation as discussed earlier (see Osolind, 2012; Serdyukov, 2017; Christensen et al., 2018; Kylliäinen, 2019). Fourthly and lastly, each full-text article was assessed according to the academic disciples it mentioned, the sustainable open HE element it had, and its reference to an SDG.

All of these descriptors informed the findings presented below. Moreover, in the discussion of the findings, these descriptors in the form of themes have been synthesized by drawing both similarities and differences.

## FINDINGS

The findings presented in this section are grounded on the data sets extracted from the 16 articles reviewed in this paper and are structured according to the manner in which these data sets have been codified, categorized, and analyzed as described above. Additionally, these findings have been framed in line with the twelve articles' characteristics investigated in this paper, and in response to the six research questions (RQs) posed in this paper.

### Authors' Countries of Origin, Years of Publication, Higher Education Institutions, Participants, and Academic Disciplines/Subjects

As illustrated in **Table 1**, all together, these articles were written by authors from fourteen countries. Except for one article, all the other articles were co-authored. Four articles are from Brazil, and two articles are from Malaysia and Mexico, respectively. While the remaining articles are from a single country each, one article represents four countries. Nine of the reviewed articles were published in 2020, whereas three of them were published in 2021. In all, the reviewed articles mentioned 20 HIEs. Two articles mentioned three HEIs each, with one of them having not specified the names of its three HEIs. Of the seventeen HEIs specified by their names, two of them, Federal University of Paraná (Brazil) and Tecnologico de Monterrey (Mexico) feature twice in the reviewed articles. Additionally, of the seventeen specified HEIs, ten are universities of applied sciences, while seven are traditional universities.

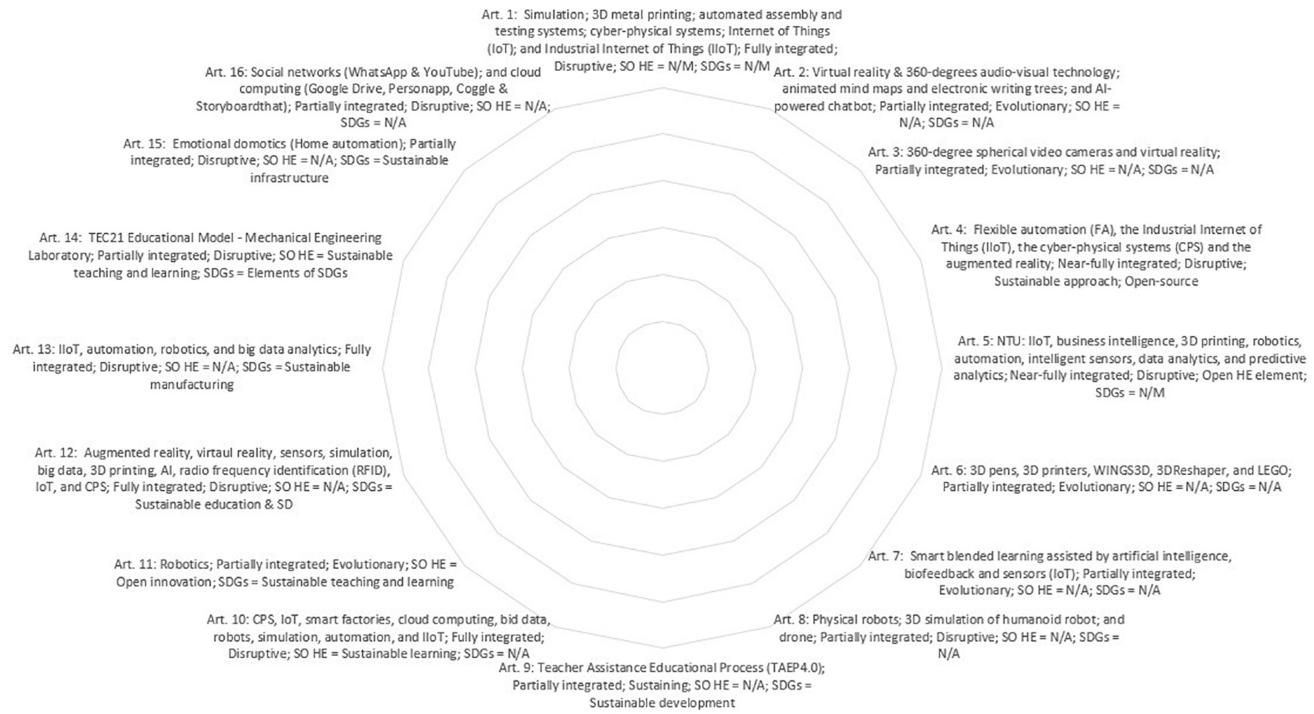


**FIGURE 2 |** Articles and Education 4.0 technologies used. N/A, not applicable; N/M, not mentioned; SO HE, sustainable open higher education; SDGs, sustainable development goals.

Barring two HEIs (Art. 1 and Art. 13) and save for one of the three collective HEIs (Art. 5), all the other reviewed articles mentioned their participants. All of these participants were mainly university students, except for one cohort that comprised both students and the community and another cohort that consisted of participants of all ages. Seven articles provided the exact number of the participants involved in in their Education 4.0 activities, with one article providing an approximate number only. The overall number of the specified participants is 824. The other articles did not specify the number of the participants involved in their Education 4.0 activities.

Pertaining to academic disciplines/subjects, all the articles specified their respective academic disciplines/subjects involved in Education 4.0 initiatives. While some of the articles stated a combination of academic disciplines and academic subjects, others mentioned specific academic subjects such as English language, Mandarin, and mathematics. The most cited overall academic discipline is engineering, and is followed by computer science.

## Education 4.0 Technologies, Types of Education 4.0, Innovation Classification, Sustainable Open HE Elements, and Sustainable Development Goals

As depicted in **Figure 2**, apart from two articles (Art. 9 and Art. 14), all the other articles have offered the specific names of the technologies used in their Education 4.0 projects. Of these, one article (Art. 5) has provided eight specific names of its Education 4.0 technologies, while two articles (Art. 10 and Art. 12) have mentioned nine and ten specific names of their respective Education 4.0 technologies. By contrast, two articles (Art. 2 and Art. 3) have cited two specific Education 4.0 technologies each, and two other articles (Art. 11 and Art. 15) have cited one specific Education 4.0 technology apiece. The most cited Education 4.0 technologies are robots (robotics) ($n$ = 8), including an AI-powered chatbot. They are followed by automation (n = 6), IIoT ($n$ = 5), and 3D technology ($n$ = 5), with IoT ($n$ = 4), simulation ($n$ = 4), and CPS (= 4) closely trailing these three sets of Education 4.0 technologies.

Of all the Education 4.0 technologies mentioned, the ones cited by four articles are fully integrated, and those cited by two articles are near-fully integrated. The other Education 4.0 technologies mentioned by the remaining ten articles are partially integrated. Ten sets of Education 4.0 technologies mentioned by ten articles have been classified as a disruptive innovation, whereas five sets of technologies have been categorized as an evolutionary innovation and one set of technologies has been identified as a sustaining innovation.

Eleven articles did not mention whether their Education 4.0 had any element of sustainable open higher education, or whether it lent itself to such a type of education. The remaining five articles hinted at the sustainability of their either open teaching and learning, open higher education, open approach, or open innovation. Similarly, nine articles did not mention whether their Education 4.0 had any sustainable development goals (SDGs). On the other hand, the remaining articles stated the following regarding their Education 4.0 vis-à-vis SDGs: open source; sustainable development; sustainable education; sustainable teaching and learning; sustainable manufacturing; and sustainable infrastructure.

## Education 4.0 Technology Affordances

All the 16 articles have provided the affordances offered by their respective Education 4.0 technologies (**Table 2**). Depending on the number of technologies used in each instance, the affordances stated are few as in Art. 2, Art. 3, Art. 7, Art. 9, Art. 10, and Art. 14, or many as exemplified by Art. 4, Art. 6, Art. 13, Art. 15, and Art. 16. Some of the affordances provided are more detailed than others as is the case with Art. 2, Art. 8, Art. 15, Art. 16. Mainly, the hard-skill affordances mentioned by these sixteen articles are technology-specific or technology-responsive.

# DISCUSSION

This part discusses the findings as presented in the previous section. Additionally, this part responds to the twelve articles' characteristics investigated in this paper and to the six research questions (RQs) of this paper. On this basis, the purpose of this study was to explore whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for HEIs. As pointed out in the previous section, of the seventeen HEIs specified by their names, ten were universities of applied sciences, while seven were traditional universities. Three countries had the larger share of the reviewed articles, with one country (Brazil) having the largest share of the articles, overall. These three countries also had the most authors of the reviewed articles, with a single country (Brazil), again, having the largest share of the authors of these articles. Similarly, of the HEIs featuring in the reviewed articles, the most were from the same three countries. In this instance, two HEIs from two countries each—Federal University of Paraná (Brazil) and Tecnologico de Monterrey (Mexico)—featured twice in the reviewed articles, more than is the case with the other HEIs. To this effect, mere Google and Bing searches of the two HEIs using the string searches, Federal University of Paraná—Education 4.0 and Tecnologico de Monterrey—Education 4.0, returned 444,000 (Google)/7,500,000 (Bing) and 732,000 (Google)/252,000 (Bing) results for each of these two HEIs, respectively, at the time of writing this paper (**Figure 3**). While these search results may reflect different variables related to these two HEIs, they nonetheless illustrate the high rate of Education 4.0 instances associated with these two HEIs. Another factor here is that most articles ($n$ = 9) were written in 2020 than in any other years in which these reviewed articles were published.

The majority of the participants mentioned are university students, especially undergraduate students. However, two articles mentioned composite participants: students and community members, and all-age participants. What can be extrapolated from this participant composition is that in the reviewed articles, Education 4.0 largely involved undergraduate students even though in two cases it involved both students and the general public. Slightly fewer articles provided the exact number of the participants that took part in their Education 4.0 initiatives. Collectively, these participants totaled 824. This means that the exact number of participants involved in the Education 4.0 activities not mentioned by many articles ($n$ = 9) remains unknown.

With reference to academic disciplines/subjects, all the reviewed articles stated the academic disciplines/subjects that were involved in their respective Education 4.0 projects. Some of the articles provided a combination of general academic disciplines and academic subjects, while others stated specific academic subjects, of which English language, Mandarin, and mathematics are examples. This implies that some of the Education 4.0 initiatives mentioned by the reviewed articles occurred within specific, micro-academic subject areas (or within a given module), whereas others took place within generic or macro-academic disciplines. Of these generic academic disciplines, engineering is the most frequently cited, followed by computer science. This development serves as the basis to argue that in this context, engineering is leading the pioneering of Education 4.0 initiatives and seems to be experimenting more with Education 4.0 than is the case with other academic disciplines. Following it closely in this regard is computer science (see Bongomin et al., 2020; cf. Chaka, 2020b, 2021).

As highlighted in the previous section, barring two articles, all the other articles mentioned the specific names of the technologies utilized in their Education 4.0 projects. These ranged from robots, automation, and simulation to IoT, IIoT, and CPS to AI, AR, VR and sensors to 3D technologies. In addition, there were big data and cloud computing (cf. Bongomin et al., 2020; Chaka, 2021). Four sets of Education 4.0 technologies cited by four articles were identified as fully integrated, while two sets of technologies were distinguished as near-fully integrated. The rest of the other sets of Education 4.0 technologies were identified as partially integrated. This identification is based on the three types of Education 4.0 proposed earlier by this paper. This particular identification is as follows: a fully integrated Education 4.0 uses many or all of the Education 4.0 technologies; a near-fully integrated Education 4.0 entails the use of a number of different Education 4.0 technologies but not all of them; and a partially integrated Education 4.0 incorporates the use of one to three different Education 4.0 technologies. When deployed as fully integrated or as near-fully integrated Education 4.0 technologies, these technologies have the potential to make Education 4.0 a sufficient innovative, and disruptive educational trend that promotes sustainable open education for HEIs.

Ten sets of Education 4.0 technologies cited by ten articles were classified as a disruptive innovation, or as disruptive Education 4.0 technologies, while five sets were categorized as evolutionary in their innovation. One set was found to have a sustaining innovation. This classification borrows from Serdyukov (2017) categorization of innovation as described earlier, and is used here to refer to the educational innovation associated with the Education 4.0 technologies cited by the

**TABLE 2 |** Articles and the affordances offered by their Education 4.0 technologies.

| Article number | Education 4.0 technology affordances |
|---|---|
| Art. 1: | Offering new technical skills that emphasize the inherent multidisciplinary nature of smart systems and advanced manufacturing; addressing the educational, research, and training components of the SEPT CPS Learning Centre. |
| Art. 2: | Simulating, recording, and sharing business and professional English interactions with students; and chatting about 1,001 items related to English using the chatbot. |
| Art. 3: | Playback immersive "real life" contents; post-processing contents into VR experiences; learner-driven learning for English as a second language, Mandarin Chinese, and Arabic learners. |
| Art. 4: | Facilitating active learning and enabling students acquire Engineering Education 4.0 competences; digitalization and automation of the industrial processes; deployment of connected devices able to identify each other with computing and communication capabilities to turn them into intelligent objects with informative and self-decision making purposes; and allowing students to design and implement its own operational functionalities. |
| Art. 5: | **Deakin:** Using cutting-edge digital technologies to digitize Deakin's physical campus environments so as to provide campus users with a smart, personalized, responsive, and enriched campus experience (embedding emerging technologies within the physical environment, combining these with organizational vision and values and placing the Campus User at the center of the experience). |
| | **NTU:** Delivering bite-size modules directly related to Industry 4.0; developing skills and knowledge across a wide range of subjects that are closely aligned to future jobs and skills. |
| | **Bath:** FutureLearn course offerings. |
| Art. 6: | Fostering engineering thinking, innovative thinking, and technical thinking. |
| | **NB:** Students were able to systematize the necessary conceptual apparatus, studied various functional capabilities of software environments and 3D printing devices, and got the opportunity to solve specific practical and socially significant problems of the future, while showing independence in choosing 3D tools, methods of cognition. |
| Art. 7: | Networking students and their wearable devices with the Learning Management System (LMS), and classifying this learning environment as an Internet of Things (IoT). |
| Art. 8: | (a) Promoting 21st century skills such as (1) creativity and innovation, (2) problem-solving, (3) communication, (4) teamwork, (5) learning to learn, and (6) organization. (b) Humanoid robot 3D football simulator—enabling students to develop heuristics in the base code so that they could add new robotic skill sets such as scoring barriers, attack strategies, and goal-kick defense. |
| Art. 9: | Promoting twenty-first century skills and competencies in the context of Education 4.0. |
| Art. 10: | Enabling students to build prototypes; and facilitating proactivity, problem-solving ability, teamwork, and leadership. |
| Art. 12: | Supporting the transfer of progressive technologies, collaboration in knowledge triangle (research-education-innovation) to improve know-how, innovations, and knowledge. Optimizing production, and predicting and minimizing errors from the production line. |
| Art. 13: | Equipping students with the fundamental tools for designing, implementing, and managing automated production environments and their computerized control systems. |
| | Smart use of the production plant and end-business mobile asset tracking technologies [e.g., bar-codes, Quick Response (QR) codes, near field communication (NFC), and radio frequency identification (RFID)]. |
| | Enabling fast adoption of the robot tool (Dobot Magician), and experimenting with its behaviors and constraints. |
| | Allowing students to study in-depth some critical components of the 4IR and the IoT. |
| | Enabling students to examine a series of business problems during the course and to solve them with BI tools such as Microsoft Power BI. |
| Art. 14: | Fostering disciplinary and transversal skills. |
| | **Disciplinary skills:** knowledge, attitudes, values, and skills necessary for professional practice. |
| | **Transversal skills:** training experiences in entrepreneurship, leadership, innovation, linking academia and the productive sector. |
| Art. 15: | Using a decision-making lab to support students' visual analysis to solve a transportation problem in Mexico City. Encouraging entrepreneurship in higher education through the sensing, smart and sustainable enterprise creation bootcamp. Fostering multidisciplinary research in higher education through the computing intelligence, mechatronics, and Biodesign Laboratory. |
| Art. 16: | Discovering the challenge; deepening the understanding; generating and refining ideas, generating and refining ideas; and prototyping ideas. |
| | **Organizational affordances:** Developing Education 4.0 strategies; developing, updating and adapting curriculum; and improving educational experience using digital technologies. |
| | **Digital teaching affordances:** constant feedback; use of needs-based technology; and use of innovative assessment methods. |
| | **Soft skills:** communication; social and cultural awareness; creativity; empathy; critical and analytical thinking; responsibility; problem-solving; and teamwork. |
| | **Hard skills:** digital technology design; technological resource management; and computational thinking. |
| | **Pedagogical affordances:** innovation approach; action-oriented learning; and blended learning. |

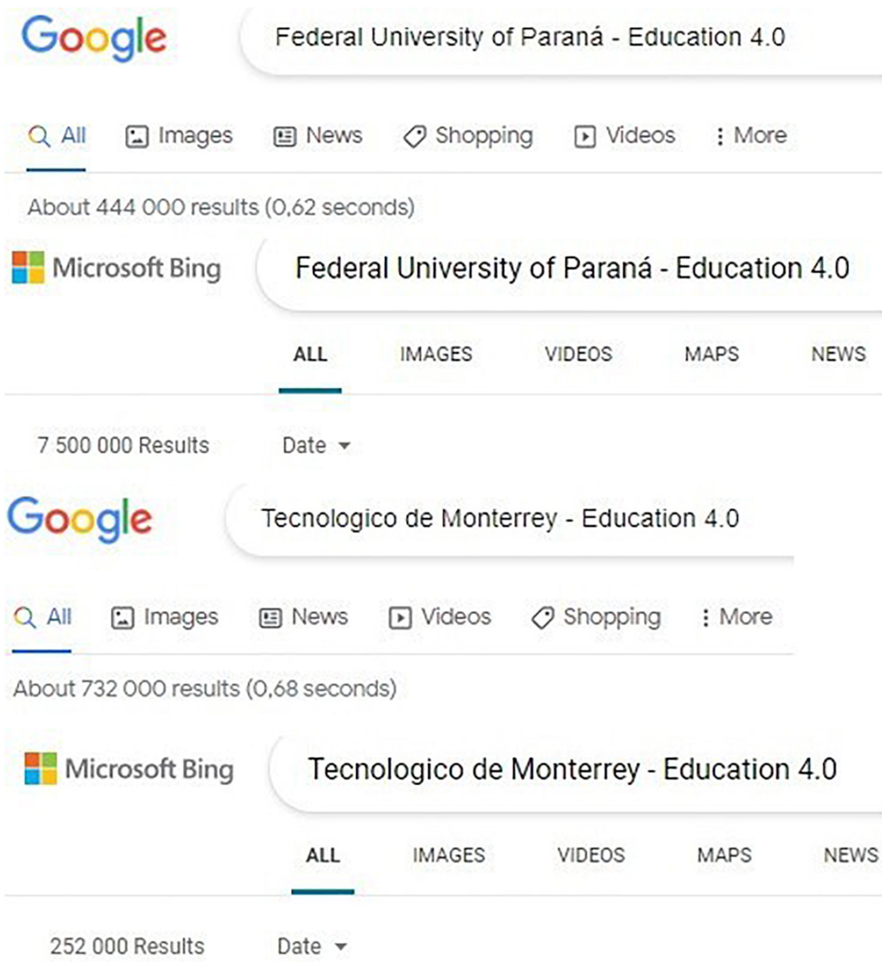


**FIGURE 3 |** Google and Bing search results for two HEIs.

reviewed articles. Those sets of technologies that have been categorized as disruptive or as having a disruptive innovation are scalable and sustainable. As such, based on this classificatory criterion, these types of Education 4.0 technologies have the prospect of promoting sustainable open higher education in line with the UN's sustainable development goals (SDGs) (see Cebrián and Junyent, 2015; Ally and Wark, 2020; Zizka and Varga, 2020; de S Oliveira and de Souza, 2022). As mentioned earlier, overall, five articles hinted at their open teaching and learning, their open higher education, their open approach, and their open innovation being sustainable. In terms of SDGs, seven articles characterized their Education 4.0 as either sustainable education/sustainable teaching and learning, open source, sustainable development, sustainable manufacturing, or sustainable infrastructure. As argued above, for any Education 4.0 in the HE sector to be open and sustainable, its Education 4.0 technologies must be fully or near-fully integrated, disruptive, and scalable. Only in this way and format can it be regarded as sufficiently innovative.

Finally, all the reviewed articles provided the affordances associated with their respective Education 4.0 technologies. Some of these affordances were specific and detailed, whereas others were general and non-specific. The examples of the former are "chatting about 1,001 items related to English using the chatbot" (Art. 2), " enabling students to develop heuristics in the base code so that they could add new robotic skill sets such as scoring barriers . . . and goal-kick defense" (Art. 8), and " critical and analytical thinking . . . problem-solving" (Art. 16). Instances of the latter are "facilitating active learning and enabling students acquire Engineering Education 4.0 competences (Art. 4) and "equipping students with the fundamental tools for managing automated production environments and their computerized control systems" (Art. 13). In addition, the hard-skill Education 4.0 technology affordances referenced by the reviewed articles are mainly technology-specific or technology-responsive. This means that they are technology-bound, or can only occur with the cited Education 4.0 technologies.

Moreover, most of the soft-skill affordances such as communication skills, social and cultural awareness skills, critical and analytical thinking skills, creativity, problem-solving skills, innovation, empathy, responsibility, teamwork, and leadership skills referenced by some of the reviewed articles are twenty-first century skills that predate the Education 4.0 era.

As such, they are not exclusive to Education 4.0 nor to 4IR/Industry 4.0. Elsewhere, Chaka (2020b, p. 372) refers to soft skills or twenty-first century skills "as *stylized facts* for 4IR." He borrows the phrase *stylized facts* from Helfat (2007) work in which it means widely accepted observations or empirical truths (also see Gomes et al., 2015; Hirschman, 2016). Even in this paper, the soft-skill affordances attributable to the Education 4.0 technologies mentioned by the reviewed articles lend themselves well as stylized facts as they do not need Education 4.0 technologies for them to be acquired by students.

## CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

Firstly, in the context of the reviewed articles, it appears that real-world Education 4.0 is confined to certain countries, and is more concentrated to a few countries and to a few HEIs. These countries, together with their respective HEIs, are geographically confined to South America. This is so notwithstanding the fact that the search strings employed in this paper were not country- or HEI-specific. Secondly, more articles dealing with real-world Education 4.0 initiatives were published in 2020. Again, this is so despite the fact that the search strings used were not year-specific.

Thirdly, according to the reviewed articles, most real-world Education 4.0 activities took place at both universities of applied sciences and traditional universities, and involved university undergraduate students. This includes those instances in which the exact number of participants was not provided. Fourthly, most of the reported Education 4.0 initiatives involved both specific academic subjects and generic academic disciplines. Regarding the latter, engineering is a generic academic discipline involved in most Education 4.0 projects, followed by computer science. Fifthly, four sets of Education 4.0 technologies and two sets of Education 4.0 technologies were identified as fully and near-fully integrated, respectively. Sixthly, ten sets of Education 4.0 technologies were classified as disruptive, scalable, and sustainable, and as holding the prospect to promote sustainable open higher education in accord with the UN's SDGs. Eighthly and lastly, the reviewed articles provided both specific and generic Education 4.0 technology affordances. However, with reference to most of the soft-skill affordances cited (especially the twenty-first century skills cited), the paper has argued that they are stylized facts as they predate Education 4.0 and are, thus, are not exclusive to it.

With regard to limitations, the current study was confined to the online databases it searched. In this case, it only reviewed sixteen articles. It did not review other forms of publications such as books and book chapters, and in doing so, it could have overlooked other real-world Education 4.0 initiatives documented in such publications. Nevertheless, it omitted these publications for uniformity and consistency purposes. Additionally, the reviewed articles were limited to those published in English.

Finally, more research on the real-world applications of Education 4.0 in the HE sector is needed. This is particularly so as there appears to be more conceptual and theoretical academic papers that focus on Education 4.0 than those that report on practical, real-world applications of Education 4.0 at HEIs. Despite the limitations associated with the current paper, the paper lends itself well as one of the key reference points for future studies on the real-world applications of Education 4.0 in the HE sector.

## AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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# Increasing Sustainability in Open Learning: Prospects of a Distributed Learning Ecosystem for Open Educational Resources

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The proliferation of Open Educational Resources (OER) constitutes an essential element for establishing education as a "public good" on the internet. A core objective of OER is to broaden access to educational material and improve the overall quality of teaching and learning. In this manner, OER contributes to the sustainable (re)use and (re)distribution of (educational) resources. The goal of sustainability is also visible in the latest UNSECO recommendation concerning OER, which intends to support the 2030 Sustainable Development Agenda, namely SDG 4 (Quality education). The support of SDG 4 is combined with the call to create sustainability models for OER at national, regional and institutional levels and the planning and pilot testing of new sustainable forms of education and learning. As a result, several repositories and referatories for OER provision have been developed and tested in educational institutions worldwide. However, each of these platforms contains only a relatively limited number of resources. In our article, we argue that when considered through the lens of learning innovation and sustainable development, it would be necessary to increase the discoverability of available resources at the different locations and platforms that currently are visible to only a limited number of teachers and students. To achieve this goal, the focus needs to shift from the creation and growth of new and competing platforms to intelligent ways of linking and increasing their interconnectedness. We use the concept of "learning ecosystems" to illustrate this approach of interconnected resources. Ecosystems go beyond the spatial dimension of learning by focussing on actors' diversity and interactions. Digital (networked) learning technology is part of an ecosystem and has itself to be understood as an actor. However, we discuss that ecosystems should be reflected with caution as they can themselves entail opening and closing mechanisms. Therefore, ecosystems that rely on mechanisms of opening their contents to other platforms can realise the full potential of open learning. We describe the implications of the concept of a distributed ecosystem by presenting case studies that show how technical solutions, including metadata standards and plugins, can link contents in repositories and referatories within ecosystems. The overarching objective is that the different repositories and referatories expand and improve the sustainable use of OER by merging into a distributed learning ecosystem.

**Keywords: open education, open educational resources, sustainability, learning ecosystems, distributed**



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## INTRODUCTION

The experiences of the COVID-19 crisis and the various studies conducted during this period (Bond et al., 2021; Khan, 2021) have made evident the lack of the digitalisation of education and demonstrated that a fundamental shift is necessary to empower learning and teaching in the digital world. However, neither pure "digital" nor pure "analog" teaching and learning can be considered as the solution but amalgamating the two based on a proper instructional design as well as a critical analysis of the respective educational context (Kerres and Otto, 2022).

Another key observation is that the internet has emerged as the central place where teaching and learning occur. Consequently, when reflecting on the consequences of the Corona-19 crisis for education, online teaching must be considered in any teaching scenario. However, one aspect rarely addressed in the discussion about online teaching is the space in which it takes place. Instead, we often treat the internet as an amorphous space and seldom ask questions about how we should design a learning architecture on the internet that enables educational practices.

In our article, we argue that the concept of open education needs to be the starting point of any deliberations. From a broader perspective, open education is on vogue, and its main ideas to lower social injustice, inequity, and the digital divide have turned out to be decisive during the phase of "emergency remoted teaching" (Hodges et al., 2020). These principles of open education are particularly vital as first analyses of the experiences gained through the COVID-19 pandemic have reinforced that teaching and learning can no longer be considered a practice bound to specific locations or places where people gather in groups or classes (Bozkurt et al., 2020). Therefore, it is hard to envisage returning to the old status before the COVID-19 pandemic. It also became manifest that various (digital) tools and resources are available for educational purposes that can support teachers in designing learning scenarios and help learners manage and steer their distinct learning paths.

During the COVID-19 pandemic, both teachers and learners were forced to leave their familiar environment and engage in their (often first) experimentation with online teaching (Khan, 2021). One problem that arose was making the (right) choices in recognising suitable educational material for online activities. In this regard, open education and the related concepts can unfold their full potential. With its core objective of broadening access to and participation in education and improving collaborative learning and teaching quality, open education can facilitate teaching and learning in the digital age (Otto et al., 2021; Otto and Kerres, 2021).

All of these characteristics of open education make it predestined for triggering learning innovations regarding the design of learning infrastructures in the digital age. Ramirez-Montoya (2020), based on her systematic literature review on challenges for open education with educational innovation, concludes that particularly Open Educational Resources (OER) should play a key role here.

From a fundamental perspective and through the lens of a hierarchical logic, OER is considered a subordinate approach to open education that addresses its design characteristics and components (Otto and Kerres, 2021). Thus, OER is an essential element of open education, with the core objective being to broaden access to educational material and improve the overall quality of teaching and learning (see **Table 1**). Both approaches are based on ideas of collaboration and common knowledge construction using digital technologies to create a wide range of open, shared and demand-driven educational resources. Making OER broadly available can thus support training processes so that students are empowered to continue learning from home on open platforms and with open materials or courses. Furthermore, by using OER, teachers can create and provide innovative open content that fits the needs of learners. Finally, it offers ways to collaboratively develop educational practices with other teachers that contribute to improving teaching quality in education. In this manner, OER can lead to new educational and pedagogical practices that enable participatory and collaborative practices.

Accordingly, it can be argued that the proliferation of OER constitutes an essential element for establishing learning innovation in open education and education in general. The latest reports on teachers' experiences with emergency remote education revealed that it led to an increased awareness of OER and showed its relevance for online teaching and learning. Exemplarily, a survey across seven European countries on teachers' practices during remote education revealed that 54% of the teachers claim that they have regularly used this type of resource (Biernat et al., 2021). This underlines that OER constitutes one of the critical pillars for online teaching.

The prospects of OER have also resulted in the UNESCO's recommendation on OER in 2019 (UNESCO, 2019). While the UNESCO ostensibly highlighted the importance of OER,

**TABLE 1** | Current approaches in the context of open education.

| Approach | Goal | Authors |
|---|---|---|
| Open Education | Widening access to and participation in education | Peters (2008), Deimann and Farrow, 2013 |
| Open Educational Resources, Open Text-books, Open Courseware | Teaching and learning materials with an open licence, e.g., textbooks, course materials, online training | Hilton (2019), Wiley (2020) |
| Open Pedagogy | Consistent opening of all pedagogical design dimensions (including lesson planning, teaching, examinations, etc.) through transparency and joint participation of teachers and learners | Hegarty (2015), Wiley and Hilton (2018) |
| Open Educational Practices | Willingness to share, cooperate and reflect together with others (teachers and students) | Ehlers (2011), Cronin and MacLaren (2018) |
| Open Informational Ecosystem | An environment that provides and shares access to materials, e.g., via metadata | Kerres and Heinen (2015) |

it also pointed to some critical challenges that OER is facing, especially regarding the sustainable use of OER and the lack of respective innovations. The goal to increase the sustainability of OER is also visible in the intention to support the 2030 Sustainable Development Agenda, namely SDG 4 (Quality education). The support of SDG 4 is combined with the call to create sustainability models for OER at national, regional and institutional levels and to plan and pilot new sustainable forms of educational models.

With our article, we want to contribute to the debate about increasing the sustainability of OER by introducing educational innovations. Following Ramirez-Montoya (2020), we understand educational innovations as contributing to the generation of new products (technology, instruments, devices, prototypes), services (care, assistance, dependence, benefits), or solutions (transformation, models, systems, methods). Therefore, producing learning innovations requires recognising puzzling situations, analysing their contexts, and critically evaluating changes that contribute to their improvement.

Based on the educational discourse on OER, its adoption into educational practices appears to be a persistent overall challenge (Mishra, 2017; Bozkurt et al., 2019; Otto, 2019). Over the last two decades, numerous studies have emerged on overcoming this lack of adoption. While in the beginning, these studies were predominantly based on individual experiences or single case studies, a recently published systematic mapping study has investigated trends and gaps in empirical research on OER (Otto et al., 2021). The emphasis of this mapping study on the empirical evidence is crucial, as many of the available studies have remained conceptual without presenting any hard evidence to validate their assumptions. One of the key findings of the systematic mapping study is that empirical research on OER mainly concentrates on the awareness of OER or the lack thereof and barriers to its use. Marginal consideration is given to the decisive matter of the infrastructure's role and a corresponding design to stimulate OER adoption (see **Figure 1**).

Against the backdrop of these findings, we argue that innovation is required to design and conceptualise a learning infrastructure for OER that increases its adoption. Due to the literature, one of the main problems is the limited availability of OER to potential users (Rolfe, 2012; Otto, 2019), Larson and Murray (2019, p. 92) pointedly state, "challenges for OER users include, first, the ability to locate the resources and second, assurance about their quality".

While, on the one hand, we acknowledge that OER is presently not available in a sufficient amount worldwide on the other hand, studies demonstrate an increase in repositories and a growing amount of resources (Santos-Hermosa et al., 2017, 2021). While the latter sounds promising at first sight, a critical distinction is needed regarding availability between a resource's existence and its discoverability. If a resource exists, but its existence is not detectable by search engines or portals, it is not available for potential users as such. Furthermore, when a resource is hypothetically available to the user in a search engine or portal, it might not be detectable because of the search strategy applied by the user or the limited description (metadata) of the resources.

In order to address this slippery slope and increase the availability of OER through learning innovations, we propose the idea to conceptualise and designing the OER infrastructural architecture as distributed learning ecosystems (DLE). We use the metaphor of "ecosystem" to illustrate our notion to establish an interconnected system of resources, repositories, and referatories. Ecosystems go beyond the purely spatial dimension of learning infrastructures and incorporate various actors and consider their interactions. Digital (networked) learning technology, in this understanding, is not distinct but part of a learning ecosystem and must itself be understood as an actor. Because of the latter, ecosystems for open education should be reflected with caution as they can themselves entail opening and closing mechanisms. Only learning ecosystems based on mechanisms of opening their contents to other repositories and

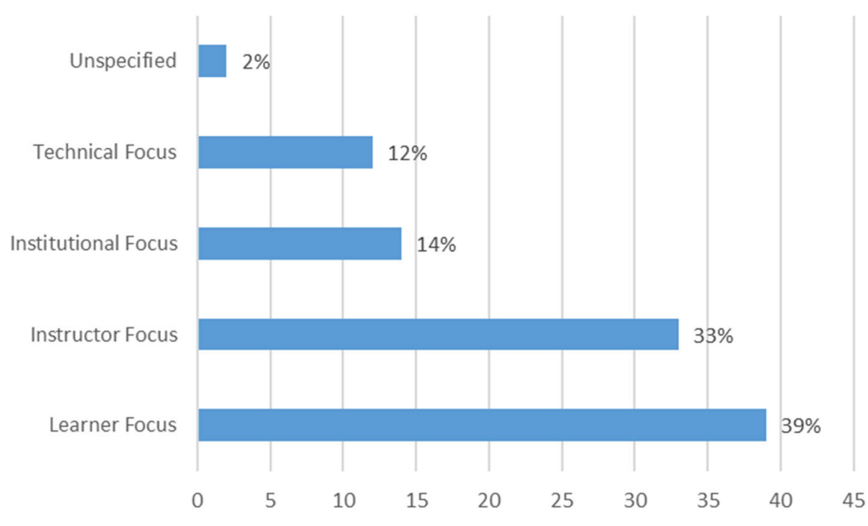


**FIGURE 1 |** Distribution of studies in systematic mapping by primary focus of the investigation, in percent (Otto et al., 2021).

referatories can unfold their full potential for OER in the context of open learning.

Regarding the structure of our article, we first define and delaminate our concept of a learning ecosystem. Then, the third chapter describes the implications of a DLE for OER and identifies the most significant challenges. As a fourth step, based on an explanatory literature review, we present case studies that demonstrate how technical solutions comprising metadata standards and plugins can link repositories and referatories within DLE. Finally, we conclude how merging the different repositories and referatories into a distributed learning ecosystem supports the goal of sustainability and OER.

## LEARNING INFRASTRUCTURES AS LEARNING ECOSYSTEMS

As aforementioned, to illustrate our idea of DLE, we first conceptualise an ecosystem. Ecosystems should be regarded as a metaphor rather than an established concept, illustrating how systems think and operate. Usually, metaphors are used in education to clarify complex objects or relationships by replacing them with something more vital, descriptive, or linguistically more substantial. A competing metaphor that can be found in educational technology is "ecologies" (Sangrá et al., 2019; Conrad and Prinsloo, 2020). However, we argue that learning ecologies' concrete meaning and impact are somewhat vivid and unclear. The concept tries to capture innovative ways of learning and shape the connection between formal and informal learning across several learning contexts through digital technologies. The problem of this bright understanding is backed by a recent systematic review that confirms the concept's vagueness and divulges that there are limited practical applications of the concept, particularly in technology-enhanced learning (Sangrá et al., 2019).

By introducing the concept of learning ecosystems, we want to reach beyond the spatial dimension, which is a subtle assumption in many concepts of learning infrastructures.

Ecosystems as a mental construct accentuate that a learning architecture is a complex ensemble of different influencing variables that are themselves in a dynamic interplay. In addition to the spatial dimension, learning ecosystems are themselves considered to be dynamically evolving. There is progress, unforeseen deviations, and parts die off, reinforce themselves, and mature in an evolutionary way. For that reason, advances in learning ecosystems can no longer be perceived linearly; instead, they have to be understood as an emergent process. Agents' actions have mutual effects and can also give rise to new developments. Knowledge no longer occurs (only) in the mediation via algorithms, programmes or designed spaces and in the exchange between teaching and learning instances. On the contrary, additional actors are incorporated: The creators of knowledge resources, the editorial offices and agencies that select, evaluate and provide them, and other intermediate actors that have a pivotal influence on knowledge environments. Consequently, digital technology itself has become the status of an actor, and alongside human actors (teachers, learners), digital technology must be understood as an actor [actor-network theory (Fenwick and Edwards, 2010)].

In conclusion, the ecosystem metaphor allows us to seize a more comprehensive perspective on a learning architecture that combines various actors and their interactions that all contribute to its composition and evolution.

Our elucidations underscore why the concept of ecosystems originates from describing living entities. Learning here is not (only) bounded in specific spaces available to teachers and learners. Knowledge is constantly transformed and (re)constructed in networks and renewed through (re)use activities. Computers and digital media remain technical objects, and thus it is debatable whether the term ecosystem is adequate or may produce misrepresentations. The technical objects comprise hardware consisting of computers, networks, and the associated operating software and must be understood as the "habitat" in which subjects create, provide, and use digital tools, applications, and content. There are certain autonomous areas in the living environment in an ecosystem where hardware and software elements interact on different levels. These areas are self-organised and mature only in a comparatively small exchange with other ecosystems. The users play an essential role by contributing to the ecosystem and keeping it "alive" through making new contributions and producing content.

Digital technology as an ecosystem was initially shaped by viewing the internet through an economic lens. Very early, the computer industry recognised that it could be attractive not only to sell a device or a software programme but also to attract people by making more comprehensive offers. Bea and Haas (2016) stress the importance of this kind of ecosystem for strategic management: Thinking in ecosystems unwraps new perspectives on customers and competition. A digital ecosystem encompasses several companies that jointly produce values for customers and are themselves part of the system. Messerschmitt and Szyperski (2005) state that software can neither be considered an intangible nor a tangible product and is thus subject to different laws of production and dissemination than traditional goods. Therefore, the creation of software takes place in ecosystems of technology providers, and producers and suppliers work in an environment that depends on the products and services of the respective provider. Interaction between the actors plays a key role here. When a connected group of entrepreneurs and users emerges, it serves as a community that creates shared value over time. Thus, in contrast to the market concept, digital ecosystems underline the distinct interconnectedness of networks of actors well known in the IT world.

## THE PIVOTAL ROLE OF OPEN EDUCATIONAL RESOURCES IN DISTRIBUTED LEARNING ECOSYSTEMS

As above-mentioned, OER constitutes a critical element of open education. OER was initially coined by the UNESCO's (2002) Forum on the Impact of Open Courseware for Higher Education in Developing Countries (2002) and can meanwhile look back on a history of 20 years. Although competing definitions exist, the UNESCO defines OER as being

> *"learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open licence, that permit no-cost access, reuse, re-purpose, adaptation and redistribution by others."* (UNESCO, 2019, p. 3 f.)

The core idea embedded in OER is to facilitate access to educational material and empower people to the 5Rs; to retain, reuse, revise, remix and redistribute them (Wiley, 2014). Consequently, engaging in these 5Rs can broaden access to education, reduce material costs, and improve teaching and learning quality. The pedagogical benefits of OER also manifest in the concepts of Open Pedagogy and Open Educational Practices (OEP), which have evolved in the debate about the educational implications of OER (See **Table 1**). Even though no rigid definition for both concepts exists, OEP describes open practices that can but do not have to involve the use and creation of OER (Cronin and MacLaren, 2018). Open Educational Resources-enabled Pedagogy, as one strand of Open Pedagogy, defined by Wiley and Hilton (2018), captures educational practices that are only possible due to the 5R activities.

While this brief reflection on the advantages of OER points to its added value for education in the digital age, OER overall adoption and use worldwide are low (Zawacki-Richter et al., 2020; Otto et al., 2021). A glance at the available literature reviews proves that numerous empirical studies have been conducted to identify reasons for this absence (Koseoglu and Bozkurt, 2018; Otto, 2019). They found that explanations for the absence are legal uncertainty, lack of time, and institutional barriers. Following Abri and Dabbagh's (2018) literature review, discovering proper OER materials is also a significant challenge for OER adoption. Consequently, many teachers and learners who are aware of OER and keen to use it in their teaching and learning scenarios face the challenge of not finding high-quality OER suitable for their needs. From a research perspective, this problem has only been addressed inadequately. Predominantly, studies are learner- or teacher-focussed, and only a tiny percentage concentrates on institutional or technical issues (Otto et al., 2021). However, insights into infrastructural challenges would be necessary as they can contribute to designing DLE. This is critical as DLE provides access to OER and increases the discoverability of the desired teaching and learning materials.

Viewing the problem of the lack of suitable OER through the lens of DLE, it appears that the challenge is not the non-existence of OER but rather its discoverability. While in the emergence phase of OER, only limited repositories and relevant resources were available to users, the situation has noticeably changed, not least due to the Corona pandemic (Zhang et al., 2020a,b). A closer look at the current OER landscape suggests that several repositories and referatories exist – with a concentration in Europe and Northern America – which comprise a substantial amount of open teaching and learning materials (Santos-Hermosa et al., 2017, 2021), Drabkin (2016), for instance, states that plenty of OER is available in the United States as several states and districts have started to produce content. However, it is only available in the respective repositories and digital libraries, and because these are decentralised, there is no connection between them.

This example illustrates that resources are often not discoverable for potential users in their familiar learning ecosystem. One reason is that OER has grown out of a dispersed system, where repositories are primarily located at educational institutions such as universities or colleges. As a result, decentralised structures of OER are dominant worldwide, so users in one country cannot find or access material that is available in other countries or regions. While decentralised structures are not a problem for OER *per se*, the lack of communication between them is (Drabkin, 2016). Hence, teachers and learners that are keen to use OER find themselves discouraged because they cannot identify appropriate resources that are relevant, up-to-date, and of high quality (Heck et al., 2020). Therefore, when teachers search for OER to enrich their learning scenarios, they habitually start by searching their institutions' repository for OER availability. If search results are insufficient, teachers can search other OER repositories that are available worldwide. However, teachers will only spend a limited time examining repositories separately, and some will end by considering OER as being demanding and time-consuming (Davis et al., 2016), which explains the success of search engines such as Google as one size fits it all offers.

## ESTABLISHING DISTRIBUTED LEARNING ECOSYSTEMS FOR OPEN EDUCATIONAL RESOURCES: CHALLENGES AND PERSPECTIVES

The challenge of OER adoption is manifold and can meanwhile look back on a history of almost two decades. We can distinguish between two prominent causes here: agent and structure for OER adoption (Otto, 2021b). As individual causes (agent), the literature highlights that perceived ease of use and usefulness are the main predictors that strengthen a person's volition which is also a critical factor influencing teachers' intention to adopt OER (Baas et al., 2019). Distributed learning ecosystems support the structural component of OER in creating a system that supports and guides agents in their use of OER. It explicitly assists agents by increasing the amount of OER available and accessible to them.

Looking at the current OER infrastructure, it could be argued that more and more repositories and referatories have become available to assist teachers in searching for OER and contribute to overcoming the decentralised structure. However, this underestimates that referatories have only limited (technical) access to the various OER repositories. This underscores that OER is not automatically visible in DLE despite continually growing. Their discoverability depends on open technological infrastructures and respective open services designed as an open informational ecosystem (Kerres and Heinen, 2015).

Hitherto, even in the case of OER repositories, we regularly find closed informational ecosystems that preserve educational resources within specific boundaries. This is confirmed when we look at the situation of repositories in higher education, where the educational landscape is highly fragmented (Santos-Hermosa et al., 2017; UNESCO IITE, 2019; Otto et al., 2021). One reason is that most countries' higher education systems guarantee their universities a high degree of independence and autonomy. Consequently, little by little higher education institutions have set up repositories to store OER and opted for specific metadata standards. Besides, they typically have high data protection and access rights, so most institutions do not grant free access to materials and metadata.

Given this decentralised OER landscape, the discoverability of OER cannot be enriched by merely launching more and more repositories or referatories for OER. Besides, the decentralised structure makes it impossible to establish single, national or European repositories and referatories, which might also not be a desirable goal. The current OER landscape has emerged from a multitude of bottom-up initiatives and services in different educational areas that all value their independence, highlight subsidiarity and rely on user loyalty. All of these causes are ranked higher by the different actors than the possible rewards of a more centralised structure.

## The Open Educational Resources Landscape as Distributed Learning Ecosystems

We have shown that the current OER landscape is highly fragmented. While networking and interconnectedness of existing (sub-) OER infrastructures/ecosystems occur erratically, advocating the idea of conceptional permeable distributed learning ecosystems would bring additional benefits. It would enable the development of pragmatic solutions such as aggregation mechanisms for digital learning resources and repositories (e.g., meta-search engines). Thereby disparately distributed and partially disconnected resources and communities could be linked through interoperable verification and exchange routines without restricting the diversity of field-specific offerings. Several international initiatives are on their way to establishing national, European or international ecosystems (e.g., 5Xgon, Open Discovery Space or ENCORE +) with the help of the latest technologies. These various initiatives demonstrate that there is no such thing as an ultimate design of an ecosystem, but the spirit of openness allows scope for experimentation so that diverse approaches can progress for many different requirements.

Competing approaches should also be supported and tested so that in the long term, providers and services can emerge that meet the needs of users in a particular way. DLE should therefore encompass a variety of methods and approaches. Therefore, it is necessary to mediate between different existing platforms, projects and institutions in the diverse ecosystems. Users can only select particularly suitable services and platforms if they are provided with an overview of the existing offerings. Only if services can be used and tested side-by-side users will be able to choose and decide based on their own experience. To this end, it seems appropriate to define technical standards for exchanging information in the medium term, which are regularly reviewed and adapted. In addition, the coordination of measures to create, connect and integrate different approaches into DLE should be subject to the principles of openness and transparency.

## Opening and Closing in Learning Ecosystems

As aforementioned, there is no availability of OER *per se*. For becoming full available further than in the respective repository and thus in DLE, a consensus is needed among the relevant stakeholders to mutually provide (meta-) information, especially outside the distinct boundaries. Without this condition, even OER repositories, which are genuinely perceived as open, have to be considered closed ecosystems that retain educational resources within their boundaries and, thus, miss their impact on DLE specifically and open learning in general.

Closure mechanisms in ecosystems can be obvious, for instance, manifest in a paywall that restricts access via pay per view or pay per subscription. Moreover, obligations to register on a website can also be regarded as instruments for "closure" because it limits instant access to resources. When users register on websites and unknowingly accept the conditions, the users might consider that this is merely time-consuming. However, they have revealed and thereby "paid" with their personal information, such as an email or home address. One might claim that specific instructional approaches require registration, such as open learning or collaboration tools and apps. In terms of DLE, concealing information behind walls or hindering their exchange has to be considered severe. As a result, search engines cannot trace and locate the resources behind such (payment or registration) walls. Moreover, if resources are traceable, they are only partially accessible without payment, like many online journalism articles (Benson, 2019).

## Prospects to Open and Connect Distributed Learning Ecosystems

We have problematised the role and function of OER and repositories in DLE and that this is not a trivial pursuit. It has become evident that educational resources are not automatically open to learners.

Consequently, we must acknowledge that there is a silent network behind the salient network that is crucial in DLE. It would be naïve just to consider the use and availability of "open" material as the most pressing issues. When teachers put resources "on the web" for others' there are no intermediary entities or institutions – private or public – that are ultimately accountable for making this resource accessible and traceable on the web. However, this production chain behind resources developmental processes to make them available is less visible, and the processing is seamless. But precisely this determines whether and how users can find resources, communicate with other users and services, eventually find a course, and how modifications or improvements to an (open) resource can be traced back. As a result, the discussion about OER specifically and open education more broadly frequently ignores the relevance of the openness of repositories and related intermediary services like, for instance, referatories and how they operate (see **Figure 2**).

For that reason, numerous learning ecosystems cannot be considered open. On the contrary, they comprise tendencies that contribute to opening and closing their boundaries. For serving as a prospering learning ecosystem, on the one hand, it must be open enough to empower teachers and learners to develop new resources and services in the ecosystem. On the other hand, it must also be close enough to allow teachers and learners to remain in control or track their resources and control and monitor how they are further used. Recent studies with OER experienced lecturers about the design of OER repositories confirm that they want to be informed about changes or improvements of their resources performed by others and desire to receive feedback on their published material (Otto, 2021a). Moreover, they require assistance and support systems, for instance, to upload resources into repositories or assign metadata to resources. The lack of quality in metadata that adequately and comprehensively describes resources is an eminent problem, and many inconsumable standards hamper harmonising metadata (Cortinovis et al., 2019). Another significant problem is that many authors of resources fail or are reluctant to deliver any metadata at all. Numerous studies have recommended metadata sets that describe OER more systematically and thereby enrich and facilitate the metadata report to improve the OER description and, therefore, the OER discoverability (Herrera-Cubides et al., 2022).

In order to address this problem of metadata standards, a communicative and collaborative approach involving as many stakeholders as possible seems advisable. In a case study, Menzel (in press) shows how commonly agreed metadata standards contribute to DLE development. The author describes how operators from OER repositories in higher education in Germany collaboratively developed a standard metadata profile. In Germany, the federal system resulted in several federal state-specific solutions for repositories from which six participated in the project (HOOU, OERNDS, ORCA.nrw, VCRP, VHB, and ZOERR). Based on the FAIR principles (Findability, Accessibility, Interoperability, and Reuse), meaningful metadata description was achieved by balancing the *prima facie* antagonistic demands of describing resources as detailed and accurate as possible by likewise only providing essential information to keep the threshold for authors as low as possible. In conclusion, Menzel stresses that metadata standards are crucial for connecting OER repositories, thereby permitting federated search and harvesting of metadata, e.g., by search engines or other interested parties.

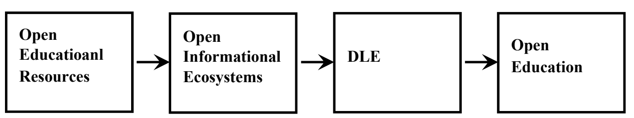


**FIGURE 2 |** An incremental representation of open educational resources (OER) and distributed learning ecosystems (DLE).

The standard metadata issue also points to the second underlying challenge of the discoverability of OER, for which there are numerous attempts to address it (Cortinovis et al., 2019; Otto et al., 2021). However, efforts mostly contain creating new OER repositories with advanced search services or federated repositories that accumulate resources from diverse repositories or institutions. Despite this being a desirable development, one may question whether establishing another OER repository or search engine improves or rather fragments the current OER landscape and, thereby, the discoverability of OER further.

The chances are that teachers and learners get lost when trying to find OER resources because of the problems with searching and locating them. The latter is reinforced by recent literature reviews confirming that searching and locating OER is still a significant problem (Abri and Dabbagh, 2018).

As already described, poor metadata assignment is one key component to locating resources. Therefore, DLE can help here by connecting the different repositories to establish an overall structure. Thus, networks of connected servers or services on the internet conjointly or cooperatively establish an environment for finding and providing resources to a larger public. This comprises functions for delivering content and related, more or less complex, value chain functions, like generating, editing, assembling, annotating, tagging, commenting, or linking information resources. Several providers correspond in such ecosystems; hence, their collaboration depends on common standards to interface content and metadata (see **Figure 1**).

When ecosystems are open, they enable a content provider to "plug into" into the ecosystem by providing metadata that can be retrieved from a reference platform (referatory) (see **Figure 3**). Contrary, closed ecosystems only provide a one-stop solution that conglomerates all the described functions. However, this is also imaginable in a network of confederated servers that conjointly maintain the system's boundaries close.

Looking into the literature, we find examples demonstrating how repositories can contribute to open ecosystems. For example, Ladurner et al. (2020) present a practical bottom-up solution to broaden access to resources for students at their university. Teachers here are enabled to use their own learning management system (LMS) for the publication of OER. The resources are thereby offered to a broad public via the university's own OER repository and the Austrian OER portal by assigning adequate metadata.

Abdel-Qader and Tochtermann (in press) provide a perfect model of how the DLE concept must be implemented from a technical perspective. In a research project, they developed a tool for connecting OER repositories using the Learning Object Metadata (LOM) standard (see **Figure 4**).

Their goal was to increase the accessibility of OER for more learners. Their article provides detailed specifications and requirements for connecting different OER repositories from a technical point of view. However, their idea is to allow non-technical staff to replicate this process to harvest data from the web.

As an outlook, Tlili et al. (2021) investigate how the current emerging technologies, such as Artificial Intelligence (AI) and blockchain, can contribute to OER development. Although the

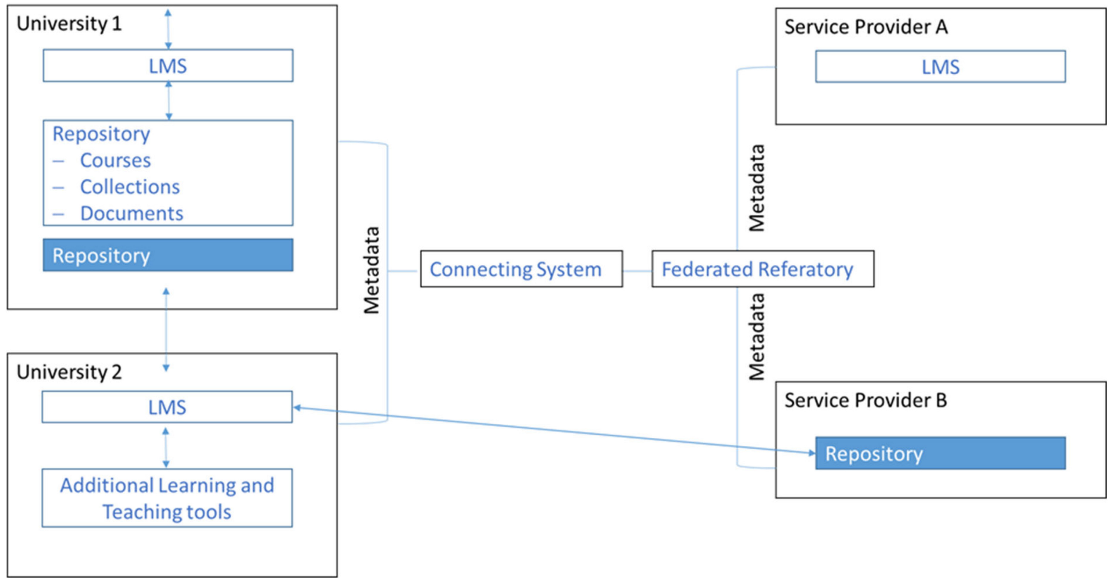


**FIGURE 3 |** Illustrative presentation of a distributed learning ecosystems (DLE).

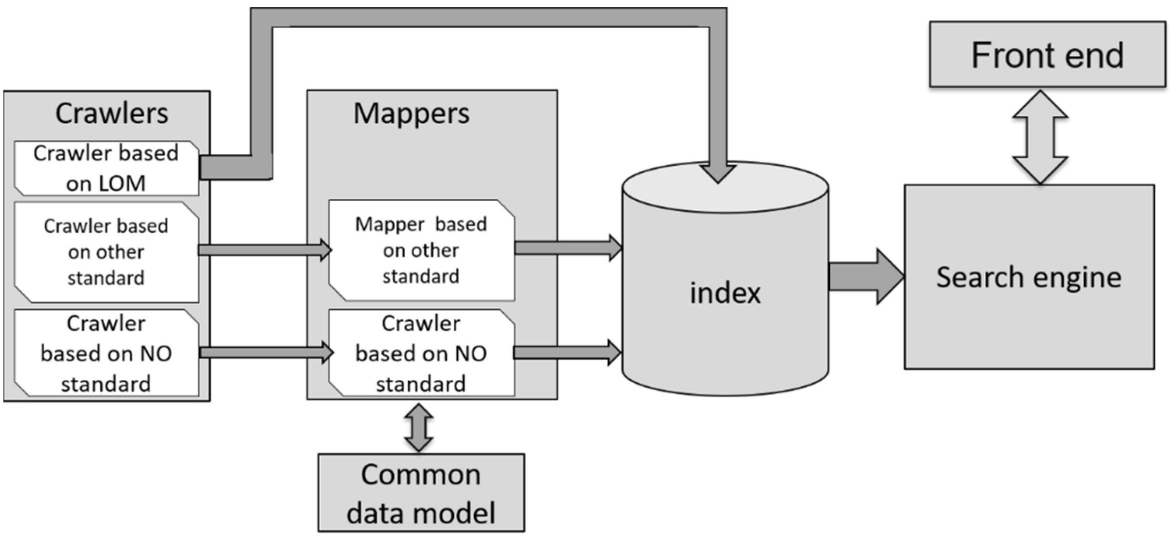


**FIGURE 4 |** A scenario of harvesting and mapping the open educational resources (OER) metadata that are modelled using the learning object metadata (LOM) standard (Abdel-Qader et al., 2021).

authors concede that technological limitations might hinder the application, emerging technologies, specifically machine learning and Natural Language Processing (NLP) techniques, can lead to automatic metadata tagging, resulting in OER with rich and more accurate metadata, which can be found more easily. In DLE, as we proposed, it would also be possible to implement the other recommendation of Tlili et al. (2021), which is to use sophisticated machine learning and NLP techniques to analyse generated metadata of the published OER to map all of these resources together and build OER recommender systems. Time and the associated technical (and political) developments will reveal whether the actual implementation of emerging technology is realisable.

## CONCLUSION: TOWARD DISTRIBUTED LEARNING ECOSYSTEMS IN OPEN EDUCATION

With our article, we contributed to the overall challenge of OER adoption in education. OER contributes to the sustainable (re)use and (re)distribution of (educational) resources. This sustainability objective is also visible in the latest UNSECO recommendation concerning OER, which intends to support the 2030 Sustainable Development Agenda, namely SDG 4 (Quality education). The support of SDG 4 is combined with the call to create sustainability models for OER at national, regional and institutional levels and the planning and pilot testing of new sustainable forms of education and learning. As a result, several repositories and referatories for OER provision have been developed and tested in educational institutions worldwide. Yet, each of these platforms contains only a relatively limited number of resources. We consider the discoverability of OER to be the major challenge here. Too often is argued that more resources are needed to increase OER adoption. However, we find that it is not solely the number of lacking resources but their availability to teachers and learners worldwide.

In our article, we argued that when considered through the lens of learning innovation and sustainability, it would be necessary to increase the discoverability of available resources at the different locations and platforms, which currently are visible to only a limited number of teachers and students. For achieving this goal, the focus needs to shift from creating and growing new and competing platforms and repositories to intelligent ways of linking and increasing their interconnectedness.

For the identified challenge of the discoverability of OER, we proposed the concept of DLE as a learning innovation. The concept of "ecosystems" illustrates this approach of interconnected resources. Ecosystems go beyond the spatial dimension of learning by focussing on actors' diversity and interactions. Digital (networked) learning technology is part of an ecosystem and has itself to be understood as an actor. Given the current fragmented nature of the OER infrastructure, we understand DLE as a design approach to contribute to the interconnectedness of repositories and referatories. However, we pointed to the pitfalls and hurdles to achieving such DLE by introducing and separating closed and open ecosystems. Therefore, ecosystems should be reflected with caution as they can themselves entail opening and closing mechanisms. Ecosystems that rely on mechanisms of opening their contents to other platforms can realise the full potential of open learning by making a valuable contribution to DLE.

We described the implications of the concept of DLE by presenting case studies that show how technical solutions, including metadata standards and plugins, can link content in repositories and referatories within ecosystems. The overarching objective is that the different repositories and referatories expand and improve the sustainable use of OER by merging into DLE.

Lastly, it has to be noted that our concept accompanies an invitation to the many researchers and practitioners engaged in the context of OER and open education. Looking at the current landscape, it is visible that many initiatives and research projects are underway that are expected to deliver essential impulses and results in the coming years. Therefore, we consider it crucial that they take on board the idea of DLE as an essential conceptual basis and try to let their project or initiative make a contribution to its concrete implementation. It might especially be promising to explore how lasted educational technology like learning analytics, blockchain, or even Artificial Intelligence (AI) can support or facilitate DLE. OER and related efforts have always benefitted from the fundamental belief of approaching new concepts and developments with an open mind to accomplish and foster open education.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## AUTHOR CONTRIBUTIONS

Both authors wrote, read, and approved the final manuscript for submission.

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# Social Network Analysis of EduTubers

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The popularity of educational videos has increased in recent years. In 2018, YouTube announced a $20 million investment to support educational video creators and organized the YouTube EduCon event to bring them together and form a community. The COVID-19 pandemic pushed educational institutions to use resources contained in public repositories, such as YouTube. The objective of this research study was to explore the dynamics of EduTubers to understand the motivations for their interactions. We used social network analysis (SNA) with YouTube data to analyze the dynamics of EduTubers' recommendation networks. Meaningful insights reveal a relationship between the level of digital engagement and the level of out-degree. Additionally, we confirm that educhannel homophily has a positive effect on the level of reciprocity. The main contribution lies in the use of theoretical concepts (reciprocity and homophily), focusing on the intrinsic motivations of EduTubers to recommend other channels. The practical implications of the results suggest that educhannels that initiate and grow digital engagement are more likely to participate in a recommendation network.

**Keywords: EduTuber, educational videos, YouTube, social network analysis, educational innovation, communities**



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## INTRODUCTION

The popularity of educational videos has increased recently. In 2018, YouTube announced a $20 million investment to support educational video creators, now called EduTubers (López, 2019; López et al., 2020; Martínez and Cedillo, 2020). YouTube also organized the annual YouTube EduCon event. In addition to providing training and development for EduTubers, this event aimed to bring them together and form a community (YouTube, 2018). Google (2019) highlights the increasing popularity of YouTube; the platform contains more than one million educational videos, which have more than one billion daily views.

Digital social networks are applications that young people use the most, with videos constituting most of their digital consumption, including videos to support their learning objectives. In Mexico, accessing social media apps is the principal activity of users (Asociación de Internet, 2021). Rangarajan et al. (2019) indicate that the innovative approach offered by social platforms, such as YouTube, has led to the increased use of videos for training. In this case, given the availability of this type of videos on the Internet and the prominence of the technology in everyday life, seeking out this type of complementary resources is becoming increasingly common for students.

The COVID-19 pandemic pushed educational institutions to use resources contained in public repositories, such as YouTube. The use of public educational content by teachers drove the increase in the possibilities in formal and informal settings (Pattier, 2021a). To address these needs, YouTube launched four strategies focused on finding learning resources more easily, including

YouTube Learning Destination, which has high-quality educational content for students, and #StudyWithMe, purposed with sharing study experiences (YouTube Official Blog, 2020). Given the evident importance of open educational content and the popularity of YouTube among the student population, the social network dynamics among EduTubers is a topic that has been increasing its presence in academic research.

YouTube channels are looking for strategies to capture consumers and grow in popularity; in this competition dynamic, measuring digital engagement is important. The literature features some studies focused on the influence and digital engagement of YouTube channels. Abdelkader (2021) proposed a model to determine the level of engagement with content published through YouTube channels. Paolillo (2008) analyzed the social structure of YouTube by studying friendship relationships and their correlation with the tags applied to the videos. Tur-Viñes et al. (2018) identified the practices of influencers on YouTube and the presence of brands in their content.

Another line of inquiry has focused on the communities formed on YouTube and the key factors for success in those communities. For example, scholars have studied the recommendations made by YouTube through its algorithms (Abul-Fottouh et al., 2020; Kaiser and Rauchfleisch, 2020), as well as the mutually beneficial behaviors and the effect that the number of subscribers and views can have (Song et al., 2019). Some scholars (Pérez-Escoda and García-Ruiz, 2020; Arroyo et al., 2021; Fortaleza, 2021; Pattier, 2021a,b,c) studied the practices and characteristics that classify educational channels among YouTube's top channels. Two key factors for our research emerge from the results: (1) the data and statistics of the channel, considering the frequency of video uploads and the average duration of the videos, and (2) the use of the YouTube platform, adding the "Community" section and offering links to other YouTube channels. To our knowledge, prior research included only a limited number of studies on the dynamics of the EduTubers' interactions and community formation.

Although YouTube is focused on content sharing, it also offers users certain socially oriented functionalities. The "Community" section extends the possibilities for creators and consumers to interact on the same platform. Thus, for the creators (in this context EduTubers), it is an additional source of the traffic to their channel that allows them to strengthen their ties with other EduTubers and create a community. Therefore, EduTubers can use strategies related to reciprocity (a behavioral response of mutual benefit) and homophily (propensity of individuals to connect with similar others) to increase traffic to their channel and their level of digital engagement because engagement in a social network is reflected in the publications and interactions shared by users (Pletikosa Cvijikj and Michahelles, 2013). In sum, content producers on YouTube benefit from social relationships for mutual support, for example, reciprocated recommendations (Paolillo, 2008), which can benefit the channel's engagement rate. Therefore, exploring mechanisms of social interaction in the context of EduTubers and educhannels is relevant.

The objective of this research is to explore the dynamics of the EduTubers' recommendation network to understand the nature of the connection between them. We used as theoretical bases (a) digital engagement to understand successful educhannels, (b) social exchange theory (SET) to understand the reciprocity phenomena, and (c) the mechanism of homophily to understand the connection mechanism between similar members of a group. The result of this research expands scientific knowledge as they allow a better understanding of the dynamics generated in the recommendation network of EduTubers and, above all, by implementing a technique that is widely used in the social sciences, such as SNA, to study a phenomenon of life on the digital plane. To do so, we created a recommendation network of 412 channels of EduTubers, gathered their main attributes, analyzed their centrality and reciprocity, and used Multiple regression quadratic assignment procedures (MRQAP) to measure their interrelation.

The main contribution of our results is the use of theoretical concepts (reciprocity and homophily), which focuses on the intrinsic motivations of EduTubers to recommend other channels. Our findings indicate that EduTubers' channels that have a higher level of digital engagement tend to recommend a higher number of other educhannels. Another detail that is important to note is that each online social network is different in nature and behavior (i.e., Facebook and Twitter). The results of this study suggest that on YouTube, and specifically among EduTubers, recommending other educhannels is a relevant factor that contributes to their digital engagement.

## THEORETICAL FRAMEWORK

In this section, we present the theoretical bases of the research that will help provide insights to understand the phenomena: digital engagement, SET, and homophily.

### Digital Engagement

The concept of engagement can take on different connotations depending on the context in which it is used. Digital engagement on a social network is reflected in the level of audience involvement based on the characteristics and content shared on the network (Pletikosa Cvijikj and Michahelles, 2013). The concept in social media is also understood as a psychological state of motivation that results in the act of following (Pérez-Escoda et al., 2020). Different perspectives and models of digital engagement can be found in the literature according to the social network studied.

Some scholars have proposed models to measure digital engagement. However, the mechanisms vary from one technological platform to another. Bonsón and Ratkai (2013) consider likes, comments, and shares as elements for measuring popularity, commitment, and virality associated with social media content. Authors such as Abdelkader (2021) point out that the content published, the number of subscribers, the number of uploaded videos, the years of experience, the length of the video, the country, and the category are the factors to determine engagement. In general, the proposals agree that these actions include (1) giving a like and (2) commenting, which are direct manifestations of engagement

(Pletikosa Cvijikj and Michahelles, 2013; Sabate et al., 2014). When measuring engagement, considering both content exposure and user participation is important.

In this sense, scholars have proposed mechanisms to measure fans' digital engagement on YouTube. Xie (2017) developed an engagement index to measure three layers of engagement in YouTube: (1) shallow engagement is calculated by four quantitative variables: view count, like count, dislike count, and comment count; (2) medium engagement is measured by the frequency of three types of interactions: conversations between the community members, comments intended to speak to the others who are watching the video and the vocabulary in the comment indicate an emotional expression; and finally, (3) deep engagement is measured by three variables related to contributing labor and money: audiences contributing subtitles, leaving long comments, and donating money to the channel. Another indicator for calculating engagement in YouTube channels is by considering likes, dislikes, and views (López-Navarrete et al., 2021). Although some of the proposals are recent, an important detail to emphasize is that YouTube has currently changed the interaction options and the number of dislikes is not available to the public. Some services on the web, such as SocialBlade, track user statistics for social media. SocialBlade provides some metrics to understand the growth and trends of accounts on social media; these statistics have also been used in other studies (Pérez-Escoda and García-Ruiz, 2020; Abdelkader, 2021; Fortaleza, 2021). According to SocialBlade (nd), they initially ranked based on the numbers of subscribers and visits, but they quickly realized that these were not very reliable indicators. Now, their algorithm aims to measure the influence of a channel based on several metrics, including the average number of visits.

## Social Exchange Theory and Reciprocity

Social exchange theory (SET) is a family of conceptual models (Cropanzano and Mitchell, 2005) that are based on the assumption that any interaction between individuals is an exchange of tangible or intangible resources (Homans, 1958). The main premise of SET is that people enter and maintain relationships with the expectation that doing so will be rewarding (Homans, 1958; Blau, 1968). Scholars have found that the level of commitment in the relationship is proportional to the number of benefits that will be obtained (Thibaut and Kelley, 1959), that interdependence is crucial to the continuance of such relationship (Emerson, 1962), and that positive economic and social outcomes increase the partners' trust over time.

Given these patterns of social behaviors, individuals who develop mutual and beneficial exchanges over time engender trust, loyalty, and commitment among the parties (Mitchell et al., 2012). When providing another with a benefit, one must trust that the other will return the benefit in time (Homans, 1958; Blau, 1964). Furthermore, SET predicts that in reaction to positive initiating actions, targets will tend to reply in kind by engaging in reciprocity (Cropanzano and Mitchell, 2005).

Reciprocity is a powerful determinant of human behavior. It is modeled as the behavioral response to an action that is perceived as either kind or unkind, and it is assessed in terms of the consequence of an action and the intentions involved (Eisenberger et al., 2001). Reciprocity has been studied in dyads and groups or networks. When a person does another a favor and receives a benefit in return directly from the same person (dyadic level), it is called direct reciprocity (Axelrod and Hamilton, 1981). When reciprocity involves a group or a network, it is referred to as indirect reciprocity (Nowak, 2006) or generalized exchange (Takahashi, 2000). In the social media arena, scholars have found reciprocity among content providers in social media (Song et al., 2019). Cheng et al. (2008) studied videos as nodes and recommendations to other videos as ties. Moreover, although Torres and Conrad (2015) studied YouTube channels that recommend other channels and analyzed the structure of the network created by such recommendations, they suggest that additional research is needed.

For instance, the ties between content providers have not been well understood, especially for their reciprocity (Song et al., 2019). The scarce literature on ties between providers has studied how ties induce the linked providers to change their content (Zeng and Wei, 2013; Wang et al., 2018) and how one-way ties benefit the initiators (Katona and Sarvary, 2008; Mayzlin and Yoganarasimhan, 2012) and the providers to which they link (Stephen and Toubia, 2010; Jabr and Zheng, 2014). Commonly, researchers rely on SNA measures in their studies to analyze their data.

Social network analysis enables the study of social systems from a structural perspective through the identification of behavioral patterns based on node and tie attributes (Freeman, 1979). In particular, degree centrality (Freeman, 1979; Borgatti, 2005) is a concept that describes how connected a node is with others in the network. It is understood as the number of direct edges a node has, such as the number of incoming recommendations and outgoing recommendations of a YouTube channel.

Given the patterns of reciprocity and how the level of digital engagement is obtained, we propose that YouTube content providers recommend other channels with the aim that the others will reciprocate their action (Homans, 1958; Blau, 1964; Mitchell et al., 2012), which in turn will increase their digital engagement on the network. We state our first research question as follows: Is there a relationship between the centrality in EduTubers' recommendation network and their digital engagement on YouTube? However, it is interesting as well to explore whom those EduTubers recommend. YouTube content creators are strongly linked to others producing similar content (Paolillo, 2008). Therefore, we find in homophily one possible answer.

## Homophily

Homophily is one of the main patterns underlying human relationships (Lawrence and Shah, 2020). It refers to the propensity of individuals to connect with similar others, that is, with those who have common attributes and values (Lazarsfeld and Merton, 1954); who are like-minded; and who share the same habits, behaviors, and beliefs (McPherson et al., 2001). A variety of lines of reasoning support the homophily principle. One of them is the similarity-attraction hypothesis (Byrne, 1971) which was presented by Heider (1958), who proposed that psychological discomfort that emerges from cognitive or emotional inconsistency can be reduced by homophily. Therefore, individuals tend to select similar others to reduce the potential areas of conflict in the relationship (Sherif, 1958), and there is an *a priori* notion that they are more likely to be accepted (Easley and Kleinberg, 2010). Consequently, trust and solidarity are expected to be more likely to be built with similar than with dissimilar counterparts (Mollica et al., 2003). Furthermore, ties among similar ones reduce the risks associated with their formation and the cost of maintaining them, and are more permanent and durable (Kossinets and Watts, 2009).

Homophily has been frequently observed in social networks, where people with similar contexts connect with each other naturally and constantly (Ma et al., 2015; Halberstam and Knight, 2016). The effect of homophily has been widely studied in social media data, from textual data to follower lists of accounts (Pan et al., 2019; Khanam et al., 2020). Most of the studies focused on textual posts, hashtags, mentions, or users' network connections. However, a research gap exists, because studies on YouTube recommendations are scarce (Khanam et al., 2020). As an exception, Kaiser and Rauchfleisch (2020) analyzed the algorithmic homophily on YouTube's channel recommendations. These authors found that the algorithm fosters the creation of highly homophilous communities. In the same line, Paolillo (2008) found that YouTube content creators are strongly linked to others that produce similar content, also based on the recommendation network. In sum, previous studies in a variety of contexts consistently found that homophilous ties are more likely to act similarly, to reciprocate, and to cooperate (Ma et al., 2015; Wang et al., 2018; Song et al., 2019). Therefore, our second research question is as follows: Is there a relationship between educhannels' homophily (channel attributes) and the level of reciprocity in EduTubers' recommendation network?

## MATERIALS AND METHODS

### Sample and Data Collection

This research aims to explore the dynamic of EduTubers' recommendation network to understand the nature of the connections between them. The research follows a design using digital methods and SNA. Digital methods are techniques for the study of social phenomena employing data available on the network (Rogers, 2015). This technique uses digital objects (links, comments, etc.) created on Internet platforms. SNA provides a means to understand the structure and information flows of social networks in both social media and academic media (Carmichael and Archibald, 2019). SNA's purpose is to examine connections between individuals and groups via the study of the structure of nodes and edges, which represent entities and relationships, respectively. The use of SNA is vast, being the common context of study knowledge sharing networks (Han et al., 2020), interlocking directorates (Wang et al., 2021), and collaboration and advice-seeking networks (Sinnema et al., 2020). Although a recommendation network analyzes the interaction of content creators, it differs somehow from the rest due to the lack of evidence of face-to-face contact and the difficulty of measuring the intensity of such interactions.

In SNA, one of the sampling methods is snowball sampling, in which relationships between participants are iteratively traced to identify new participants in the network (Paolillo, 2008). We used this approach because it has a particular value in network circumstances with unavailable pre-existing lists (Doreian and Woodard, 1992). For this study, as entry points, 37 educhannels owned by the most recommended EduTubers were identified and selected. To avoid bias, the selected educhannels were about different topics, targeted different audiences, and were created in different countries. Entry points were identified through a Google search. For the search, we use the terms "top 10 edutubers" and "top edutubers," and we found seven web pages with a list of EduTubers[1,2,3,4,5,6,7], which meets the exploratory nature of this study.

The relational data were collected based on information gathered from each channel in the section "Channels," which contains the channel recommendations of the owner. The collected data allowed the creation of an ego network that differs from a full network in the sense that it is created from first-degree connections and the interlinkage among them. The full network requires a full list of actors from the beginning of an SNA study (Stolz and Schlereth, 2021). The ego network data were integrated by using the information of recommended channels in an iterative process to find new educhannels. Notably, for the owners, the "Channels" section is an additional source of traffic to their channel and strengthens their ties with other creators, hence creating a community and increasing their digital engagement. Furthermore, channel recommendations are not personalized on a user level. Thus, every time a channel page is opened even by different individual users, the same set of channels is recommended (Kaiser and Rauchfleisch, 2020). At the end of the third iterative process, 412 educhannels were selected to integrate the recommendation network with 1,303 edges.

The data for the analysis were collected during October 2021. The following attributes were obtained for each channel: year of creation, number of subscribers, number of videos, number of channel views, category of the topic covered in the videos based on OECD's classification (Organization for Economic Co-operation and Development, 2007), target audience, type of content developed, country, and level of digital engagement. The 412 educhannels considered for this study were created between 2005 (foundation year of YouTube) and 2021. **Table 1** shows the attributes and categories used in this study.

The format of 46.6% of the educhannels is as a class and 40.3% is as science communication. Eighteen percent of the educhannels are from Latin America, 23.1% are from Spain, and 37.6% are from non-Spanish-speaking countries. Furthermore, most of the channels are rated B (9.2% B+, 35.2% B, 29.1% B−), and 17.7% are rated C+. Finally, 38.1% of the channels talk about

[1] https://www.lanacion.com.ar
[2] https://www.elcorreo.com/
[3] https://www.clubinfluencers.com/
[4] https://brandme.la/
[5] https://www.familyon.es/
[6] https://www.bebesymas.com/
[7] http://teneightymagazine.com/

**TABLE 1 |** Attributes and categories for each educhannel.

| Topics | % | Target audience | % | Format of content | % | Country | % | Level of digital engagement | % |
|---|---|---|---|---|---|---|---|---|---|
| Natural sciences | 38.1 | Teenagers and adults | 38.1 | Class type | 46.6 | Non-Spanish-speaking country | 37.6 | A+ | 0.0 |
| Humanities | 16.7 | Adults | 23.3 | Sciences communication | 40.3 | Spain | 23.1 | A | 0.0 |
| Social sciences | 7.3 | Children | 15.5 | Do it yourself (DIY) | 13.1 | Latin America | 18.0 | A- | 0.5 |
| Health and medical sciences | 4.1 | General | 14.6 | | 100.0 | No information | 21.4 | B+ | 9.2 |
| Engineering and technology | 4.1 | Only teenagers | 8.5 | | | | 100.0 | B | 35.2 |
| Agricultural sciences | 0.5 | | 100.0 | | | | | B– | 29.1 |
| Various subjects | 29.1 | | | | | | | C+ | 17.7 |
| | 100 | | | | | | | C | 4.4 |
| | | | | | | | | C– | 0.5 |
| | | | | | | | | D+ | 0.2 |
| | | | | | | | | D | 0.7 |
| | | | | | | | | D– | 0.0 |
| | | | | | | | | No information | 0.0 |
| | | | | | | | | | 100 |

*Source: Own elaboration based on data collection. The level of digital engagement goes from A+ to D–, where A+ is the higher level and D– is the lower level (SocialBlade, nd).*

natural science, 16.7% talk about humanities, and 29.1% discuss a variety of subjects.

## Measurement

To build the YouTube Channel Recommendation Network, we directed a graph where the nodes are all channels found in the data collection process and the edges are the creators' recommendations to other channels. Our unit of analysis is the relationship between pairs of educhannels, meaning that all the variables are dyadic (Borgatti and Cross, 2003).

For the first research question, our dependent variable is the level of digital engagement. As previously mentioned in this document, the metrics commonly used for digital engagement analysis are based on videos. However, in our study, we analyzed channels and their connectivity. Therefore, we could not apply those metrics. As a result, to triangulate the sources of information and strengthen the results, we obtained this metric from SocialBlade, which is a trustable Internet site and used in other studies (Pérez-Escoda and García-Ruiz, 2020; Abdelkader, 2021; Fortaleza, 2021; SocialBlade, nd). It is useful to understand the growth and trends of accounts on social media. The level of digital engagement is given from A+ to D—, where A+ is the higher level and D— is the lower level (To see how this level is calculated, visit https://socialblade.com/youtube/help). For the independent variables, we calculated the degree centrality (in-degree and out-degree) and the reciprocity of each educhannel. Out-degree measures the number of ties or recommendations from a focal node or YouTube channel to others, and in-degree measures the ties or recommendations into the given node. Reciprocity measures the number of reciprocated ties in a network. A tie is reciprocated if a recommendation is made from educhannel B to educhannel A whenever a recommendation is made from educhannel A to educhannel B (UCINET 6.0).

For the second research question, the dependent variable is the reciprocity of each educhannel. The independent variables are four of the attributes collected for each educhannel (**Table 1**): country, audience, topic, and format.

## Analysis

The analysis consisted of two main steps. First, matrices were created to obtain the SNA measures. Second, correlations and regressions to test the proposed relationship within our research questions.

First, the recommendation matrix was constructed by 412 columns and 412 rows, with a number "1" being assigned when a recommendation from one educhannel to another was present and "0" when such recommendation was absent. For each educhannel attribute (level of digital engagement, in-degree, out-degree, reciprocity, country, audience, topic, and format), we transformed the 412 rows and 1 column into a matrix with 412 rows and 412 columns by using a procedure called attribute to matrix-exact matches from the statistical package UCINET 6.0 (Borgatti, 2002). Here, "1" means that one educhannel shares the same attribute with another educhannel, and "0" is given when it differs. For example, two educhannels from Latin America will have a value of "1" in the row and column where they are related and a "0" with an educhannel from Spain. Notably, to avoid possible non-agreement because of using numeric variables such as in-degree, non-degree, and reciprocity, we categorize these three into low, medium, and high values. We applied the same categorization for digital engagement. The frequency of

**TABLE 2 |** Categorization: low, medium, and high value.

| | Low | Medium | High |
|---|---|---|---|
| Digital engagement | 14 | 213 | 185 |
| In-degree | 279 | 67 | 66 |
| Out-degree | 299 | 69 | 44 |
| Reciprocity | 255 | 93 | 64 |

*Number of educhannels in each category.*

educhannels for each category and variable is shown in **Table 2**. We ended up with eight attribute matrices.

Second, a quadratic assignment procedure – correlation and regression (QAP/MRQAP) (Hubert, 1987; Krackhardt, 1988; Borgatti and Cross, 2003)—was used to analyze the data and to test the proposed relationships. These procedures are commonly used to analyze the association between networks (Han et al., 2020; Rivera et al., 2020). In QAP, one is an observed network, while the other is a model or expected network. In the first step, the algorithm computes Pearson's correlation coefficient between corresponding cells of the two matrices. In the second step, it randomly permutes the rows and columns of one matrix synchronously and recomputes the correlation. The second step is performed hundreds of times to compute the proportion of times that a random measure is larger than or equal to the observed measure calculated in step 1. QAP and MRQAP methods generate significance levels (*p*-values) of the matrix relationship. P-values that are less than <0.05 suggest a strong relationship between the matrices that is unlikely to have occurred by chance (Dekker et al., 2003; Borgatti et al., 2013). In other words, *p*-values higher than 0.05 can be interpreted as not significant. In particular, in MRQAP, one matrix is the dependent network and is regressed on one or more independent matrices. MRQAP generates a pseudo R2 that may be interpreted analogously to the R2 statistic in ordinary least squares regression (Long and Chen, 2021). A high R2 corresponds to better model fit. The statistical package UCINET 6.0 (Borgatti, 2002) was used to conduct both statistical procedures. Results are presented and described in the following section.

## RESULTS

To facilitate the presentation and interpretation of the results, we divided the section into two parts, each focused on a research question.

*RQ1: Does a relationship exist between the centrality and reciprocity in an EduTuber's recommendation network and their level of digital engagement on YouTube?*

**Table 3** shows the results for the QAP correlations. Out-degree and digital engagement ($p < 0.01$; β = 0.038) are positively and significantly correlated. However, in-degree ($p <$ n.s.; β = 0.011) and reciprocity ($p <$ n.s.; β = -0.007) do not have a significant correlation with the level of digital engagement. Moreover, out-degree and in-degree ($p < 0.01$; β = 0.428), as well as reciprocity and out-degree ($p < 0.01$; β = 0.124) have a significant, positive, and strong relationship. β indicates the strength and direction of

**TABLE 3 |** QAP correlations for research question 1.

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1 | Digital engagement | 1 | | | |
| 2 | In-degree | 0.011 | 1 | | |
| 3 | Out-degree | 0.038*** | 0.428*** | 1 | |
| 4 | Reciprocity | –0.007 | 0.118*** | 0.124*** | 1 |

*Not significant.* (shaded cells)
***$p < 0.01$.
*All significance based on 5,000 permutations; Dependent variable: Digital engagement.*

**TABLE 4 |** MRQAP for research question 1.

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1 | Intercept | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| 2 | In-degree | 0.01092 | | | –0.00554 |
| 3 | Out-degree | | 0.03784*** | | 0.04161*** |
| 4 | Reciprocity | | | –0.00678 | –0.01130 |
| | $R^2$ | 0.00012 | 0.00143 | 0.00005 | 0.00159 |
| | Adj. $R^2$ | 0.00011 | 0.00142 | 0.00003 | 0.00156 |

*Not significant.* (shaded cells)
***$p < 0.01$.
*All significance base on 5,000 permutations; Dependent variable: Digital engagement.*

the relationship and proportionality between the two matrices. Then, the strongest relationship between the variables is with the out-degree and in-degree. Notably, in **Table 3**, these results refer to exact matched attributes with low, medium, and high values. Thus, the relationships can be interpreted as follows: Channels with a similar level of digital engagement (higher levels) have a significant correlation with channels with similar levels of out-degree (higher levels). In other words, channels with higher levels of digital engagement tend to have higher levels of out-degree. In addition, channels with similar levels of out-degree (higher levels) significantly correlate to channels with similar levels of reciprocity (higher levels). That is, channels that recommend more channels tend to have higher levels of reciprocity.

**Table 4** shows the MRQAP results. To test for causality, we ran different models to compare the adjusted R2, which is the best indicator of the model fit. Model 1 includes the in-degree, Model 2 includes the out-degree, Model 3 includes the reciprocity, and Model 4 includes all three independent variables. As a result, only the out-degree has a significant and positive effect on the digital engagement in Model 2 ($p < 0.01$; β = 0.03784) and in Model 4 ($p < 0.01$; β = 0.04161), because the *p*-values are lower than 0.05. β is the standardized regression coefficient and represents the ratio in which the independent variable affects the dependent one. Then, the strongest beta corresponds to the out-degree in Model 4.

We compared the models and found that the best fit is for Model 4 (Adj. $R^2$ = 0.008). Perhaps the adjusted R2 is small because other variables are not included in this study and can explain the variance of the dependent variable better. Another

**TABLE 5 |** QAP for research question 2.

| | | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|
| 1 | Same reciprocity | 1 | | | | |
| 2 | Same country | 0.080*** | 1 | | | |
| 3 | Same audience | 0.027** | 0.040*** | 1 | | |
| 4 | Same topic | 0.039*** | 0.021*** | 0.149*** | 1 | |
| 5 | Same format | 0.004 | 0.021*** | 0.027*** | 0.073*** | 1 |

*Not significant.*
****p < 0.01, **p < 0.05.*

**TABLE 6 |** MRQAP for research question 2.

| | | Models | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | Intercept | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| 2 | Same country | 0.079*** | | | | 0.078*** |
| 3 | Same audience | | 0.02676** | | | 0.018 |
| 4 | Same topic | | | 0.03924*** | | 0.034*** |
| 5 | Same format | | | | 0.00389 | −0.0008 |
| | $R^2$ | 0.00640 | 0.00072 | 0.00154 | 0.00002 | 0.0081 |
| | Adj. $R^2$ | 0.00639 | 0.00070 | 0.00153 | 0.00000 | 0.0080 |

*Not significant.*
****p < 0.001, **p < 0.05.*
*All significance based on 5,000 permutations; Dependent variable: Reciprocity.*

**TABLE 7 |** Reciprocity analysis by groups of channels that share similar attributes.

| | | 1 | 2 | 3 | 4 | | | |
|---|---|---|---|---|---|---|---|---|
| | **(A) Same country** | | | | | | | |
| 1 | Non-Spanish-speaking country | 0.22 | | | | | | |
| 2 | Latin America | 0.43 | 0.46 | | | | | |
| 3 | Spain | 0.25 | 0.47 | 0.50 | | | | |
| 4 | No information | 0.15 | 0.31 | 0.20 | 0.41 | | | |
| | **(B) Same audience** | | | | | | | |
| 1 | Only teenagers | 0.63 | | | | | | |
| 2 | Teenagers and adults | 0.35 | 0.24 | | | | | |
| 3 | Adults | 0.50 | 0.49 | 0.37 | | | | |
| 4 | General | 0.50 | 0.36 | 0.12 | 0.47 | | | |
| 5 | Children | 0.18 | 0.26 | 0.33 | 0.50 | 0.48 | | |
| | **(C) Same topic** | | | | | | | |
| 1 | Agricultural sciences | 0.00 | | | | | | |
| 2 | Health and medical sciences | 1.00 | 0.29 | | | | | |
| 3 | Natural sciences | 0.33 | 0.33 | 0.32 | | | | |
| 4 | Social sciences | 0.00 | 1.00 | 0.50 | 0.19 | | | |
| 5 | Humanities | 0.00 | 0.25 | 0.21 | 0.52 | 0.49 | | |
| 6 | Engineering and technology | 0.00 | 0.00 | 0.47 | 0.71 | 0.33 | 0.29 | |
| 7 | Various subjects | 0.00 | 0.00 | 0.16 | 0.00 | 0.26 | 0.00 | 0.41 |
| | **(D) Same format** | | | | | | | |
| 1 | Science dissemination | 0.29 | | | | | | |
| 2 | DIY | 0.10 | 0.50 | | | | | |
| 3 | Class type | 0.25 | 0.30 | 0.42 | | | | |

*Own elaboration.*
*Higher reciprocity between groups.*
*Higher reciprocity within groups.*

possibility is the manner in which the relational data and the digital engagement were collected; all of them came from a database and were not obtained through questionnaires. Lastly, 5,000 permutations were run, which can reduce the size of the adjusted R2. The in-degree and reciprocity do not have a statistically significant effect on digital engagement. Therefore, the first research question is partially supported by the results. In particular, a high level of out-degree in EduTubers' channels correspond to their higher digital engagement.

In sum, considering the results of the analyses, we find a statistically significant and positive relationship between the level of digital engagement and the level of out-degree, but not with the in-degree and reciprocity. In the next section, we present the results of the analysis to answer research question 2.

*RQ2: Does a relationship exist between educhannel homophily (same country, audience, topic, and format) and the level of reciprocity in an EduTuber's recommendation network?*

**Table 5** shows the QAP results and shows that same country ($p < 0.01$; β = 0.080), same audience ($p < 0.05$; β = 0.027), and same topic ($p < 0.01$; β = 0.039) have a significant and positive correlation with the level of reciprocity, whereas channels with the same format do not (n.s.; β = 0.004). Thus, homophily (same country, same audience, and same topic) can be interpreted to be related to the same level of reciprocity. Notably, the strongest correlation is between the same topic and the same audience ($p < 0.01$; β = 0.149), which is expected in the EduTubers' recommendation network. This result occurred because collaboration and cooperation, instead of competition, seem to be particular attributes of EduTubers' behavior. In sum, for the second research question based on the QAP analysis, results suggest a statistically significant relationship between homophily and the level of reciprocity.

To test for causality, we ran different models to compare the adjusted R2. **Table 6** displays the MRQAP results. Model 1 includes the same country, Model 2 includes the same audience, Model 3 includes the same topic, Model 4 includes the same format, and Model 5 includes all the independent variables. As a result, the same country ($p < 0.01$; β = 0.079), same audience ($p < 0.05$; β = 0.026), and same topic ($p < 0.01$; β = 0.039) have a statistically significant and positive effect on the level of reciprocity. However, the same format (n.s.; β = 0.0038) has no effect. Model 4 shows the best fit (Adj. $R^2$ = 0.008). Therefore, for the second research question, we statistically confirm based on the MRQAP results that homophily in terms of the same country, same audience, and same topic has a positive effect on the level of reciprocity. Thus, homophily influences the level of reciprocity in the recommendation network of the studied EduTubers.

To explore this answer in a more in-depth manner, finding which categories of the independent variables have a higher level of reciprocity is relevant. **Table 7** shows the level of reciprocity between and within groups of channels that share the same attributes.

**Table 7A** shows that channels from Spain ($R$ = 0.50) have a higher level of reciprocity within the group compared with the other groups. Between groups, the higher level of reciprocity is in channels from Spain and channels from Latin America

($R$ = 0.47). Such results suggest that language is a relevant aspect of the EduTubers' recommendation network. As expected, in **Table 7B**, the channels focused on teenagers ($R$ = 0.63) have a higher level of reciprocity within, followed by the channels focused on children ($R$ = 0.48). This result occurred perhaps because the number of specialized educhannels focused on these audiences is small. **Table 7C** shows that channels focused on humanities ($R$ = 0.49) have a higher level of reciprocity among them compared with the other groups. Interestingly, channels related to health and medical sciences have a strong reciprocity with channels of agricultural sciences ($R$ = 1.0) and social sciences ($R$ = 1.0) but have non-reciprocity with all with channels related to engineering and technology ($R$ = 0). Finally, **Table 7D** shows that DIY channels have strong reciprocity within their group ($R$ = 0.50).

In sum, we find that a statistically significant relationship exists between educhannels homophily (same country, audience, and topic) and the level of reciprocity, but not with the same format. For instance, an increase in the level of homophily will increase the level of reciprocity. Furthermore, the greatest reciprocity occurs within the Spanish educhannels and between these and the Latin American educhannels. This finding suggests that language is a relevant aspect of the recommendation network. Finally, educhannels focused on the same audience also have higher levels of reciprocity.

## DISCUSSION

The main objective of the research is to explore the dynamics of EduTubers' recommendation network to understand the nature of the connection between them. In this regard, to answer the research questions that guided this study, we created a recommendation network of EduTubers' channels, gathered their main attributes, analyzed their centrality and reciprocity, and measured their interrelation. We found that on YouTube, and specifically among EduTubers, cooperation and collaboration are essential.

*RQ1: Does a relationship exist between the centrality and reciprocity in an EduTuber's recommendation network and their level of digital engagement on YouTube?*

The results suggest that a relationship exists between the level of digital engagement and the level of out-degree. In this sense, EduTubers' channels that have a higher level of digital engagement tend to give a higher number of recommendations. This idea seems logical; while increasing the collaboration between channels, the traffic on the channel could be increasing too. However, Song et al. (2019) suggest that current policies of various digital platforms that encourage creators to connect with other channels are not optimal because they cause subscriber growth to decrease, thus compromising digital engagement. Even though, we found similar results as Sanders et al. (2019) in a retweet network, where results indicate that a twitter account with higher out-degree has also a higher digital engagement. Yet the data obtained from the network under study do not indicate any significant relationship between digital engagement and in-degree or reciprocity. However, some researchers report different results; for example, Wu et al. (2020) found positive effects of direct reciprocity when the channels have the same level of popularity. In addition, Wattenhofer et al. (2021) found a low level of reciprocity on channels with many subscribers. As Rowe and Alani (2014) demonstrated, the effect on the engagement varies in different social media platforms, or across different non-random datasets from the same. Thus, the causes perhaps are related to idiosyncrasies of the used datasets or applied analysis, which remarks the need for reproducing these types of studies over multiple datasets and social media platforms.

*RQ2: Does a relationship exist between educhannel homophily (channel attributes) and the level of reciprocity in an EduTuber's recommendation network?*

The results confirm the positive effect of homophily (country, audience, and topic) on the level of reciprocity, i.e., an increase in the level of homophily will increase the level of reciprocity. The results suggest that language is a relevant aspect of the EduTubers' recommendation network. The highest reciprocity occurs within the Spanish educhannels and between these and the Latin American educhannels. This finding suggests that language is a relevant aspect of the recommendation network. In addition, educhannels that focus on the same audience also present higher levels of reciprocity, perhaps because of the fewer specialized educhannels that focus on these audiences. In line with these results, Kaiser and Rauchfleisch (2020) found that the algorithm encourages the creation of highly homophilic communities and the factors of such recommendations are topics, language, and location. Another study that also found homophily in the results is that of Gruzd and Hodson (2021), who found the presence of gender homophily in channel recommendations. In addition, Wu et al. (2020) found that content creators who prefer to collaborate with smaller or larger creators would be more likely to choose others in the same content genre. Moreover, content creators who prefer to cooperate with others with similar popularity were more likely to collaborate with ones that specialize in different content genres. Our results are also similar to those of studies such as Song et al. (2019), who found that content similarity and common links increase the probability of reciprocity.

Our research makes key contributions to the literature. As Arora et al. (2019) suggested our research integrated network metrics to better understand the influence of the actors on a network. Khanam et al. (2020) pointed out, the lack of academic research based on SNA leads to a lack of knowledge about the effects of the degree of homophily on online platforms of images and videos. The main contribution of our results consists of the use of theoretical concepts (reciprocity and homophily), which focuses on the intrinsic motivations of EduTubers to recommend other channels. Another important detail to note is that each online social network is different in nature and behavior (i.e., Facebook and Twitter), which implies that dynamics in their interactions will differ (Rowe and Alani, 2014; Khanam et al., 2020). In this study, the results suggest that on YouTube and specifically among EduTubers, cooperation and collaboration are essential, unlike in other types of digital networks, which are by nature more competitive. Wu et al. (2020) proposed that cooperative behavior could help creators diversify their content, blur the community boundary, increase in size, and strengthen one's own identity.

With regard to the practical implications, our results suggest that educhannels that are initiating and growing their digital engagement are more likely to participate in a recommendation network, i.e., make sure to recommend channels, especially channels with similar characteristics. This idea is based on our results, which indicate that a high number of channels recommended corresponds to high levels of digital engagement. This strategy may increase content exposure and discoverability, which could affect the growth of the channel (Wu et al., 2020). Furthermore, Wattenhofer et al. (2021) indicate that homophily can help information reach like-minded individuals more quickly. Thus, the recommended channels must be channels with similar content and common links (Song et al., 2019). In addition, from the content, channels are recommended to form a community among channels from the same country and with the same type of audience.

## CONCLUSION

Despite the differences in the nature of today's online social media, content creators must identify those strategies that help them capture the audience's attention. This way, they can be recognized for their popularity, stand out from other creators, and increase digital engagement. This study finds that on YouTube, specifically in the EduTubers network, cooperation and collaboration are fundamental strategies. For instance, educhannels that are initiating and growing their digital engagement tend to participate in a recommendation network. Thus, the higher the number of channels recommended by an EduTuber, the higher the probability of increasing their digital engagement. These tactics can help them increase content exposure and discoverability, which could affect the growth of the channel (Wu et al., 2020). In addition, our results suggest that in the recommendation network, an increase in educhannel homophily will increase the level of reciprocity. Then, EduTubers should recommend similar educhannels in the same country and with the same audience and topics to increase their reciprocity. Therefore, although homophily is a fundamental phenomenon underlying human relationships in social networks, recognizing those specific attributes that enhance reciprocity and ultimately affect digital engagement will be important.

This research has a few limitations in terms of data. First, the sample of collected entry points is likely not representative of YouTube channels in general, and the resulting crawl is potentially biased by this approach. In addition, it could be considered a bias effect in some of the results of the studied indicators. Although our sample size is larger than that of other studies of EduTubers (Kaiser and Rauchfleisch, 2020; Pérez-Escoda et al., 2020; Pérez-Escoda and García-Ruiz, 2020; Arroyo et al., 2021; Fortaleza, 2021; Marcelo and Marcelo, 2021; Pattier, 2021a), we recommend future research to collect more data to analyze a more complete network of EduTubers. Second, this work is a cross-sectional study conducted at one time point. The nature of YouTube, as a dynamic platform, poses complication characteristics for academics who want to avoid this limitation. Future research could examine the evolution of the network over time to analyze changes in the community structure.

Some of the results of this study motivate us to further study the topic of the EduTuber community. Future research could explore the possibility that newer channels rely more on recommendations to increase their digital engagement rate compared consolidated channels that may use another type of strategy. Our results also suggest that some characteristics of specific conditions, such as the same country, audience, and topic, are needed to increase the reciprocity level. Future research may study this issue to confirm the thesis, find these factors, and compare it with other social networks such as Twitter or Facebook. Furthermore, future research could extend the analysis to other relevant factors such as gender, for example, as in Pattier (2021d).

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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# Facilitating Mathematical Competencies Development for Undergraduate Students During the Pandemic Through *ad-hoc* Technological Learning Environments

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In this article we show how to facilitate the development of mathematical skills using 3D surface visualization tools and virtual environments in an online, project-based learning context. The "Lumen" software is presented, which is an *ad-hoc* solution, designed and developed to visualize and combine mathematical surfaces in 3D, based on their associated equations. Several activities were designed with the use of Lumen, to measure the learning gain and problem-solving skills of the students, obtaining that a mean learning gain of 43% was observed on 242 students on the analysis of the pre- and post-tests for the first monitored activity, while a mean learning gain of 30% was observed on 210 students on the analysis of the second monitored activity. Based on these analyses, we make the point that although remote learning in the context of the COVID-19 pandemic poses difficult challenges for learners and professors, the use of *ad-hoc* technological applications is an important resource that supports the reinterpretation of the learning process, as it shifts the focus to the development of skills through active learning.

**Keywords: virtual environments, educational innovation, spatial visualization, mathematics teaching, competencies development, complex thinking, higher education**

## INTRODUCTION

Mathematical skills are important for different areas in life, so there has been an important need to develop them in students, as they are part of the foundations needed to develop other elements. One example of these competences is spatial visualization skills that are needed in different knowledge areas like design (Suh and Cho, 2020), arts (Pérez-Fabello et al., 2018), and engineering (Buentello-Montoya et al., 2021). Research has been done like in LeBow et al. (2018), Medina Herrera et al. (2019), Casey and Ganley (2021), and Johnson et al. (2022) exploring different topics like gender characteristics, school level, subject applied to or educational technology. On the other hand, research shows the constant search for tools and methodologies that can motivate and engage students in the study of mathematics to create a meaningful teaching-learning process (Xiao et al., 2018; Trujillo-Torres et al., 2020; Hagen et al., 2022). Gamification and edutainment systems have drawn attention to electronic devices and game-like environments. The use of virtual environments allows to increase motivation and can be used also to develop important skills such as mathematical visualization, problem solving and logical thinking. Additionally, this type of environment would be a useful tool, for teachers and students, in distance learning-based courses like those that had to be implemented in the recent pandemic. In this work, we present an implementation of a virtual learning environment designed to help active learning courses to develop visualization skills and mathematical competencies in undergraduate students. Also, we present the corresponding for a pre-test and post-test process.

This document is organized as follows:

- Introduction. This section.
- Section "Mathematical Competencies and Meaningful Learning" describes the characteristics of a mathematical learning environment and the need of meaning while learning.
- Section "Technological Learning Environments and the Development of Mathematical Competencies" introduces the use of technological elements to support learning and presents de Lumen software.
- Section "Implementation Methodology" describes the study in this work and its results.
- Section "Discussion" presents the discussion and conclusion of this work.

## MATHEMATICAL COMPETENCIES AND MEANINGFUL LEARNING

In recent decades, universities have carried out educational innovation with the purpose of enhancing students' motivation and achievement (Denham et al., 2021; Mainali, 2021). Reaching a deep understanding of complex ideas, meaningful learning implies that knowledge can be manipulated and applied to a variety of situations and contexts. Whereas traditional mathematics teaching focused on the transmission of mathematical knowledge and concepts through repetition and memorization, for the last half century, instructional models that emphasize approaches based on meaning, processes, and problems have increased attractiveness (Algani, 2019). Meaningful learning is associated with active, constructive, intentional, and authentic learning (Koskinen and Pitkäniemi, 2022). The process of meaningful learning occurs when students build knowledge and cognitive processes which are required to prefer a problem-solving task. Another important characteristic of meaningful learning is one that can be context-bound and transferable to real-life professional settings and practices. Fink (2013) presents a taxonomy that identifies the different ways in which learning can be meaningful that includes six kinds of significant learning: (1) Foundational Knowledge, responsible for providing the basic understanding that is necessary for other kinds of learning. (2) Application allows other kinds of learning to become useful. (3) Integration, when students can see and understand the connections between different things. (4) Human Dimension, when students learn something important about their own self and/or about others, it enables them to interact more effectively with themselves or with others. (5) Caring, when students care about something, they then have the energy they need for learning more about it and making it a part of their lives. (6) Learning How to Learn, this occurs when students learn something about the process of learning itself.

Meaningful learning in mathematics is closely linked to the development of eight important competencies which can be classified into two groups: The first group of competencies are to do with the ability to ask and answer questions in and with mathematics: thinking mathematically, posing, and solving mathematical problems, modeling mathematically, and reasoning mathematically. The other group of competencies are to do with the ability to deal with and manage mathematical language and tools: representing mathematical entities, handling mathematical symbols and formalisms, communicating in, with, and about mathematics and making use of aids and tools. Competence-based learning emphasizes the process, rather than obtaining results (Niss et al., 2016; Niss and Højgaard, 2019; Dunagan and Larson, 2021). **Figure 1** shows the relationship between meaningful learning and the development of mathematical skills.

The competencies approach seeks to change the role of the student in the learning process by promoting the exchange of ideas and experiences with their peers, which allow them to build knowledge to transfer it to everyday contexts and situations.

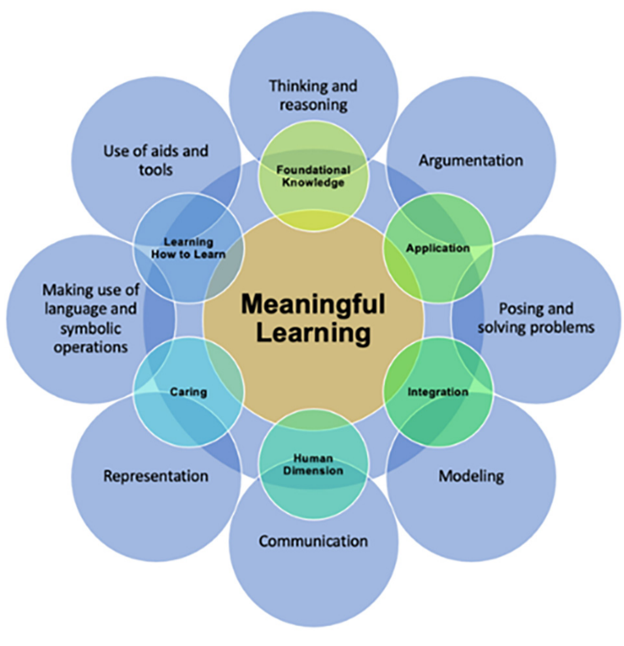


**FIGURE 1** | Mathematical competencies and meaningful learning.

## TECHNOLOGICAL LEARNING ENVIRONMENTS AND THE DEVELOPMENT OF MATHEMATICAL COMPETENCIES

Technological Learning Environments have proven to be ideal places for the development of mathematical skills. Medina Herrera et al. (2019) show that using augmented reality, virtual reality, and 3D printing, students can develop spatial visualization and problem-solving skills. These environments are also ideal for the use of important methodologies such as problem-based learning, projects and gamification, whose achievements in the development of mathematical competencies are well known (Huesca Juárez and Medina Herrera, 2019; Medina Herrera, 2020; Medina Herrera et al., 2020).

Pedagogical activities with the use of virtual environments, grants students to develop spatial orientation and visualization skills by allowing them to observe and manipulate surfaces in space and solve problems related to these figures. The individual and team work to which the students were exposed, which we will describe later, requires that the students think and reason, make models and argue each of the steps they take in search of the solution to the problem. As part of the process, communication with team members and with the teacher and the use of symbolic language are present.

### Learning in Unified Mathematics Environments: Lumen Software

The Lumen (Learning in Unified Mathematics Environments) software is a mathematical tool whose purpose is to visualize the relation of geometric shapes in 3D with their quadratic equation representation, showing, in real-time, that the changes in parameters for these equations produce changes in the geometry and topology of their three-dimensional representation. Originally, Lumen was designed as a Technological Learning Environment, assembled with software components to provide functionalities for: multi-user remote and local execution, VR, AR, and 3D printing in the PC, iOS, and Android platforms. The authors' aim is to develop an integrated tool that provides these functionalities during the same experience, since there are different options that provide these functionalities, but in separate programs that are not meant to share the formats for the mathematical shapes. The authors believe that this kind of unified tool will be able to provide a richer learning experience.

Developed from scratch by the authors as part of a Novus project, using the Unity video game engine platform, the original functionality of the Lumen application included multiuser execution *via* a cloud-enabled runtime for the modalities: desktop, cellphone (iOS and Android), tablet (iOS and Android), VR (Oculus Go), AR (iOS and Android), and 3D printing. Since the development of Lumen spanned from 2018 to 2020, the scope of its functionality had to be adapted to the development restrictions imposed by the pandemic. The final functionality for testing with the mathematical activities described in Section "Mathematical Activities Using Lumen" was set to:

- Multiuser execution *via* a cloud-enabled runtime.
- Desktop.
- Cellphone and Tablet (Android).

To help describe the general architecture of the Lumen software, **Figure 2** shows the main software components that provide the functionality described next.

#### User Interface Components

The Camera, Axes, Log Manager, and UI Control are code objects designed to manage and display the user interface objects that are present during the program execution: the user's point of view, orientation and zoom level, the 3D axes and scale reference, the event log, the 3D scene, and menus to interact (**Figure 3**).

##### *Equation Menu*

Presents interaction elements that allow the user to:

- Define a quadratic equation, either by setting each parameter manually or by choosing one of 17 presets and visualize its graphical representation.
- Control the camera point of view through rotations and zoom gestures.
- Visualize changes in geometry by modifying the equation parameters.
- Hide or show visual aids such as the event log, the axes, and the axes grids.
- Find the volume (when the equation represents a closed shape) and area of the displayed shape.
- Add, delete, or update one or all the displayed shapes. Lumen supports up to 10 simultaneous shapes.
- Export the selected shape to a file. Lumen supports exporting to the OBJ and STL file formats, suitable for 3D digital design and 3D printing, respectively.

##### *Operations Menu*

Presents interaction elements that allow the user to perform Constructive Solid Geometry (CSG) operations (Section "Constructive Solid Geometry Operation Component").

##### *Other Shapes Menu*

Presents interaction elements that allow the user to define and visualize a plane, by establishing its normal vector, its center point, width, and depth.

##### *Network Menu*

Presents interaction elements that allow the user to join or create an on-line session (Section "Network Components").

#### Network Components

The Network Camera, Network Manager, IP Manager, and Network Quadratic Configuration components are code objects designed to support local or cloud-based networking functionality.

- Local networking functionality. Hosted by the local network infrastructure.
- Cloud-based networking functionality. Hosted by Unity's cloud-enabled runtime.

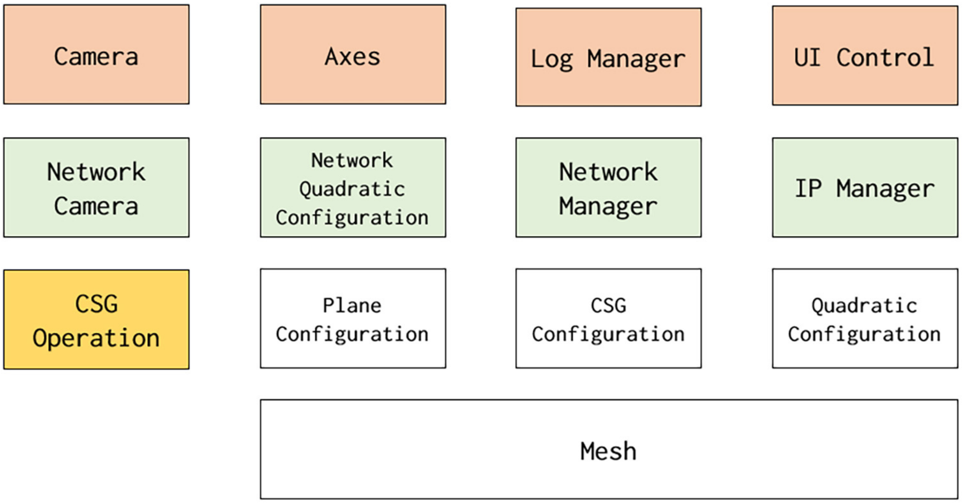


**FIGURE 2 |** Main components of the Lumen software.

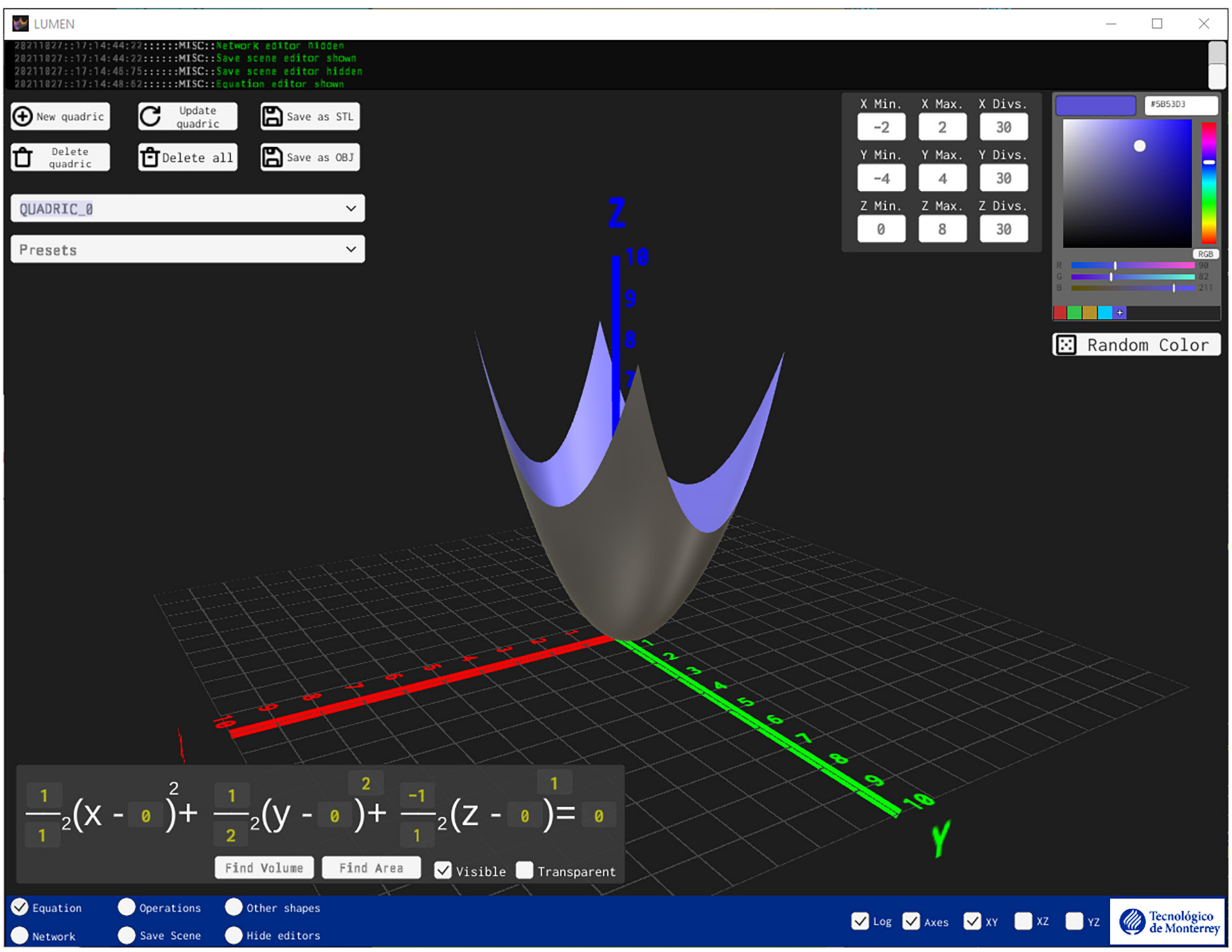


**FIGURE 3 |** User interface and menus for the Lumen application.

Whether it is local or cloud-based, the network functionality works under the lobby-room analogy, in which a lobby is a virtual waiting-room to assign participants into a virtual interaction room, where all participants share real-time updates that are triggered from the application's functionality. Participant devices in the network session may be any of the ones defined in Section "Learning in Unified Mathematics Environments: Lumen Software."

For Lumen, during a network session the instructor has the previously described menus and functionality unlocked to guide students, who may only see the interaction until the instructor decides to unlock it. This element was designed to favor the learning process by first allowing the instructor to remark important theoretical elements, before allowing the students to confirm them while exploring the experience of using the application.

#### Constructive Solid Geometry Operation Component

Once at least two closed shapes have been defined using the Equation menu, the coded CSG operation component provides algorithms that allow the user to perform union, intersection, and difference operations between them.

#### Configuration Components

Configuration components are coded objects that store information and actions that may be performed with the three kinds of mathematical elements supported by Lumen: quadratic shapes, CSG shapes, and planes.

#### Mesh Component

In Computer Graphics, as well as in Lumen, a mesh is a collection of connected triangles that form a surface. Whether the configuration comes from a quadratic shape, a CSG shape, or a plane, this information will be processed by the Mesh component algorithms to produce a triangular mesh that can be displayed in Lumen. The Mesh component code also stores the routines that compute the volume (when the mesh belongs to a closed shape) and area of the mesh. Finally, the Mesh component stores the routines required to export the triangular collection into a supported file format.

### Mathematical Activities Using Lumen

In this section we will present the activities that have been used to measure the development of mathematical competencies using Lumen. The mathematical concepts have been worked on with the teacher in previous sessions. The activity has three moments, in the first, the students solve a pre-test without support of technological tools. The students work on an activity intended to help the development of the eight mathematical competences, the students are asked to use the software, which allows them to carry out the tests and modifications that lead to the solution of the problems and questions posed. Before the end of the class, the students individually solve the post-test.

Two activities were specially designed for this purpose. The first is in a context of surfaces in three-dimensional space, this activity works on rotations, translations, operations with surfaces, and problem solving. Teamwork is important, as it helps ideas to move from the mind to natural language and from natural language to mathematical language. The computational tool allows three-dimensional visualization, operations between surfaces and calculation of volume and areas. The software allows students to observe the relationship between the coefficients of the variables of a quadratic equation and the graphs. The questions they must solve require reasoning and mathematical thinking and the answer must be argued. Teamwork promotes the development of communication.

**Figure 4** shows an example of a simple question, the answer to which requires reasoning, logical thinking, and problem solving.

The second activity is in the framework of double and triple integrals to find the volume of pieces formed with various surfaces. In this activity, the use of mathematical competencies for its resolution is also evident. Students continue to work hard with argumentation and using language and symbolic operations. Using technological tools, students observe and perform Boolean operations between surfaces and perform area and volume calculations. Students work with simple mathematical models to find intersections, maximum and minimum curves, and solve optimization problems related to volume, area, and manufacturing costs.

**Figure 5** shows an example of a question that allows the use of argumentation for its solution. Several figures are presented with the same base, it is requested to order them from smallest to largest volume, justifying the reason. Volume calculation is not required. Please note that the figures may not be on the same scale.

Throughout the course, a virtual environment was used to explain calculation concepts in three-dimensional space. Computational tools are especially useful to help describe regions in space, first using natural language, which is then translated into descriptions with the use of inequalities and other types of symbolic language. Lumen is used by the teacher to work on concepts such as volume and area of surfaces, as well as to solve problems related to unions, intersections, and other Boolean operations. Throughout the course students are constantly exposed to the practice and development of spatial skills.

## IMPLEMENTATION METHODOLOGY

### Student Learning Gain

The study was conducted between February and May 2021. Due to pandemic conditions, the course was conducted entirely online. 226 students participated in 9 groups of 4 teachers. The students in the sample are enrolled in a multivariate calculus course in the second semester of engineering. They have taken subjects from the common core: mathematics, physics, chemistry, and computing.

This section presents the variables that will be used to measure and compare the pre-test and post-test results of each of the activities. The first activity that was measured was applied in the first third of the course and the second in the second third.

The pre-test and post-test were graded using a well-defined rubric for questions on a 0–100 scale, and students were given

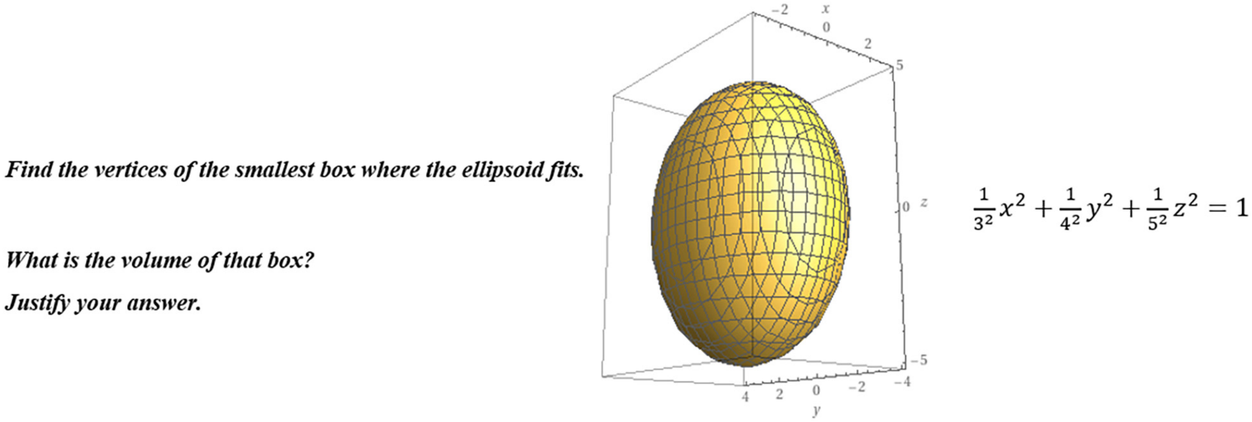


**FIGURE 4 |** A question that implies reasoning, logical thinking, and problem-solving skills to be answered.

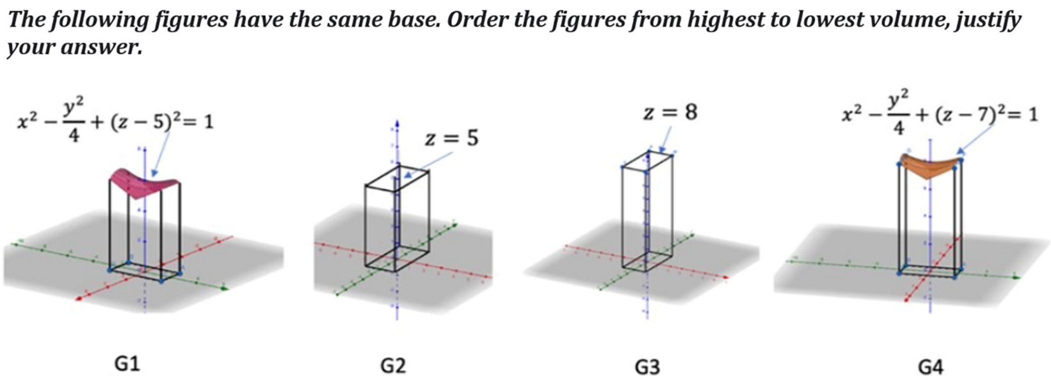


**FIGURE 5 |** Example of an argumentative question: Order the figures from largest to smallest according to volume. Justify your answer.

approximately 15 min to answer each test in the classroom. The post-test was applied after using technological tools and teamwork for 40 min. in the classroom, without the teacher's intervention. The two activities were carried out as a team, but the tests were individual.

To proceed with the data analysis, we used the following variables (see Hake, 1998).

Average pre-test grade:

$$< Pre > \; = \frac{1}{N}\sum_{i=1}^{N}(Pre_i)$$

where $(Pre_i)$ is the pre-test grade of the student *i*; and the average post-test grade:

$$< Post > \; = \frac{1}{N}\sum_{i=1}^{N}(Post_i)$$

where $(Post_i)$ is the post-test grade of the student *i*.

Student learning gain:

$$G_i \; = \; < Post_i > - < Pre_i >$$

Group learning gain:

$$G \; = \; < Post > - < Pre >$$

Student relative learning gain:

$$g_i \; \frac{Post_i - Pre_i}{100 - Pre_i}$$

The relative learning gain for a given student is a measure of the actual gain that the students achieved $Post_i - Pre_i$ with respect to the maximum gain that they could have obtained $100 - Pre_i$. The group relative learning gain has a similar meaning but refers to the whole group:

$$g \; = \; \frac{< Post > - < Pre >}{100 - < Pre >} \; = \; \frac{G}{100 - < Pre >}$$

In the next section, we present an analysis of the different gains of the students and group.

# Results

## Learning Gain

The results of the first activity show that there is a group relative learning gain (total sample) of 50%. Hake (1998) defined the

**TABLE 1** | Learning gain in the first activity.

| | *N* | <Pre-test> | <Post-test> | *G* | *g* | *Gi* < 0 | % *Gi* < 0 |
|---|---|---|---|---|---|---|---|
| T1 | 47 | 58.07 | 80.94 | 22.87 | 0.55 | 4 | 9% |
| T2 | 59 | 53.47 | 83.61 | 30.14 | 0.65 | 3 | 5% |
| T3 | 39 | 61.96 | 82.26 | 20.3 | 0.53 | 4 | 10% |
| T4 | 108 | 53.93 | 66.50 | 12.57 | 0.27 | 20 | 19% |
| Total | 253 | 56.86 | 78.33 | 21.47 | 0.50 | 31 | 11% |

*N, Group's number of participant students for the first activity; Pre-test, Group's average pre-test grade for the first activity; Post-test, Group's average post-test grade for the first activity; G, Group's learning gain (defined as–); g, Group's relative learning gain [defined as G/(100–)]; g, (Total) Relative learning gain for the four groups combined; Gi, <0 Number of students in the group, for whom the learning gain is less than zero; % Gi, <0 Percentage of the group for which the learning gain is less than zero.*

following ranges: low normalized learning gain for courses with a value below 0.3; medium normalized learning gain for courses with a value between 0.3 and 0.7; and high normalized learning gain for courses with a value above 0.7.

Also Coletta et al. (2007) say that interactive engagement courses (that use methods for hands-on activities with immediate feedback) have a normalized learning gain in the range of 0.3 and 0.6. **Table 1** shows the results of the 4 different teachers, all of them show positive group relative learning gain: 55, 65, 53, and 27%. Only 11% of the students did not obtain an increase in learning gain, most of them are concentrated in the group that had the lowest average gain.

The pre-test mean grade is 56.8 and the post-test is 77.6, an average increase of almost 20 points (19.77). With a significance level of 95%, a mean difference *t* test shows that the post-test grade is significantly higher than the pre-test. **Table 2** shows the results of the paired samples for the *t*-test.

**Figure 6**, on the left, shows the confidence intervals of the mean grade for the pre-test and post-test. The intervals do not overlap, showing a significant difference of the means, at 95% confidence. On the right, the confidence intervals of the mean grade of pre- and post-tests per teacher are shown. There is no significant difference in the pre-test mean grade of the different groups. In all cases, the post-test mean grade is higher than the pre-test, the difference being statistically significant in 3 of the 4 teachers, with 95% confidence. In the case of the teacher, where the difference was not significant (T4), a greater dispersion of the pre-test results is observed than in the other groups.

Student relative learning gain (*gi*) statistics are shown in **Table 3**. This variable is calculated for the 242 students who had a pre-test different from 100. On average the students had a relative learning gain of 45.5%.

In total, 50% of the students had a relative learning gain greater than 55%, 25% of the students had a relative learning gain greater than 79.6 and 25% of the students had a relative learning gain less than 20%.

An analysis of variance for relative learning gain (*gi)* shows that there is no significant difference between the means between teachers, with 95% confidence, using the De Wilks and Lawley-Hotelling criteria. An analysis by pairs shows that the students of teacher T4 ($gi = 0.31$) obtained a significantly lower relative learning gain than T2 ($gi = 0.67$) and T3 ($gi = 0.58$). **Figure 7** shows 95% confidence intervals for relative learning gain of the different groups.

The differences between the teachers could be explained by their skills in the use of technology and group management. The 4 teachers have similar years of teaching experience, they are of the same gender and have approximate ages. They also have similar studies. Teachers T1 and T2 have a high domain of technology, the domain of T3 is regular and T4 low. Teacher T2, on average, obtains the best student evaluations (95/100) (institutional survey applied to students) followed by T1 (92/100) and T3 (90/100). Professor T4 has the lowest evaluations (80/100).

The second activity was applied by teachers T1, T2, and T4 to $N = 210$ students. The results of the second activity show that there is a group relative learning gain (all the sample) of 46%. **Table 4** shows the results of the 3 different teachers, all of them show positive group relative learning gain: 82, 32, and 25%. 17% of the students did not obtain an increase in learning gain.

The pre-test mean is 50.76 and the post-test mean is 69.16, an average increase of 18.42 points. With a significance level of 95%, a mean difference paired sample *t* test shows that the post-test is significantly higher than the pre-test. **Table 5** shows the results of the *t*-test.

**Figure 8**, on the left, shows the confidence intervals of the mean for the pre-test and post-test grade to the second activity. The intervals do not overlap, showing a significant difference of the means, at 95% confidence. On the right, the confidence intervals of the mean pre- and post-tests grades per teacher are shown. There is no significant difference in the pre-test mean grade of the different groups. In all cases, the post-test mean grade is higher than in the pre-test, with 95% confidence. T1 post-test mean grade is significantly higher than T2 and T4.

Student relative learning gain (*gi*) statistics are shown in **Table 6**. This variable is calculated for the 208 students who had a pre-test different from 100. On average the students had a relative learning gain of 32%.

In total, 50% of the students had a relative learning gain greater than 33%, 25% of the students had a relative learning gain

**TABLE 2** | Paired mean differences sample test between pre- and post-tests in the first activity.

| | Paired differences | | | | | *t* | *df* | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. deviation | Std. error mean | Interval of the | | | | |
| | | | | Lower | Upper | | | |
| Post-Pre | 19.77 | 36.74 | 2.31 | 15.22 | 24.32 | 8.56 | 252.00 | 0.00 |

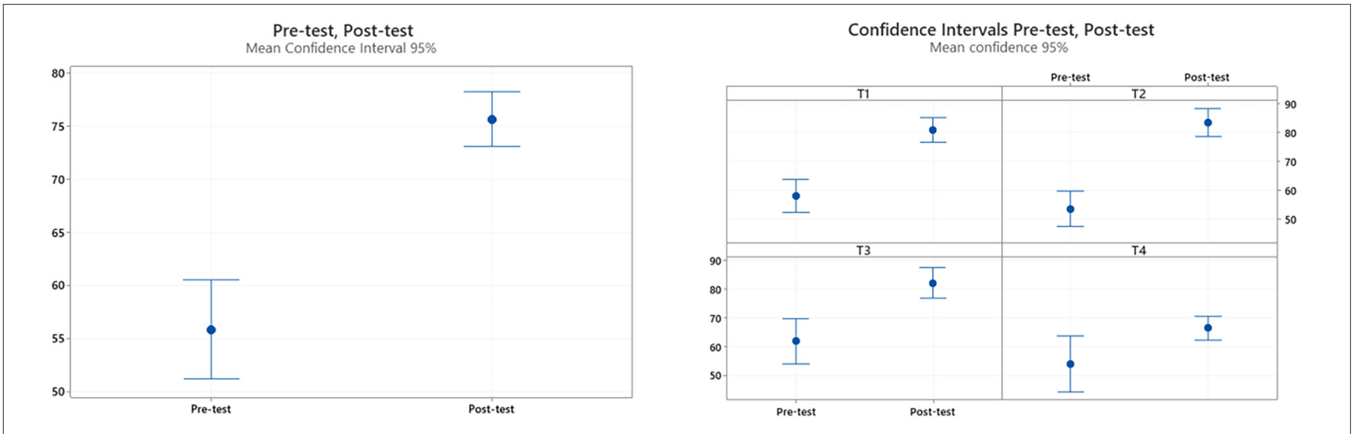


**FIGURE 6 |** Mean confidence intervals for the pre- and post-test. The entire sample and per teacher for the first activity.

**TABLE 3 |** Students relative learning gain (*gi*) statistics for the first activity.

| | Student relative learning gain (*gi*) statistics | |
|---|---|---|
| *N* | 100-Pre ≠ 0 | 242 |
| | 100-Pre = 0 | 11 |
| **Mean** | | 45.5% |
| Percentiles | 25 | 20.2% |
| | 50 | 55.1% |
| | 75 | 79.6% |

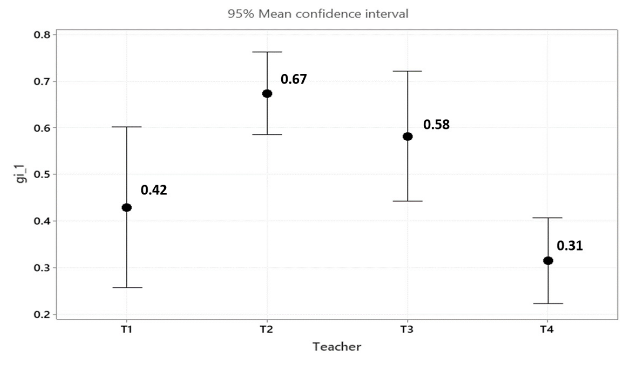


**FIGURE 7 |** 95% Mean confidence intervals for students relative learning gain (*gi*) first activity.

greater than 71 and 30% of the students had a relative learning gain less than 15%.

An analysis of variance for relative learning gain (*gi*) shows that there is no significant difference between the means between teacher groups, with 95% confidence, using the De Wilks and Lawley-Hotelling criteria. An analysis by pairs shows that the students of teacher T1 ($gi = 0.75$) obtained a significantly lower relative learning gain than T2 ($gi = 0.25$) and T4 ($gi = 0.16$). **Figure 9** shows 95% confidence intervals for relative learning gain of the different groups.

**Figure 10** shows a graphical summary of the results in both experiences.

## Perception Questionnaire

Students were asked to answer a perception survey about the software Lumen. Only 35 responses were obtained, but we believe the results are valuable. We believe that the low participation of students in this survey was due to the fact that it was applied in an exam week and did not give extra points, contrary to activities 1 and 2, which did have value in the final grade.

In total, 74% of students would recommend Lumen. The most frequent words they used to describe it are: Useful, didactic, and fun. Some of them found it complicated. See **Figure 11**.

In summary, the reasons why students would recommend Lumen are: good methods of graphing and projection. It helps to understand the concepts. It has many functions that facilitate the learning and visualization of the figures. It is complete in terms of functions; it gives you the volume of a figure and it is intuitive. It is a practical way to recognize the equations of the formed surfaces since you must write it in its most basic form. It is also a good, easy-to-use visualization resource.

The reasons they wouldn't recommend it are: Perhaps due to its complexity, it is a software that requires a lot of attention to see every part of it and use its potential. It is not easy to use and everything that can be done with the application is not adequately

**TABLE 4 |** Learning gain in the second activity.

| | *N* | <Pre-test> | <Post-test> | *G* | *g* | *Gi* < 0 | % *Gi* < 0 |
|---|---|---|---|---|---|---|---|
| T1 | 45 | 57.11 | 92.22 | 35.11 | 0.82 | 1 | 2% |
| T2 | 59 | 50.00 | 65.93 | 15.93 | 0.32 | 10 | 17% |
| T4 | 106 | 48.49 | 61.23 | 12.74 | 0.25 | 25 | 24% |
| Total | 210 | 51.87 | 73.13 | 21.26 | 0.46 | 36 | 17% |

*N, Group's number of participant students for the second activity; Pre-test, Group's average pre-test grade for the second activity; Post-test, Group's average post-test grade for the second activity; G, Group's learning gain (defined as–); g, Group's relative learning gain [defined as G/(100–)]; g (Total) Relative learning gain for the three groups combined; Gi, <0 Number of students in the group, for whom the learning gain is less than zero; % Gi, <0 Percentage of the group for which the learning gain is less than zero.*

**TABLE 5 |** Paired mean differences sample test between pre and post-tests in the second activity.

| Paired samples test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Paired differences | | | | | ***t*** | ***df*** | **Sig. (2-tailed)** |
| | | **Mean** | **Std. deviation** | **Std. error mean** | **Interval of the** | | | | |
| | | | | | **Lower** | **Upper** | | | |
| Pair 1 | Post-Pre | 18.42857 | 23.57736 | 1.62699 | 15.22115 | 21.63599 | 11.327 | 209 | 0.000 |

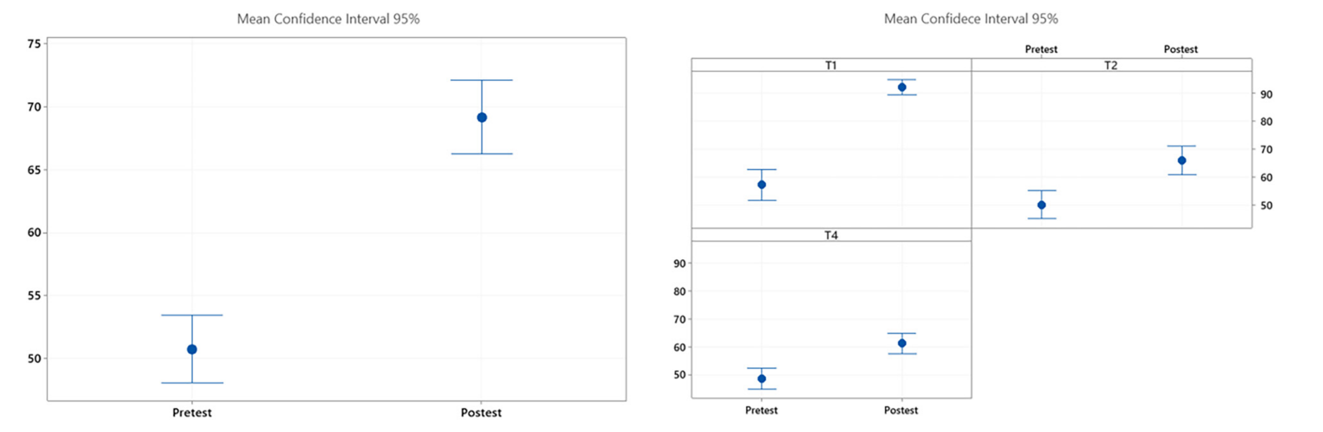


**FIGURE 8 |** Mean confidence intervals for the pre- and post-tests. The entire sample and per teacher for the second activity.

explained. Correct malfunctions. Installation is not easy. The user manual needs to be improved.

Teachers find Lumen well suited to perform spatial visualization and math skills development activities in a three-dimensional context.

## DISCUSSION

The use of computational tools such as Lumen has been found to help develop spatial visualization skills, improve understanding of mathematical concepts, and develop mathematical skills among them, problem solving. Medina Herrera et al. (2019) presented two software, one for augmented reality and the other for virtual reality, and showed that it helped them increase spatial visualization skills in students. Lumen contains the functionalities of the aforementioned software plus the adjustments suggested by students and teachers. Buentello-Montoya et al. (2021) presents a comprehensive review of works using Virtual Reality and/or Augmented Reality for teaching mathematics of the last 5 years, they claim that these technologies have an impact on education, by facilitating the teaching of subjects such as mathematics. Lumen computational tools have a greater impact in class if they are used as part of a pedagogical design of activities.

The students involved in the study obtained an average learning gain of 48%. The tests that were used to measure learning gain were designed to measure visualization and mathematical competencies, so the learning gain refers precisely to the development of visualization skills and mathematical competencies. The results of the pre- and post-tests, in effect, show a gain in visualization. The grades correspond to how well the students were able to rotate, project, perform Boolean operations between surfaces, use mathematical language, discuss, argue, and solve a problem, the last four are important characteristics of meaningful learning (Fink, 2013).

The study shows empirical evidence of the development of visualization skills through the use of this 3D multi-tool, but it also seems to be evidence of the relationship between spatial skills and problem solving, a relationship that some authors have proclaimed (Duffy et al., 2018; Muñoz-Rubke et al., 2021). Although no test was designed to investigate this last hypothesis, the four teachers involved have a strong impression that it is. It will have to be proven.

The results of this research suggest that the use of software and activities specially designed to develop mathematical skills helped students to:

**TABLE 6 |** Students relative learning gain (*gi*) statistics for the second activity.

| Student relative learning gain (*gi*) statistics | | | |
|---|---|---|---|
| *N* | | 100-Pre≠0 | 208 |
| | | 100-Pre = 0 | 2 |
| | **Mean** | | 32% |
| Percentiles | | 30 | 15% |
| | | 50 | 33% |
| | | 75 | 71% |

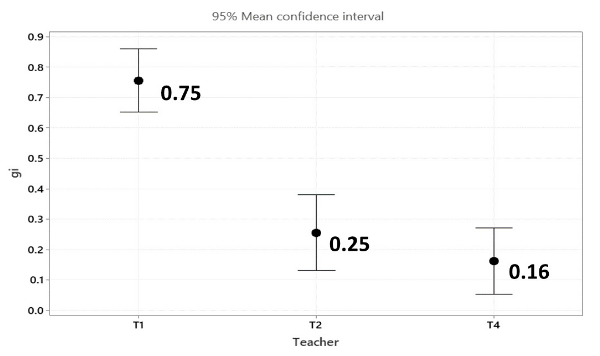


**FIGURE 9 |** 95% Mean confidence intervals for students relative learning gain (*gi*) second activity.

- Design objects that model reality. As part of Activity 1, using Lumen, students designed a cookie jar, made up of quadratic surfaces.
- Acquire Foundational Knowledge and put it into practice. Lumen helps teachers explain calculus concepts in 3D space and students internalize them by applying them to problem solving.
- Develop communication skills by working as a team. These communication skills include moving from the natural language with which they describe the designed objects, to the mathematical language to be able to describe them accurately. After an individual design of the cookie jar, students were asked to select one per team and work on the box that contains it.
- The flexibility of Lumen and the design of the activities allowed that the answers were not unique, which promoted discussion and argumentation.

Each question and problem in Activities 1 and 2 was designed to relate to one or two mathematical competencies. This is in accordance with the mathematical competencies presented in Niss et al. (2016). The reported learning gain shows that the students developed competencies (mathematical and spatial) and learned concepts in a context. At first Lumen seems to be just

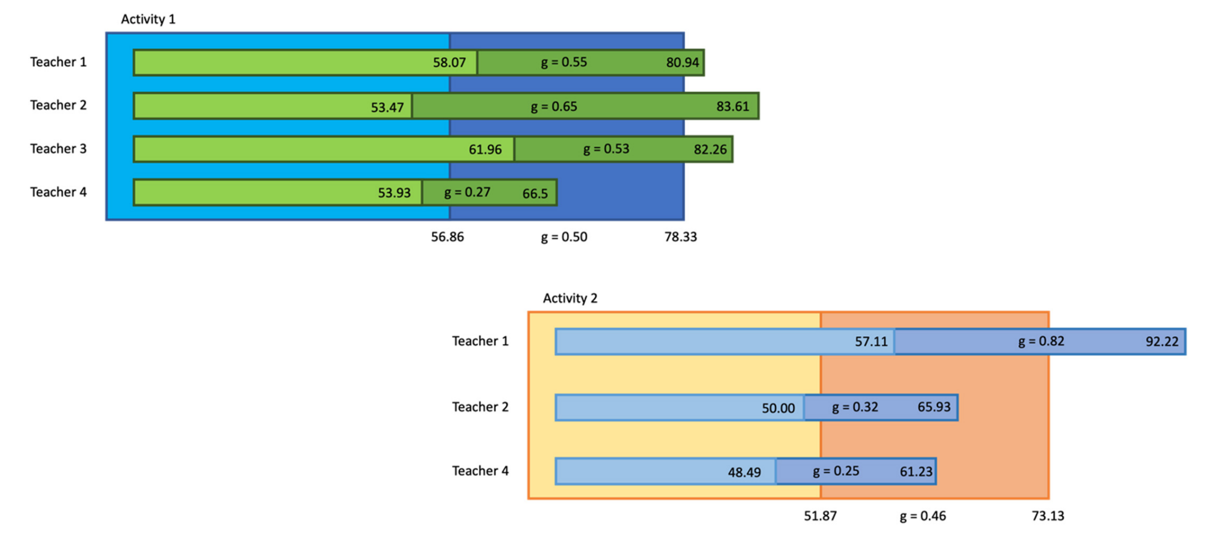


**FIGURE 10 |** Summary of results showing pre-test, post-test, and normalized learning gains (g) values for each group/teacher and in average, by activity.

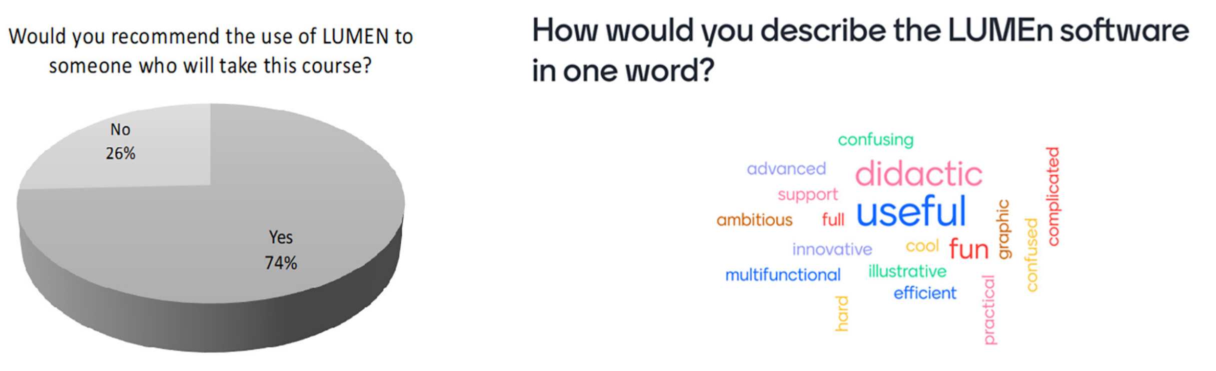


**FIGURE 11 |** Student opinion on Lumen.

a tool, used to solve activities and teach concepts. But with continued use, the same students find it useful to learn and have fun. Students have found uses for Lumen that were not in the minds of teachers. The students showed engagement with each of the activities. The activities and the use of Lumen used in this investigation have all the ingredients that (Koskinen and Pitkäniemi, 2022) mentions: active, constructive, intentional, and authentic learning. These pedagogical activities were designed to reinforce the understanding of the concepts and put them into practice, while mathematical skills went hand in hand with the process.

Buentello-Montoya et al. (2021) comment on the need for math teachers to have skills in the use of technology.

Although the students of the 4 teachers obtained learning gain. It could be that the skills in the use of technology and the general performance of the teacher have some influence, these two variables seem to represent the main differences between the 4 teachers in the study (as described in Section "Learning Gain").

Lumen is a software with great potential, new functionalities have been proposed by teachers and students that can be developed in the next stage. The calculation of the volume of surfaces obtained from Boolean operations is one of the successes of Lumen, which cannot be found in the most used graphing software tools. Also, for the next stage of Lumen, the user manual will be improved, operation corrections will be made, and it can also be made available and tested for the iOS platform (as described in Section "Learning in Unified Mathematics Environments: Lumen Software").

Due to the pandemic and the absence of presence in the classes, the augmented reality part of Lumen could not be used in class. Future studies intend to separate each of the mathematical competencies and measure the individual impact of the Lumen software on them.

We believe that the use of these types of tools in class improves students' attention, retention, and engagement. Proof of this is required.

## DATA AVAILABILITY STATEMENT

The data that supports the results of this work is available from the corresponding author, SR (sergio.ruiz.loza@tec.mx), upon reasonable request.

## AUTHOR CONTRIBUTIONS

SR: conceptualization, data curation, funding acquisition, project administration, supervision, and writing—original draft preparation. SR and LM: figures and tables preparation and visualization. LM: formal analysis, investigation, and validation. LM and GH: methodology. GH: resources. SR and JM: software. SR, LM, GH, and JM: writing—review and editing. All authors have read and agreed to the published version of the manuscript. Please turn to the CRediT taxonomy for the term explanation.

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# T-MOOC for Initial Teacher Training in Digital Competences: Technology and Educational Innovation

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Massive open online courses (MOOCs) are perceived as emerging technologies for training and innovation in the educational context. They have become approaches for distance education in the face of the new challenges, changes, and crises experienced by the COVID-19 pandemic. They represent, in turn, new emerging opportunities as a response to the United Nations recommendations for open education and the development of sustainable goals. The presence of technologies in the development of educational tasks means that the acquisition of Digital Competences (DC) by teachers and students in training goes beyond the mere mastery of content and teaching methodologies. The research presented aims to analyze the educational possibilities of T-MOOCs for the development of DC in teachers, and as resources that favor autonomous and collaborative learning in innovative scenarios. The study sample is made up of 313 students of the Primary Education Degree at the University of Seville (Spain). For this purpose, two online questionnaires (Google Forms) were applied at the beginning of the course: the Digital Teaching Competence Questionnaire (DigCompEdu), and the Content Questionnaire: Digital Resources and Digital Pedagogy. The results obtained show that the students' level of both digital competences and subject content is low to medium, so that training in educational technology is required for the acquisition of key digital competences. Based on the data obtained, the following actions are proposed: (a) The concretion of the contents structured by means of a learning guide and e-activities to be developed by the student body, taking into account the United Nations guidelines with regard to the Development of Sustainable Objectives; (b) The creation of a training and innovative environment under the T-MOOC architecture, based on open and distance learning due to the current health situation of COVID-19, which, on the one hand, empowers students to use digital tools, and on the other hand, facilitates the acquisition of the SDGs; and (c) The evaluation of the T-MOOC designed as a resource for autonomous, collaborative, guided learning in emerging contexts in which technologies and educational innovation play an important role for sustainable development.

**Keywords: digital competences, T-MOOC, initial training, educational innovation, e-activities, undergraduate**

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## INTRODUCTION

The economic, political, technological, social, and educational changes raise the need to look for other ways of: relating, communicating and organizing, disseminating information, generating resources, creating alternative and innovative pedagogical models, with methodologies that deploy other methods that favor the teaching-learning processes. Creativity, knowledge, and technology are key to achieving the SDGs in all contexts. The incorporation of technologies in institutions in general, and in the educational system in particular, involves responding to current demands, requirements and trends. In these transformation processes, higher education institutions play an important role in the promotion of knowledge, the acquisition of competencies, the development of innovation and digital metamorphosis, which invite to adapt to new times, crossing time, and space boundaries (Tang, 2017; Gudmundsdottir and Hatlevic, 2018; Ithurburu, 2019; Martínez-Pérez and Rodríguez-Abitia, 2021).

In this sense, MOOCs (Massive Open Online Courses) emerge from the open educational resources movement (Pilli and Admiraal, 2016), for lifelong learning, and can be seen as a disruptive innovation (Al-Imarah and Shields, 2019) and a technology that have been gaining ground, increasing their practices and transforming teaching and learning processes (Gordon and Wiltrout, 2021). They also emerge as a new pedagogical approach to address diversity and interculturality with the purpose of promoting an inclusion of opportunities for more active participation, and meeting learning needs in an open and distributed way (Boaler et al., 2018; Beltrán and Ramírez-Montoya, 2019; Khalid et al., 2020; Cabero-Almenara et al., 2021b). Moreover, they have the potential to contribute to innovation under pedagogical strategies, enabling co-creation, knowledge acquisition, and fostering professional and competence development (Gudmundsdottir and Hatlevic, 2018; Ruiz-Palmero et al., 2021). As proposed by Kady and Vadeboncoeur (2013), Watson et al. (2017), García-Peñalvo et al. (2018); Zawacki-Richer et al. (2018), Cornelius et al. (2019), and Deng et al. (2020), these can: (a) Generate global learning opportunities, where student participation and engagement are key, (b) Provide access to open and shared content, leading to emergent knowledge; (c) Have a significant impact on Higher Education; and (d) Foster educational quality and instructional design. MOOCs therefore represent an impetus to enhance and promote the 2030 Agenda and the SDGs (Hueso, 2022).

Doherty et al. (2015), Drake et al. (2015), and Raposo-Rivas et al. (2017) pointed out that, for the development of MOOCs and to avoid possible dropout and abandonment, the pedagogical design (autonomy, diversity, openness, and interactivity), which in turn has to be attractive, and the principles by which they are governed (meaningful, engaging, measurable, accessible, and scalable) are key elements that pivot on the students and their learning process; especially when outlining materials, providing resources and planning activities, seeking a shared construction based on autonomous, self-regulated, rhizomatic, situated and collaborative mediated learning, and horizontal communication between peers and teachers (Escudero-Nahón and Núñez-Urbina, 2020). In this sense, the study by Albelbisi et al. (2018) highlights the relevance of taking into account 12 main factors for a successful implementation of MOOCs "earner characteristic with sub -factors (learner demographics, learner motivation, and interactivity), instructor, pedagogy, pattern of engagement, instructional design, assessment, credit, plagiarism, sustainability, learning analytics, student dropout rate, and MOOC quality" (p. 3006).

Taking all these elements into account, it should be noted that MOOCs have resulted in the emergence of several variants: xMOOC (visualized as traditional courses, focused on the acquisition of content by students), cMOOC (referring to connectivism, to the connections that students are able to establish in training environments), hMOOC (hybrid models between xMOOCs and cMOOCs), bMOOCs (combining the advantages of online learning and face-to-face interaction), sMOOC (the "s" of social and seamless, enhancing interactions in learning and without breaks, are constantly accessible), tMOOC (transfer massive open online courses, the participants, through collaborative work, acquire competences to put into practice tools, learning methods, co-evaluations in relation to the theme chosen for their course), and SPOCs (small private on-line courses, maintaining the structure and methodology of MOOCs but with restrictions on the number of students and their access) (Aguayo and Bravo, 2017; García-Peñalvo et al., 2018; Osuna-Acedo et al., 2018; Zhao and Song, 2020; Cabero-Almenara et al., 2021b). In this line, Pilli and Admiraal (2016) performed a taxonomy of different MOOCs according to two dimensions: massiveness (number of participants) and openness (degree of accessibility and flexibility); classifying them into four classes according to these dimensions: (i) Small scale and less open, (ii) Small scale and more open, (iii) Large scale and less open, (iv) Large scale and more open.

Among the MOOC typologies, the tMOOC is selected for this study. These are based on the transfer of learning, pedagogical transformation, and the development of different tasks that students must perform to continue advancing in the course and to be able to demonstrate that they have mastered the competencies that are deployed in the tMOOC (Osuna-Acedo et al., 2018; Cabero-Almenara et al., 2021a). Along the same lines, Pilli and Admiraal (2016) affirm that these types of MOOCs are supported by instructivism and constructivism, whose student body presents an active participation in the educational process. For their part, Albelbisi et al. (2018) point out that a key element of success of MOOCs is evaluation. This assessment becomes a critical variable in this MOOC format so that the subject progresses in the training action (Cabero-Almenara et al., 2021b).

Thus, taking into account the different authors, MOOCs are an excellent strategy for the development of e-activities and the training of future teachers in digital competences under the Digital Teaching Competences Framework "DigCompEdu."

UNESCO (2018) defines a key competence as the "combination of knowledge, skills, and attitudes adapted to the context" (p. 7). Being competent is related to everything that society requires overcoming the obstacles of the time in which it develops; one of the fundamental competencies of today's society is digital competence. In this sense, teacher training is considered of great importance. For the European Union (2019), a Digital competence "involves the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society. It includes information and data literacy, communication and collaboration, media literacy, digital content creation (including programming), safety (including digital wellbeing and competences related to cybersecurity), intellectual property related questions, problem solving, and critical thinking" (p. 10).

To assess the importance of a Digital Competences Framework for teachers, in the studies conducted by Cabero-Almenara and Palacios-Rodríguez (2020) and Cabero-Almenara et al. (2020) to 179 national and international experts on digital competences, it was concluded that the DigCompEdu Framework was the most highly valued, making it the most suitable for use in the university context, hence its importance and having taken it as the object of study in this research. The study values very positively its pedagogical component, the main advantage over other frameworks. In contrast, the other frameworks analyzed pay special attention to the technological dimension of digital competence, leaving aside the pedagogical competence.

The DigCompEdu framework (Redecker and Punie, 2017; Ghomi and Redecker, 2019) focuses, as shown in **Figure 1**, on three broad dimensions of competencies: educators' professional, educators' pedagogical, and student competences. DigCompEdu is a digital competence model with six differentiated competence areas: (i) Professional engagement, (ii) Digital resources, (iii) Teaching and learning, (iv) Assessment, (v) Empowering learners, and (vi) Facilitating learners' digital competence. Each area has a series of competencies that "teachers must have in order to promote effective, inclusive and innovative learning strategies, using digital tools" (Redecker and Punie, 2017, p. 4). In addition, the DigCompEdu framework proposes six progressive levels of competence: A1 (newcomer), A2 (explorers), B1 (integrators), B2 (experts), C1 (leaders), and C2 (pioneer).

Focusing on the development of tasks by students to continue advancing in the course and to be able to demonstrate that they have mastered the competencies that are deployed in the tMOOC, Cabero-Almenara and Palacios-Rodríguez (2021), taking into account the above, emphasize the need to perform e-activities, defining them as all the tasks developed by the student individually or collectively in a digital environment, whose purpose is the acquisition of specific learning. The difference between virtual and face-to-face activities lies in the possibilities offered by virtual environments, since these can be more motivating and less frustrating, to promote an interactive context between information and participants (students and teachers) (Gómez-Rey et al., 2018); and, in turn, promote reflective and collaborative learning, and acquire the competence of learning to learn (Luo et al., 2017).

Furthermore, Gros (2018) points out the importance of the pedagogical design of the tasks, and states that the success of e-activities will depend on "the student's ability to direct and manage their own learning process, establishing objectives, and appropriate strategies to achieve their goals" (p. 74). In this sense, Maina (2020) lists different types of e-activities to be deployed in MOOCs: (i) Analysis and synthesis, (ii) Research and/or problem solving, (iii) Interaction and communication,

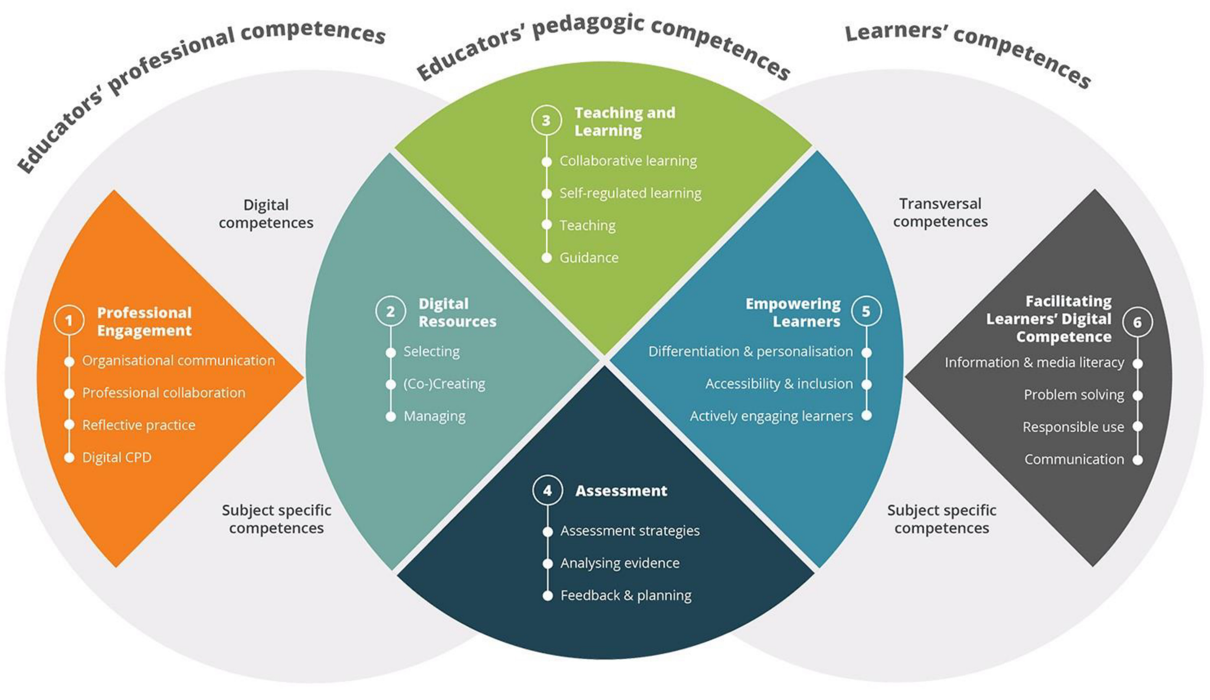


**FIGURE 1 |** The European Framework for the digital competence of educators (DigCompEdu).

(iv) Collaborative construction of knowledge, and (v) Reflection. In addition, Cabero-Almenara and Palacios-Rodríguez (2021) emphasize the relevance of incorporating meaningful elements for all students, with quality e-activities, designed with technical and pedagogical criteria, adapted to the context.

This paper aims to analyze the educational possibilities of T-MOOCs for the formation of digital competences of teachers, as resources that favor the concretion of the contents structured in e-activities, and the autonomous and collaborative learning in innovative scenarios under the T-MOOC architecture.

## MATERIALS AND METHODS

### Research Aims

In order to analyze the educational possibilities of T-MOOCs for the development of Digital Competences in teachers, and as resources that favor autonomous and collaborative learning in innovative scenarios. The research objectives being pursued are as follows:

- To analyze the level of Digital Teaching Competence in initial teacher training.
- To elaborate a training proposal to improve the level of Digital Teaching Competence of the trainee teachers.

### Participants

The sample was made up of 313 students (23,3%, $f = 73$ were male and 76,7%, $f = 240$ were female) of the Primary Education Degree at the University of Seville (Spain), of the basic training course "Information and Communication Technologies Applied to Education," which is taught in the first year of the Degree, second quarter (February–June). The average age of the students was 20 years old.

### Data Analysis Procedure

A cross-sectional descriptive research design is proposed that takes into account the participation of the students of the Primary Education Degree. The reliability, discriminate validity, and convergent validity of the Digital Teaching Competence questionnaire (DigCompEdu Check-In) were calculated using the coefficients: Cronbach's Alpha, McDonald's Omega, Composite Reliability (CR), Average Variance Extracted (AVE), and Maximum Shared Variance (MSV). The construct validity of the test was obtained by means of an exploratory factor analysis (EFA). The method used for factor selection is the principal components method. The factors obtained are orthogonally rotated using the Varimax method with Kaiser Normalization. Once the number of factors has been determined, a confirmatory factor analysis (CFA) is performed. Confirmatory factor analysis is used to check whether the theoretical measures of the model are consistent through the modeling of diagrams and the use of structural equations (Ruiz et al., 2010). In other words, it is tested whether the data fit the hypothetical measurement model yielded by the exploratory factor analysis. The method used to test the theoretical model was weighted least squares (WLS), which provides consistent estimates in samples that do not fit normality criteria (Ruiz et al., 2010). For the latter procedure, the AMOS software has been used, capable of revealing hypothetical complex relationships between variables, using structural equation modeling (SEM). At the same time, it has been verified that the data are not normally distributed through a descriptive study in which skewness and kurtosis have been taken into account. The Kolmogorov-Smirnov goodness-of-fit test confirmed this finding, with significance ($p$-value) equal to 0.000 for all items, a non-normal distribution according to Siegel (1976). Consequently, in response to the first research objective, the means and standard deviations of the questionnaire items, dimensions, and total values are presented.

### Instruments

The data collection instruments are Digital Teaching Competence Questionnaire "DigCompEdu" (Cabero-Almenara and Palacios-Rodríguez, 2020) and the Content Questionnaire: Digital Resources and Digital Pedagogy. Regarding the first questionnaire, it is an adaptation of the DigCompEdu European Framework for Digital Teaching Competence analysis instrument validated by Ghomi and Redecker (2019). This competency framework is selected as the most appropriate for assessing the Digital Teaching Competence of university faculty by means of expert judgment (Cabero-Almenara et al., 2020).

The first questionnaire is composed of 7 items/dimensions, which refer to the 2 competency areas worked in the subject: digital resources (3 items) and digital pedagogy (4 items). Each of the items measures the different competencies that make up the competency framework: B1–selecting digital resources; B2–creating and modifying digital resources; B3–managing, protecting and sharing digital resources; C1–teaching; C2–guiding; C3–collaborative learning; C4–self-directed learning.

The instrument lacked analyses to confirm exploratory and confirmatory validity, because this was performed and checked. The exploratory factor analysis (EFA) was used under the maximum likelihood method with varimax rotation. The KMO test (Kaiser–Meyer–Olkin) was 0.924 and Bartlett's test was significant ($p < 0.05$). The final version explained 85.65% of the true variance of it. On the other hand, the confirmatory factor analysis (CFA) showed that the teachers' data fitted correctly to the theoretical model proposed by Cabero-Almenara and Palacios-Rodríguez (2020). The coefficients were correct and respected the thresholds established by Schumacker and Lomax (2004) and Bentler (2006). This model supported the factorial structure formulated in the CFA, formed by two correlated latent variables. The structural equation model was performed with AMOS V.24 software. In addition, the reliability of the selected items was examined through Cronbach's Alpha ($\alpha = 0.949$) and McDonald's Omega coefficient ($\Omega = 0.945$), for each of the instrument's scales. Both coefficients obtained very satisfactory values.

The values for the different dimensions analyzed through the instrument were also obtained; presenting the results of both Cronbach's Alpha and McDonald's Omega remained sufficiently high and significant. All coefficients are shown in **Table 1**.

The second questionnaire consists of 20 a multiple-choice question (**Table 2**) in which only one option is correct (test).

**TABLE 1 |** Exploratory and confirmatory factorial results and reliability of the instrument.

| Model fit summary | $\chi^2$ | *p* | CFI | TLI | IFI | NFI | RMR | RMSEA |
|---|---|---|---|---|---|---|---|---|
| | **3.014** | **0.001** | **0.925** | **0.942** | **0.926** | **0.936** | **0.049** | **0.077** |
| | **Dimensions** | **Dim. 1** | **Dim. 2** | | | | | |
| Validity analysis | CR | 0.919 | 0.929 | | | | | |
| | AVE | 0.798 | 0.812 | | | | | |
| | MSV | 0.502 | 0.552 | | | | | |
| Test reliability | α | 0.919 | 0.901 | | | | | |
| | Ω | 0.929 | 0.908 | | | | | |

Both instruments were administered online, through the Google Forms platform. The anonymity of the participants is assured at all times. The following links show the general structure of the data collection instruments: https://cutt.ly/IUnEyCg (DigCompEdu Check-In) and https://cutt.ly/5UnEssX (questionnaire content).

## RESULTS

The results obtained from the two questionnaires: DigCompEdu Check-In and questionnaire content are shown below. Results that subsequently help, on the one hand, to demonstrate the knowledge, content, and skills acquired by the students of the Primary Education Degree of the University of Seville; and subsequently, to respond to the second objective of this study, to design a training proposal to improve the level of Digital Teaching Competence of teachers in training under the architecture of the T-MOOC.

### DigCompEdu Check-In

The results obtained after administration of the DigCompEdu Check-In questionnaire provide the frequencies and percentages (valid and cumulative) (**Table 3**) for each of the items comprising the seven key dimensions: (i) Use different internet sites (web pages) and search strategies to find and select a wide range of digital resources; (ii) Create my own digital resources and modify existing ones to adapt them to my needs as a future teacher; (iii) Able to securely protect sensitive content. For example: photographs, videos, files, exams, grades, personal data.; (iv) Consider how, when, and why to use digital technologies in the teaching-learning process, to ensure that their added value is exploited; (v) Consider the supervision of the activities and interactions of my future students with ICT in my educational proposals; (vi) Consider cooperative work with ICT to acquire and document knowledge in my educational proposals; and (vii) Consider the use of digital technologies to allow my future students to plan, document, and evaluate their learning by themselves.

It should be noted that the first three dimensions are included in area 2 "digital resources/content"; and the remaining four dimensions in area 3 "teaching and learning" of the "Digital competence of teachers in training (DigCompeEdu)" questionnaire. As can be seen in **Table 3**, the results show that in the first dimension, "use different internet sites (web pages) and search strategies to find and select a wide range of digital resources", 38% ($f$ = 119) of the students indicate that they use search engines (e.g., Google) and/or educational platforms to find educational resources; followed by 30% ($f$ = 94) who state that they evaluate and select the digital resources I find based on their suitability for my needs as a student and future teacher. The most significant data is found in the item: "rarely use the Internet to find resources," with only 0.6% ($f$ = 2) of the participants.

As regards the second dimension, create my own digital resources and modify existing ones to adapt them to my needs as a future teacher, the item: "I create digital slideshows. For example: Power Point, Prezi." with 56.5% ($f$ = 177); as opposed to 3.5% ($f$ = 11) and 4.5% ($f$ = 14) of the items: "I create activity sheets with the computer and then print them out" and "I configure and adapt complex and interactive resources," respectively. The third and last dimension within the area "digital resources," able to securely protect sensitive content, we find, as significant data regarding the secure protection of sensitive content, that 31.3% ($f$ = 98) and 31.9% ($f$ = 100), respectively, protect their personal data and their own passwords; only 2.2% ($f$ = 7) indicate that they do not need to do so. This fact leads us to think about the little importance that some students give to pedagogical competencies as future teachers, competencies such as protection, creation and collaboration, and protection, management and exchange of digital content.

In relation to the second area "teaching and learning," the three dimensions to be analyzed are. First, the dimension: carefully consider how, when and why to use digital technologies in the teaching-learning process, to ensure that their added value is exploited, it is striking how only 0.6% ($f$ = 2) do not consider the use or rarely use technology in future teaching-learning strategies; that in contrast, 30.7% ($f$ = 96) and 26.5% ($f$ = 83) consider the use of digital tools as an opportunity to implement innovative pedagogical strategies in their teaching practices, and as key elements to systematically improve their own educational proposals. The results converge with the "teaching" competency of the DigCompEdu framework, "program and implement digital devices and resources in the teaching process to improve the effectiveness of teaching interventions; manage and coordinate adequately digital didactic interventions; experiment with and develop new formats and pedagogical methods for teaching" (Redecker and Punie, 2017; Ghomi and Redecker, 2019).

**TABLE 2 |** Transfer massive open online courses content questionnaire.

| Item/question | Multiple-choice |
|---|---|
| 1. What is NOT a tool used in gamification? | - Kahoot.<br>- Quizizz.<br>- Mentimeter.<br>- Padlet. |
| 2. Among the different possibilities that the teacher has for the use of technological resources, the one that best adapts to the characteristics of the material produced and the needs of the students is the following. | - Imitative.<br>- Creative.<br>- Adaptive.<br>- None of the above possibilities meets the stated objective. |
| 3. What is NOT an emerging educational strategy? | - Gamification.<br>- Cooperative Learning.<br>- Flipped Classroom.<br>- Educational robotics. |
| 4. If I detect a security gap in my context, how should I act? | - I try to work it out for myself.<br>- I do not communicate anything to anyone.<br>- I notify both the university institution and the Data Protection Agency.<br>- None of the above actions is correct. |
| 5. Taking into account your knowledge about the possibilities of technologies and their correct integration in educational contexts, it is interesting that: | - The teacher does not have a large number of technologies at his or her disposal.<br>- The teacher has at his/her disposal a large number of technologies.<br>- The teacher has access to the latest technologies available on the market.<br>- The teacher is an expert in the use of technologies. |
| 6. Among the following programs, which would be the best option if we want to make a collective presentation? | - Google Slides.<br>- Bing.<br>- Microsoft Teams.<br>- Edmodo. |
| 7. The TLK are. . . | - Information and Communication Technologies.<br>- Technologies for Learning and Knowledge.<br>- Technologies for Cooperative Learning.<br>- Technologies for Continuous Learning. |
| 8. In order to carry out the tutorial function, the teacher must rely on different synchronous and asynchronous communication tools. | - True.<br>- False. |
| 9. What is NOT an online collaborative learning environment? | - Moodle.<br>- Blackboard.<br>- Google Classroom.<br>- Mentimeter. |
| 10. Among the basic rules that can help us to mitigate the risks of identity theft are: | - Knowing with whom information is shared, personally investigating the identity of the person with whom I share information, storing and disposing of information securely.<br>- Store and delete information securely, know with whom information is shared, ask questions before deciding to share information, and maintain an appropriate level of security on our devices.<br>- Do not share information as a general rule and know with whom the information is shared.<br>- None of the above options is correct. |
| 11. In order to achieve an effective search, it is advisable to contemplate some rules such as, for example: | - Do not use more than 10 words because some search engines do not consider them.<br>- The order in which you put the words is important.<br>- Generally, search engines do not identify short words, except for "AND" and "OR."<br>- All options are correct. |
| 12. If you intend to search for information on the web about the rankings of soccer teams in the 1979 and 2019 league championships. What term would you place to refine your search? | - Soccer league standings 1979–2019.<br>- Soccer league standings 1979 2019.<br>- Soccer league standings 1979 OR 2019.<br>- Soccer league standings 1979 AND 2019. |
| 13. Which is NOT a blogging tool? | - Blogger.<br>- Blogia.<br>- Weebly.<br>- Blogly. |
| 14. Which is NOT one of the chat planning stages? | - Planning.<br>- Production.<br>- Development.<br>- Completion. |

*(Continued)*

**TABLE 2 |** (Continued)

| Item/question | Multiple-choice |
|---|---|
| 15. What is a characteristic of collaborative learning? | - Individual responsibility of the person in the participation in the project, as well as group responsibility in the acquisition of the objectives and in the configuration of quality educational actions.<br>- Individual responsibility of the person in the participation in the project.<br>- Group responsibility in the acquisition of the objectives and in the configuration of quality educational actions.<br>- Learning is only achieved through interaction. |
| 16. Among the general principles to be taken into account for the selection and use of ICT in education we find: | - The learner is a passive processor of information.<br>- ICTs work in the same way in any context and are not conditioned by it.<br>- ICTs are vicarious transformers of reality.<br>- The main task of the teacher is to find the supertechnology that will help him/her to solve his/her educational problems. |
| 17. When it comes to the curricular integration of any resource, we have to consider: | - Learning objectives, context, pedagogical approach and characteristics of the group of students.<br>- Technical characteristics of the resource, learning objectives, context, pedagogical approach, and characteristics of the learner group.<br>- Learning objectives and technical characteristics of the resource.<br>- Context, pedagogical approach, characteristics of the learner group and technical characteristics of the resource. |
| 18. Bauman (2010) points out that we live in a society that is. | - Modern.<br>- Post-modern.<br>- Liquid.<br>- Liberal. |
| 19. A PLE is. | - Personal Learning Environment.<br>- Personal Development Environment.<br>- Virtual Learning Environment.<br>- Online Learning Environment. |
| 20. What evaluation strategy requires a final version of the program: | - Self-assessment by producers.<br>- Consultation with experts.<br>- Evaluation "by" and "from" the users.<br>- Illuminative evaluation. |

In second place, the dimension "consider the supervision of the activities and interactions of my future students with ICT in my educational proposals," the most significant data is found in the item: "regularly consider the intervention with comments to motivate or correct the activity proposed online" with 44.1% ($f$ = 138), compared to the 1.6% ($f$ = 5) found in the item "do not offer educational proposals that contemplate the use of ICT" in contrast to the competence "guidance and support in learning, oriented to: "use digital technologies and services to improve individual and collective interaction with students inside and outside the teaching sessions; use digital technologies to provide relevant and specific guidance and assistance; and experiment with and develop new ways and formats to offer guidance and support" (Redecker and Punie, 2017; Ghomi and Redecker, 2019).

In third place, the dimension "consider cooperative work with ICT to acquire and document knowledge in my educational proposals," yields significant data showing high values for the items "collaborative work proposals, I always contemplate the use of the Internet to find information and present the results in digital format" and "consider the exchange and creation of group knowledge in different online collaborative spaces, e.g., class blog, virtual platform, wiki" with 41.2% ($f$ = 129) and 37.4 ($f$ = 117), respectively. At the other extreme, low values can be found in the response of two students with 0.3% ($f$ = 1), respectively, to the items: "my educational proposals do not contemplate group work" and "I do not feel able to integrate digital technologies in group work." Both participants consider or do not contemplate the importance of group work and, consequently, the added value of collaborative learning; perhaps a first reading could be found in the lack of training of some students to use technologies as part of collaborative tasks and the joint creation of knowledge.

Finally, the fourth dimension, consider the use of digital technologies to allow my future students to plan, document and evaluate their learning by themselves, shows data of 75.4% ($f$ = 236) in relation to the competence "self-regulated learning," in which the importance of using digital technologies to promote and encourage learning processes, where students can plan, document, and reflect on their own learning, is expressed. In this sense, the student body apparently presents certain abilities to share ideas and creative solutions through the use of digital tools. Only 3.5% ($f$ = 11) do not feel trained or qualified to deploy the variety of digital tools available to them.

**Table 4** shows the average (m) and deviation (SD) achieved for each of the dimensions analyzed. The values range from 1.96 (basic level) to 3.15 (intermediate level). Specifically, the students present a basic level in the use different internet sites (web pages) and search strategies to find and select a wide range of digital resources; a fact that leads us to think about the relevance of promoting and enhancing competences oriented to

**TABLE 3 |** Digital teaching competence questionnaire check-in item results (response percentage).

| Frequency | Percentage | Valid percentage | Cumulative percentage | |
|---|---|---|---|---|
| *I use different internet sites (web pages) and search strategies to find and select a wide range of digital resources.* | | | | |
| - I advise colleagues on appropriate digital resources and search strategies. | 14 | 4,5 | 4,5 | 4,5 |
| - I compare resources using a series of criteria relevant to my needs as a student and my future educational practice. For example: quality, pedagogical fit, design and interactivity. | 84 | 26,8 | 26,8 | 31,3 |
| - I evaluate and select the digital resources I find based on their suitability for my needs as a student and future teacher. | 94 | 30,0 | 30,0 | 61,3 |
| - I rarely use the Internet to find resources. | 2 | 6 | 6 | 62,0 |
| - I use search engines (e.g., Google) and/or educational platforms to find educational resources. | 119 | 38,0 | 38,0 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I create my own digital resources and modify existing ones to adapt them to my needs as a future teacher.* | | | | |
| - I configure and adapt complex and interactive resources. | 14 | 4,5 | 4,5 | 4,5 |
| - I create activity sheets with the computer and then print them out. | 11 | 3,5 | 3,5 | 8,0 |
| - I create digital slideshows. For example: Power Point, Prezi. | 177 | 56,5 | 56,5 | 64,5 |
| - I create and modify different types of digital resources. | 74 | 23,6 | 23,6 | 88,2 |
| - I do not create my own digital resources. | 37 | 11,8 | 11,8 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I am able to securely protect sensitive content. For example: photographs, videos, files, exams, grades, personal data.* | | | | |
| - I avoid storing personal data electronically. | 61 | 19,5 | 19,5 | 19,5 |
| - I don't need to do that. | 7 | 2,2 | 2,2 | 21,7 |
| - I protect some personal data. | 98 | 31,3 | 31,3 | 53,0 |
| - I password protect files with personal data. | 100 | 31,9 | 31,9 | 85,0 |
| - I protect personal data thoroughly. For example: combining hard-to-guess passwords, encrypting files, performing frequent software updates. | 47 | 15,0 | 15,0 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I carefully consider how, when and why to use digital technologies in the teaching-learning process, to ensure that their added value is exploited.* | | | | |
| - I consider the basic use of the equipment available in the classroom. For example: audio equipment, television, projector, digital whiteboard. | 60 | 19,2 | 19,2 | 19,2 |
| - I consider the use of digital tools to systematically improve my educational proposals. | 83 | 26,5 | 26,5 | 45,7 |
| - I consider the use of digital tools to implement innovative pedagogical strategies in my future educational proposals. | 96 | 30,7 | 30,7 | 76,4 |
| - I consider a wide variety of digital strategies in my future educational proposals. | 72 | 23,0 | 23,0 | 99,4 |
| - I do not consider the use or rarely use technology in future teaching-learning strategies. | 2 | 6 | 6 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I consider the supervision of the activities and interactions of my future students with ICT in my educational proposals.* | | | | |
| - I regularly consider the intervention with comments to motivate or correct the activity proposed online. | 138 | 44,1 | 44,1 | 44,1 |
| - I occasionally consider the review and keep in mind. | 54 | 17,3 | 17,3 | 61,3 |
| - I do not consider monitoring student activity in the online environments we use. | 11 | 3,5 | 3,5 | 64,9 |
| - I do not offer educational proposals that contemplate the use of ICT. | 5 | 1,6 | 1,6 | 66,5 |
| - I regularly consider the supervision and analyze the online activity of my students. | 105 | 33,5 | 33,5 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I consider cooperative work with ICT to acquire and document knowledge in my educational proposals.* | | | | |
| - I consider the exchange and creation of group knowledge in different online collaborative spaces. For example: class blog, virtual platform, wiki. | 117 | 37,4 | 37,4 | 37,4 |
| - I consider searching for information online or presenting results in digital format in my cooperative work proposals. | 65 | 20,8 | 20,8 | 58,1 |
| - In my collaborative work proposals, I always contemplate the use of the Internet to find information and present the results in digital format. | 129 | 41,2 | 41,2 | 99,4 |
| - My educational proposals do not contemplate group work. | 1 | 3 | 3 | 99,7 |
| - I do not feel able to integrate digital technologies in group work. | 1 | 3 | 3 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |
| *I consider the use of digital technologies to allow my future students to plan, document, and evaluate their learning by themselves. For example: self-assessment tests, digital portfolios, blogs, forums.* | | | | |
| Sometimes I use, for example, tests for self-evaluation, blog, portfolio... | 103 | 32,9 | 32,9 | 32,9 |
| - I systematically integrate different digital tools to plan and reflect on progress. | 54 | 17,3 | 17,3 | 50,2 |
| - I don't feel qualified to use these kinds of digital tools. | 11 | 3,5 | 3,5 | 53,7 |
| - They reflect on their learning, but not with digital technologies. | 12 | 3,8 | 3,8 | 57,5 |
| - I use a variety of digital tools to plan, document or reflect on learning. | 133 | 42,5 | 42,5 | 100,0 |
| Total | 313 | 100,0 | 100,0 | |

**TABLE 4 |** Digital teaching competence questionnaire check-in items results (Likert scale 0–4).

| Item | Average | Deviation |
|---|---|---|
| - I use different internet sites (web pages) and search strategies to find and select a wide range of digital resources. | 1,96 | 0,924 |
| - I create my own digital resources and modify existing ones to adapt them to my needs as a future teacher. | 2,05 | 0,961 |
| - I am able to securely protect sensitive content. For example: photographs, videos, files, exams, grades, personal data. | 2,38 | 1,031 |
| - I carefully consider how, when and why to use digital technologies in the teaching-learning process, to ensure that their added value is exploited. | 2,67 | 1,122 |
| - I consider the supervision of my future students' activities and interactions with ICT in my educational proposals. | 3,15 | 0,937 |
| - I consider cooperative work with ICT to acquire and document knowledge in my educational proposals. | 3,15 | 0,776 |
| - I consider the use of digital technologies to allow my future students to plan, document and evaluate their learning by themselves. For example: self-assessment tests, digital portfolios, blogs, forums. | 2,66 | 0,927 |

*The scale of values is between 0 and 4 points, where the values between 0 and 1 represent a low level of competence, 2 and 3 points an intermediate level, and 4 a high level.*

the selection, creation, protection, management, and exchange of digital resources and contents. As for the competencies that stand out (intermediate level), they are focused on teaching and learning, and mainly refer to orientation and support in learning, whether autonomous, self-regulated, or collaborative. That is to say, the student body indicates ($m$ = 3.15) that as teachers they have to contemplate and carry out educational proposals using technologies in their teaching-learning processes.

In closing, **Table 5** shows the average and deviation with respect to the level of digital competence in initial teacher training with respect to two key axes: resources and the pedagogical nature of all training.

The table shows that the student body is at an intermediate level in terms of resources ($m$ = 2.13; $D$ = 0.972) and pedagogy ($m$ = 2.91; $D$ = 0.941), Through the implementation of the T-MOOC, the objective would be for students to reach all levels, until they reach a high level (leaders or pioneers) in terms of digital competencies.

## Content Questionnaire

The purpose of this questionnaire was to inquire about the students' knowledge of digital resources, emerging educational strategies, and the use and possibilities of technologies in educational contexts in accordance with the contents of the subject "Information and Communication Technologies Applied to Education." And in this way, to design the contents of the T-MOOC for the development of digital competence in teaching, which is presented in the following section.

**TABLE 5 |** Digital teaching competence questionnaire check-in dimensions and total results (Likert scale 0–4).

| Digital kind | Average | Deviation |
|---|---|---|
| Digital resources | 2,13 | 0,972 |
| Digital pedagogy | 2,91 | 0,941 |
| Total | 2,52 | 0,957 |

The answers obtained are shown as a percentage of correct answers (% hits) to the 20 questions asked (**Table 6**).

A high percentage of correct answers was observed in the questions/items: 8 "To carry out the tutorial function, the teacher must have different synchronous and asynchronous communication tools," 95.9% answered correctly; 4 "If I detect a security gap in my context, how should I act?" with 87.6%; 9 "What is NOT an online collaborative learning environment?" with 80.7%; and 11 "To achieve an effective search, it is advisable to contemplate some rules" with 77.9%. In contrast, the questions/items with the lowest percentage of correct answers were 17 (15.5%) "When integrating any resource into the curriculum, it is necessary to consider"; 3 (19.7%) "Which is NOT an emerging educational strategy?"; 2 (28.6%) "Among the different possibilities that the teacher has for the use of technological resources, the one that best suits the characteristics of the material produced and the needs of the students is the following"; 14 (32.1%) "Which is NOT one of the planning stages of the lecture?"; 13 (32.4%) "What is NOT a blogging tool?"; 1 (35.9%) "What is NOT a tool used in gamification?" and 12 "If you intend to search for information on the web about the rankings of soccer teams in the 1979 and 2019 league championships. What term would you place to refine your search?" (36,2%)." The percentage of correct answers for the rest of the items/questions answered by the students ranged from 44.1 to 66.2%.

## T-MOOC Design

After obtaining the results from the students of the DigCompEdu Check-In and content questionnaires, and taking into account the responses of the students, we proceed to create a training and innovative environment under the tMOOC architecture. The purpose is to promote the acquisition of digital competences by the teachers, in our case, for the initial training of the teachers of

**TABLE 6 |** Test results content (% hits).

| Item/question | % hits |
|---|---|
| 1. What is NOT a tool used in gamification? | 35,9 |
| 2. Among the different possibilities that the teacher has for the use of technological resources, the one that best adapts to the characteristics of the material produced and the needs of the students is the following. | 28,6 |
| 3. What is NOT an emerging educational strategy? | 19,7 |
| 4. If I detect a security gap in my context, how should I act? | 87,6 |
| 5. Taking into account your knowledge about the possibilities of technologies and their correct integration in educational contexts, it is interesting that: | 51 |
| 6. Among the following programs, which would be the best option if we want to make a collective presentation? | 54,1 |
| 7. The TLK are. . . | 66,2 |
| 8. In order to carry out the tutorial function, the teacher must rely on different synchronous and asynchronous communication tools. | 95,9 |
| 9. What is NOT an online collaborative learning environment? | 80,7 |
| 10. Among the basic rules that can help us to mitigate the risks of identity theft are: | 64,8 |
| 11. In order to achieve an effective search, it is advisable to contemplate some rules. | 77,9 |
| 12. If you intend to search for information on the web about the rankings of soccer teams in the 1979 and 2019 league championships. What term would you place to refine your search? | 36,2 |
| 13. Which is NOT a blogging tool? | 32,4 |
| 14. Which is NOT one of the chat planning stages? | 32,1 |
| 15. What is a characteristic of collaborative learning? | 64,8 |
| 16. Among the general principles to be taken into account for the selection and use of ICT in education we find: | 44,1 |
| 17. When it comes to the curricular integration of any resource, we have to consider: | 15,5 |
| 18. Bauman (2010) points out that we live in a society that is. | 52,4 |
| 19. A PLE is. | 65,5 |
| 20. What evaluation strategy requires a final version of the program: | 44,8 |


**FIGURE 2 |** Transfer massive open online courses for the acquisition of digital teaching competencies.

the University of Seville. For this purpose, the platform chosen for the design and development of the t-MOOC was Moodle (**Figure 2**).

To access the T-MOOC, each user is assigned an identifier and a password. Once inside, students are presented with the structure of the course. First, there is a presentation of the course and the DigCompEdu Framework through two animations: one with instructions on how to proceed through the course, and the other with the DigCompEdu model with its different areas and competencies. After viewing the videos, the different areas are shown (**Figure 3**). Each competency area is composed by its respective competencies and each competency by its corresponding level (beginner, intermediate, and advanced). Each competency with its corresponding presentation for its correct procedure, levels, tasks and forums (**Figure 4**).

The T-MOOC has a diversity of programs (ExeLearning, VYOND, Genially, Photoshop, Adobe Premiere, and Audacity), distributed as follows: two general animations (one with navigation instructions and use of the t-MOOC, and the other on DigCompEdu); 22 animations specific to each DigcompEdu competency; 16 animations integrated in the different learning modules; 66 learning modules, 230 e-activities distributed in the different modules; 24 infographics and 11 multimedia, both resources integrated in the different learning modules.

The presentation of the tasks (e-activities) is done through a guide that incorporates aspects such as: their identification, recommendations for their completion, a checklist for the user to check the quality of the delivery, and an evaluation rubric that is used by t-MOOC tutors.

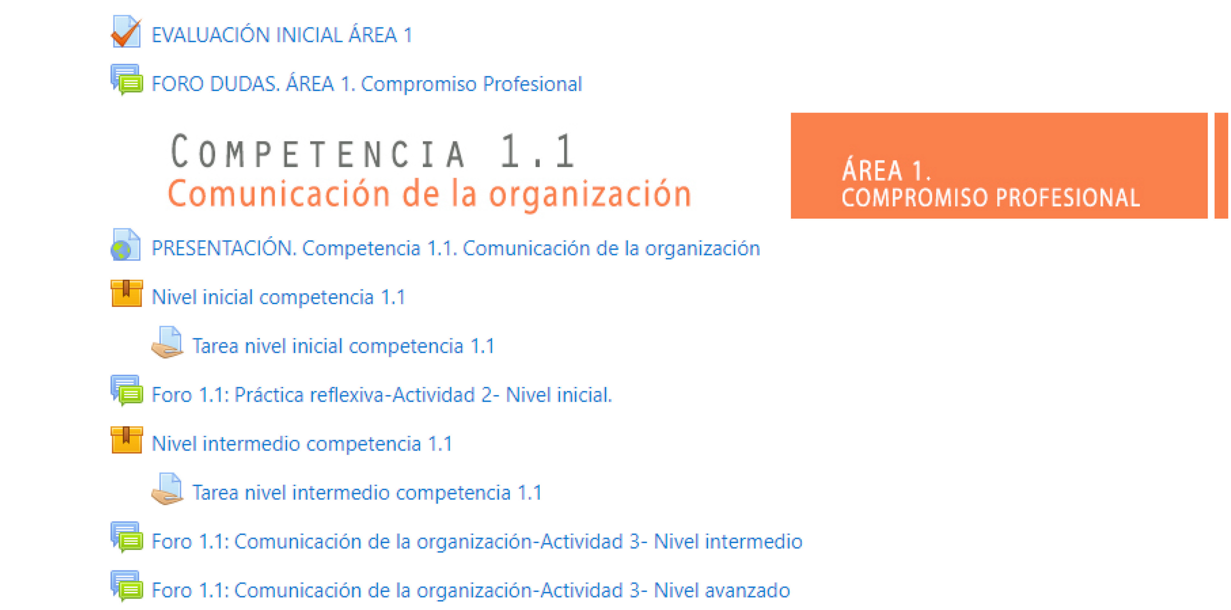


**FIGURE 3 |** Areas and competencies.


**FIGURE 4 |** Area and competencies development.

It should be noted that the e-activities proposed are of various types: making concept maps, participating in forums, building a blog, creating a PLE with certain tools, creating learning communities, among others. As for the resources used in the learning modules: didactic animations, polimedia recordings, videos, infographics, web addresses, and complementary documents. In addition, several forums have been designed: for general doubts about how t-MOOC works, for doubts about each competency area and specific forums for activities.

## DISCUSSION AND CONCLUSION

Based on the results, we can corroborate those presented by Luo et al. (2017) and Gudmundsdottir and Hatlevic (2018), and which highlight the concern on the part of teachers about their training in digital competencies. The presented research implies a transformation in traditional training and educational structures, methods, and assumptions. This is why, as Cabero-Almenara and Palacios-Rodríguez (2020) pointed out in their research, there is a need to rethink other ways of approaching teacher training in order to promote authentic competence development for the current demands of society.

It should be noted that the period of data collection and the results obtained present an overview of the initial training of future teachers in reference to digital competencies at a time when the pandemic situation generated by COVID-19 led us to teach in virtual mode (February–June 2021). These results are similar to those of another study (Cabero-Almenara et al., 2021a), showing teachers in training with a moderate level (basic-intermediate) in terms of digital competencies (Redecker and Punie, 2017; Ghomi and Redecker, 2019).

In order to analyze the educational possibilities of T-MOOCs for initial teacher training in digital competencies, and as resources that favor autonomous and collaborative learning in innovative scenarios, the results of the different analyses carried out provide answers to the two objectives presented: (i) To analyze the level of Digital Teaching Competence in initial teacher training through the DigCompEdu Check-In and content questionnaires; (ii) To develop a training proposal, under the innovative architecture of the T-MOOC, to improve the level of Digital Teaching Competence of teachers in training.

In relation to the implementation of online courses for teachers, and taking into account the research of Drake et al. (2015), Boaler et al. (2018), Beltrán and Ramírez-Montoya (2019), and Escudero-Nahón and Núñez-Urbina (2020), we consider, after the results obtained from the participating students, that for the acquisition of digital competencies, a change of mentality, methodologies, strategies and pedagogical resources is important; whose principles are the use of the Internet in order to access digital resources and content, networked learning and horizontal communication. And, in turn, they are envisioned as a means of opportunities for effective teaching and for the involvement of teachers in training, as pointed out by Cornelius et al. (2019) in their study; not to mention the entire organizational structure and pedagogical design, as pointed out by Raposo-Rivas et al. (2017) and Gros (2018) in their research. It is hoped that with the implementation of the T-MOOC presented in initial teacher education, the inclusion of opportunities for more active participation will be promoted.

It is understood that the conclusion presented should be interpreted with caution. The type of non-experimental design and the size of the sample imply some restrictions for the generalization and application of the results. Future research could consider larger samples and carry them out in other subjects and university careers. Therefore, the purpose is to continue improving and expanding the characteristics of this study, in order to contract results.

In view of the above, it is considered that the present research adds value to the field of educational innovation and technologies, as it opens new perspectives for further research in future studies related to the T-MOOC phenomenon in terms of the acquisition of digital teaching skills, both for teachers who are currently working as well as for those who are undergoing initial training (students). It may also be of interest to educational administrations in order to structure and evaluate training plans and improve the level of digital competencies of teachers.

## DATA AVAILABILITY STATEMENT

The datasets generated during the current study are not publicly available because the identities of some participants are visible, undermining privacy protection. Requests to access the datasets should be directed to SM-P, smartinezperez@us.es; JC-A, cabero@us.es; JB-O, jbarroso@us.es; AP-R, aprodriguez@us.es.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

SM-P and AP-R wrote the first draft. All authors listed have made a substantial, direct, and intellectual contribution to the work, read and edited each draft, and approved it for publication.

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# Building Capacities in Open Knowledge: Recommendations for Library and Information Science Professionals and Schools

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The impact openness to knowledge is having, not only in the Higher Education (HE) sector but at the public and institutional policy level, is largely due to the efforts of information professionals and researchers, and thanks to these two groups, initiatives such as open access (OA), open education (OE), and open science (OSC) have changed the way in which research is being taught, conducted, and communicated. Openness is a way to democratise access to knowledge developed through public funds, and this movement has been led by informational professionals worldwide; however, we have observed that to a large extent, professional development in different areas of openness is rather self-taught, informal, mentored, or continuous, but not formalised in information science, documentation, or scientific educational programmes. In this exploratory research, we gathered evidence on how (or if) openness to knowledge is being taught by reviewing a series of syllabi from undergraduate and postgraduate programmes in Library and Information Science (LIS) schools sampled from universities that either (a) are leading the agenda in OA, OSC, or OE; or (b) have policies in OA, OSC, or OE; or (c) have national/federal mandates, policies, or regulations regarding OA, OSC, or OE and also from a range of non-formal and/or lifelong learning training programmes offered in these same three areas. We found that while LIS schools are not providing formal training to gain skills and competencies in openness, their libraries are offering different kinds of training in this respect. On the other hand, the good intentions and openness awareness of policies have not yet materialised in actions to ensure capacity building. Research implications aim to influence the development of capacity building in open knowledge, by providing solid evidence for enhancing curriculum advancement in LIS schools and by proposing some recommendations in this direction.

**Keywords: open Knowledge, Library and Information Science (LIS) schools, information professionals, LIS curriculum, capacity building, policies, open science, open education**



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## INTRODUCTION

Librarians are amongst the key catalysers in fostering openness in the HE sector alongside educators, learning technologists, and researchers, as their role goes beyond platform and information management, because they are immensely responsible for building capacities in open access and open science, and production of Open Educational Resources (OERs) amongst educators, scientists, policymakers, and their own peers, while putting in openness in practice through publications, data, repositories, and OERs (Manca et al., 2017; Santos-Hermosa et al., 2020). We consider that preparing information professionals with open knowledge is strategic. Experts insist on the importance of investing in training strategies for future and qualified professionals to develop and promote openness across all levels, from open access to open data, open platforms, and OERs (Atenas and Havemann, 2013; Atenas et al., 2015; Santos-Hermosa, 2019; Ferreira Borges et al., 2020), and on the need to update the syllabi to integrate new educational approaches (Ramírez-Montoya et al., 2021). Thus, LIS schools should adopt an open education approach to build capacities toward enhancing their contribution and impact on society in democratising access to knowledge, since one of the problems of LIS professional training programmes is the traditional nature of the curriculum design (Fabián Maina et al., 2020).

According to the IFLA Guidelines for continuous professional learning (CPL) (Varlejs, 2016; de Alwis Jayasuriya et al., 2021), there is a gap in the research on professional development in the LIS sector; likewise, there are no comprehensive studies about how or if openness is included in Library and Information Science (LIS) programmes. However, there are some interesting studies regarding continuing education for LIS professionals in the South and South-East Asian Regions (such as Pakistan, Maldives, and Indonesia) (Saleem and Ashiq, 2020; de Alwis Jayasuriya et al., 2021) and some studies about the general development of library staff (Welz, 2017; Haglund et al., 2018).

As argued by Borrego (2015), the study of educational programmes in LIS studies tends to focus on other parts of the world rather than Europe; thus, it can be understood that there is no common European approach to LIS education. Consequently, the studies have been focussed on describing the general situation of education in LIS schools (Borrego, 2015) and on the evolution of the Information Schools (iSchools) network (López-Borrull and Cobarsí-Morales, 2017); so, the lack of regional studies in the European region is a research gap that we would like to address. Furthermore, these studies provide a contextual framework of LIS education, but they do not address the specific topic of the "openness," which according to Ramirez-Montoya (2020) is understood as the capacity to bring together diverse sectors (educational, research, social, enterprise, and cultural) and is also one of the current challenges in the open science, open innovation and research, and open education landscapes.

Our research aims at addressing the following question: What is the state of capacity building in openness/Open Knowledge for LIS professionals? With the aim to support and enable the development and implementation of capacity-building strategies and programmes in openness, it is necessary to provide the stakeholders in the HE sector with the evidence needed to include elements of capacity building in strategies and policies, and in curricula, to narrow the gap between the current needs in professional development and what is in offer training-wise in open knowledge.

We aim at providing such evidence, and guidance, by showcasing the activities that library schools and university libraries across Europe are carrying out in regards to professional development in openness to knowledge from an undergraduate level to peer-enabled learning, including policymaking and training for fellow librarians, researchers, and students. The uptake and widespread of open science, data, access, and education across Europe require the development of new skills in the HE sector, as recommended by the European Open Science Cloud (EOSC) Skills and Training Working Group (European Commission (Eu) Directorate-General for Research and Innovation, 2021). Therefore, it is key to provide LIS schools with the resources needed to embed openness as a key component of the training program for current and future librarians. Despite the slow but steady increase in data literacy education in librarianship training (Wang, 2018), such as the inclusion of the "Story of Data" course in the Master's program in LIS taught at the City, University of London, training in openness as a wider concept seems to be still pending, as openness is a key element of the work of academic libraries and open access, open science, open data, and open publishing are currently the heart of academic work.

## Originality

By reviewing the panorama in capacity building in openness in the HE sector, which includes outcomes of research and projects, and also policies and strategies at supranational, national, and institutional levels, we have noticed a gap in regards to capacity building for researchers and educators, and a wider gap in regards to capacity building for librarians, as libraries tend to be the main hub for training and capacity building on openness to knowledge.

The value of this paper is to present the first analysis of the capacity building in openness that sheds light on its presence in policymaking (national and institutional policies and strategies) and in Higher Education (more concretely, in LIS Schools and libraries) in Europe. This study also provides valuable evidence of the situation of capacity building in openness in a specific LIS university curriculum design and important insights to improve and transfer it to other fields beyond this discipline; thus, its originality relies not only on filling the gap, but also in the three-tiered model of analysis, aiming at providing recommendations that can be openly and widely adopted in the HE sector.

## Implications

Our study provides stakeholders in the HE sector with the evidence needed to include elements of capacity building in strategies and policies and in curricula. New information placed in the public domain has implications for universities when designing open initiatives and curriculum design (Fabián Maina et al., 2020) in open knowledge. Thus, the analysis of different sources (supranational declarations, national, and institutional policies, HE syllabus, and librarian training services) will demonstrate what is the current situation and enable the identification of good practices to be followed and the gaps to be addressed. The recommendations proposed in our study will foster the adoption and capacity building of openness.

## Context

Capacity building in openness can be understood as the process of training and fostering practical, technical, and social skills in relation to openness to knowledge. In order to catalyse and enable openness to knowledge, the idea of building capacity for communities to openly and effectively participate in science and education needs to be included in the processes of shaping policies with regard to access to information and democratisation of knowledge. openness to Knowledge can be transformative at the HE level, as when a large group of people can participate in activities related to access and creation of knowledge, a long-lasting cultural change can occur at the institutional level, enhancing the experience of researchers, educators, learners, and information professionals (Arza and Fressoli, 2018; Hecker et al., 2018; Fell, 2019; Mwelwa et al., 2020; Agata and Rupert, 2021).

Open knowledge policies should enable informal and certified continuous professional development opportunities to support educators and instructional designers, therefore incorporating learning opportunities both in pre- and in-service training programmes to enhance capacity in a wide range of open practices, from the copyright and licensing to data management, content development, knowledge co-creation, and also training others. Thus capacity building should lay emphasis on developing pedagogic and technical competencies for the creation, use, reuse, and production of open resources, fostering engagement with wider communities through open social learning with peers, considering that the practices and products derived from these capacity-building activities should be aligned with curricular development policies and strategies, as well as considered in promotion and tenure processes when people invest in building capacities in their communities of practice (Nerantzi, 2018; Neumann et al., 2018; Morgan, 2020; Tur et al., 2020; Rodés and Gewerc, 2021).

Training to acquire open skills and competencies has become essential. According to the European Commission (2021) and its European Skills Agenda[1], more training is needed to provoke a cultural change and advance in the adoption of open science, open education, and the rest of the open ecosystem. Some examples of the current train-the-trainer programmes, offered by diverse associations, aiming at developing and keeping trainers skilled to engage several stakeholders for an effective openness implementation are, for example, LIBER[2] (Ligue des Bibliothèques Européennes de Recherche—Association of European Research Libraries); OpenAIRE,[3] SPARC Europe,[4] and the Research Data Netherlands (which has created the Essentials 4 Data Support course) and collaborative projects like the Open Science MOOC[5] and FOSTER Open Science.[6]

## METHODOLOGY

Due to the nature of this exploratory study, we frame our research in the context of European HE institutions, as we needed a wide range of elements to be compared within a landscape. Hence, we chose Europe as a framework to pilot our approach, aiming at providing a methodology that can be later replicated in other contexts.

To identify good practices in capacity building in openness to knowledge for LIS professionals, a qualitative analysis of text-generated data was conducted through content analysis. This technique involves the identification of core concepts through the review of the frequency of units of meaning, indicators, keywords, and patterns in texts (Kripendorff, 2004; Palmer and Coe, 2020), and has offered us an approach that allowed us to explore the data in the web content analysis of policies and LIS courses, programmes, and research activities of LIS schools in Europe following the recommendations of Audunson and Shuva (2016).

Once we have gathered data, we carried out a conceptual analysis based on a series of steps. We started by mapping the relevant documents and information about the research topics. Then, we determined the occurrence of units of meaning and indicators in the selected documents, such as "openness" and "capacity building." In order to organise the data and its outputs, our research approach was to analyse the data in categories from macro to a micro level, as can be seen in **Figure 1**.

At the macro level, we reviewed 11 supranational declaration recommendations about openness, from the Budapest Open Access Initiative in 2001 to the UNESCO (2021) Recommendation on Open Science to understand how or if these guidelines provide advice for professional development or capacity building for LIS professionals. At the meso level, we reviewed national policies and strategies in open access and/or open science in 10 European countries drawn from the 17 European countries represented in the 36 HE institutions that host a list of LIS schools analysed in this study, to find whether these policies acted as a catalysing agent to promote training in openness,

In regards to the 36 LIS schools reviewed, due to the lack of a European Directory of LIS Schools like the American Library Association (ALA), a searchable database of ALA-accredited programmes (American Library Association (ALA), 2022) in library and information studies in the US, we used several sources to sample a list of LIS schools across Europe, including a study by Borrego (2015) which identified 220 institutions offering LIS education in 26 European countries, the list of member institutions of non-profit associations that promote the European cooperation between LIS schools such as BOTCATSS,[7] and from the European chapter of the Information Schools (iSchool) network,[8] which brings together faculties, or university departments, that share the recognition of information as a field of academic study. Most of our sample was retrieved from the iSchools network, as it also incorporates institutions from different academic traditions, such as library science, information management, information technology, and systems, which gave us a wider perspective of a LIS panorama.

From these 36 LIS schools, we conducted a three-tiered review. First, we assessed if these had institutional policies and

[1] https://ec.europa.eu/social/main.jsp?catId=1223&langId=en
[2] LIBER: https://libereurope.eu/webinar-recordings/
[3] OpenAIRE https://www.openaire.eu/tag/webinars/training
[4] SPARC Europe: https://sparceurope.org/
[5] Open Science MOOC https://opensciencemooc.eu/
[6] FOSTER Open Science https://www.fosteropenscience.eu/
[7] BOTCATSS https://bobcatsss.info/board-members/
[8] European chapter of the Information Schools (iSchool) consortium https://ischools.org/.

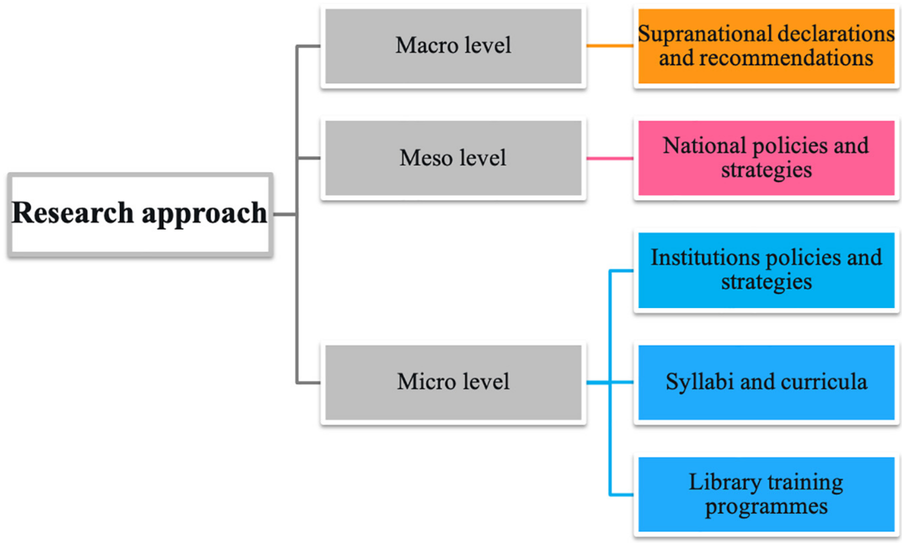


**FIGURE 1 |** Levels of the research approach.

strategies in open access or open science, and in those that had one, we reviewed if there were institutional commitments to build capacities for librarians and other professionals and students in openness to knowledge. Then, we reviewed their syllabi and curricula to understand how or if openness is taught at undergraduate and postgraduate levels. Finally, we reviewed the nature of training on openness provided by these university libraries to the members of their communities.

For the macro and meso analysis, we analysed the full text of the supranational declarations and national and institutional policies by searching the text using keywords, such as "capacity building," "Skills development," and "Training" to identify concrete mentions about capacity building, and then we summarised the information. For the micro level, we first identified a list of 80 potential universities that may have had a LIS school, and checked whether these have information displayed on their website in English or another language we were familiar with. After identifying a LIS school or department, we reviewed their websites to identify the availability of the description of their programmes, study plans, curricula, or syllabi. Finally, we identified 36 LIS schools that have a document providing curricular information at undergraduate and postgraduate levels, which were further examined to identify if there were any relevant studies with an openness component.

As for the training offered by the academic libraries, which correspond to the HE institutions that have a LIS school selected for this study, the analysis has also been carried out using the information available on each library web page, specifically by two strategies: a general search (Open) in the searching engine or browsing to identify concrete sections about open access (OA), open science (OSC), or open education (OE), and also reviewing the sections on "library services" and events looking for the training and courses provided.

# RESULTS

Our results, obtained through a (macro, meso, and micro) exhaustive three-tiered review across Europe, show a panorama of the professional development opportunities for the LIS sector, which allow us to indent good practices and gaps in capacity building in openness to knowledge.

In the following sections, we present the outcomes for each tier review.

## Supranational Declarations

To understand how or if the international organisations and coalitions are promoting, guiding, or supporting the development and advancement of openness, we reviewed a series of supranational recommendations and declarations in OA, OSC, and OE from 2001 to 2021 to see whether these include strategies to support the development or enhancement of capacity building programmes for LIS professionals (see **Table 1**).

It can be observed that until 2012, the development of capacities was not clearly and explicitly addressed in the supranational recommendations and declarations. From the launch of the Budapest Open Access Initiative in 2001, we can observe that the emphasis on the declarations is opening up access to knowledge in the shape of academic publications, although there are, if, some scarce yet implicit indications of building knowledge, but we cannot observe any explicit mention of training or capacity building until the 2012 Paris UNESCO OER recommendation which states in its point E to:

Support capacity building for the sustainable development of quality learning materials. Support institutions, train and motivate teachers and other personnel to produce and share high-quality, accessible educational resources, taking into account local needs and the full diversity of learners (UNESCO, 2012, p. 2).

**TABLE 1 |** Capacity building in OA, OSC, and OE, a review of recommendations and declarations.

| Declaration | Year | Theme | Summary and capacity building mention |
|---|---|---|---|
| Budapest Open Access Initiative | 2001 | Open access | It states that academic literature should be freely accessible online without expectation of payment. encompassing peer-reviewed journal articles, and any unreviewed preprints, encouraging governments, universities, libraries, editors, publishers, foundations, societies, professional associations, and individual scholars to remove the barriers to open access and building a future in which research and education in every part of the world are free. However, there is no explicit mention of capacity building |
| UNESCO's 2002 Forum on the Impact of OCW for HE in Developing Countries | 2002 | Open education | It promotes the adoption of OCW to improve access to quality education and coins the term OER, however, the concept of capacity building for educators and librarians in developing OER and managing OCW platforms is not addressed, however, it is proposed to create communities of practice to develop OER while training should be arranged to promote the adoption of creative commons |
| Bethesda Statement on Open Access Publishing | 2003 | Open access | Open Access is described as irrevocable, worldwide and perpetual free access to use, distribute, transmit, and publicly display and distribute the published contents through the appropriate recognition of authorship and are promoted through education and outreach activities, giving high priority to teaching users about the benefits of open access publishing and open access journals, but capacity building for librarians and other professionals is not mentioned. |
| Berlin declaration on open access to knowledge in the sciences and humanities | 2003 | Open access | The Open access paradigm is encouraged to maintain quality assurance standards and good scientific practices and promotes establishing open access as a worthwhile procedure by committing each and every individual producer of scientific knowledge and holder of cultural heritage. Open access contributions include original scientific research results, raw data and metadata, source materials, digital representations of pictorial and graphical materials and scholarly multimedia materials, however, training and capacity building is not mentioned. |
| Salvador declaration on open access: the developing world perspective | 2005 | Open access | Governments are urged to make Open Access a priority in science policy, requiring that publicly funded research be made available to the public, strengthening Open Access journals, repositories and other relevant initiatives in promoting scientific information, however, capacity building it is not addressed in this declaration |
| Bangalore declaration: A national open access policy for developing countries | 2006 | Open access | The statement emphasises the benefits of Open Access publishing for developing countries, but it does not address elements of training or capacity building for researchers and librarians. |
| Cape Town open education declaration: Unlocking the promise of open educational resources | 2008 | Open educational resources | It encourages governments and universities to make Open Education a priority. Accreditation processes should give preference to OER and repositories should actively include these within their collections. It mentions the participatory culture of learning, creating, sharing and cooperation that rapidly changing knowledge societies need and encourages educators and learners to actively participate in the emerging open education movement. Capacity building to education and information professionals is not explicitly addressed |
| 2012 World open educational resources (OER) congress | 2012 | Open educational resources | It promotes the development and promotion of OER, as well as to adopt adequate open standards to favour and facilitate the use of these resources at all educational levels. It explicitly addresses support capacity building for the sustainable development of quality learning materials (point e) |
| UNESCO Ljubljana action plan, UNESCO 2nd World OER. Congress | 2017 | Open educational resources | This action plan is explicit in addressing the need of capacity building for librarians and educators, by stating the need to support training from Governments, educational institutions, to teachers and librarian training, which are key necessary for the realisation of the suggested actions in this area. |
| UNESCO OER recommendation | 2019 | Open educational resources | This declaration aims at supporting member states in developing their OER adoption at strategic level and explicitly includes Librarians as part of the key stakeholders in open education. This declaration promotes education and lifelong learning in two of their key points promoting providing systematic and continuous capacity building to all key education stakeholders. |
| UNESCO Recommendation on open science | 2021 | Open science | It promotes the adoption of open science as a catalyser for good science, and states that open science requires investment in capacity building and human capital promoting the use of OER as an instrument for open science capacity building to increase access to open science educational and research resources, improve learning outcomes, maximise the impact of public funding and empower educators and learners to become co-creators of knowledge. |

Librarians and other LIS professionals are not mentioned as part of key stakeholders in regards to building capacities until the UNESCO Ljubljana action plan which states in point 1. Building the capacity of users to find, reuse, create, and share OER recommends to:

Effectively use OER, educators, learners and librarians need the capacity to find, re-use, modify and share materials created under an open license. Furthermore, user-friendly tools to locate and retrieve OER need to be mainstreamed. Support and action in particular from Governments, educational institutions, especially teacher and librarian training institutions as well as professional associations; are necessary for the realisation of the suggested actions in this area (UNESCO, 2017, p. 3).

The OER UNESCO (2019) recommendation (4), in its point (i) "*Building capacity of stakeholders to create, access, re-use, adapt and redistribute OER, the list of stakeholders in the formal, non-formal and informal sectors,*" includes a wide range of actors, yet librarians and information professionals are not explicitly listed; however, they are included in "*cultural institutions (such as libraries, archives, and museums).*"

Finally, the UNESCO (2021) recommendation on Open Science explicitly includes librarians and information specialists as stakeholders in research and innovation systems, and it fosters funding and investment policies and strategies for science that include capacity building of all actors, as in its point IV, it promotes: Investing in human resources, training, education, digital literacy, and capacity building for open science by:

*a. Providing systematic and continuous capacity building on open science concepts and practices, including broad comprehension of the open science guiding principles and core values as well as technical skills and capacities in digital literacy, digital collaboration practices, data science and stewardship and. . .[]d.* Promoting the use of OER as an instrument for open science capacity building (UNESCO, 2021, p. 36).

We consider that it is key for any forthcoming declaration and recommendation to continue to explicitly address the importance of capacity building both at the pre-service and professional development level, including elements such as funding and curriculum design for information, education, and science professionals to advance the adoption of OA, OSC, and OE.

At the supranational level, 3 of the 11 recommendations and declarations reviewed for this research mention the need of supporting developing capacities for librarians; however, it is not until the UNESCO (2017) Ljubljana action plan in that librarians were explicitly addressed. Until then, there was an implicit message with regard to who and how one should be trained. However, the latest supranational recommendations (2019 and 2021) are addressing capacity building for librarians as key stakeholders in the development of skills for others.

## National Plans and Strategies

After reviewing supranational declarations and recommendations to understand the guidance given to countries and institutions in regards to the adoption and advancement of OA, OSC, and OE, we have reviewed whether the countries of the LIS schools selected for this study have any sort of policy or strategy on these themes and if the institutions that host the 36 LIS schools also hold a policy and strategy to promote them.

Out of the 17 European countries represented in the 36 LIS schools analysed, we found 10 that have a national policy, action plan, or national strategy to promote OA, OSC, or OE (see **Table 2**).

In general terms, most of these national strategies ensure open access to Research and Development results in line with European legislation to increase their integration into the European Research Area, as per the European Commission Recommendation 2018/790, of 25 April 2018, on access to and preservation of scientific information requests to member states to "set and implement clear policies (as detailed in national action plans)" (European Commission (EU), 2018, p. 3) and covering OA to publications, management of research data, preservation and reuse of scientific information, infrastructures for open research, skills and competencies, and incentives and rewards.

Also, in these 10 national plans, we reviewed if these address capacity building in openness and whether these promote any programme in this regard. As a result, three main patterns were identified in four of them, from less to more involvement (see **Table 3**): those offering some support to capacity building, those including a section or specific mention to open skills need, and those that promote some action or training programme or the provision of human resources.

Therefore, further commitment to openness is observed in national strategies and plans rather than in capacity building, depending on the approach and the specific mentions regarding its content.

## Three-Tiered Review Across Europe: Curricula, Institutional Policies, and training

Here, we present the results of the three-tiered analysis conducted at the micro level, as we first reviewed the institutional policies and strategies in open access/open science of the 36 selected institutions. Then, we analysed the syllabi and curricula courses about openness to knowledge in their undergraduate and postgraduate programmes, and, finally, we reviewed the training provided by their university libraries toward building capacities in OA, OSC, and OE.

**Table 4** showcases the three levels of data analysed across the HE institutions and LIS schools: their institutional policies and the mention of capacity building in these contexts, the inclusion of openness across the taught courses, and capacity building and training programmes in the academic libraries. In the following subsections, we present the outcomes for each tier review.

### Openness in the Library and Information Science Syllabi—Education at Undergraduate and Postgraduate Levels in Openness to Knowledge

After carefully and thoroughly reviewing the curricula and syllabi of the aforementioned 36 LIS schools on themes related to openness to knowledge, we did not find any evidence of pre-service training being included in curricula either at programme or at the module level, both in undergraduate and postgraduate programmes in any of the institutions reviewed. The only exception is the Universitat de Barcelona, which has recently launched a postgraduate certificate program in Open Science in their LIS school named "Open Science: promotion, support and assessment",[9] which is intended for:

staff from university and research libraries, management teams in university and research centres, and staff from management units in research institutes, centres, and facilities, who carry out activities related to research assessment, research support, and knowledge management, and who want to improve their knowledge, incorporate the experience into their work, and reflect on their adaptation to this new environment.

Most of the curricula reviewed put emphasis on information management and information architecture, and there is still loads of traditional librarianship being taught in LIS schools, such as cataloguing and classification. However, there is quite a lot of advancement in areas of information literacy, preservation, and

[9]https://www.ub.edu/portal/web/information-audiovisual-media/openscience_introduction

**TABLE 2 |** National policies, action plans, or strategies to promote OA, OSC, or OE.

| Country | National plan or strategy (year) | Summary |
|---|---|---|
| Croatia | Croatian Research and Innovation Infrastructures Roadmap (2014) | This roadmap fosters the promotion of open access to research data, especially data funded from public sources and promotes cooperation between various scientific and research institutions and allow open access to the use of research infrastructure |
| Czech Republic | National Research, Development and Innovation (NDI) Policy of the Czech Republic 2021 + (2020) | The vision of the National Policy is to use efficient support and targeting of research, development and innovation to contribute to the prosperity of the Czech Republic |
| Finland | Policy for Open Access to Research Data and Methods (2020–2025)<br>Policy for Open Access to Scholarly Publications<br>Policy for Open Education and Open Educational Resources | Finland has a series of national policies in different areas of openness to knowledge that include long term action plans for the HE sector. |
| Ireland | National Framework on the Transition to an Open Research Environment | It proposes that Those involved in each stage of the research process should have the capacity and skills necessary to enable FAIR data. |
| Netherlands | National Plan Open Science | It states that as a matter of principle, it is important that society as a whole should benefit from publicly funded research. An innovative open model needs to be developed to enable target audiences such as SMEs3, municipalities and the "ordinary citizen" to access research results |
| Slovenia | National Open Science Portal | The Slovenian strategy is focused in promoting and supporting HEIa and scholars in using a national repository built following the EU Commission on OA and the compliance of the portal with the OpenAire guidelines |
| Spain | Estrategia Española de Ciencia, Tecnología e Innovación 2021–2027 | Designed to facilitate the articulation of the Spanish R&D&I policy with the EU framework program for science and innovation, Horizon Europe (2021–2027). Open science is one of the pillars of Goal 4 (Generation of knowledge and scientific leadership), which is aimed to favour the generation of knowledge of high quality and impact, as well as its transmission to society. |
| Sweden | National Policy | In 2015, the Swedish Research Council developed a proposal for national guidelines for open access to scientific information, including publications, research data and artistic works. The proposal has been adopted and states that research results must be accessible to everyone *via* the Internet. The results must be available free of charge on the internet no later than 6 months after they are published. |
| Switzerland | Swiss National Science Foundation (SNSF) Open Access to Publications Policy | The SNSF open access policy goes hand in hand with the national strategy pursued by the Swiss higher education institutions. They decided that all publicly funded publications must be freely accessible as of 2024 |
| United Kingdom | Research Excellence Framework (REF) Open Access Policy 2021 | It states that the Author-Accepted Manuscript of all articles and conference proceedings must be deposited in an open access institutional (i.e., Open Research Online) or subject repository within 3 months of the date of acceptance with the publisher although articles published as Gold open articles are exempt from the policy requirement |

data management, although there is a gap in curricular training in openness to knowledge despite being in the library and policy field for nearly 20 years. We assume that capacity-building and awareness-raising programmes are embedded in the teaching models and subjects, but they are not visible when reviewing the curricula made available to the public, thus our results coincide with the information available in the institutional portals.

## Inclusion of Capacity Building for Library and Information Science Professionals in Institutional Policies and Strategies

At the policy level, 27 out of the 36 institutions reviewed have an institutional OA policy and or a mandate, while another 3 have an open strategy. The remaining six institutions do not have an OA policy; however, three of these institutions are aligned with their national strategy.[10] Thus, 84% of the total institutions reviewed have an institutional or national policy or strategy aiming at fostering, promoting, and adopting openness to knowledge.

[10]LIS in Croatia, Sweden, and Switzerland.

We have observed some particularities in the identified policies. First, we noted that some institutions have two or more policies, which tend to be general and specific policies, for example, Oxford University has an OA statement (2013) and a policy (2018), while Northumbria University has a first OA policy from 2005, a subsequent one from the UK Research Council (2013), and a current one from the UKRI OA Policy (2021). Finally, Manchester Metropolitan University has an OA policy (2019) and a more specific policy for Research Data Management that includes OA (2020).

With regard to the three institutions that do not have an institutional OA policy, Charles University has signed the Berlin OA Declaration and includes the OA focus in its Code of Ethics and in their Editorial policy, Linnaeus University has a vice-chancellor OA guideline for electronic publishing, and Seinäjoki University of Applied Sciences is part of an open project of the Finnish Ministry of Education along with 25 other universities of applied sciences in the country. Thus, as can be seen, there might be a wide commitment toward enhancing and fostering openness to knowledge in the HE European landscape.

**TABLE 3 |** Capacity building in national policies or strategies.

| Approach | Detail in the policy | Country |
|---|---|---|
| Mentioning support to capacity building | "Support for training, innovation and the development of technology" along with supplying scientific communities with data production and processing services. | France (Second National Plan for Open Science) |
| Section or mention on "Skills for open science and open data" | Capacity building and empowerment in these areas have been accorded high importance in Portugal since the beginning of 2000. Moreover, given the current financial crisis and high rate of unemployment, "Portugal is seeking to invest in training in data-related areas, specifically in courses designed to develop digital skills in big data, data management and business analytics".[a] | Portugal |
| | Are mentioned "measures include putting in place personal development and career plans and expanding continued education and lifelong learning. It comprises steps to develop the necessary skills and expertise in research and managerial work and teamwork enabling cooperation with other RDI actors to develop and deepen" (p. 33). | Czech Republic |
| Mention some action or training program or human resources provision | "Action 26" in which two training strategies are proposed:<br>-The Ministry of the Interior will set up an innovation laboratory to overarch the systemic measures. The innovation lab's activities will focus on supporting and fostering innovative thinking, capacities and leadership, and will do this *via* training programs and workshops for public administration employees and their superiors<br>-The IPO (Industrial Property Office) website will offer free teaching aids for educators created by the European Patent Organisation (EPO) and European Union Intellectual Property Office (EUIPO) or interactive e-learning courses on the basics of industrial rights. | Czech Republic |
| | One of the approaches designed to achieve the objective of promoting R&D&I and its transfer is to use trained human resources in open access to data, microdata, publications, code (software) and, in general, to all results of publicly funded research. | Spain |

[a] *Portugal - Open science country note https://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/content/portugal-open-science-country-note/index.html.*

Out of the 30 institutional policies reviewed, we found out that 9 mention training in openness; thus, the outlook varies slightly following a diverse range of perspectives (which are detailed in **Table 5**): a general approach to the topic, raising awareness and promoting OA, including responsibility for the provision of training, providing concrete actions to support and monitor it, and fostering training focussed on doctoral schools.

Results suggest that although most of the institutional policies reviewed aim at fostering openness to knowledge in some way, there are different speeds and working rates to implement capacity building.

## Training for Researchers and Students in Academic Libraries

To understand how these 36 universities commit to developing capacities in OA and OSC, we reviewed their library websites as these usually have a web service or section dedicated to OA/OSC. We noticed that, despite not including openness in their LIS courses, 34 of the HEIs offered some kind of training on aspects of openness, which we classified into four key types of capacity-building programmes in academic libraries (see in **Table 6**): training materials (subject guides, video tutorials, etc.), workshops and webinars (face-to-face and online), one-off training events (organised for a specific occasion), and courses.

All these types of training usually are available as part of the Library Support for researchers or the training services. In addition, in some libraries there is an open access team, responsible to organise training and other events; a Library's Open Access Helpdesk, to assist and create guides about OA; or even an OA department, such as the OA Support Centre of the Central Library of Charles University; or an Office for Open Science at UCL. Some of these workshops are organised with organisations such as OpenAIRE, while others are created on the occasion of the Open Access Week[11] or because of a collaboration with the doctoral schools or an OA Support Centre (such as the one at Charles University).

## Joint Initiatives—The Role of Library Consortia in Capacity Building

Through our research in academic libraries, we noticed two additional scenarios. Some libraries tend to collaborate as consortia and some others have an inter- and cross-university partnerships with other libraries and departments. Such partnership models often have worked quite well when buying books or negotiating deals with publishers (consortia deals), and also seem to be key to collaboration for capacity building, as we found joint initiatives in the shape of online courses on open science and open access. Some examples are listed below.

1. Research data management website of Humboldt-Universität zu Berlin[12]: it is a joint initiative of the central units of Computer and Media Service (CMS), Research Service Centre, as well as University Library and Vice President for Research of the university. In addition to specific information and support, they offer video tutorials and training workshops.[13]
2. Hamburg Open Science: it is the implementation of a cross-university strategy by the University of Hamburg (UHH) in cooperation with the University Information and Library

[11] Open Access week http://www.openaccessweek.org/

[12] Research data management website of Humboldt-Universität zu Berlin https://www.cms.hu-berlin.de/en/dl-en/dataman-en/

[13] Training, workshops, and other events of the research data management initiative. https://www.cms.hu-berlin.de/en/dl-en/dataman-en/support/training

**TABLE 4 |** LIS schools: openness in curricula and capacity building in policies and library training.

| Country | Institution | LIS school/department | OA policy | OSC policy | Education at UG and PG in openness | Library training in OA/OSC/OE |
|---|---|---|---|---|---|---|
| Croatia | University of Osijek | Josip Juray Strossmayer | No | No | No | Yes |
| Czech Republic | Charles University in Prague | Institute of Information Studies and Librarianship (IISL), Faculty of Arts | No | Yes | No | Yes |
| Finland | Seinäjoki University of Applied Sciences | Library and Information Studies—School of Business and Culture | No | Yes | No | Yes |
| | University of Tampere | Communication Sciences Unit | Yes | Yes | No | Yes |
| France | ENSSIB | Ecole National supérieure des sciences de l'information et des bibliothèques | No | No | No | Yes |
| Germany | Hochschule Hamburg | Library and Information Management- Bachelor of Arts, Department Of Design, Media and Information | Yes | No | No | Yes |
| | Humboldt-Universität zu Berlin | Berlin School of Library and Information Science | Yes | Yes | No | Yes |
| | Universität Siegen | School of Media and Information | Yes | Yes | No | Yes |
| | University of Regensburg | Institute for Information and Media, Language and Culture | Yes | Yes | No | Yes |
| Ireland | University College Dublin | Faculty of Engineering in cooperation with the Faculty of Arts | Yes | Yes | No | Yes |
| Italy | University of Bologna | Library and Archive Science—Cultural Heritage | Yes | No | No | No |
| MALTA | University of Malta | Faculty of Media and Knowledge Science- Department of Library and Archive Sciences | Yes | No | No | Yes |
| Netherlands | University of Amsterdam | Communication and Information Studies | No | Yes | No | Yes |
| | University of Groningen | Graduate School of Humanities, Archives and Information Studies | Yes | No | No | Yes |
| Norway | Oslo Metropolitan University | Department of Archivistic, Library and Information Science | Yes | Yes | No | Yes |
| Portugal | Nova University Lisabon | Information Management School | No | Yes | No | Yes |
| | University of Porto | Faculty of Engineering in cooperation with the Faculty of Arts | Yes | Yes | No | Yes |
| Slovenia | University of Ljubljana | Department of Library and Information Science and Book Studies | Yes | No | No | Yes |
| Spain | Polytechnic University of Valencia | School of Informatics | Yes | Yes | No | Yes |
| | Universidad Carlos III de Madrid | Department of Biblioteconomía y Documentación, Faculty of Humanities, Communication and Documentación | Yes | Yes | No | Yes |
| | Universidad de Granada | Facultad de Comunicación y Documentación | Yes | Yes | No | Yes |
| | Universitat de Barcelona | Facultad de Información y Medios Audiovisuales (FIMA) | Yes | Yes | No | Yes |
| | Universitat Oberta de Catalunya | Information Science and Communication Studies[a] | Yes | Yes | No | Yes |
| Sweden | Linnaeus University | Information Institute (iInstitute) | No | Yes | No | Yes |
| | University of Boras | The Swedish School of Library and Information Science (SSLIS) | No | Yes | No | Yes |
| Switzerland | University of Applied Sciences of the Grisons | Swiss Institute for Information Science | No | Yes | No | Yes |
| United Kingdom | City University | Department of Library and Information Science | Yes | No | No | Yes |
| | Manchester Metropolitan University | Department of Computing and Information Sciences | Yes | Yes | No | Yes |
| | Northumbria University | Computer and Information Sciences | Yes | Yes | No | Yes |
| | Oxford University | Digital Humanities—Department of Engineering Science | Yes | Yes | No | Yes |
| | Robert Gordon University | Department of Information Management of Aberdeen Business School | Yes | Yes | No | Yes |
| | University College London | Department of Information Studies- Faculty of Arts and Humanities | Yes | No | No | Yes |
| | University of Glasgow | Digital Media and Communications | Yes | Yes | No | Yes |
| | University of Sheffield | Sheffield Business School | Yes | No | No | Yes |
| | University of Strathclyde | Computer and Information Sciences | Yes | Yes | No | Yes |

[a] *Unfortunately, and despite the efforts of the academic body, the LIS school at UOC will soon cease its activities. However, some LIS courses are still taught.*

Service (HIBS), and other universities[14] have created the *Hamburg Open Science program*.[15]

[14] The Technical University of Hamburg (TUHH), the University of Applied Sciences Hamburg (HAW), the HafenCity University Hamburg (HCU), the University of Fine Arts (HfBK), the Hamburg University of Music and Theatre (HfMT), the University Medical Center Hamburg-Eppendorf (UKE), and the State and University Library Hamburg Carl von Ossietzky (SUB) together with the Authority for Science, Research, Equal Opportunities, and Districts (BWFGB).

[15] Hamburg Open Science program https://openscience.hamburg.de/de/startseite-hamburg-open-science/

**TABLE 5 |** Capacity building in institutional policies.

| Approach | Detail in the policy | Institution |
|---|---|---|
| General approach | "Adequate support for—and the central coordination of—training courses will ensure that tailor-made solutions can be more widely used by the faculties" | University of Groningen |
| | "Where appropriate, provide discipline-specific data management training, support and advice, particularly on aspects such as data ownership and ethics" (University of Glasgow). | University of Glasgow |
| Stating explicitly responsibility for the provision of training | "Support and advice on research data management" | Manchester Metropolitan University |
| | "Information and advice on OA matters *via* the Bodleian Libraries" | Oxford University |
| | "Implement any training or skills development required by researchers to execute their responsibility" | University College London |
| | "Training, awareness training and guidance for the teaching and research staff about open access and open science" *In this last case, it is specified that "is responsibility of the Library and Learning Resources Department, the Research and Innovation Department and Personnel" (Universitat Oberta de Catalunya, 2021, 10) | Universitat Oberta de Catalunya |
| Providing concrete actions and monitoring | "Support and monitoring": 4.1 Adoption of Open Access shall be supported through the organisation of seminars, awareness raising events, and educational and training ventures" | University of Malta |
| Through raising awareness and promoting OA | "The procedures, organisational aspects, regulatory details, promotion, training, awareness raising and support activities for the implementation of Open Access will be the subject of specific documents drawn up after an initial experimentation phase" | University of Bologna |
| Fostering training focus on doctoral schools | "The Graduate Schools will ensure that arrangements are made with Ph.D. students regarding data management and the recording of such arrangements in these students' training and supervision plans. | University of Groningen |

3. Researcher Development Programme for Postgraduate Student: library services of the Northumbria University together with Graduate School, Vitae, career support, AHRC Centre for Doctoral Training, and research bursaries.
4. The 4EU + European University Alliance: it is a European association of six partner universities—Charles, Heidelberg, and Sorbonne Universities, and the Universities of Copenhagen, Milan, and Warsaw. It offers a series of workshops: *Open for you! An introduction series to open science*.[16]

To summarise the results, at **the macro level,** we have found that until 2012 the development of capacities was not clearly addressed in the supranational recommendations and declarations and that librarians were not explicitly mentioned until the UNESCO (2017) Ljubljana action plan in At **the meso level**, while most of the revised national strategies guarantee some kind of openness (mainly related to open access to research results, in line with the European Research Area and legislation), capacity building is not regarded as a priority or addressed at a lower level. At the **micro level,** the outcomes of the three-tiered analysis first showcase a gap in curricular training in openness to knowledge (almost no evidence of LIS university programmes has been identified). Second, most institutional policies reviewed foster openness to knowledge (in a diverse range of perspectives), but at the same time, there are different speeds and working rates in regards to capacity building. Finally, most evidence and ideas on the capacity building can be found in the programmes from academic libraries that offer training on openness (including training materials, workshops, one-off training events, and courses) and they collaborate together (through consortia and cross-university partnerships) by providing joint training initiatives.

[16]*Open for you! An introduction series to open science* https://4euplus.eu/4EU-273.html

## DISCUSSION

So, what is the state of capacity building in openness/Open Knowledge for LIS professionals? After reviewing the landscape of LIS professional development in openness, we can argue that despite the enormous efforts made by librarians to advance the understanding and adoption of open knowledge, most of the OSC training activities in universities are prepared and conducted by academic librarians (Schöpfel et al., 2019) and libraries usually are leading or acting as main coordinators in OSC training (Ayris and Ignat, 2018; Swiatek, 2019), the results of this research clearly show that LIS schools are not providing training to gain skills and competencies in openness and, therefore, need to be prepared to the changing demands of the twenty-first century users (Shonhe, 2020) in an expanding job landscape.

The analysis by Rafiq et al. (2017) revealed that training offered in LIS Schools are not fulfilling the requirements of LIS professionals. Some studies (López-Borrull and Cobarsí-Morales, 2017; de Alwis Jayasuriya et al., 2021; Muzamil and Nabeel, 2021) indicate that there is a lack of suitable training programmes and that LIS professionals are equipped with traditional knowledge for specialised librarianship roles, but the skills required in the new academic context and job market are given little importance in the existing LIS curriculums. Considering the ever-evolving ICT environment, LIS professionals need to develop high skills to adapt to these changes; thus, Ameen (2009) suggests that LIS schools should come forward to play their role in training working librarians. Furthermore, Tyagi and Yanthan (2016) add that the revision of

**TABLE 6 |** Capacity-building programmes in academic libraries.

| Type | Number of libraries | Detail |
|---|---|---|
| Training materials | 22 | Mainly subject or research guides about Open Access, Open Science, Open Publishing and Research Data Management. There are also video-tutorials, specialised blogs (e.g., Open Science blog[a] from the University of Groningen Library), etc. |
| Workshops and, webinars | 9 | Face-to-face and online or webinars (e.g., *Open Access in a nutshell*[b], from the Charles University) |
| One-off training events | 6 | Some examples are the *Open Access Publication in the Spotlight* event[c] University of Groningen Library o *Library Presentation Menu*[d] with sessions such as "Open Access with one click" or "Open Access for Dummies," at the Swedish School of Library and Information Science (SSLIS) or the *Open for you* event[e], from the Charles University. |
| Courses | 4 | These are usually held in an LMS or VLE. For instance, the research data management[f] and open access courses[g] from Charles University. These kinds of courses seem to be, mainly, for Ph.D. students but also for researchers. |

[a]*Open Science blog: https://www.rug.nl/library/open-access/blog/open-access-publication-in-the-spotlight-november-long-term-effects-of-acceptance-and-rejec.*
[b]*Open Access in a nutshell https://www.youtube.com/watch?v=VWQQ1_OVxaw.*
[c]*Open Access Publication in the Spotlight event https://www.rug.nl/library/open-access/blog/open-access-publication-in-the-spotlight-january-planetary-limits-to-soil-degradation.*
[d]*Library Presentation Menu https://www.hb.se/en/university-library/support-for-researchers/support-and-services/library-presentation-menu/.*
[e]*Open for you event https://4euplus.eu/4EU-273.html#7.*
[f]*Research data management https://openscience.cuni.cz/OSCIEN-66.html#2.*
[g]*Open access courses https://openscience.cuni.cz/OSCIEN-66.html#4.*

the syllabus every 5 years would be beneficial for both theory and practical courses. Ashiq et al. (2018) also suggest working with library associations and professional bodies in the design of the LIS curriculum.

In Europe, most of the LIS schools have already integrated digital librarianship in their taught programmes, and recently, there has been an increase in data literacy, as data is a core field of action for the European chapter of iSchools and one of the priorities of the European Commission and its European Data Portal (Audunson and Shuva, 2016; López-Borrull and Cobarsí-Morales, 2017; Wang, 2018; Van Hesteren and van Knippenberg, 2021). However, there is still a gap in education about openness (Rodriguez, 2015), which has not yet been fully embraced by LIS schools or programmes (Chiware, 2020).

Despite the lack of training in openness identified in the LIS curricula, we have noticed that academic libraries are using their experience and internal training to support the understanding of openness by offering training materials at workshops, webinars, and other related events. As Rodriguez (2015) suggests, the OA week events and webinars organised by academic libraries are often an entry point for library staff to the basics of openness and an opportunity for their professional development. All these library-based training activities, together with professional networking, for example, social media and mailing lists, can be considered as CPD (Robinson and Glosiene, 2007).

Thus, CPD is addressing the gap between formal education and practice in the field, which is useful for qualified librarians who want to update their knowledge. However, early career LIS professionals should have had openness embedded into the LIS school curriculum; thus, as recommended by Ashiq et al. (2020) and de Alwis Jayasuriya et al. (2021), it is key to formalise the relationship of CPD with professional associations and LIS Schools, to enhance the training programmes these can offer, as shown by the results obtained in this research, since joint training initiatives in which the library is involved (as a leader or as a mere participant) tend to be quite successful.

Since librarians are becoming co-researchers and liaisons in teaching, they should have sufficient open skills and confidence to support their academic communities (Wang, 2018; Chiware, 2020; Saleem and Ashiq, 2020). Also, since there is a long tradition and experience between libraries and the open movement (Mukherjee, 2010), core competencies for LIS professionals have been mapped and included, such as Digcomp 2.0, the FOSTER + learning resources, and the LIBER Open Science Roadmap focus areas. Furthermore, LIBER and its Digital Skills for Library Staff and Researchers Working Group have identified the skills and knowledge needed to practice openness effectively (McCaffrey et al., 2020), which in addition to Scholarly Publishing, FAIR data, and Citizen Science, also includes Metrics and Rewards and Research Integrity. Libraries are also becoming one of the crucial stakeholders in the advancement of OER implementation (Santos-Hermosa et al., 2020) and in open access book publishing, although the latter has not (yet) gained momentum in Europe (Morka and Gatti, 2021).

Thus, librarians are key for supporting OA and OSC, from supporting researchers in the self-archival of publications in repositories, to helping scientific journals to become openly accessible (Abadal, 2013) and advocating for the development of open policies and licensing copyright services, while participating in negotiations with commercial publishers and enabling transformative agreements (Ayris and Ignat, 2018), and also developing open FAIR data ecosystems (Swiatek, 2019; Swiatek et al., 2020) has changed the librarians' field of action dramatically, but their formal education has not.

More recently, the COVID-19 pandemic has also served as a disruptor in the role of libraries, as, for example, librarians had to develop new skills to help deploy extra support to researchers and educators in the shape of OER and workshops. In this sense, an emergent job market constitutes a potential growth area for LIS schools. Understanding this will provide a roadmap to LIS schools for the future direction of their programmes (Malik and Ameen, 2021). Furthermore, as noted by Peekhaus (2021), the faculty in LIS schools are relatively engaged in OA matters, so LIS scholars should be at the forefront of efforts to expand openness to their teaching. Hence, conversations on enhancing practice need to happen at the faculty level toward co-designing of the curriculum in partnership with those already championing the building of capacities in the field.

At the policy level, our analysis has evidenced that these instruments need to stress the importance of training in openness (as can be seen in numerous mentions) by providing guidance and funding schemes to enable capacity-building programmes. Although some policies focus on capacity building and training empowerment, it seems that it is more a declaration of intent than a reality, since we observe that, with the exception of some cases, the intention has not yet materialised in formal training courses in the universities.

Our Contribution To The Field is to help address the gap in education and training in openness to knowledge, and provide evidence, good practices, and recommendations for the HE sector. This research contributes to support the sustainable development of open knowledge policies in HE and, more specifically, to foster capacity building in LIS schools to present and future LIS professionals, by putting into practice the principles of the European Pillar of Social Rights[17] and The European Skills Agenda[18] access to education, training, and lifelong learning for everybody and everywhere in the EU.

## CONCLUSION AND RECOMMENDATIONS

Our analysis showcases an existing dichotomy in the academic sector, as institutional policies assign libraries the responsibility for raising the awareness, guidance, and training of openness to faculty and students (such as the UOC and Oxford); however, their library staff is not "officially" trained for it, or, at least, they have neither received formal training nor they have been given the opportunities to gain a qualification in the area. Hence, these are relying on the capacity of LIS professionals to self-acquire the skills needed to perform their jobs (Rodriguez, 2015; Swiatek, 2019; Santos-Hermosa et al., 2021).

The current gap in the capacity building provides us with a unique opportunity to open a conversation in the sector that includes academics, professional bodies, librarians working in openness, and also users from the libraries. We propose that openness is fostered as part of the core digital skills a librarian should have, so they are not only capable of providing support in opening up knowledge, but in contributing to a fair knowledge ecosystem for the society, supporting peers, educators, and researchers in co-creating, generating, reusing, and sharing knowledge, thereby facilitating access beyond the walls of their own library and thus democratising information.

Thus, we recommend considering the following points at policy and strategy levels:

At the macro level:

1. Promote the inclusion of capacity building as the core element of openness to knowledge, including elements of budgeting and funding for training activities
2. Include, as part of the recommendations, good practices in capacity building in openness to knowledge
3. Promote the development manifestos that support the development of curricula in openness to Knowledge for LIS professionals

At the meso level:

1. Define a series of competencies and literacies in the different areas of openness to outline appropriate strategies that can be put in place to incorporate them into the existing LIS curricula.
2. Ensure that open knowledge policies and strategies include a budget for capacity building for librarians
3. Emphasise the importance of including openness to knowledge as one of the areas of specialised librarianship

At the micro level:

1. Co-create curricula and OERs in openness to knowledge for LIS learners and professionals that can be adopted by any library school
2. Reorienting LIS academic programmes and redefining the curriculum toward including openness across every course.
3. Provide open and flexible CPD that can be used in formal or informal LIS education programmes.

### Future Scope of the Study

We aim at widening participation in the future stages of this research, including other stakeholders in further exploring the challenges and barriers to capacity building in openness to knowledge, toward driving a collective agenda in building context and culturally appropriate curriculum in different elements of openness to knowledge, such as open access, open data, open education, and open software.

In this sense, as part of this research, we are collectively working on developing a collaborative toolkit to help in opening up and designing open syllabi that can be useful to adopt and adapt programmes or elements of programmes in curriculum development to facilitate the adoption of openness.

## DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

[17]https://ec.europa.eu/info/strategy/priorities-2019-2024/economy-works-people/jobs-growth-and-investment/european-pillar-social-rights_en
[18]https://ec.europa.eu/social/main.jsp?catId=1223&langId=en

## AUTHOR CONTRIBUTIONS

GS-H: supervision and leadership of the research activities, including the coordination of the article. Literature review, analysis of the national, institutional policies/strategies, and library training programmes, discussion, co-design of the research, co-analysis of results, and conclusion. JA: co-design of the research, analysis of the supranational declarations and LIS curricula, co-analysis of the results, editorial work, and translation. Both authors contributed to the article and approved the submitted version.

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# Sustainable open textbook models for social justice

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Growing inequity continues to manifest within and between higher education institutions, highlighting the plight of the disadvantaged versus the advantaged. Against this backdrop, students' ability to access quality textbooks and educational resources with locally relevant content presents a critical equity issue. Open textbooks provide opportunities to address social justice in the classroom. Highlighting the injustices which motivated authors in the Digital Open Textbooks for Development (DOT4D) initiative at the University of Cape Town (UCT), this study uses Catherine Bovill's framework of inclusion to examine the processes of 11 open textbook initiatives at UCT in terms of their degrees of inclusivity, with a focus on student participation. The authors draw on the work of political philosopher Nancy Fraser and her central norm of "parity of participation" in order to analyze the cases in terms of their ability to provide affirmative or transformative remedies to injustice. The data presented in this study were derived from a mixed-methods research and implementation approach, in which a survey was administered to the lead authors of the 11 open textbook initiatives. The proposals submitted by ten of these initiatives in their application for a DOT4D grant and their grant reports were also an important data source. These data, combined with insights from two rounds of in-depth interviews with five authors from the study sample provides insight into the injustices academics were grappling with and the ways in which they endeavored to address them. This article articulates four open textbook models with varying degrees of colleague and student inclusion. Examining authorship, quality assurance and publishing activities as nodes of inclusivity, the article provides insight into the strategies open textbook authors at UCT adopt in order to address social injustice in the classroom related to access and representation. It also considers ways in which higher education institutions can address sustainability in order to support the endeavor.

KEYWORDS

**co-creation, models, open education, open textbooks, social justice, sustainability**

## Introduction

Growing inequity continues to manifest within and between higher education institutions (HEIs) of the Global North and Global South, highlighting the plight of the disadvantaged versus the advantaged in the system (Hölscher and Bozalek, 2020). University fees are a barrier to access and even if students manage to find the money (on their own or with government support), the life of a student is expensive. Additional challenges related to the cost and appropriateness of textbooks in higher education (HE) have been exacerbated by the COVID-19 pandemic and the widening inequality that has manifested as a result (Hargreaves, 2021; Williams and Werth, 2021).

Internationally, research has highlighted the importance of providing access to textbooks and online educational resources in order to maximize returns on remote learning necessitated by the pandemic, particularly in the context of unequal access to learning materials and curricula (Mishra et al., 2020; Reimers and Schleicher, 2020).

In South Africa, the Department of Higher Education and Training (DHET) *Access to and Use of Learning Materials: Survey Report 2020* shows a strong, ongoing reliance on the traditional prescribed textbook (Department of Higher Education and Training [DHET], 2020a). Of the 53 223 university students who participated in the DHET survey, 87% indicated that their modules made use of a prescribed textbook (Department of Higher Education and Training [DHET], 2020a).

Given this reliance on textbooks, students' ability to access these resources presents a critical equity issue. If students do not have equal access to textbooks on their first day of class (Rambow, 2021), they do not have full equal access to education. Similarly, if students do not equally relate culturally and politically to the context/content presented in the textbooks with which they are taught[1], they do not have equal epistemic representation. In this context, the lack of epistemic representation/justice relates to existing power asymmetries in knowledge production, "not solely with respect to dominant (Western) perspectives, concepts, and terminologies but also blind spots where existing knowledge is ignored, neglected, or even destroyed" (Mignolo, 2009 cited in Khoo et al., 2020, p. 55).

Around the world, the prevalence and use of open textbooks is gaining momentum[2]. Digital and freely available online, these scaffolded collections of teaching and learning content are published under Creative Commons licenses on platforms and in formats that allow for free access and legal reuse, as well as the integration of multimedia and content from other sources. Technical innovation and the use of more open, collaborative authorship, quality assurance and publishing approaches enable the integration of multiple voices and perspectives.

Proponents have highlighted how open textbooks allow for opportunities to disrupt and innovate in HE (Hilton and Wiley, 2011; Bliss et al., 2013). Much of the research on open textbooks has not only highlighted their value in terms of addressing issues around cost and utility, but has also worked to define these resources, understand their production and show the impact of the use of these resources in various contexts (Frydenberg and Matkin, 2007; Pitt, 2015). At the University of Cape Town (UCT), the Digital Open Textbooks for Development (DOT4D) initiative is working with academics who are adopting collaborative approaches to open textbook production that are student-centered and aim to address social injustice in the classroom (Cox et al., 2020).

This article builds on previous DOT4D research on the role of open textbooks in addressing social injustice in the classroom at UCT (Cox et al., 2020). Expanding the analysis, it examines the production activities of 11 open textbook initiatives, some of which are completed while others are in progress or have been placed into incubation due to circumstance. Lessons can be learned from these successes and failures. The initiatives originate in a range of topics/disciplines; namely: abstract algebra, architecture, chemistry, complex numbers, computer science, construction management, general surgery, marketing, mechanical engineering, orthopedic surgery and statistics.

Conceived with an explicit social justice and intersectionality focus, the focus of the DOT4D project has been on investigating and supporting the interventions required to promote open textbook production that improve affordable access and support curriculum transformation efforts. In addition to research and advocacy components, the DOT4D project also ran a grants program aimed at building the capacity of open textbook authors through modest financial aid and support in designing, writing, editing and publishing these texts/materials in the period 2019–2021.

This article identifies drivers for open textbook production and articulates open textbook models with varying degrees of colleague and student inclusion. Examining authorship, quality assurance and publishing activities as nodes of inclusivity, the article provides insight into the different strategies open textbook authors at UCT adopt in order to address social injustice in the classroom related to access and representation. It also considers ways in which higher education institutions (HEIs) can address sustainability in order to support the endeavor.

The foundational hypothesis of this work is that inclusivity is a key dimension of both social justice and sustainability, in that multiple voices are required in order to achieve more equal epistemic representation. In order for open textbook activity to be sustainable, it needs to be "effective" (i.e., fit for purpose), making the efforts of the lecturer and students and the investment of the institution worthwhile. The sustainability factor therefore also relies on the extent to which students feel represented in the resource and the extent to which its development process addresses social (in)justice in the classroom. This resonates with the findings of Tlili et al. (2020), who state that collaboration, apart from being a characteristic of open educational resources (OER) production, can be a way to achieve cost advantage and economies of scale.

1 https://blog.oxford.co.za/five-factors-to-consider-when-prescribing-a-textbook/

2 https://www.unisa.ac.za/sites/corporate/default/News-&-Media/Articles/The-case-for-using-open-textbooks-in-HE-is-growing

## Social (in)justice in the classroom: Drivers for open textbook production

There are several social justice drivers for open textbook production. In this article, we focus on the injustices which motivated authors in the DOT4D initiative at UCT, namely: lack of affordable access to appropriate textbooks and the need for curriculum transformation and/or multilingualism.

### Affordable access

The high cost of textbooks (Senack and Donoghue, 2016), surging inflation rates[3] and commercial publisher profiteering[4] are by now widely acknowledged as being at odds with the development agenda. As Williams and Werth (2021, p. 2) point out, "[t]he social justice dilemma created by requiring students to purchase publisher content goes against the liberatory potential of higher education."

This cost crisis is amplified in the context of COVID-19 and remote online teaching and the economic pressures which have accompanied this fundamental shift. "First [electricity], then devices, then connectivity, then good quality content supported by interactive learning interactions—these emerged as the basics" (Czerniewicz et al., 2020, p. 955).

Jenkins et al. (2020) draw attention to textbook affordability as a social justice issue and highlight the role of OER as a potential avenue for realizing a more socially just HE experience. Within this context, they highlight the affordances of OER to reach socially excluded students, increase participation among underrepresented groups and bridge the gap between formal and informal education.

### Curriculum transformation

Research at UCT shows that even when students can afford to buy textbooks, the cases and examples they provide are often not relatable to lived experience, there is a lack of a recognizable voice and students are constrained in terms of engaging in learning with these materials (Cox et al., 2020).

In South Africa, 26% of students who participated in the 2020 DHET survey chose to forgo purchase of prescribed textbooks entirely due to issues of cost constraint and appropriateness (Department of Higher Education and Training [DHET], 2020a). The curriculum transformation and decolonization agenda in South African HE aims to address a range of systemic injustices related to accessibility and inclusivity (Mendy and Madiope, 2020). These include the need to address better inclusion of marginalized and disabled students, more democratic epistemic representation of students in curriculum articulation and an expanded approach toward multilingualism (Heleta, 2016; Walton, 2018; Mendy and Madiope, 2020).

Textbooks and other learning resources are one of the primary means through which curriculum is captured and conveyed. As such, they comprise a key mechanism through which to address curriculum transformation and epistemological representation. A reframing of curriculum for a pluralist society includes an interrogation of whose cultural values are recognized and valued and how students can be included in "decision-making roles and procedures" (Luckett and Shay, 2017, p. 9).

### Multilingualism

There is evidence of the dominance of the English language in HE globally. It has been argued that English "has become the tertiary education language par excellence and plays a key role as a commodity of globalization" (Doiz et al., 2013, p. 407).

In the Global North, countries have addressed multilingualism through developing strategies that promote the development of educational programs in languages other than English in HEIs (Gao and Zheng, 2019). There are also increasing debates around "language-related inequalities" as academics and practitioners grapple with ways in which to meaningfully engage with issues around multilingualism in a manner that reflects the sociolinguistic realities of local universities and local colonial histories (Shin and Sterzuk, 2019, p. 149).

In the South African HE context, multilingualism is considered to be pivotal in promoting equality of access and improved academic success for all students. It is also a central aspect of institutional transformation and changing the historical identities of HEIs (Mbulungeni, 2010). However, the country's revised Language Policy Framework for Public Higher Education Institutions (Department of Higher Education and Training [DHET], 2020b, p. 5) highlights "the challenges of the underdevelopment and underutilization of official African languages at higher education institutions while simultaneously sustaining the standard and utilization of languages that are already developed." The Language Policy Framework calls for HEIs to make greater investment in the development of official languages in the spheres of teaching and learning, scholarship and research; "[t]he alternative is to continue producing students who are detached from their own heritage, or detached from society generally because they remain in an unrealistic monolingual vacuum."[5]

In the context of this study, the production of open textbooks provides an opportunity to address affordability, curriculum transformation and multilingualism through inclusive approaches toward creating learning materials

3 https://www.nbcnews.com/business/business-news/students-are-still-saddled-soaring-textbook-costs-report-says-n516011

4 https://www.businessinsider.com/why-college-textbooks-expensive-textbook-publishing-2018-12?IR=T

5 https://theconversation.com/how-south-africas-universities-are-making-more-students-multilingual-116638

that are available without cost to the student and capture cultural-linguistic diversity.

## Open textbook production activities as nodes of inclusivity and collaboration

Open textbook authors undertake a range of production activities, each of which themselves present opportunities to address injustice in the classroom. In this article, we focus on authorship, quality assurance and publishing, as these were the key activities in the DOT4D initiative in which different degrees of collaboration and inclusivity were manifest.

Authorship refers to the conceptualization, pedagogical planning and development of content, and is, as such, a key activity node in which issues of student voice and representation are manifest.

In this context, student voice is understood as the ability for students to express themselves and more meaningfully participate in their education (Könings et al., 2021). Könings et al. (2021) highlight the need to create a collaborative community and give students autonomy in order to create space for student voice. Without this opportunity, they are, as Fraser (2013) describes the experience of the alienated, "rendered passive, positioned as potential recipients of predefined services rather than as agents involved in interpreting their needs and shaping their life-conditions" (p. 71).

Co-creation and active learner involvement in the design and development of education is garnering growing attention in educational practice and research. Involving learners in the design of teaching and learning contributes to improvement in the quality of education by addressing perspectives of different stakeholders and stimulating teachers' growth. It also motivates learners by enhancing their feelings of engagement, ownership and empowerment (Cook-Sather et al., 2014 cited in Könings et al., 2021).

The level of learner involvement in the formulation and delivery processes of their education should be aligned with the purpose of the chosen educational design approach (Martens et al., 2019 cited in Könings et al., 2021). The academics in the DOT4D initiatives began their open textbook authorship processes from different starting points, in that some created (or aimed to create) a textbook from scratch, some adapted (or aimed to create) their already existing course materials or textbook, and some adapted (or aimed to create) a textbook that someone else had authored.

### Quality assurance

As Roussouw (2015) points out, quality, along with social justice and accountability, are key requirements for successful school systems and societies. Roussouw (2015) also states that while quality is a "pivot element" in education, it remains "slippery" to define. This is largely due to the fact that perception and indicators of quality depend on whose perspective you adopt (Commonwealth Educational Media Centre for Asia [CEMCA], 2014).

In the context of OER, the concept of fitness for purpose is typically viewed as the dimension most relevant to quality, along with cost efficiency and potential for transformative learning (Commonwealth Educational Media Centre for Asia [CEMCA], 2014).

In the context of this study, quality assurance refers to the measures taken by authors to ensure resource efficacy and academic accountability in the context of its desired social justice purpose. Quality is also viewed as a central component in addressing sustainability, in that the extent to which a resource is fit for purpose is a critical aspect in determining its lifespan and ongoing evolution.

In this article, we identify the quality assurance processes undertaken by authors in the DOT4D study before commencement of a course, during a course and in the resource publishing process. These relate particularly to appropriateness of context, representation and voice, and a professional approach to design and publishing.

Publishing refers to the process of preparing, disseminating and marketing content that is deemed ready for public release.

The concept of individuals, units and institutions functioning as publishers is by now a well documented phenomena in HE[6,7] and is part of an attempt on the part of institutions and academics to wrest back power from profit-driven publishing companies controlling global knowledge production and dissemination.

Weiner (1998, p. 2), in a discussion on the hegemonic practices of traditional publishers, draws attention to "the power of certain groups ('experts') to shape and confirm the production of certain kinds of knowledge." Publishing is thus a key element for consideration when addressing social (in)justice in textbook production.

Weiner further states that through the power/knowledge configurations established by traditional publishers, "'outsider' or unofficial knowledge may be disqualified and dismissed as non-rigorous, undisciplined, and unprofessional" (1998, p. 2). As such, publishers are typically viewed as gatekeepers in the dissemination process, in that they control not only *how* content is released, but also *what* content is released. Open publishing approaches allow individual authors to take control of the *what* and *how* of the publishing process and push back against the "corporatization or new managerialism where performance of academics is to a significant extent measured and evaluated on the basis of their record in publishing in the right places" (Meriläinen et al., 2008, p. 630).

Open publishing approaches enable a higher degree of agency on the part of both students and academics in terms of the power to shape content and influence diversity in epistemic

6 https://www.insidehighered.com/news/2014/07/17/self-publishing-option-academics-periphery

7 https://oedb.org/ilibrarian/the-academics-guide-to-self-publishing/

perspective. Today, academics, students, academic departments, research units and institutions act as publishing entities on an array of different kinds of scholarly outputs. Open textbooks form part of this contribution.

In line with the rise of the institution as publisher (Slowe, 2018), institutional co-publishing arrangements (either within or between institutions) are a means through which to draw on internal expertise, resources and infrastructure, providing for greater sustainability than a solo self-publishing approach or reliance on commercially published materials (Barker, 2015).

As these new approaches to publishing take root, academics and other institutional stakeholders are challenged to get to grips with new roles and responsibilities. Institutions are also navigating the challenge of articulating sustainable production and publishing models, and trying to provide the skills development, technical infrastructure and recognition required to facilitate ongoing engagement of this kind.

Given the current austerity and inequality in global HE (Hargreaves, 2021), it is compelling to consider how open, innovative authorship, quality assurance and publishing approaches can be used to maximize efficiencies between colleagues and institutions in order that they may serve as a mechanism to promote social justice in digitally enabled education.

## A social justice framework for inclusivity and parity of participation in open textbook production

### Open textbooks and parity of participation

This article argues that open textbooks provide an opportunity to address injustice beyond cost saving and equity of access to materials. The relationship between OER, open educational practices (OEP) and open textbooks and social justice has been explored in recent literature (Hodgkinson-Williams and Trotter, 2018; Bali et al., 2020; Cox et al., 2020). These articles draw on the work of political philosopher Nancy Fraser who developed a multi-level theory of justice in which she describes three dimensions of social injustice: (1) economic maldistribution; (2) cultural misrecognition; and (3) political misframing. These "species" of injustice are objects that need to be dismantled (Fraser, 2005, p. 72).

Fraser aims to illuminate the injustices of gender inequality, racism, colonialism and neoliberalism. In this regard, her work provides a set of tools and principles that can be used to examine the injustices in HE.

The emphasis in this article is on carefully unpacking the underlying central norm of Fraser's theory: "parity of participation." This is a principle of "equal moral worth," in that "justice requires social arrangements that permit all to participate as peers in social life" and overcoming injustice means "dismantling institutional obstacles that prevent some people from participating on a par with others" (Fraser, 2009, p. 16). This parity of participation can be both an *outcome* "where all relevant actors participate" and a *process* "in fair and open processes of deliberation" (Fraser, 2005, p. 84).

People are impeded from participation because of economic structures that deny them the resources to interact with peers, resulting in distributive injustice or maldistribution. This economic dimension is related to the class structure of society. The second dimension of cultural misrecognition is where "institutionalized hierarchies of cultural value that deny them [people in society] the requisite standing" (Fraser, 2005, p. 72). The problem here is the status order. The third dimension of justice is the political. "The political furnishes the stage on which struggles over distribution and recognition are played out" (2005, p. 73). The political dimension determines who counts as a member, and therefore who is included or excluded, highlighting the political constitution of society. The political dimension establishes social belonging and representation in society. All three dimensions are "inextricably interwoven" together (Fraser, 2005, p. 74). Fraser argues that "representation is always inherent in all claims for redistribution and recognition" (2005, p. 77).

### Affirmative and transformative remedies to address injustice in the classroom

Fraser (2005) provides two "frames" or remedies for injustice (p. 78). An affirmative remedy may redraw boundaries, or even create new ones within the existing political frame and accepts the "who" of the current political community and it does therefore not challenge the underlying "deep grammar" of injustice (p. 79).

A transformative remedy challenges the underlying frame-setting or grammar which is "out of synch" and causes injustice (Fraser, 2005, p. 79). A transformative approach to misframing goes beyond changing the boundaries of *who* is included, to questioning *how* those boundaries are drawn. Fraser (2005, p. 81) suggests the "all-affected principle" as a frame to aspire to: "all those affected by a given social structure or institution have moral standing as subjects of justice in relation to it" (p. 80).

In summary, the distinction between the two is that affirmative remedies correct "inequitable outcomes of social arrangements," whereas transformative remedies correct "inequitable outcomes precisely by restructuring the underlying generative framework" (Fraser, 2008, p. 288). Fraser (2008) is critical of affirmative remedies, as they can promote group differentiation; while transformative remedies "tend to destabilize or blur it" (p. 292).

A study by Hodgkinson-Williams and Trotter (2018) reveals that OER provide an affirmative remedy by lowering costs of materials production for the "student, educator, institution or funder" (p. 220). They also go some way to addressing cultural injustice when materials are translated and localized. The cases examined by Hodgkinson-Williams and Trotter do, however, not adequately address the political dimension, in that the main "political" challenge cited in their case studies was that intellectual property (IP) policy frameworks inhibited educators from sharing the course materials they had created. The authors argue that in their study, OER has fallen short of a transformative approach. For cultural injustice to be remedied, they coin a new term: "re-acculturation." This is identified as a pluralist approach and in the context of this article suggests the inclusion of multiple voices, specifically colleague and/or student collaborators. This term encourages the "re-mixing of OER critically to engage with and challenge hegemonic perspectives," to share those materials publicly and create new OER (p. 219). For political justice, the authors call for a re-framing of IP legislation to enable authors to share content and for the "creation of OER and engagement with OEP that balances power" (p. 219).

In a critical analysis of social justice implications of eight examples of process-focused OEP, Bali et al. (2020) outline a typology that includes content-, teacher-, and learner-centric OEP across a continuum. In this article, we are most concerned with Bali et al.'s (2020) description of "student-created OER/content" (p. 7), which can be an affirmative remedy if diverse identities and marginalized groups are represented and transformative if the power of decision-making over content and epistemological frameworks is shared with students. The authors conclude that OEP which empower learners can impact positively on social justice. They argue that OEP is not necessarily aligned with social justice, but suggest that open educators could realign their approaches to make them "deliberately orientated toward justice" (p. 12).

In the context of the role of open textbooks as a form of remedy for injustice, resources of this kind by their nature save students money, thereby enabling economic redistribution. Open textbooks also have the potential to provide the opportunity for recognition of multiple cultural values and enable representation of multiple voices (Cox et al., 2020). As Fraser (2005) argues, these remedies are entwined and the cultural and political dimensions enable a potential transformative response.

## Co-creation and inclusion

Digital open textbooks enable collaboration and co-authoring with peers and students. In HE, activities with students have been labeled interchangeably as partnerships or co-creation activities (Bovill, 2020). Bovill (2020) proposes a framework that can be used to describe the range of activities and roles that colleagues and students take on.

The first term Bovill discusses is one of "*student engagement*" which can include a range of activities that lecturers use to motivate student interest. The time and effort that students give to these activities benefits their learning. Secondly, students as "*partners*" implies a much deeper involvement and agency, suggesting an equal partnership that is collaborative and reciprocal. The third term, "*co-creation*" refers to a new pedagogical idea that emphasizes "learner empowerment" (Bovill, 2020, p. 1,024). Bovill situates co-creation between student engagement and partnership, as it includes collaboration with staff and how both the learning process and resources are constructed together. The fourth term is "*participatory design*," which involves a collaboration of a group of stakeholders to develop and design course and course materials. These stakeholders are "testers" and do not have a high level of agency (Bovill, 2020, p. 1,024). This fourth term of inclusion ("*participatory design*") is situated above "*student engagement*" as both are broader terms with low levels of student involvement.

Co-creation can be divided into four roles (Bovill et al., 2016). A "*representative*" role is when a small group represents a large group, as in a sample group. A "*consultant*" is a selected colleague or student who is brought into the process with a specific focus and is paid or remunerated in some way. The "*co-researcher*" and "*co-designer*" roles can be a small group of colleagues and/or students or a whole class of students. A whole-class approach enhances inclusion and builds positive student–teacher relationships, although it comes with the challenges of time constraints, large participant/student numbers and sustainability issues, to name a few (Bovill, 2020).

This article will provide an overview of drivers for open textbook production and a framework which considers three main areas that future authors and institutions can consider, namely: authorship approaches, quality assurance and publishing. It also examines the role of institutional support in promoting and sustaining this work on an ongoing basis. Eleven different approaches to these activities are analyzed using this framework. Overlaps in aspects of the framework enable the formation of models for undertaking authorship, quality assurance and publishing. These models cluster around four modes of inclusion (how authors work with colleagues and students). The models are arranged and critically analyzed using social justice principles. **Table 1** provides a summary of the models ranked from least to most inclusive.

# Methodology

## Digital open textbooks for development

The DOT4D initiative investigates the current ecosystem of open textbook publishing and provides implementation

TABLE 1 Bovill's (2020) terms of inclusion framework and roles within co-creation (adapted from original).

| **Terms of inclusion** |
|---|
| **Participatory design:** stakeholders contribute to the design and development of initiatives, including curriculum; students are "testers" or "informants" and don't have a high level of agency. |
| **Engagement:** activities to motivate and interest students; can include engagement in teaching and learning. |
| **Co-creation:** contribute new pedagogical ideas; empowerment; meaningful engagement; students construct understanding and learning resources. |
| ***Roles within co-creation*** |
| ***Representative:*** elected role; small group representing whole group. |
| ***Consultant:*** students selected and paid to collaborate. |
| ***Co-researcher:*** collaborating meaningfully on teaching and learning research or subject-based research. |
| ***Co-designer:*** sharing responsibility for designing learning, teaching and assessment. |
| **Partnership:** collaborative; contribute equally; some pedagogical conceptualization and decision-making; implementation and analysis. |

support in open textbook publishing activity at UCT. In its efforts to support the production of open textbooks and grow a community of practice, DOT4D partnered with 11 open textbook initiatives to various degrees, ten of which participated in the DOT4D grants program and received funding on the basis of their grant proposals in which they were required to address imperatives related to access, social justice in the classroom and sustainability.

The grants program ran from March 2019 to February 2020; however, DOT4D's relationships with the grantees extended beyond the formal grant period and, in some instances, included additional funding and consultation that extended into the year 2022. These interactions allowed DOT4D to develop a longitudinal research approach, in which it could track the initiatives over an extended period of time. As such, the work done with open textbook creators at UCT has enabled the articulation of the different approaches to open textbook production that are being employed by academics attempting to address social justice in the classroom through content creation.

The terms used to describe their processes are those of the DOT4D initiative and have been developed in order to make sense of various content development approaches from an overarching perspective.

## Data collection

The data presented in this study were derived from a mixed-methods research and implementation approach, which was comprised of a range of data collection activities. These activities included a survey administered to the lead authors of the 11 initiatives, which examined their demographic profile and their use of technology, as well as providing an opportunity for personal reflection. As such, the survey consisted of a range of questions exploring disciplinary background and teaching experience, student and course details, technology tools and skills, and reflections regarding teaching practices and personal motivations. The survey also included the Internal Conversation Indicator (ICONI), a tool developed by Margaret Archer (2007, 2008), which was designed to identify a person's dominant mode of reflexivity.

The grant proposals submitted by the ten grantees in application for the DOT4D grant and their final grant reports also constituted an important data source. Two rounds of in-depth interviews (of approximately 1.5 h each) were conducted with five UCT open textbook authors from the study sample of 11 initiatives. The interviews sought to further probe the injustices that academics were grappling with and the different ways in which they were endeavoring to address them. The interviews included questions relating to historical legacy, motivations for creating open textbooks, disciplinary norms, authors' content development approaches, and reflections around curriculum transformation and decolonization. These data collection activities were supported by the field notes of the DOT4D Publishing and Implementation Manager tracking interactions with the UCT open textbook community.

## Data analysis

As part of the project's mixed-method approach, survey data were tabulated and analyzed according to the metrics of the ICONI tool. In addition to this, interviews were transcribed and the data were analyzed using NVivo software. Finally, the data from the field notes collected from the various interactions with grantees, the grant proposals and the grant reports that were submitted by grantees were captured and synthesized using Microsoft Excel spreadsheets. Data were analyzed by the DOT4D Principal Investigator and Researcher and the results of their analyzes were triangulated in order to ensure rigor in the analysis process (Cohen et al., 2007). Numerous themes were utilized in the coding process: social justice dimensions, production activities and terms of inclusion.

From this, the study identified the key activities or nodes of open textbook production which surfaced in the DOT4D process, namely: authorship, quality assurance and publishing. Each node was analyzed against Bovill's frameworks of inclusion in order to map the varied forms of collaboration employed. The data analysis process also explored whether collaboration took place before or during the course and whether it involved part of or the whole class.

The interview and survey data collection processes engaged academics who were selected on the strength of written proposals for funding to support open textbook initiatives with a social justice focus. This has resulted in selection bias. The views of the participants should therefore not be considered representative of all UCT academics, but rather a purposive sampling of academics identified as part of an innovative cohort pioneering OEP and the production of open textbooks at UCT for social justice purposes.

# Findings

This findings section presents the social justice imperatives behind open textbook initiatives at UCT and the associated production activities in the context of frameworks for collaboration and inclusion in order to articulate sustainable open textbook models and mechanisms for institutional support.

## Social injustice in the classroom driving open textbook production

The academics in this study embarked on open textbook initiatives in response to a largely mutual set of social injustices they witnessed in their classrooms related to affordable access, curriculum transformation and multilingualism.

In the DOT4D study, the starting point for all authors in their open textbook development processes was the recognition of the classroom injustice(s) they intended to address (Cox et al., in press). The acknowledgment and articulation of these injustices – combined with the nature of the classroom context as relates to discipline, degree level and class size – led authors to adopt different authorship, quality assurance and publishing approaches with varying degrees of inclusivity as relates to colleague and student participation.

All 11 of the academics in this study indicated that they were driven by imperatives relating to curriculum transformation, with three having a specific focus on multilingualism (in chemistry, statistics, and computer science). Curriculum transformation in this context included embedding local examples and case studies in the content (in marketing, architecture, and construction management). Several authors (in chemistry, computer science, and statistics) also recognized how important it was for students to have key concepts and terms translated into languages other than English.

Eight of the authors indicated that they were motivated by issues related to cost and access and mentioned the high cost of prescribed textbooks (in abstract algebra, complex numbers, computer science, construction management, general surgery, marketing, mechanical engineering, and orthopedic surgery).

## Authorship

Authorship refers to the conceptualization and writing of content. In the DOT4D context, we can differentiate between *solo authorship*, in which an author works entirely alone in conceptualizing and producing the resource, and the role of *lead author as editor-in-chief with colleague co-authors*, in which an editor-in-chief plays a coordinating function and the responsibility for conceptualizing and writing content is shared with colleagues. In some instances, collaboration also takes place with *institutional intermediaries*, such as library staff or learning designers.

In instances where student participation was sought in order to better address issues of representation and inclusivity, lead academics in the DOT4D context operated as an *editor-in-chief with student co-authors* or a *content development facilitator with student authors*. In the latter instance, students were given full authorship responsibility and the content development facilitator provided expert guidance and coordination rather than producing content.

These approaches allow for varying degrees of inclusivity in the content development process.

In the DOT4D cohort, three authors (in abstract algebra, construction management and mechanical engineering) adopted a solo approach with some colleague and student engagement and partnership. Two of these initiatives drew on colleagues' expertise. In one case, the author in mechanical engineering engaged a member of the DOT4D project who acted as an institutional intermediary in providing editorial and resource design support; while in the other case, the author in computer science partnered with a colleague to write a chapter in order to develop aspects of the textbook in a more collaborative manner.

All four of the solo authors solicited assistance from students. In the case of abstract algebra, mechanical engineering and general surgery, students reviewed textbook content through a process of engagement. In the construction management process, students assisted in the production of graphics and figures as co-creators.

The most popular approach was to adopt the role of editor-in-chief with colleagues and/or student co-authors (used in architecture, complex numbers, marketing, general surgery, and orthopedic surgery). Within this approach, there were a range of co-creation activities. These included a process where the academic in orthopedic surgery acted as an editor-in-chief and brought consultant/co-researchers in practice and academia into the open textbook development process to collaboratively scope and author content.

There were five instances (in architecture, chemistry, complex numbers, marketing, and orthopedic surgery) in which editors-in-chief extended their processes and drew students into co-creation, in that they were provided with an opportunity to co-author content. In the complex numbers initiative, students collaborated as co-creators and co-researchers in authoring content, consultants in pedagogical approach and representatives in providing classroom feedback. In the orthopedic surgery initiative, students participated as representatives of the class in providing insight into new, key curriculum elements and as co-designers in the production of content. The marketing initiative also worked with students as co-designers of content, while in architecture and chemistry they functioned as co-researchers. In the general surgery initiative, it was envisioned that students would be brought on board in a participatory process, in which they would contribute to scoping and design of course material, including curriculum. In a similar process, the academic in marketing brought colleagues on board in a co-creation and co-design process, in which co-authors had a high level of input and degree of autonomy in the content authorship process. In the architecture textbook development process, students were co-researchers producing pages as part of a classroom assignment.

There were two instances (in statistics and chemistry) in which academics acted as centralized content development facilitators and worked with colleagues and/or students who authored content. This was done with consultant/co-researcher colleagues and a student who were brought in to translate a chapter from an existing English first-year statistics textbook into isiXhosa. Students and colleagues were also involved in a chemistry open textbook initiative, in which they were co-researchers and collaboratively developed content.

The particular collaborative approach utilized in chemistry was adopted in order to foster a team effort around the content development work that was being undertaken. As such, the content for the textbook was developed in consultation with the teams of students who would convene to discuss the work. Various methods such as surveys and focus group discussions were used to capture input and feedback from the students. Throughout their authorship processes, the authors saw themselves as facilitating the collaborative process and had a keen interest in highlighting the voices of participating students.

Three authors (in chemistry, complex numbers, and computer science) partnered with colleagues and included students as co-creators. The author in computer science chose to extend the student role to facilitate their participation as co-creation consultants, whereby they were given the opportunity to independently author some of the content for their textbook. In these processes, students were acknowledged for their contributions and, in some instances, financially compensated for their work. The involvement of students was seen as a key feature in recognizing different perspectives on the content being created and, in one instance, was also considered to be an opportunity for mentorship.

In line with the variable approach adopted toward authorship, it is important to note that the entry point to the content development process for these authors varied. Of the 11 authors profiled, seven (in architecture, chemistry, complex numbers, marketing, mechanical engineering, orthopedic surgery and general surgery) created (or aimed to create) their own content from scratch using the funding received as part of their DOT4D grant. Three (in abstract algebra, computer science, and construction) revised their own already existing course materials and one (in statistics) adapted an already existing textbook which was published as an OER.

## Quality assurance

Quality is important to all academics, particularly in the context of sustainability. In the DOT4D study, quality assurance was both a process and an outcome. Dynamic, innovative, collaborative approaches toward quality assurance enabled academics to bring multiple perspectives into their resource production and review processes.

In the DOT4D sample, quality assurance processes took place prior to the course being developed, during the period in which the course was delivered and in the textbook production process (which took place concurrently with or after the course was delivered).

In addressing quality assurance prior to the development of a course, one important aspect of quality identified in the DOT4D context was the appropriateness of the curriculum for context.

The orthopedic surgery textbook development process aimed to improve learning and teaching in orthopedics in Southern Africa and to provide much needed, locally authored learning materials that are tailored to local pathology and circumstances. In order to identify the topics which needed to be integrated, the editor-in-chief led a process in which students and practitioners engaged in a Delphi consensus study in order to identify key aspects for incorporation into the textbook and the undergraduate teaching curriculum. Within this process, students were invited into the textbook development process in order to identify experts' blind spots in the authoring of content and to provide feedback and edit chapters as part of their coursework.

Quality assurance processes also took place in the course; that is, while the course materials were being developed and used in the classroom. Textbooks that are designed to integrate multiple voices and epistemologies and address social (in)justice in the classroom rely on multiple stakeholders participating in the review process. In the DOT4D context, different levels of review activity took place with colleagues and students.

All authors made use of some form of colleague review. In five initiatives (abstract algebra, construction management, marketing, mechanical engineering, and general surgery) academics adopted a participatory design approach, in which colleagues who were academic experts and industry leaders were called on by authors to proofread chapters and provide feedback on content. In three instances, authors in complex numbers, computer science and chemistry partnered with colleagues in an ongoing process to oversee the quality of the content as it was being produced. In two cases, authors in architecture and orthopedic healthcare engaged colleagues to check quality and provide comments on and corrections to the content and material being developed.

In one last case, the author in statistics adopted a co-creation approach, in which colleagues played consultative and co-researcher roles in the textbook's collaborative quality assurance process.

In all eleven instances, authors included student review as part of their quality assurance processes. Four authors (complex numbers, construction management, mechanical engineering, and general surgery) established a participatory design approach, in which students provided input and feedback about the efficacy and appropriateness of the material developed and informed the content development process. This was done through surveys and other ways of soliciting student insights as they tested the material.

In four other initiatives that utilized student review, authors in architecture, complex numbers, computer science and marketing engaged students in an ongoing process to provide feedback about gaps students identified in the material produced as they made use of it in the classroom. In one instance, the author in statistics employed a co-creation approach, in which the collaborating student participated in the quality assurance process as a consultant co-researcher with the colleagues involved. As such, the process became a brokered conversation between all individuals involved, reflecting both academic rigor and the student perspective. In another instance, authors in chemistry also co-created with students in their authorship process and included them in a representative manner where they would provide feedback on content and concepts within the material being produced.

There were additional elements of quality assurance which took place in the textbook production and publishing process.

A professional approach to resource design and production were seen as critical quality elements that influence students' ability to engage with the resource. They were also seen as a key factor for consideration when other academics consider using your textbook. In the DOT4D context, three academics (in architecture, marketing, and mechanical engineering) drew on the expertise of members of the DOT4D project team. This entailed providing expertise in areas such as resource design and cohesion, project management, proofreading and copy-editing, editorial style sheet articulation, author publication agreements, and issues related to copyright and licensing.

In some cases, academics made use of institutional intermediary editorial support as part of their quality assurance processes, in which they solicited assistance from institutional partners for various editorial aspects of their work. Two authors (in marketing and mechanical engineering) employed a participatory design approach, working with a member of the DOT4D team who provided editorial guidance. The author in architecture chose to employ the services of graduate students as assistants in a co-creation relationship, in which they consulted on the quality of the textbook through developing a formatting guideline, a matrix and a checklist for students to follow in the production of content.

In addition to editorial support, the two academics in marketing and architecture also sought publishing support from a DOT4D team member who provided strategic guidance. In one instance, the relationship was consultative in terms of co-creation, while in the other it was through participatory design.

In one instance, the author in marketing, in collaboration with DOT4D, also fostered a co-publishing partnership with UCT Libraries, which provided access to a team of content publishing professionals who participated in the design of the textbook through formatting content for delivery across a range of devices according to international best practice. In the latter instance of library co-publishing, the relationship was one of co-creation: consultant.

Drawing on external editorial expertise was also seen as an important element of quality assurance in three of the initiatives (abstract algebra, construction management, and marketing), where authors sought out professional editing and proofreading as part of their textbook development process. One of these authors (in mathematics), although they did not complete their textbook development process, had envisioned that they would engage the services of a professional proofreader when the content of her textbook had reached an appropriate stage of maturity. The other authors in construction management and marketing sought out the support of external editors and proofreaders in a participatory design approach, whereby these stakeholders contributed to the design and further development of the textbook.

Three authors (in architecture, construction management and marketing) also explored professional layout and design as an extension of their quality assurance process. In the case of marketing and construction management, the authors adopted a participatory design approach. In one other instance, the author in architecture co-created and made use of colleague layout and design support with an external graphic designer who worked as a consultant in the textbook process for the production of the book's cover and layout, establishing a professional look and feel.

Only one author (in construction management) chose the route of publisher peer review and within it extended their quality assurance process by drawing on the services and expertise provided by the publisher in a participatory design approach, whereby comments from reviewers could be addressed prior to publication.

## Publishing

Providing students with free access to up-to-date, locally relevant resources entails a dynamic approach to creating and updating content, which poses difficult questions in terms of knowing when a resource is "finalized" and ready for publishing – that is, the online release of openly licensed content on a website, repository or other publishing platform for classroom and public consumption, as opposed to "closed" classroom interaction with the resource via a learning management system or other restricted-access portal.

The publishing process, in which content is prepared for public dissemination, whether in the context of a formal, professional production process or reaching the point where a cohesive, internally produced version of the content can be released online, can be viewed as a "last mile" process in which the textbook creation process is "completed." DOT4D research does, however, suggest that there are a range of subsidiary activities involved in the publishing process, many of which are ongoing with protracted timeframes. These activities include the establishment of mechanisms for ongoing review and student feedback after publishing, marketing of the resource, gathering usage data and general ongoing "maintenance" of content in terms of ensuring multimedia and external links function correctly, refining accessibility and the user experience, and the general process of evolving the resource so that it is "fit for purpose."

The DOT4D implementation process suggests that the whole idea of publishing is so new to many academics that it is especially difficult to navigate this process because they "don't know what they don't know," and therefore find it difficult to articulate processes or explicitly identify resourcing and capacity requirements. The question of who or what entity is regarded as the official publisher of a work is often unexamined in open textbook production until the question of how to cite a resource is raised, there are formal considerations such as logo design and placement on a cover, and legal documents such as publication agreements to be signed.

The general set of uncertainties experienced by academics around publishing also appears to compound the difficulty of how to bring students into this process, as is demonstrated by the fact that no authors in this study collaborated with students in any aspect of the publishing process.

In the DOT4D context, six authors chose to adopt an "author as self-publisher" approach. Two authors in computer science and complex numbers adopted a participatory design approach with colleagues, whereby they published their work themselves but also made use of departmental, institutional, and external partners to further disseminate their resources. Four of these authors (in mechanical engineering, statistics, general surgery, and abstract algebra) envisioned collaborating with colleagues in some way in the publishing of their textbooks, but were unable to complete their textbook development processes within the period of the DOT4D study.

In the case of architecture, chemistry and orthopedic surgery, the publishing process was done under the auspices of a broader initiative extending beyond the textbook production process. In these instances, an "initiative as publisher" approach was adopted, in that decision-making around branding, design, and dissemination was strongly influenced by the ethos of the overarching initiatives out of which they emerged. In all of these instances, the initiative was also seen as an overarching entity under which a more distributed content development and publishing processes would continue to take place. In these contexts, the lead academics saw themselves as facilitators of the process rather than being the publisher entities.

The author in orthopedic surgery engaged and co-created with colleagues in a consultative process, wherein the author operated in the role of editor-in-chief on behalf of the textbook initiative and was responsible for content, quality control and publishing. He made use of the department's website and the institutional learning management system in the dissemination of the textbook content in order to maintain a level of control over the publishing process. The author in architecture chose a similar approach, acting in the role of editor-in-chief. In this instance, the author worked with colleagues and a graphic designer in a participatory manner with regards to editing, publishing and proofreading textbook content.

The author in marketing adopted an "institutional co-publishing" approach in their process in a participatory manner, whereby the academic department in which the work was produced formed a partnership with UCT Libraries, with DOT4D functioning as a facilitating institutional intermediary. Within this approach, the department and UCT Libraries operated as co-publishing entities, the former as primary driver and owner of the content development process and the latter as the publisher. This allowed for all parties to focus on a combined effort to support transformation in teaching and learning at UCT and promote visibility of African scholarship. Included in this publishing approach was also the assistance of a graphic designer who was responsible for the design of the textbook cover and pages as well as the typesetting of the book. The textbook's publishing process later also extended to include the services of a South African open access publisher and academic publishing service provider which was commissioned to produce a print version of the textbook and explore print-on-demand options.

The expansive approach toward publishing adopted by academics in the DOT4D context extended beyond the institution in the case of construction management, in which the author chose to adopt an "external commercial publishing" approach. In this process, the author worked with an overseas online publisher in a participatory manner, in which the publisher provided the professional editorial and layout services which were seen as an important factor that would contribute to the textbook's professionalism for student use and its impact on industry. The author chose to work with the publisher based on its "open access" approach, which allows students to access and link to its textbooks free of charge. The content could not, however, be considered to be authentically, legally "open" because the published resource was not openly licensed.

## Mechanisms of institutional support

The DOT4D was an external grant-funded project from 2018 to 2021, but in 2022 the team was recognized for their efforts and are now salaried UCT staff members. The DOT4D initiative is now a feature of the UCT landscape and can continue its research, implementation and advocacy work with institutional support.

The timing of this open textbook project and support from the UCT Deputy Vice-Chancellor (DVC) for Teaching and Learning has created a tipping point and although this work is on a small scale, further hard work on advocacy and awareness-raising will enable the production of more open textbooks. The DVC Teaching and Learning Open Textbook Award[8], which is focused on social justice principles and carries a small monetary prize, has been an important incentive mechanism, giving authors recognition and reward for their efforts.

In terms of the sustainability and scalability of open textbook publishing at institutional level, the cases presented here suggest that the time commitment entailed in authorship and quality assurance may prove too intensive for some authors to make it as far as the publishing process, or that the timeframes involved in doing so will be lengthy and a challenge to sustain.

# Discussion

The main objective of this article is to provide open textbook creators with sustainable models of production that manifest "parity of participation" as the just end point of social justice. Guided by Fraser's approach of frame-setting, these models include consideration not only *who* is involved but also *how* they are involved. The models are evaluated and positioned as affirmative or transformative remedies.

All forms of open textbook production – creation, revision and adaptation – represent the spirit of "open" and could be placed on a continuum that differentiates which production form has the most potential for parity of participation. In this study, there are examples of different degrees of inclusion of colleagues and students in authoring, quality assurance and publishing of the work. The degree of inclusion was not necessarily informed by whether the resource was created, a revision of the author's own already existing content, or the adaptation of a published open textbook or other third-party resource. In this Discussion, these three starting points will be discussed with the four inclusion types suggested by Bovill (2020): partnership, co-creation, participatory design and engagement. Inclusion strategies of particular initiatives varied across authoring, quality assurance and publishing activities.

8 http://www.cilt.uct.ac.za/cilt/open/otaward

TABLE 2 Social injustice remedy continuum.

| | Affirmative remedy | | Transformative remedy | |
|---|---|---|---|---|
| None | Participatory design | Engagement | Co-creation | Partnership |

In order to rate the extent of the "remedy" using the affirmative and transformative frames of Fraser (2008, p. 291), a color-coded heat map was introduced to illustrate the positioning of models on the "conceptual spectrum." Colors blue and orange indicate affirmative remedies and yellow and pink are transformative (**Table 2**). Fraser provides these two options, but because of the complexity of these examples a more nuanced approach to discussing and evaluating each remedy was required. The inclusion of colleagues and students was considered across all aspects of textbook production. Models are chosen because of the dominance of certain inclusion strategies across activities and in some cases model formulation overlaps. The heat map (**Table 3**) enables the clustering of approaches into models according to remedy strength based on the level of inclusion (participatory design, engagement, and co-creation and partnership); participatory design being the least inclusive and partnership being the most.

The heat map approach enables a clustering of degrees of inclusivity through which four models can be distinguished: the Participatory/Engagement Model, the Participatory/Engagement and Co-Creation Model, the Co-Creation Model, and the Co-Creation/Partnership Model.

## The participatory/engagement model

Four initiatives in this study adopted the Participatory/Engagement Model (abstract algebra, construction management, general surgery, and mechanical engineering). These authors set out with the intention of transforming the curriculum and increasing their students' access to materials. The mechanical engineering and general surgery authors created materials from scratch, whereas abstract algebra and construction authors set out to revise their own materials. The four examples represented in this model do not have exactly the same inclusion categories for their textbook development activities (**Table 3**). They follow either *solo authorship*, or *lead author as editor-in-chief with colleague co-authors* approaches. These authors have very little collaboration with colleagues and some engagement and participation with students in authorship. Engagement was the most frequent process used to include students. Colleague participation featured most often in publishing. This model is positioned as affirmative with less inclusion and collaboration with colleagues and students than the other models. The abstract algebra, mechanical engineering, and general surgery

TABLE 3 Heat map ranking initiatives in terms of degree of social justice remedy (least to most, colleague versus student).

| | Terms of inclusion: colleagues | | | Terms of inclusion: students | | | Model |
|---|---|---|---|---|---|---|---|
| | Authorship | Quality assurance | Publishing | Authorship | Quality assurance | Publishing | |
| Mechanical engineering | Engagement | Participatory design | None | Engagement | Participatory design | None | Participatory design/engagement model |
| General surgery | Participatory design | Participatory design | None | Participatory design | Participatory design | None | |
| Abstract algebra | None | Engagement | None | Engagement | Engagement | None | |
| Construction management | None | Participatory design | Participatory design | Engagement | Participatory design | None | |
| Marketing | Co-creation: co-design | Participatory design | Participatory design | Co-creation: co-design | [Ongoing: engagement] | None | Participatory/engagement and co-creation model |
| Orthopedic surgery | Co-creation: co-design | Engagement | Engagement/co-creation | Co-creation: co-designer/representative | Engagement | None | |
| Architecture | None | Co-creation: consultant | Participatory design | Co-creation: co-researcher | [Ongoing: engagement] | None | |
| Statistics | Co-creation: consultant/co-researcher | Co-creation: consultant/co-researcher | None | Co-creation: consultant/co-researcher | Co-creation: consultant/co-researcher | None | Co-creation model |
| Complex numbers | Partnership | Partnership | Participatory design | Co-creation: co-researcher. Co-designer, representative, consultant | Participatory design | None | Co-creation/partnership model |
| Computer science | Partnership | Partnership | Participatory design | Engagement. Co-creation: consultant. | [Ongoing engagement] | None | |
| Chemistry | Partnership | Partnership | Participatory design | Co-creation: co-researcher | Co-creation: representative | None | |


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textbook development processes were the only three of the 11 initiatives profiled here which were not completed.

## The participatory/engagement and co-creation model

Three initiatives utilized the Participatory/Engagement and Co-Creation Design Model, in which they all created content from scratch (architecture, marketing, and orthopedic surgery). All three took on *editor-in-chief with colleagues and/or student co-authors approaches.* They collaborated with colleagues and included students as co-creators of content. The example from architecture is unique in comparison to all the other initiatives, in that all students in a second-year class created the first draft of the open textbook. This inclusive approach was intended to offer all students in the class a sense of accomplishment in terms of being part of the process, thereby disrupting the traditional power balance in the classroom where the teacher creates all the content. The pedagogical strategy of bringing the whole class into the process has the potential to be more inclusive, building positive relationships between staff and students (Bovill, 2020). This kind of whole-class co-creation strategy responds to Fraser's principle that social justice is only achieved if the "all affected" principle is applied. In marketing, the students received attribution for their roles in contributing local content. Thorough quality assurance mechanisms were put in place with participation from colleagues and students. This model straddles the affirmative and transformative remedies. The aspects of co-creation move this model toward a rethinking and restructuring of how textbooks can be created.

## The co-creation model

There is one example of a Co-Creation Model, in which colleagues and students had consultant and co-researcher roles across authorship and quality assurance processes (statistics). In this example, the authors translated a chapter of a first-year statistics open textbook into isiXhosa. The author took on the role of a content development facilitator and worked with colleagues and students who authored content. This model moves toward an equitable outcome where colleagues and students engage in meaningful collaboration. This co-creation approach is considered transformative, in that the voices of colleagues and students construct knowledge.

## The co-creation/partnership model

The transformative Co-Creation/Partnership Model sees authors including colleagues and students in innovative ways (complex numbers, computer science, and chemistry). The complex numbers author created chapters from scratch that will eventually form part of a new first-year mathematics open textbook. The author took on the *editor-in-chief with colleagues and/or student co-authors approach*, partnering with colleagues in authoring and quality assurance processes. In this initiative, students took on all four co-creation roles: co-researcher, co-designer, representative, and consultant. The computer science textbook was a revised and updated version of the lecturer's already existing textbook. This author used an *editor-in-chief with colleagues and/or student co-authors approach* and also partnered with a colleague to write a new chapter and engaged students as consultants. The third example of this Co-Creation/Partnership Model includes partnering with colleagues as well as co-creation with students. In this example from chemistry, the authors used a *content development facilitator role and worked with colleagues and students who authored content*. The authors used more inclusive methods such as surveys and focus group discussions in order to include the voice of students in the content. All three initiatives partnered with colleagues in both authorship and quality assurance processes where colleagues were in a "participatory design" role in the publishing of the open textbooks. This Partnership/Co-Creation Model is the most transformative model, in that it promotes "re-acculturation" (cultural recognition), in which multiple voices represent local knowledge, creating relevant materials and nullifying the need to rely on traditional hegemonic perspectives (Hodgkinson-Williams and Trotter, 2018, p. 220; Khoo et al., 2020). This model also remedies political misrepresentation/misframing by "re-framing" the balance of power in the authoring of textbooks (Hodgkinson-Williams and Trotter, 2018, p. 220).

The models presented engage students at varying levels and to varying degrees.

## Student inclusion in open textbook authoring, quality assurance, and publishing

The national and international calls for the inclusion of students in the development of educational materials are heeded in the open textbook cases presented here (Cook-Sather et al., 2014; Martens et al., 2019; Könings et al., 2021). In seven initiatives, students took on various co-creation roles in authorship and in three they were co-creators in quality assurance processes. These authors found ways in which to not only capture students' lived realities in the published end product, but also to include their feedback into the quality assurance of their resources. Students were not involved in any of the publishing processes.

Student participation is a critical aspect of the institutional transformation agenda, in that it addresses social justice and inequity in the classroom.

### Institutional support and sustainability

Three of the open textbook initiatives were not completed. The authoring journeys suggest that there were complex, often personal, reasons for this and all three authors have subsequently left UCT (Masuku et al., 2021). Even with funding, authoring and editing support from DOT4D, this work could not be completed. Considering these complex personal stories, it is difficult to argue convincingly that the downfall of these projects was because they were solo-authored with very little collaboration (in that they all used the Participatory/Engagement Model). It is possible though that if there was more colleague and/or student involvement, the projects would have progressed differently.

Institutional support is necessary to grow and sustain open textbooks. The implementation grants administered by the DOT4D initiative sparked innovation and this seed money enabled academics to progress on their journeys as open educators (Masuku et al., 2021). DOT4D author support continued beyond the 1-year grant period and there is ongoing work and further discussion around content development with a number of these authors.

The UCT Open Textbook Award introduced in 2020 was a breakthrough event in raising awareness and recognition of the importance of this work institutionally. In addition, the technical infrastructure provided by UCT Libraries has proved essential for authors to complete their authoring processes, from recognition of drivers and the problem at hand to authorship, quality assurance and finally to publishing. Institutional support should ideally include grants for authors, some form of institutional recognition, such as a prize or acknowledgment in promotion criteria, and publishing infrastructure.

## Conclusion

This article offers models of open textbook authoring, quality assurance and publishing that follow affirmative or transformative remedies for social justice. The models are positioned on a continuum with the co-creation and partnership/co-creation models moving toward the social justice aspiration of parity of participation.

The models have emerged as a result of open textbook authors grappling with the dynamics of open textbook production (many of them for the first time) and are all useful possible pathways for future authors. The degree of colleague and student inclusion of future initiatives should depend on the purpose of the materials that are being designed. If the goals of social justice – which include economic redistribution, cultural recognition and political representation – are being pursued, then inclusion in the form of partnership and co-creation where participants contribute equally in all open textbook production activities is required.

The lecturer from architecture also expressed that while she currently adopted a certain content creation model, her ideal was to evolve to a more distributed approach in terms of giving her students more authorial voice in future textbook development processes. This suggests that authors are not fixed on a particular approach, but can instead adapt (or aim to adapt) their production activities based on the context they find themselves operating in.

The four models discussed here suggest that collaboration may be an important aspect of sustainability.

The issue of institutional support and recognition is relevant in the context of sustainable authorship models – particularly in light of the fact that institutions do typically not recognize this work in formal promotion. Fraser (2005, p. 92) argues that "overcoming injustice means dismantling institutionalized obstacles" and some of these institutional measures at UCT (such as grants, the award and library publishing infrastructure) are providing authors with space and creativity not previously possible in traditional textbooks authoring in order to be more inclusive in their content creation processes.

Future research should/will include further investigation into the process of collaboration with colleagues and students to surface finer detail relating to the student experience, collaboration with colleagues and the extent of their different roles "in" the course or "of" the course. Interviews with academics, student co-creators and students who use these open textbooks can potentially set out a way forward that will transform the creation of course materials and address social injustice in the classroom.

## Data availability statement

The raw data supporting the conclusions of this article cannot be shared for ethical and privacy restrictions, in accordance with the ethical consent provided by participants on the use of confidential/identifiable human data.

## Ethics statement

The studies involving human participants were reviewed and approved by Centre for Higher Education Development Research and Ethics Committee, University of Cape Town. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

All authors made equal contributions to the conceptualization, theory, analysis, writing, and revisions of this manuscript.

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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.

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# Revisiting Education: On the Role of Imagination, Intuition, and Other "Gifts" for Open Scholars

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The knowledge society is not a final state; rather, it is a collective task that we all must work towards. This reflective report, conducted in a Scholarship of Teaching and Learning approach by a scholar who teaches research methods and has been reflecting on research method education for a number of years, is a contribution to this endeavor. Its purpose is to share praxis, in the Freiran sense, on Open Education and Open Science as public good and commons through a specific example of Open Educational Practice (OEP). The report's first finding involves documenting that OEP and providing some conceptual tools and suggestions for scholars who would like to move towards Openness. Its second finding, rooted in a previous SNSF research project, focuses on epistemology to raise awareness on the importance of philosophical and historical approaches to education. Without this knowledge, scholars find themselves closed in models that they replicate without consciously considering the values and methods they convey. The report's third finding is a model of the knowledge creation process that considers knowledge as commons and incorporates a theoretical framework of absences and emergences that encompasses ignorance, inspiration, imagination, creativity, and intuition. Einstein called these faculties "gifts," and we argue that scholars should learn to leverage them within an overall open framework.

**Keywords: open education, absences, emergences, collective intelligence, epistemic sustainability commons, imagination, open educational practice**

## INTRODUCTION

The call for submissions reads "Open Education for Sustainable Development: Contributions from Emerging Technologies and Educational Innovation." This paper will address neither development nor technologies, for reasons that will be explained below. Instead, it will address education, the primary focus of Open Education, and research methods in education, for their contribution to education as an area of study.

The paper is conducted in a Scholarship of Teaching and Learning (SoTL) approach (Boyer, 1990) and aims to share reflections and practice in the area of Open Scholarship, leveraged through Open Educational Practices (OEP) (Cronin and Maclaren, 2018; Huang et al., 2020;

Werth and Williams, 2022). To prepare students for their role as full-fledged stakeholders in the knowledge society, it is important for them to experience OEP, make choices, take on responsibilities, and contribute to meaningful findings. For colleagues who would like to try out new ways of teaching and conducting research, this article provides conceptual tools and perhaps an inspiring example.

It is no secret that we live in a time of transition, as modern societies and economies shift towards knowledge societies and economies. Openness is one characteristic of knowledge societies, and the progress of Open Science in the last decade is an indicator that cannot be overlooked (e.g., Ramjoué, 2015; Beck et al., 2020). In the same vein, commoning, universal sharing, and empowerment help to build a collective intelligence that transcends individual languages, disciplines, and epistemologies (Innerarity, 2015b).

Openness has existed for several centuries, with the essential features of freedom and transparency (Baker, 2017). In scholarship, its origin can be traced to 1373 when the people of Florence requested public lectures on Dante. This movement led to the emergence of European universities in Paris, Bologna, Oxford, and Cambridge, which were founded in response to students' demands for lectures. Openness was driven by internationally mobile students and scholars and was based on a growing curiosity about and awareness of the value of education (Peter and Deimann, 2013). However, this did not last. Over the last 700 years (1300–2000), "we can see periods of freedom and transparency in the dissemination of knowledge animated by empowered learners alternating with periods of public and/or ecclesiastic control on knowledge" (Class, 2022, p. 650).

We will first give an overview of the key topics dealt with in this paper, including the knowledge society, the public good addressing specifically information and knowledge commons, and Open Education. We will then present the paper's theoretical framework, which consists of the epistemologies of absences and emergences (Santos, 2016) and experiential learning (Usher, 2018). We will discuss the SoTL approach adopted for this article in the method section before sharing our findings and recommendations. We will conclude by highlighting how this reflective report contributes to epistemic sustainability (Class, 2022) through an understanding of the knowledge creation process that takes into account ignorance and imagination as key players. To contribute to Open Education and Openness in general, we advocate for promoting education in line with Einstein's insights on inspiration, intuition, and other human gifts (Hayes, 2007).

# LITERATURE REVIEW

## Knowledge Society

A knowledge society is characterized by increased creativity in redefining norms, values, epistemologies, and research methods. Scholars in a knowledge society are tasked with putting together bits and pieces of data, information, knowledge, and ignorance to form the collective intelligence that is sought after (Innerarity, 2015a; Farmer, 2019). This idea can be traced back to open scholars like John Dewey, who discussed the importance of building social and collective intelligence from individual experiences and minds in order to achieve cultural advancement as a community (Dewey, 1937, cited by Farmer, 2019).

Because a knowledge society questions norms, values, and epistemologies, it is first and foremost a society that produces ignorance. Science and research are no longer considered definitive authorities, but, when they articulate new knowledge, sources of instability, and incertitude. A knowledge society is thus a society of ignorance that is aware of this fact and acts accordingly. That is why contemporary societies are in a continuous process of learning and consider learning as active experimenting. Certainties are scarce in any field, debate is the rule, and risk-taking and creativity are guiding principles. Knowledge is both revisitable and revisited; it is closely related to ignorance and involves an element of risk. The unknown (i.e., uncertain knowledge, forms of non-scientific knowledge, and ignorance) is considered as a pool of resources and opportunities instead of a deficit of knowledge.

In decision-making, ignorance is seen as an opportunity for creative action (Innerarity, 2015a). It is a form of the unknown that is unrelated to a temporary lack of information. This kind of ignorance has been generated by the progress of science: It grows in tandem with (and even faster than) scientific knowledge. Ignorance has thus an irreducible dimension that we must understand, accept, and use as a resource. Assessing whether unknown unknowns are relevant or not becomes the central question, as there is not any "superior knowledge" that will completely discover unknowns (Innerarity, 2015a, pp. 56–65).

In the introduction, we stated that we will not talk about development, despite the invitation to do so in the call for papers. Here, we briefly explain why. Our reasoning is based on the work of Santos (2021), who shows how the discipline of sociology emerged in Western societies in order to analyze the problems these societies were facing at the time of the industrial revolution (i.e., around 1760). Although the foundations of sociology had been laid by Ibn Khaldun (1332–1406), scholars did not acknowledge his methodological contribution and at best considered his writings as ethnographic testimonies. After World War II, this same discipline of sociology disseminated the concept of development. Problematized exclusively by Western-centered stakeholders, it resulted in placing "the majority of countries on the wrong side of history, the world of underdevelopment" (p. 291). The concept of development covers several aspects of the human being and human society, from the spiritual to the political to the economic. It also adopts an extractivist perspective toward the planet (Santos, 2016)—the limits of which we can see today, most importantly at the ecological level. We thus think that if we are to attain sustainability, we must base our understanding of the world on concepts—not yet defined, but in the process of being articulated (e.g. Arauz, 2022)—that are different from and independent of development.

## The Public Good: Commons

*Commons* can be understood as resources managed collaboratively by a community that establishes rules and governance with the goal of preserving and sustaining these resources (LePortailDesCommuns, no date). Defined in the Middle Ages on the basis of Aristotelian principles, it "referred to a good belonging to and attainable only by the community yet individually shared by its members." The public good is at the same time individual and pertains to the community. It is holistic in the sense that the sum of the individual goods "exceeds the goals of inter-individual transactions" (Dupré, 1993, p. 687).

Natural-resource commons have been studied extensively and from several perspectives (e.g., Ostrom, 1990; Haller et al., 2019, 2021). Collaboratively managed digital commons, the most well-known of which are Wikipedia or Linux, have revived this approach of managing goods (Bollier, 2014). Recently, it has been considered at the intergovernmental level with the concept of the digital public good (DigitalPublicGoodsAlliance, 2021). In defiance of private property laws, markets, and states, advocates for commons have shown that this is an efficient and effective way to move forward. Specific communities are responsible for and guarantors of certain resources they have committed to. Regardless of whether the resource is material or immaterial, the commons are defined by a set of social practices and cultures that transcend the collective management of the resource.

The guiding principle of commons is not the resource itself but the sustainability of the community that manages it and of the social rules, values, and ethics that are developed for this purpose. The underlying vision of commons is to serve humanity through social cooperation and mutual support. From a conceptual perspective, the focus of commons is on human, social, and civic concerns. These typically include, for example, openness and feedback, shared decision-making, diversity, society equity, and sociability in the commons (Bollier, 2004, p. 275).

Distinguishing information commons from knowledge commons seems obvious, as information is distinct from knowledge. Knowledge is a cognitive processing capability that results in empowerment and requires intellectual and/or physical effort from those who enact it. Information, by contrast, is formatted and structured data available in the world; it is instantiated only and only when a knowledge processing action takes place (David and Foray, 2003).

### Information Commons

Information commons emerged in the 1950s and consist of an openly shared set of information and tools to handle information (Aigrain, 2005, p. 74). Information commons are composed of at least three layers: the physical layer, the logical layer, and the content layer. The physical layer consists of the electromagnetic spectrum, cables, wires, and fibers. The logical layer consists of software and technical protocols that allow expression to be carried over the physical layer. The content layer consists of information, expression, and culture (Benkler, 2001; Bollier, 2004, p. 276).

Information commons is a conceptual tool to raise awareness about collectively owned and managed resources (e.g., Internet, broadcast airwaves) and the claim for legal authority and social norms to control and manage those resources (Bollier, 2004, p. 280). This conceptual tool helps when discussing digital aspects of democratic culture in a knowledge society.

To move from information to knowledge commons, it is worth looking at learning commons. In past decades—particularly with the shift from teacher-centered to learner-centered pedagogies and to the digitalization of human activities—libraries created the concept of the learning commons. Learning commons are collaborative learning spaces that contain various technologies, resources, and services provided by diverse academic units (Blummer and Kenton, 2017, p. 331). Similar to maker spaces (another example of community-led knowledge commons), libraries are considered a "third place" (Blummer and Kenton, 2017, p. 333) where people can access knowledge through different means, resources, and interactions. This third place is also managed from the perspective of the public good, that is, shared decision-making, openness, and feedback. As a side note, it is interesting to underline the key role of librarians in the development of Open Science in academia today. Not only do librarians offer support for new practices related to Open Science, but they can also help design these practices (e.g., Class et al., 2021).

### Knowledge Commons

Hess and Ostrom (2007) rely on the relationship established by Machlup (1983) between knowledge, information, and data. This relationship has similarities with David and Foray (2003) theory, discussed above, but incorporates data as a third element. In it, data are considered as raw bits of information, information as organized data in context, and knowledge as the assimilation of information and understanding of how to use it. Finally, knowledge "refers to all intelligible ideas, information, and data in whatever form in which it is expressed or obtained" (Hess and Ostrom, 2007, p. 7).

Hess and Ostrom (2007) caution that research on knowledge commons does not take into account the breadth and depth of the literature on natural-resource commons. Knowledge commons are analyzed both from the perspective of enclosure and the perspective of openness/inclusiveness (i.e., democracy and human rights). In the former, threats take the form of property legislation that prevents open access to knowledge. In the latter, which draws on Benkler (2001), the focus is on digital interoperability, Open Science, and networks to the detriment of the importance of sharing and using shared knowledge to support sustainable democratic societies (Hess and Ostrom, 2007, p. 13). What is needed is a framework that respects the fundamental properties of commons, including the sustainability of the community, shared, and collaboratively managed resources. As a reminder, Ostrom (1990)'s principles for the successful management of natural-resource commons are as follows: clearly defined community boundaries, congruence between rules and local conditions, collective choice arrangements, monitoring, graduated sanctions, conflict resolution mechanisms, local enforcement of local rules, and multiple layers of nested enterprises (Rozas et al., 2021). Inspired by research on natural-resource commons, a similar framework could organize research on knowledge commons. Indeed, research is emerging that attempts to apply the management of natural-resource commons to knowledge commons (e.g., Sanfilippo et al., 2018 see Figure 1 and Table 7 specifically; Stuermer et al., 2017).

## Open Education

### Education and Research in Education

In Western societies, education as a field of research is relatively young: about 100 years old (Van der Maren et al., 2019). For several decades, researchers argued about the status of education: is it a craft, an art or a science (Burkhardt and Schoenfeld, 2003)? This dispute can be clearly seen in the "paradigm war" among educational researchers (Reeves, 1999; Teddlie and Tashakkori, 2009), who wrangled over whether qualitative or experimental research should be the dominant approach in educational research. The field also underwent substantial changes after World War II (Laot and Rogers, 2015).

The International Bureau of Education (IBE) was founded in 1925 by leading figures in the New Education movement, such as Edouard Claparède, Pierre Bovet, Adolphe Ferrière, and Béatrice Ensor. These leaders advocated for learner-centered education rather than organizational, curricula- and teacher-centered education (Hofstetter and Schneuwly, 2013, p. 216). Some 20 years later, in 1945, UNESCO was created with the pacifist aim of working towards IBE's goal of building a better world through education. However, in 1957, UNESCO added an economic objective to its initial endeavor, recommending that countries put 5% of their GDP towards schooling in order to support development (Laot and Rogers, 2015). In addition, in the 1940s and 1950s, several supranational organizations either began to focus on education or were created to promote education and scientific research in education (e.g., the International Association for the Evaluation of Educational Achievement, OECD, NATO). These organizations attempted to stimulate economic progress through the education, training, and qualification of the working-class population. At the same time, philosophy and history of education, which were key components of university curricula in education, were replaced by scientific approaches borrowed from the natural sciences, for example, experimental methods (Rohstock, 2015).

Education as a scientific field has a responsibility with regard to research methods both for young and senior researchers. In the social sciences, research method education has been studied for more than a decade, beginning with the seminal work of Garner et al. (2009). Researchers have uncovered valuable insights for the praxis (e.g., Garner et al., 2009; Wagner et al., 2011, 2019; Earley, 2014; Kilburn et al., 2014; Lewthwaite and Nind, 2016; Nind and Lewthwaite, 2018), including the necessary mastery of Shulman (1987)'s pedagogical content knowledge (PCK) in the domain of research methods education (Nind, 2020). A recent call for the creation of new methods to study Open Education is also underlined (Ramirez-Montoya, 2020; Savin-Baden, Accepted). For these reasons, research methods might better be presented as a topic of ignorance (see the section below on the knowledge society), rather than from a deterministic perspective. In addition, the philosophy and history of education are essential parts of Content Knowledge (CK) in the domain of research methods education and need to be revisited with Openness and mastered as complex, dynamic, and diverse knowledge.

Education as a practice has been shown to require knowledge and competencies (Jonnaert et al., 2020), but concepts like imagination, creativity, inspiration, and intuition (Hayes, 2007) have been largely ignored in this field. To what extent could these constitute important building blocks for education? With reference to Einstein's insights, we share here an understanding of these important concepts. "The use of logic permits a person to move from point A to point B; by contrast, imagination can take the mind in any direction it chooses, without restraint" (Hayes, 2007, p. 150). Einstein said that "the intuitive mind is a sacred gift, while the rational mind is only its faithful servant," but "our society honors the servant and has forgotten the gift" (Waks, 2006; Culham, 2015;, p. 1). Intuition is a form of understanding that is rapid and spontaneous, without the need for conscious thought (Dörfler and Eden, 2014), which can weigh and integrate many factors in split seconds (Dijksterhuis, 2007). It can facilitate direct knowing (Sinclair, 2011), fast problem solving, decision-making, and creativity (Dane and Pratt, 2009) and can even be more accurate than reasoning in complex situations (Pretz, 2011; Sipman et al., 2021, p. 1). Unconventional approaches that engage body and mind and oriented toward finding solutions lead to engagement and deep learning and generate creativity, ingenuity, and inspiration (Nordstrom and Korpelainen, 2011).

### Open Education

Open Educational Practices (OEP) offer the opportunity to explore unconventional educational approaches. OEP have been studied for 15 years (e.g., Cronin and Maclaren, 2018; Paskevicius and Irvine, 2019; Bali et al., 2020b; Huang et al., 2020; Clinton-Lisell, 2021; Werth and Williams, 2022), and research shows that five conditions are enabling: (i) Open Educational Resources (OER) as input and output; (ii) enabling technology to support a connected learning community where OEP can flourish; (iii) open teaching approaches that empower students to construct their own learning pathways; (iv) open collaboration to reach out to concerned communities for students to interact with stakeholders outside of academia; and (v) open assessment through peer evaluation, reflective practice, and evaluation by third parties (Huang et al., 2020). Six reasons to adopt OEP resonate with the five conditions and are foregrounded as follows: (i) sharing, that is, the freedom to create, share, and reuse knowledge; (2) transparency, that is, the capacity to trace the knowledge construction process and underlying values and transparency in the entire process from admission to certification; (iii) collaborative knowledge construction, that is, participate in the building of the collective intelligence; (iv) deconstructing power structures in the educational environment, that is, giving voice to everybody; (v) personalized learning, that is, learners have authority to determine their learning needs and learning path; and (vi) learner empowerment, that is, learners are involved as active full-fledged stakeholders in each step of the learning process from the choice of learning outcomes to the design of assessment (Werth and Williams, 2022).

This perspective of OEP is primarily oriented towards pedagogical aims. It is important to be aware that other dimensions are currently being researched. Framing OEP from a social justice perspective (Bali et al., 2020a,b) sounds particularly challenging but all the more relevant within educational endeavours. It echoes other parts of this text that focus on decolonisation, absences and emergences. Authors discuss the impact of OEP and the extent to which they can be considered socially just. They particularly identify actors and contexts where OEP support social justice at cultural, economic and/or political levels and classify them on a continuum from transformative to negative in terms of impact (Bali et al., 2020b).

Keeping in mind this complex background and recalling the history of Open Education (e.g., Weller, 2014; Blessinger and Bliss, 2016; Weller et al., 2018; Bozkurt et al., 2019), the question remains: where should scholars put emphasis today? On the "Open" aspect? On the "Education" aspect? On "Open Education" as a construct and potential means of renewing education?

In this paper, we have deliberately positioned Open Education within the conceptual approach of the public good and commons. This is important to underline with regard to the three strategies used to define approaches to openness. The first strategy associates openness with historical periods or movements in which it thrived (e.g., Florence in 1373, open-source software movement); the second examines the philosophical and conceptual underpinnings of openness, such as the public good; and the third seeks ways to operationalize the concept of Open Education (e.g., with licenses that privilege copyleft over copyright). Constructs common to the three strategies include "the role of freedom, justice, respect, openness as attitude or culture, the absence of barriers, promotion of sharing, accessibility, transparency, collaboration, agency, self-direction, personalization, and ubiquitous ownership" with freedom and transparency as the two essential values from which the remaining derive (Baker, 2017, p. 131).

Again, despite the reference in the call for papers to emerging technologies, in this article we deliberately separate Open Education from technology. In Peter and Deimann (2013)'s history of Open Education, the authors emphasize the importance of dissociating the essentials of this construct from technology. For instance, in the Florence period mentioned above, books were socially perceived as a means of bypassing state and religious authority, which allowed the printing press to develop rapidly; in other words, the values preceded the technology. It can also be interpreted the other way round, that is, the technology enabled the book to become socially what it became. Technologies like printing, railways, computers, and Internet did and do play a role in Open Education, but this is the case throughout the continuum of education, up to and including "closed and controlled education." In the 1980s, technology started to be foregrounded as a vector of change. This idea is supported by leading economic organizations like WEF, the World Bank, or OECD, which advocate for change through technology and the capitalist economy. Today, this agenda is questioned and even described as "digital feudalism" (Morozov, 2016 cited by Deimann, 2020). In our opinion, therefore, technology should not be foregrounded as the exclusive vector of Openness. Moreover, focusing on Open and Human values, in complementarity with technology, seems to be a more sustainable avenue for future endeavors.

# THEORETICAL FRAMEWORK

The primary theoretical framework adopted for this SoTL study is the sociology of absences and emergences. Experiential learning theory is used to conceptualize engagement through active learning. Both combined are deemed relevant to conduct research in the knowledge society because they provide a means of theorizing ignorance and experience.

## Sociology of Absences

The sociology of absences aims to show that what "does not exist" is in fact actively produced as non-existent, that is, a non-credible alternative to what exists. This transgressive approach breaks with the positivist principle of reducing reality to what exists and to what can be analyzed using the methodological and analytical instruments of the modern social sciences. The sociology of absences aims precisely to consider what exists beyond this "abyssal line"—to make possible objects that are impossible and make present those that are absent. There is not a single and unique way not to exist. Not existing is the result of certain processes and logic applied to everything that does not fit into the linear temporality and whole of metonymic reasoning. The sociology of absences focuses on social experiments that have not been entirely colonized by metonymic reasoning. It seeks to explore what exists in the South that is independent from the constructed North/South dichotomy. It is about researching what exists beyond the abyssal line using non-modern mindsets and epistemologies (Santos, 2016, p. 251 and following). We consider it as a concrete intellectual tool to operationalize UNESCO (2021, p. 15) recommendation to open up to diverse knowledge: "Open dialog with other knowledge systems refers to the dialog between different knowledge holders, that recognizes the richness of diverse knowledge systems and epistemologies and diversity of knowledge producers."

## Sociology of Emergences

While the sociology of absences broadens the range of social experiences that are already available, the sociology of emergences broadens the range of possible social experiences. This is where imagination comes into play. The sociologies of absences and emergences are deeply connected: The first builds on social experiences and the second on anchored social expectations.

The sociology of emergences aims to symbolically increase the importance of knowledge, practices, and actors in order to identify future trends and thereby make hope more probable than frustration. Such symbolic amplification is essentially a kind of sociological imagination that allows researchers to better investigate the conditions that make hope possible and better define the principles for action that will promote the fulfillment of those conditions. The sociology of emergences acts on possibilities (i.e., potentials) and capacities (e.g., legitimate authority, power) and focuses on care, without being deterministic.

**Figure 1** (below) is a visual representation of the theoretical framework for this SoTL study, which should help readers

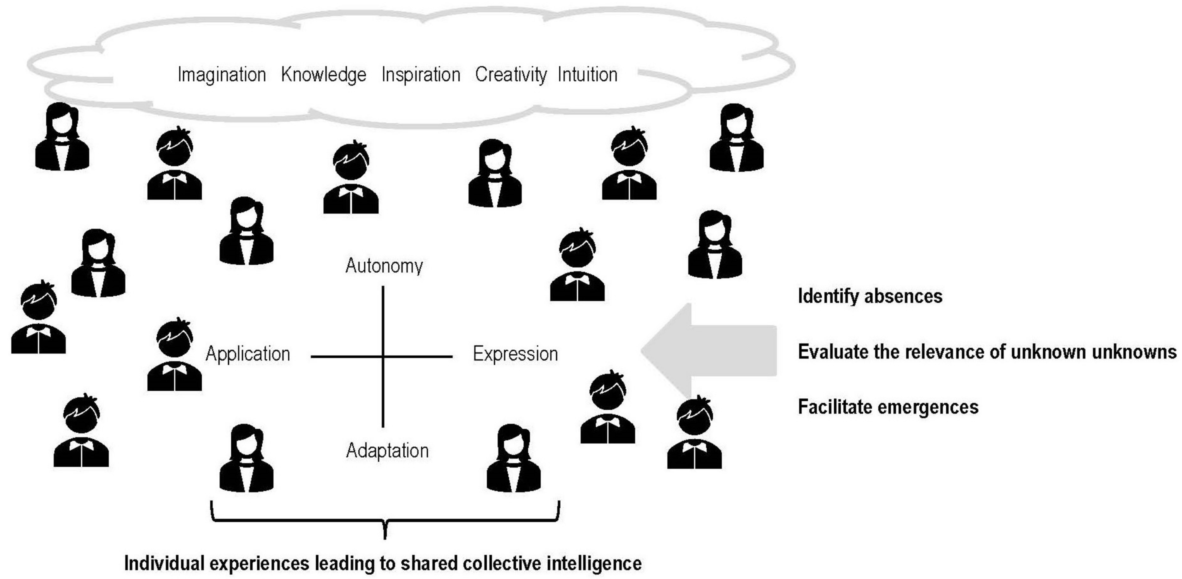


**FIGURE 1 |** Visual representation of the theoretical framework, drawing on Santos (2016) and the previous studies (Usher et al., 1997; Usher, 2018).

to synthesize and grasp the main concepts presented here. The framework flourishes from the concept of experiential learning. It is considered from the socio-cultural environment and organized on two continua Autonomy–Adaptation and Expression–Application. The first continuum expresses the degree of empowerment and the second the degree of creativity of individuals interacting with their environment (Usher et al., 1997, pp. 104–114). Individual experiences in identifying absences and facilitating emergences will contribute to larger, similar endeavors. Imagination, knowledge, inspiration, creativity, and intuition all guide scholars and other stakeholders toward collective intelligence.

## MATERIALS AND METHODS

Open Education impacts our scholarly praxis. Praxis is to be understood in the Freiran sense (Freire, 1994) of reflexion and action deeply entangled and aimed at transforming the world by leveraging (epistemic) justice. Adopting a critical perspective conducted through a SoTL study (Boyer, 1990) was motivated to explore some of this impact. **Table 1** outlines the study's guiding research question and the resulting process used to reach findings (Hubball and Clarke, 2010, p. 4).

## FINDINGS

> "*I believe in intuition and inspiration. Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution. It is, strictly speaking, a real factor in scientific research.*"—Einstein.

### Findings With Regard to Open Educational Practices

The first finding of this study consists of an example of a contribution to the knowledge society by one higher education research methods teacher (the author) through an Open Educational Practice (**Table 2**).

First, I assessed my Open Education capacities with a recent practice-oriented inventory (Universidad-Internacional-de-La-Rioja, no date). This inventory addresses key questions with regard to OEP and offers a summary in the form of a synthetic table together with recommendations for further improvements. **Table 2** captures each dimension—from design to assessment through to content and teaching—and the three levels: foreign to OEP, starting to engage, and advanced.

Reaching the advanced level depicted in **Table 2** (blue font) requires professional development from the teacher, that is, interest, commitment, and work. In my case, this development has been conducted on a personal-initiative basis through an extremely interesting course on Open Education developed from previously existing Open Educational Resources (OpenMed, 2015). I participated in this 40-h course offered within a Moroccan project (Univ-Ouverte@Maroc, 2021) during the 5 weeks that partly ran in parallel with the research method course I was teaching and that is reported below as an example of OEP. Although I was already an Open educator in many respects, this course was an excellent occasion not only to learn and read more and advance my reflection but also further my praxis. In particular, it was after taking this inventory that I began involving external stakeholders in assessing students' work (Achour Rahmani et al., 2021).

Huang et al. (2020) have identified five conditions for effective OEP, which are shown in the left column of **Table 3**. The right column explains how each condition has been scenarized

**TABLE 1 |** SoTL approach used in this study.

| SoTL research context | Central SoTL research question | Methodological approach | Data | General outcome |
|---|---|---|---|---|
| Freedom and transparency are guiding principles for scholars engaging in Open Education. Sustainability, sharing, contributing and collaborative management of resources are at the heart of the public good. Open scholars try to make the public good and commons a reality in higher education contexts. | How can Open Educational Practices look like in qualitative research methods education? | Reflection is informed by research conducted on Open Education and Open Science. Action was guided by previously gathered interview and focus group data, previous personal experience of qualitative research methods teaching, and outputs from the literature. | Interview data with one francophone research methods teacher and one focus group with two anglophone research methods scholars from a previous SNSF project.[1] Analysis of the scenario of the 2021 qualitative research methods course[2] (**Table 3**). | Invite scholars to reflect on: (i) education and Open Education; (ii) the roots of any research method used; (iii) the role of imagination in the knowledge creation process. Share the teaching and learning experience as an Open Educational Practice that can be inspiring. Contribute to the discussion on the Open paradigm shift. |

*[1] https://data.snf.ch/grants/grant/190634. Please note that no analysis is performed here. We simply report the passages on the epistemology of the interview and focus group because they align with Rohstock (2015), discussed above.*
*[2] The scenario, in French, is available from: https://tecfa.unige.ch/perso/class/ScenarioDetailles2014-2020/.*

**TABLE 2 |** Summary table to situate the scholar's Open Educational Practices.

| A. Open Learning Design | B. Open Content | C. Open Teaching | D. Open Assessment |
|---|---|---|---|
| A3. Open Designer | B3. OER expert user | C3. Open teacher | D3. Open evaluator |
| A2. Collaborative designer | B2. Familiar with OER | C2. Engaging teacher | D2. Innovative evaluator |
| A1. Individual designer | B1. New to OER | C1. Traditional teacher | D1. Traditional evaluator |

*Recommendations to improve your teaching openness.*

**TABLE 3 |** Implementation of the five OEP conditions in a qualitative research method course at the master's level.

| Five conditions identified for OEP | Implementation in the research methods course |
|---|---|
| Open Educational Resource (OER) – input and output | Use as input: the "textbook" of the course (Class and Schneider, no date) is an OER that was started in 2014 on the EduTechWiki and to which several groups of students have contributed. Use as output: the article that reports on the work conducted throughout the course is available on Zenodo (Achour Rahmani et al., 2021) for future use and as a meaningful learning contribution. |
| Enabling technology to support a connected learning community where the OEP can flourish | Moodle LMS was used to store all official information related to the course, such as grading. A Mattermost environment was used to support learning conceived as a conversation (Laurillard, 2002) with ongoing discussion/production/feedback/new production loops. |
| Open teaching for self-regulated students' pathways | Students first worked in pairs on a single component of the research cycle (e.g., literature review, research question, method, etc.). Later, the components were adjusted to align into a coherent research design. |
| Open collaboration to participate in open communities | This dimension was not prioritized and should be improved. Students had access to two discussion communities: one made up of their peers and teaching staff, and the other solely of their peers. Access to a broader community was lacking and should be granted. |
| Open assessment—peer and community-based | Students reviewed each other's work when combining the separate research components into a coherent whole. Two external evaluators – a librarian and a research methods teacher – were asked to assess the final product. |

and implemented within a 2-ECTS qualitative research method course offered at the master's level.

In future editions of the course, it will be important to discuss qualitative research methods that are epistemologically aligned with knowledge society paradigm shift. For instance, Reader et al. (2021, p. 1) ask questions to which we do not have answers yet but are important to raise in order to investigate new, unknown dimensions. Examples of the questions asked by the authors—one of whom is a research methods teacher—include "Where do the mythical, mystical and spiritual end and the rational, objective and empirical begin?" and "How do we find our bearings in the midst of this complexity and where do we search for resources that are trustworthy and reliable?" Introducing this kind of questioning will balance the pedagogical and social justice aspects of the OEP (Bali et al., 2020b).

## Interview Findings

The study's second finding focuses on epistemology and is based on one interview with a francophone research methods teacher in the area of education and one focus group with anglophone scholars who have been studying research methods education for many years.

The francophone teacher explained that in her university, there used to be a course entitled *Epistemology of research* *in education,* which was compulsory for all students. When the teacher who used to offer this course retired, her position—Chair of knowledge sociology—was discontinued, as the institution chose to prioritize other directions for research. Her course continued to be offered for some years before it was also discontinued. The interviewed teacher noted that she has observed a narrowing of epistemological questions at the institutional level, resulting in both teachers and students lacking fundamental knowledge. She underlined two current unproductive attitudes: first, that epistemology goes without saying and as such it is not necessary to teach it; second, that all researchers are able to teach epistemology. Restoring a broad mindset on these key questions of how knowledge is produced and utilized seems timely with the Open paradigm.

The focus group with anglophone scholars was organized in order to compare research findings to their own research findings in an anglophone context. We will focus on one salient aspect of this focus group that concerns epistemology. First, the group noticed that epistemology was not a major topic in their research interviews, nor one that was spontaneously brought up: "This is the kind of things [epistemology] that people learn when they are doing their formal research methods training and then just kind of move on from. It sort of all becomes so embedded that they do not use those words and framing to talk about it." They also found that talking about practice and observing actual classroom teaching were sometimes quite different because research method teachers lacked a pedagogical vocabulary. As a result, scholars of the focus group ended up acting as information brokers to help their interviewees articulate their pedagogical practices[1].

[1]It would be interesting to investigate the extent to which the teachers who are the research participants of the anglophone scholars, possess epistemological knowledge and concepts to articulate it.

## Modeling the Knowledge Creation Process

The previous sections of this paper—specifically, those that link knowledge commons to a theoretical framework of absences and emergences to address ignorance in a knowledge society—form the core of the study's third finding. Within research method education, axiology, ontology, and epistemology are important to understand, as they constitute the breeding ground of research methods. It is fundamental to the work of research method teachers to question the methods inherited by modern societies, with a view to helping researchers to unveil research objects, that is, emergence process. Up to now, huge efforts have been made towards achieving the Open Access part of Open Science. It is now time to investigate the many remaining facets of Open Science and Open Education: for instance, what science means, making sense of the Open paradigm, reaching out to a variety of knowledge systems (UNESCO, 2021), and working together to build a collective intelligence.

To sum up this third finding, we have provided a visual representation (**Figure 2**) that builds on Class et al. (2021, Figure 8).

To properly understand the core process (depicted in the center circle), it is important to underline that the process is not linear and that each individual element loops on itself. Data are considered as raw bits of information that turn into information when structured. Information is organized data in context that becomes knowledge when it is assimilated by actors who understood how to use it. Knowledge is a cognitive processing capacity that leads to both empowerment and ignorance when fully explored with diverse epistemologies. Ignorance is a form of available knowledge that needs to be recognized as such and that involves imagination. Imagination is a way of broadening the range of possible knowledge and experiences, particularly through

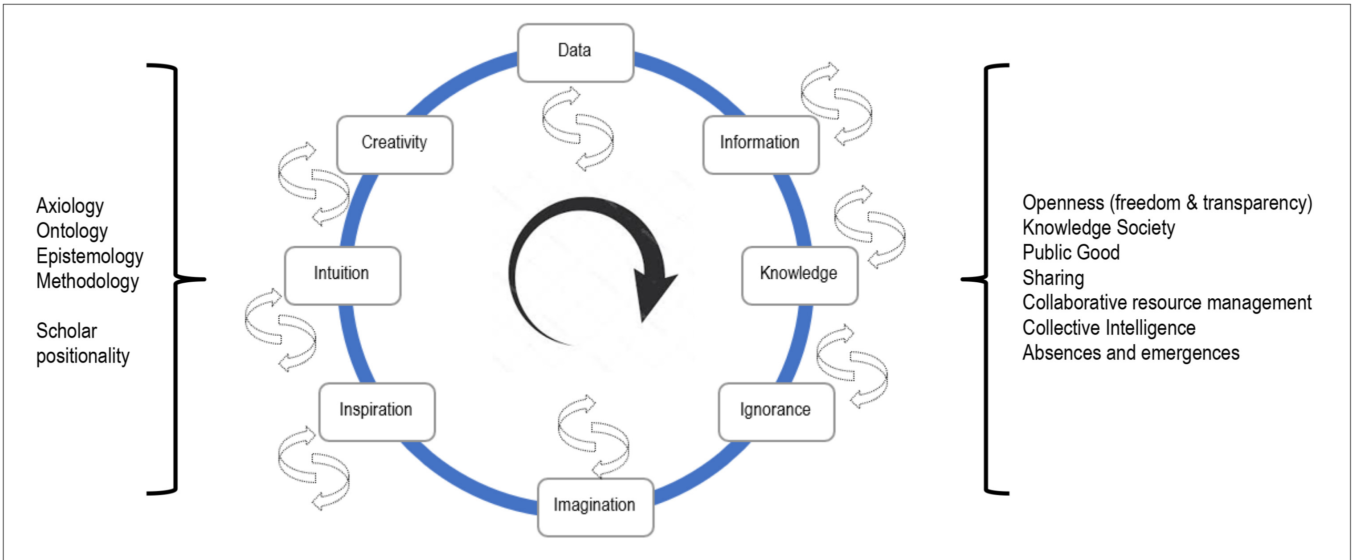


**FIGURE 2 |** Toward Openness in the knowledge creation process, building in ignorance, imagination, inspiration, intuition, and creativity.

inspiration, intuition, and creativity, which are "gifts" that need to be recovered.

The backdrop framework for this process (depicted on the sides) is twofold and relies on knowledge creation processes seen from the scientific-creation perspective (left) and the social perspective (right), as well as on a variety of key elements such as Openness, the knowledge society, and collective intelligence.

## SUGGESTIONS FOR THE ADOPTION AND ADAPTATION OF OPEN PRACTICES

As with a design-based study that produces design principles (McKenney and Reeves, 2019), and following reviewers' comments, scholars can find here some conceptual tools and suggestions for potential adaptation. Indeed, one feature of OEP is making practices transparent so that others can adopt and adapt them and share them again as renewed practice. The breadth and depth of the practices will evolve with time.

Conceptual and positioning tools:

➢ *PCK (Shulman, 1987) and TPACK (Koehler et al., 2013) frameworks*

These frameworks help scholars to unpack the different types of knowledge that are involved in an area of study. Taking time to identify the pedagogical, content, technological, and combined types of knowledge (e.g., technological and pedagogical) is part of basic educational work. Conducting this work with colleagues and stakeholders from the discipline is worth the huge effort it demands. In addition to the current body of knowledge, scholars can draw on competencies frameworks, professional bodies' frameworks, knowledge that reside in communities, etc.

➢ *Inventory by Universidad-Internacional-de-La-Rioja (no date)*

This is a powerful starter tool for evaluating a teacher's OEP proficiency. Teachers can answer the inventory and then analyze the recommendations, find open courses to improve, read, etc., according to their needs. We recommend that this be done with some colleagues for community spirit, as this will help provide support when crossing thresholds (Meyer et al., 2010). Changing one's praxis touches on professional identity and requires teachers to have support.

➢ *Frameworks for developing inspiration, creativity, and imagination*

We do not yet know of any framework in this area, but tools are emerging. For instance, Henriksen et al. (2016) define creativity as a goal-driven process of developing solutions that are novel, effective, and whole. Henriksen (2018) lists seven core transdisciplinary skills involved in creativity: (1) observing; (2) patterning; (3) abstracting; (4) embodied thinking; (5) modeling; (6) play; and (7) synthesis. Taking time to reflect and apply these skills might be a good start. With regard to intuition, Figure 3 from Sipman et al. (2021) represents an interesting flow and the bibliography of the article is rich and can be an excellent resource.

As Einstein said, intuition, imagination, etc., are gifts. It is important to learn to include them in our scholarship, and so it is each scholar's responsibility to find creative ways to do it.

➢ *UNESCO (2021) recommendations for Open Science*

Teachers should read the recommendations carefully, evaluate what their country/institution already offers (e.g. roadmaps, services) and evaluate how they want to/are invited to change their practice. They can examine the relationship between Open Science and Open Education and seek coaching if they need it. A very inspiring example to scaffold a deep approach to Openness is that led by Ecuador under the name of buen vivir and buen conocer (Arauz, 2022).

➢ *Self-assessment tool for institutional open education practices*

This tool (Morgan et al., 2021) enables practitioners to understand where their institution stands in terms of Openness. Change agents may also want to approach decision-makers inviting them to reflect on the four following dimensions - advocacy, policy, leadership and institutional culture – mandate, reputation, centralization/decentralization – as a starting point for future action.

Suggestions:

➢ *Adopt a critical perspective and question the methods you are using.*

Whether in teaching or in research, we are usually "reproducing" models from different origins. Question your schema, methods, and practices. Where do they come from? Are you deliberately using them and do you agree with their values, epistemologies, etc.? In other words, avoid reproducing approaches "within institutional positivism" (Piron, 2019; Godrie et al., 2020) and question and document yourself until you reach schema, methods, and practices you are aligned with. This takes time, usually months or years.

➢ *Involve learners, communities, and stakeholders in the design of your course.*

Involve learners and other actors in a participatory way from the beginning (e.g., Funk, 2021) and have them choose the learning outcomes that best suit each of them. Depending on how you teach, it might be difficult to change your posture; the Eduvista scale, designed for introducing technology in one's teaching, might be helpful in this respect (Eduvista, 2010–2014).

➢ *Read scholars with experience in Openness.*

Educators who have practiced Openness are numerous. Among the most well-known are John Dewey, Maria Montessori, Paulo Freire, Ivan Illich, and Jacques Rancière.

➢ *Keep up to date with the literature on Open education.*

The literature on Open Educational Practices, Open Educational Resources, and more generally on Open Education is increasing as funded research in this area becomes more common. Try to find inspiring theories, examples, and case studies in this wealth of literature (e.g., Weller, 2014, 2020;

Inamorato dos Santos et al., 2016, 2017; Inamorato dos Santos, 2019; Jung, 2019; Bali et al., 2020a; Burgos, 2020; Farrow and Mathers, 2020; Farrow et al., 2020; García-Holgado et al., 2020; Pitt et al., 2020; Burgos and Berrada, 2021; Burgos et al., 2021; Class, 2021; Stracke et al., 2021; Tlili et al., 2021).

## DISCUSSION AND CONCLUSION

In this reflective paper, we share three findings. The first is at the level of practice: we share an Open Educational Practice (Anderson, 2009; Cronin and Maclaren, 2018; Bali et al., 2020a; Huang et al., 2020; Werth and Williams, 2022) in research methods teaching at the master's level. More generally speaking, this practice opens up discussion for broader suggestions and conceptual tools for scholars willing to adopt Open Scholarship practices.

The second is at the level of reflection and concerns the history and philosophy of education. The findings from the interview and focus group (which encompass samples from both the French- and English-speaking worlds) echo the literature, specifically Rohstock (2015) observation that after World War II, supranational organizations dedicated to education replaced philosophy and history of education with so-called scientific approaches inspired from natural sciences. Reintroducing the former approaches is both called for and timely in the knowledge society.

The third is at the level of theory of knowledge. It concerns Openness in the knowledge creation process, considers knowledge as a common, and links it with scientific (i.e., epistemology, positionality) and social perspectives (i.e., collective intelligence) (Santos, 2016), incorporating factors such as ignorance (Innerarity, 2015a), inspiration, creativity, and imagination (Hayes, 2007).

We think that Open Education is a full-fledged construct that scholars, communities, and other stakeholders must learn about in depth. The public-health crisis has already forced societies to envisage life differently and prepared the ground to weave sustainable Open practices into education. As Peters et al. (2020, p. 1) write: "Historically, pandemics have forced humans to break with the past and imagine their world anew. This one is no different. It is a portal, a gateway between one world and the next. We can choose to walk through it, dragging the carcasses of our prejudice and hatred, our avarice, our data banks and dead ideas, our dead rivers, and smoky skies behind us. Or we can walk through lightly, with little luggage, ready to imagine another world. And ready to fight for it."

The literature shows that over and over again, education and scholarship have been locked into the same roles, actions, and dichotomies—that is, openness vs control, qualitative vs quantitative, free vs paywall, etc.,—endorsed by different actors throughout history (e.g., the state, supranational organizations). Rather than taking a binary approach, that is, on/off (Baker, 2017, p. 132), would not it be more productive to acknowledge that openness coexists with closed/controlled education? A more sustainable approach might be to weave into the fabric of higher education the strong threads of Open Scholarship that have existed at least since the Middle Ages, in a way such that they can thrive in future. Imagination, inspiration, intuition, and creativity should be part of this fabric (Hayes, 2007) to support humanity and its ecosystem[2] (Pelluchon, 2021).

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://doi.org/10.26037/yareta:h7f5kymcnzco5l3xttmfooxwya.

## AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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[2] In our efforts to build a collective intelligence, we might just discover something similar to a universal underlying *golden ratio* (https://en.wikipedia.org/wiki/Golden_ratio) *of Education and Openness*!

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# From understanding a simple DC motor to developing an electric vehicle AI controller rapid prototype using MATLAB-Simulink, real-time simulation and complex thinking

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Electric drives have been used in several applications, such as electric vehicles, industry 4.0, and robotics. Thus, it is mandatory to promote updated electric drive courses that allow students to design novel solutions in these engineering areas. However, traditional undergraduate courses that only cover theoretical aspects and do not allow students to interact and produce practical results through experimentation are insufficient today. The students are not exposed to educational innovation, so they have difficulties proposing original solutions. On the other hand, conventional theoretical and laboratory courses in which students follow specific directions for achieving predefined goals do not allow students to create novel solutions and integrate the innovation process as a standard methodology. Moreover, beginning in 2020, the COVID-19 pandemic forced professors to implement digital tools and materials to continue education intensively. This proposed course presents an alternative to promote practical and theoretical knowledge in students. Besides, engineering students must create innovative solutions to increase the quality of life in rural and urban communities, which calls for novel experimental approaches. Electric drives are fundamental elements in electric systems and industrial processes proposed to save energy or control electric machines. In addition, industries urge specialized engineers who can tackle complex industrial problems. The proposed educational methodology can be implemented in manufacturing, agriculture, robotics, and aerospace. Hence, low-cost devices to validate the proposed solutions became used by students to achieve novel solutions using electric drives. This paper describes an undergraduate course called "Digital Control of Electric Machines" (electric drives) and its implementation of the Tec21 Educational Model of Tecnologico de Monterrey, V Model, MATLAB/ Simulink, low-cost hardware, and complex thinking. The content of the course begins with electric machine models and power electronics that allow students to move from the basic to the advanced industrial electric drive problems in a friendly manner. In addition, the V-model and Modelo Tec 21 are used as fundamental pillars of the leading innovative structure of the proposed course. The results showed that students mastered several soft and hard skills to accomplish complex design goals, including controlling an electric rapid prototype vehicle.

KEYWORDS

**Electric drives, model Tec21, V model, complex thinking, electric vehicle, educational innovation, undergraduate education, rapid prototype**

## Introduction

Since industry and several applications (agriculture and electromobility, for example) require novel electric drives to improve their manufacturing and systems processing, students must have classes that challenge them to propose innovative solutions. Thus, some universities connect their theoretical classes with laboratories that simulate real-world conditions or problems. However, specialized laboratories sometimes have specific schedules and practices that limit their availability and access. Thus, students do not always have exposure to experimental requirements.

On the other hand, students could use low-cost devices to acquire experimental knowledge. Moreover, they can use these devices needed without specific schedules. The Arduino microcontroller board (Banzi and Shiloh, 2022) and MATLAB (MATLAB-SIMULINK (2022)) implement basic and advanced electric drives well. Thus, several applications have used Arduino and MATLAB. For instance, MATLAB and Arduino have been implemented to control a 3-phase inverter with an induction motor, as Zulkifli et al. (2014) presented. Also, Zulkifli et al. (2016) demonstrated that students can implement and use power electronics in experimental work. With the proper selection of low-cost microcontrollers, the students could also develop the PWM switching pattern necessary to drive the converter.

On the other hand, Mi et al. (2005) proposed a continuing course in power electronics that allows students to gain a solid functional understanding of vehicle power electronics, the fundamentals of power semiconductor devices, and the fundamental operation of commonly used power converter circuits. Besides, the students had to solve practical problems such as power device selection and thermal control. This course includes theoretical and experimental content so the students can have an integral vision of the topic. However, when the course is online, low-cost materials must be used. For instance, Asato et al. (2015) showed a low-cost platform to teach mechatronics based on Arduino and a DC drive.

This paper proposes an electric drive course where students learn conventional theoretical concepts and apply them in experimental conditions using low-cost components. One of the proposed course's main goals is to provide students with product design competencies and skills in electric drives. Thus, students must understand and apply the theoretical concepts in experimental scenarios. The practical scenarios similarly give a broad vision of each course topic's design limitations and needs. This course covers basic concepts such as graphical programming, modeling DC and AC motors, DC-DC converters, DC – AC converters, PWM techniques, and Motor control (Bose, 1986; Rashid, 2017). This course could benefit different undergraduate degrees since electric drives are used in applications in several areas. The simulations and experiments are performed using Arduino, MATLAB, and Simulink because the necessary time for developing and testing theoretical ideas is as soon as possible. The students have to learn how to create rapid prototypes quickly. If they take too long to create a rapid prototype, they do not get feedback about it to improve the design.

Moreover, they need to gain practical knowledge when designing experimental prototypes, so making mistakes is desirable; they must learn from them. Errors also help them acquire the knowledge they need. If they complete an advanced prototype that requires changes in the design, they spend more money and time adjusting this advanced prototype than modifying a simple one. So the students need to develop rapid prototyping skills at the beginning of the course. They can use low-cost hardware such as Lego robots and Arduino and focus on specific solutions based on software.

In addition, some experimental exercises are implemented in real-time (OPAL-RT, Bian et al., 2015, and MATLAB/Simulink) to achieve a high fidelity model such as a DC-DC or DC-AC converter in power electronics for electric drives. Thus, students understand industrial drives in a friendly manner. Since MATLAB/Simulink is also used by industry, students can continue using these programs in their professional careers. Besides, the conventional simulations based on Simulink blocks for power electronics converters can be implemented in real-time simulation without changes.

## The general structure of the proposed course

Low retention rates and students' decrement of knowledge in specific areas imply that the students need different educational structures to solve complex problems. Moreover, they usually do not connect their courses with the real world (Arthur James, 2015; Tao et al., 2017). Besides, complex thinking requires analyzing specific problems from different perspectives, proposing and assessing several solutions, and being cognitively and emotionally flexible to create innovative solutions (Bartunek and Louis, 1988). To promote complex thinking, this course integrates theoretical concepts, industrial needs, and the creation of rapid prototypes.

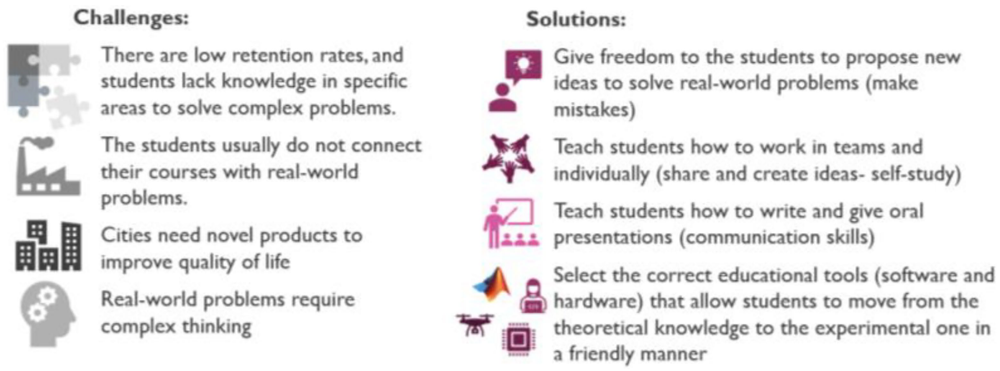


FIGURE 1
Some of the most critical challenges and solutions in the course.

Figure 1 shows the challenges and solutions implemented in this course. This electric drive course has three main components: conventional theory, experimental exercises, and the generation of new solutions (innovation). The conventional theoretical concepts covered in this course are presented in Table 1; the students have to do homework, projects, and exams on each topic.

After completing each theoretical section, the student has to run an experimental project connected with a real problem; industry partners usually provide these problems. Thus, the student has to apply the theoretical concepts and develop a rapid prototype using the components implemented in the experimental section of the course to validate the proposed solution. In addition, students have to present their proposals and research document. The undergraduate course was designed to reference the V-Model and the Tec-21 educational model so that the students could create solutions faster than in conventional classes. Figure 2 shows the V-Model in which the design stages for achieving a rapid prototype and the acquired competencies. The presented V-model for education was established as an inherent structure that could be incorporated when real solutions are created.

The Tec21 Educational Model of Tecnologico de Monterrey (Tec 21 Model, 2018) integrates a Challenge-Based-Learning framework that improves course flexibility and tailors the learning experience. Hence, students gain a focused specialty in the professional areas that motivate them [Tec 21 Model]. In addition, the Tec21 model is for Higher Education Institutions that seek more experiential learning and academic motivation and commitment. This paper shows how the educational TEC 21 model[1] proposed by Tecnologico de Monterrey and the V model (Shuping and Ling, 2008; Mathur and Malik, 2010) used in industry to develop products are integrated into an undergraduate course promoting complex thinking. It allows students to apply the theoretical concepts in experimentation in a friendly and swift manner using advanced software tools such as MATLAB and Simulink.[2]

1 https://tec.mx/es/modelo-tec21#section2

2 https://www.mathworks.com/products/matlab.html

Moreover, at the end of the undergraduate course, the students can solve real problems using complex thinking to combine practical and theoretical knowledge to solve advanced real engineering problems. As presented by Alkhatib (2019) and Ramírez-Montoya et al. (2022), complex thinking allows students to identify and define problems, create solutions, evaluate the outcomes, and satisfy the requirements of "Education 4.0." Thus, the course material aims to promote complex thinking and combine theoretical and practical knowledge to create solutions.

Figure 2 shows the competencies developed in the V-model. The developed competencies in the Tec 21 model are transversal and disciplinary as follows [Tec 21 model]:

Transversal competencies: self-knowledge and management, innovative entrepreneurship, social intelligence, ethical and citizen commitment, reasoning to face complexity, communication, and digital transformation.

Disciplinary competencies: theoretical knowledge and skills necessary for professional practice in the selected career.

As a result, the V-model and Tec 21 model can be integrated educational tools in a challenge-based learning structure. The course evaluation is based on students' competencies and knowledge; memorization of concepts is not allowed in the class. This course led students in the following:

- The students are guided to propose innovative solutions.
- They experience active learning.
- The students acquire deep learning.
- They learn backward reasoning.
- The students reflect on their learning.
- They gain research skills.
- They acquire self-directed learning skills.

The proposed electric drive course at Tecnologico de Monterrey is associated with the electrical energy program. This course has 48 h provided over 16 weeks. Each class is planned on a 3-h basis, so the topics are distributed among the classes. As mentioned, the V-model structure is implemented in this course to familiarize students with designing rapid prototypes that can be evaluated.

TABLE 1 Main content of the course.

| Topic /theoretical content | Educational Tool Implemented |
|---|---|
| Model of DC motors (dynamic and stationary models) | MATLAB and Simulink (simulations and validation in the laboratory) |
| Model of AC motors (dynamic and stationary models) | MATLAB and Simulink (simulations and validation in the laboratory) |
| Introduction of digital systems and DC-DC converters | MATLAB/Simulink and Arduino Real-time simulation using OPAL-RT |
| Sequential process using ON–OFF controllers | Simulink/Arduino Simulation and Experimental design |
| P+I+D controllers (closed-loop) using DC motors | Simulink/Arduino Simulation and experimental design |
| P+I+D controllers tuned by genetic algorithms | MATLAB and Simulink/Arduino Simulation and experimental design |
| Fuzzy logic controllers type 1 and 2 | MATLAB and Simulink/Arduino Simulation and experimental design |
| Perceptron and artificial neural networks (multilayer controller) | MATLAB and Simulink/Arduino Simulation and experimental design |
| DC-AC converters (real-time)<br>PWM Sinusoidal/Space vector | OPAL-RT/MATLAB and Simulink/<br>Arduino |
| V/F control for AC motors | Opal-RT MATLAB –Simulink |
| Vector control for AC MOTORS | MATLAB and Simulink Simulation and industrial equipment |
| Direct torque control for AC motors | MATLAB and Simulink Simulation and industrial equipment |

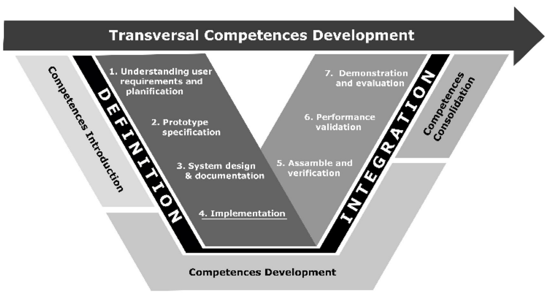


FIGURE 2
V-model and the developed competencies.

The course content is divided into three main modules. Industries are invited to provide an industrial challenge for students to resolve in each module, so they also get information from their experience with real problems requiring novel solutions (see Figure 3). At the end of each module, the students develop a project connected with an actual application. The final project is the combination of the content of the complete course. Besides, students continuously develop rapid prototypes using software and hardware, allowing them to define and validate complex solutions with low-cost hardware. The primary software programs are MATLAB and Simulink. Figure 4 presents the essential content of the course. The course evaluation is based on projects, homework, and exams. Projects are created in teams of no more than four members who participate in theoretical and practical approaches to each topic. Each team is permitted to propose its emphasis as part of the project description. As a result, several project deliverables with distinct methods emerge. Also, each student is responsible for giving a grade to other pupils (it is a different grade used as feedback for the team). The written report format is based on scientific journals such as IEEE.org. After team members have graded several projects, they can discuss their results concerning ways of improving the projects. As Tlhoaele et al., 2015 suggested, some students learn better from their classmates' feedback.

There are several papers about teaching electric drives in undergraduate courses; however, there is a gap in teaching electric drives using projects based on experimental designs using low-cost hardware to implement complex systems that are linked with industrial needs. Moreover, low-cost hardware can be used to implement advanced controllers that can improve the performance of conventional ones. For example, Arduino is a basic microcontroller that can be used as an acquisition system and running the main control algorithm programmed in Simulink into a conventional PC so advanced controllers can be implemented and evaluated by students. On the other hand, Simulink is a high-level programming language so that students can learn it in a short period of time. This course starts teaching the fundamentals of electric machines and finishes teaching vector control and direct torque control (DTC) using AI, which are advanced topics. It is difficult to teach those topics using conventional educational methodologies; thus, the proposed methodology promotes theoretical and experimental activities so students can learn from these two sources.

On the other hand, this course has been running online since the COVID-19 pandemic forced us to have virtual courses. Students adopted and accepted the course since they could continue getting theoretical and practical knowledge without attending laboratory sessions. One of the main concerns in distance education is experimental knowledge because engineering courses focus on solving real problems, and those experimental exercises are crucial for developing practical skills. It has been demonstrated that simulation-based labs cannot give the complete practical knowledge required in engineering (Borrego et al., 2009; Bielefeldt, 2011). Thus this course provides a solution because the students gain meaningful and relevant experimental knowledge using low-cost material. Also, this course allows students to conduct basic and advanced exercises to solve real problems presented by industry. In general, the skills and knowledge that students gain during the proposed curse are presented below.

- Gain the ability to solve real problems regarding electric drives.
- Understand DC and AC machines.
- Understand basic and advanced industrial controllers for electric drives.
- Gain the ability to design and select hardware components to solve complex problems.
- Conduct real experiments and analyze data.
- Understand clearly the results of the experiment to improve the proposed solution.

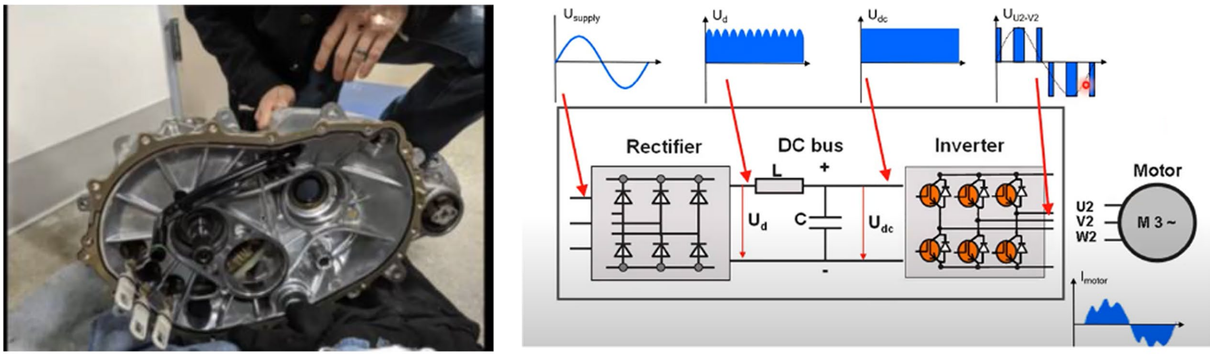


FIGURE 3
Industrial speakers invited to show industrial challenges (electric vehicles and pumping) in the class (National Instruments and ABB).

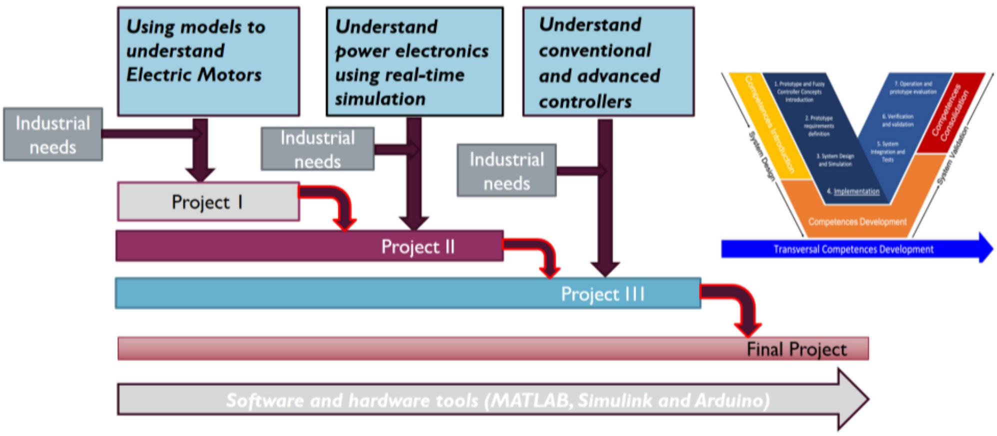


FIGURE 4
Fundamental course content.

- Work in collaborative teams and individually.
- Communicate orally and written effectively.
- Learn the necessary engineering tools regarding electric drives for engineering practice.

On the other hand, the main disadvantage of this methodology is presented below.

Some students do not connect theoretical knowledge completely with practical exercises, so they require more time to complete them during class. Besides, creating support videos is time-consuming for professors; sometimes, the students do not watch the complete video, do not get all the information shown, and ask about topics presented in the supported videos. The cost of the components is low, but the shipping time could be high, so the material has to be shipped before the course starts to avoid a negative impact on the timetable. The complexity of industrial problems must be adjusted to get the correct timetable and complexity, so some industrial projects are partially solved or eliminated from the industrial problem list.

## Content of the course and supportive materials

The proposed course includes simulation and experimental exercises that allow students to gain practical experience. Hence, the students can detect specific engineering areas that could be improved in real applications. The first section of the course deals with electrical machine models. These are explained to achieve models based on the first principles, gray box, and black-box models. The second section deals with the design of electric drive controllers, and the third stage covers advanced electric drive controllers using AI controllers. Table 1 shows the main activities developed on each topic.

It is essential to mention that short demonstrations and validations of theoretical concepts are also conducted after the end of each section. For instance, when DC motors are explained, steady and dynamic models are covered, and the motor's performance is demonstrated in the laboratory to confirm the results. Figure 5 shows different DC machine models and the comparison against experimental results from an actual motor. A Simulink diagram for getting the torque and speed curves in a transitory response model and steady stay are deployed. Also, students learn how these models could be used to describe the performance of the DC motor. Some experimental results, such as a field weakling region, are also validated in the laboratory in steady-state and transitory states. As an example, Figure 5 illustrates how a black-box model can be implemented to get a second-order transfer function in MATLAB and how the transfer function can be obtained using the System identification toolbox. For deriving the second-order transfer function of the DC motor, equations from (1) to (12) are used. The input is a step voltage, and the output is the motor speed; the experimental values are collected in the laboratory to find the transfer function. These equations presented below illustrate how a DC motor can be modeled using a simple black box model using a second order transfer function that is possible to implement when the poles p1 and p2 are far enough. Since the main idea of the course is to show basic and advanced models of electric machines, these equations describe a straightforward methodology for modeling DC motors at the beginning of the course as an initial topic in which students go to the laboratory to collect experimental data and use it to determine the transfer function.

$$Y(s) = \frac{k}{s(s+p_1)(s+p_2)} = \frac{A}{s} + \frac{B}{s+p_1} + \frac{C}{s+p_2} \tag{1}$$

$$A = sY(s)\big|_{s=0} = \frac{k}{p_1 p_2} \tag{2}$$

$$B = (s+p_1)Y(s)\big|_{s=-p_1} = \frac{k}{p_1(p_1-p_2)} \tag{3}$$

$$C = (s+p_2)Y(s)\big|_{s=-p_2} = \frac{k}{p_2(p_2-p_1)} \tag{4}$$

Speed time value:

$$y(t) = \left[A + Be^{-p1t} + Ce^{-p2t}\right]u(t) \tag{5}$$

$$z(t) = A - y(t) = -Be^{-p1t} - Ce^{-p2t} \tag{6}$$

$$z(t) = -Be^{-p1t} \tag{7}$$

From the experimental response A and p1, we find:

$$y_f(t) = A + Be^{-p1t} \tag{8}$$

$$B = \frac{y(t) - A}{e^{-p1t}} \tag{9}$$

$$C = -(A + B) \tag{10}$$

$$p_2 = -\frac{B}{C}p_1 \tag{11}$$

$$k = A p_1 p_2 \tag{12}$$

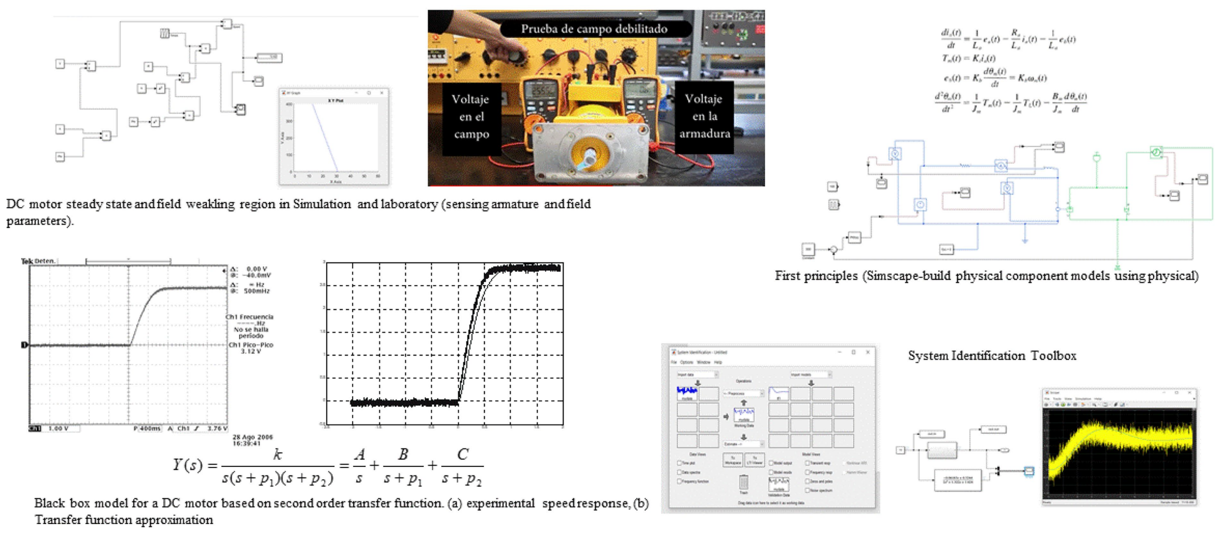


FIGURE 5
DC motor steady-state response, dynamic response, and field weakling operation region in simulation and laboratory (sensing armature and field parameters).

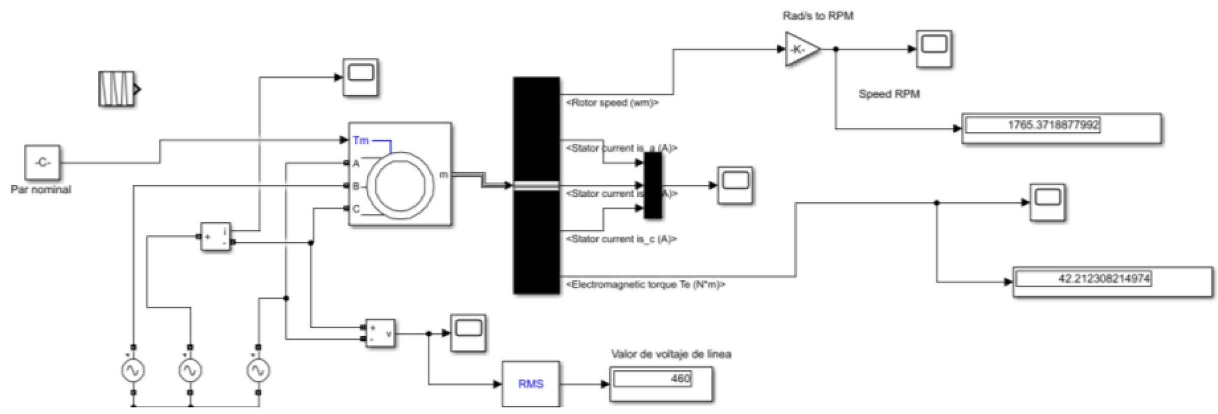


FIGURE 6
Model of the induction motor using a Simscape induction motor block diagram (stationary reference frame).

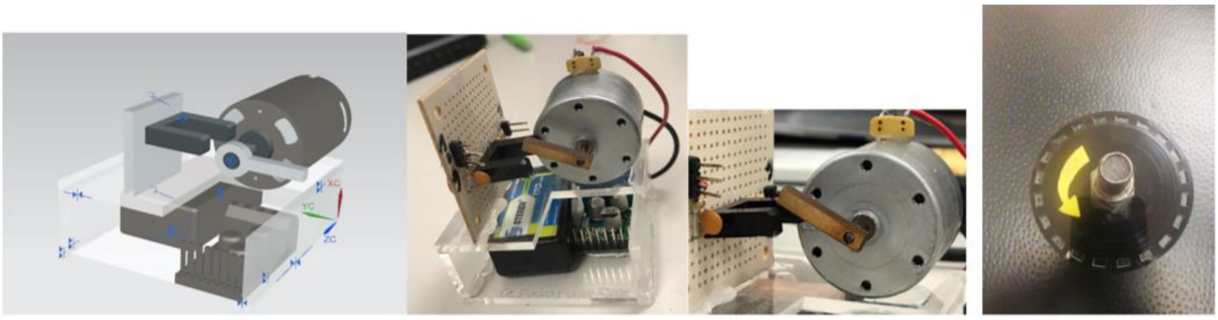

FIGURE 7
Essential speed and position sensor for teaching operation in a closed-loop.

Similarly, AC motors are studied using steady and dynamic models; the students can develop a block diagram of AC machines using a stationary or rotatory reference frame, as shown in Figure 6. Then they can use the model of an AC machine in Simscape [MATLAB]. It is essential to show that students also create models using Simscape/MATLAB. They can build physical component models using physical connections linked with block diagrams to represent the physical elements involved in the system instead of using generic transfer functions only (see Figure 5).

Also, it is noteworthy that students at the beginning of the course do not know how to program in MATLAB or Simulink. Thus, students must run basic models and increment the complexity of the programming tasks as the course moves forward. Additional online resources are reviewed by students, such as MATLAB on Ramp and Simulink on Ramp.[3] An Arduino board is one of the students' first approaches to digital controllers. Since the program is in a graphical language (Simulink), they can move to advanced digital systems such as C2000 micro-controller/Texas Instruments. Students also develop basic sensors to understand how speed and position sensors work in a closed-loop control (see Figure 7).

As a result, they can generate advanced electric drives (Rashid, 2017). The power electronics stage (converters DC-DC and DC-AC) is studied using real-time simulation since converters require high fidelity to be modeled. Besides, hardware in the loop can be validated using the same Simulink block diagrams used in a conventional simulation. Figure 8 depicts the real-time simulation running power electronics converters that allows students to accomplish high-fidelity models.

When conventional controllers such as ON–OFF and Propor tional+Integral+Derivative controllers are studied (Voda and Landau, 1995), additional material is provided for validating the theoretical concepts during experimental exercises. The students interact with the Arduino board to develop some controllers, and thus, students can get experimental knowledge. Figure 9 illustrates some examples of conventional controllers implemented using MATLAB/Simulink and Arduino. In addition, a series of supporting materials are created to self-study so students can confirm theoretical aspects with experimental ones. Moreover, the students can propose new solutions to practical problems.

Some additional optimization techniques are also presented in the course, such as genetic algorithms to tune conventional controllers offline (Thomas and Poongodi, 2009). This optimization technique has been used in several applications of

3 https://matlabacademy.mathworks.com/

electric drives (da Silva et al., 2000; Montazeri-Gh et al., 2006). The optimization editor developed by MATLAB is used, so students do not have to focus on programming the algorithm, and they are focused on creating an optimal solution using the optimization methodology (see Figure 10).

Advanced and conventional control topologies for controlling AC machines are also presented. In the beginning, scalar control (V/F), Peña and Díaz (2016), is studied and analyzed during different industrial applications, and students simulate the electric drive and connect the simulations with real applications (see Figure 11). Students must understand that DTC (El Ouanjli et al., 2019) and vector control are designed to obtain two main control channels, one for the torque and the other for the flux, like a conventional DC drive. Thus students can use the traditional controllers to generate speed or position controllers. These topologies are well known and implemented in several applications. However, some industrial applications improved their performance using artificial intelligence systems. Thus, students need to know intelligent systems to create innovative solutions. When intelligent controllers (Neuro controllers, Fuzzy Logic Controllers, and ANFIS controllers, Vas, 1999; Ponce-Cruz and Ramírez-Figueroa, 2009) are presented, supplementary material is provided to give complete information about the theoretical and practical concepts necessary to implement advanced controllers. Some examples are developed in classes, and advanced exercises are proposed as a solution for industrial applications. The MATLAB editor of Fuzzy logic and artificial neural networks is used ([MATLAB]), so students focus on creating solutions that improve the performance of conventional control structures of electric drives. Figure 12 illustrates the fuzzy editor and a temperature controller using a DC motor (a fan). Figure 13 shows the DTC topology and a proposed scheme to

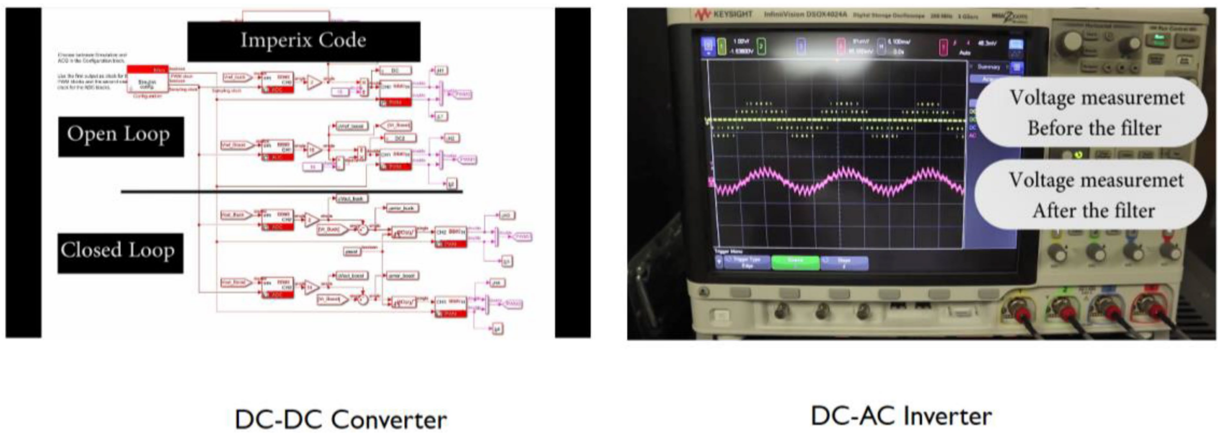


FIGURE 8
Real-time simulation DC-DC and DC-AC converters.

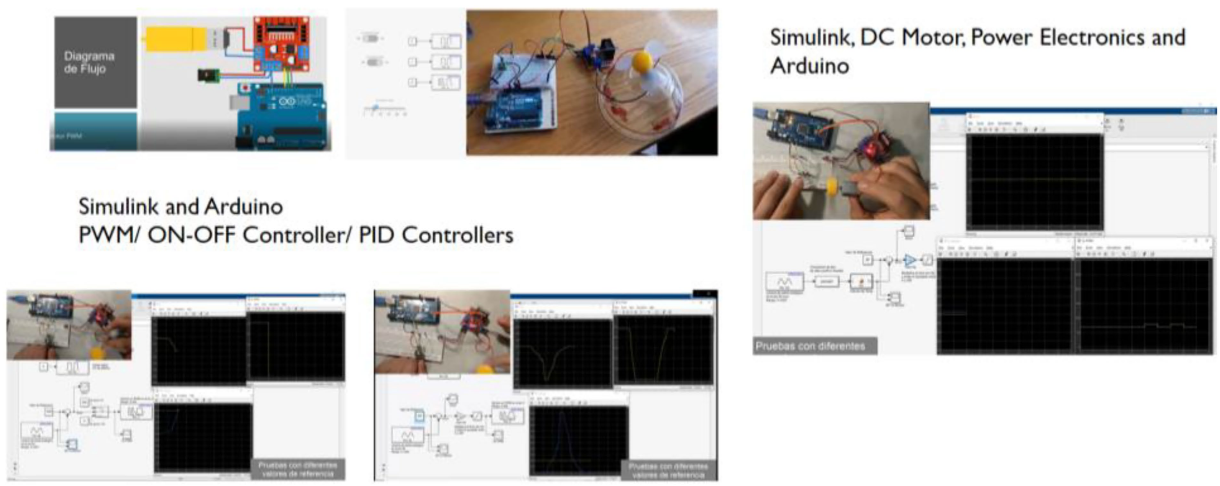


FIGURE 9
Implementation of conventional controllers.

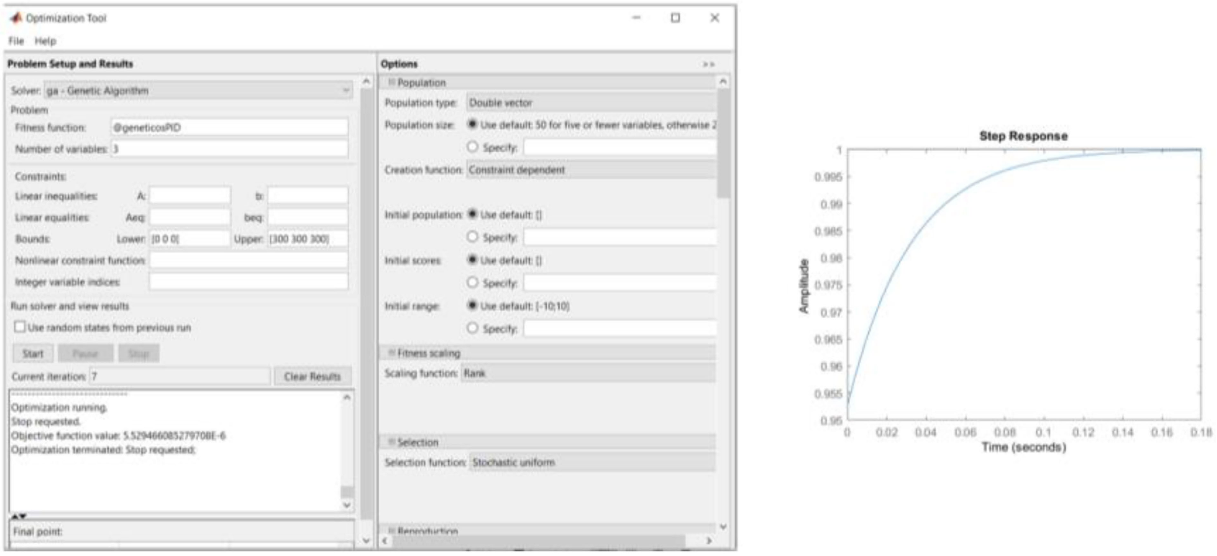


FIGURE 10
Tuning a conventional PID controller using genetic algorithms.

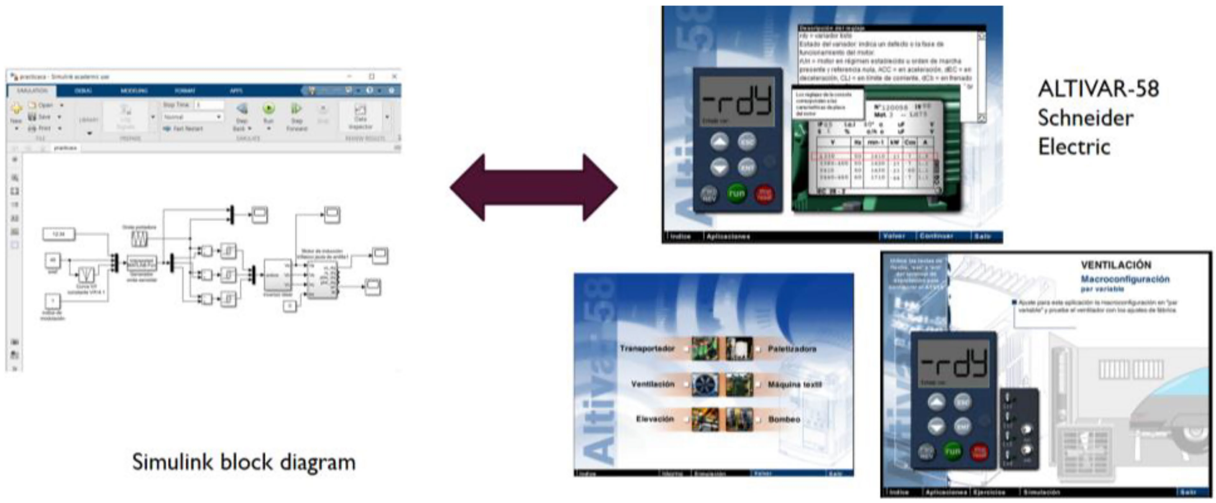


FIGURE 11
Industrial applications solved using an industrial drive (Altivar-58) and the Simulink block diagram designed by students to understand and propose new solutions.

reduce the torque and flux ripple using fuzzy logic controllers and artificial intelligence. Conventional vector control and proposed topology for AC drives are presented in Figure 14.

## Electric vehicle rapid prototype

Students use low-cost materials to develop a proposed rapid prototype of an electric vehicle, which is a complex problem. The main goal is to develop solutions that improve the performance of the electric vehicle in specific operating conditions such as navigation or parking (Chan, 1993; Wirasingha and Emadi, 2010). Sometimes, students propose using intelligent controllers like artificial neural networks or fuzzy logic controllers. The rapid prototype is not entirely functional since it is only used to validate the specific performance during an operation. Potentiometers, like analog inputs, implement different sensors, so students can add the number of sensors they require without spending money. After the students validate the rapid prototype, some continue developing a complete version of the functional prototype. In this stage, students understand the models and the conventional control algorithms for DC and AC electric drives and power electronics deployed in electric drives. Figure 15 presents a

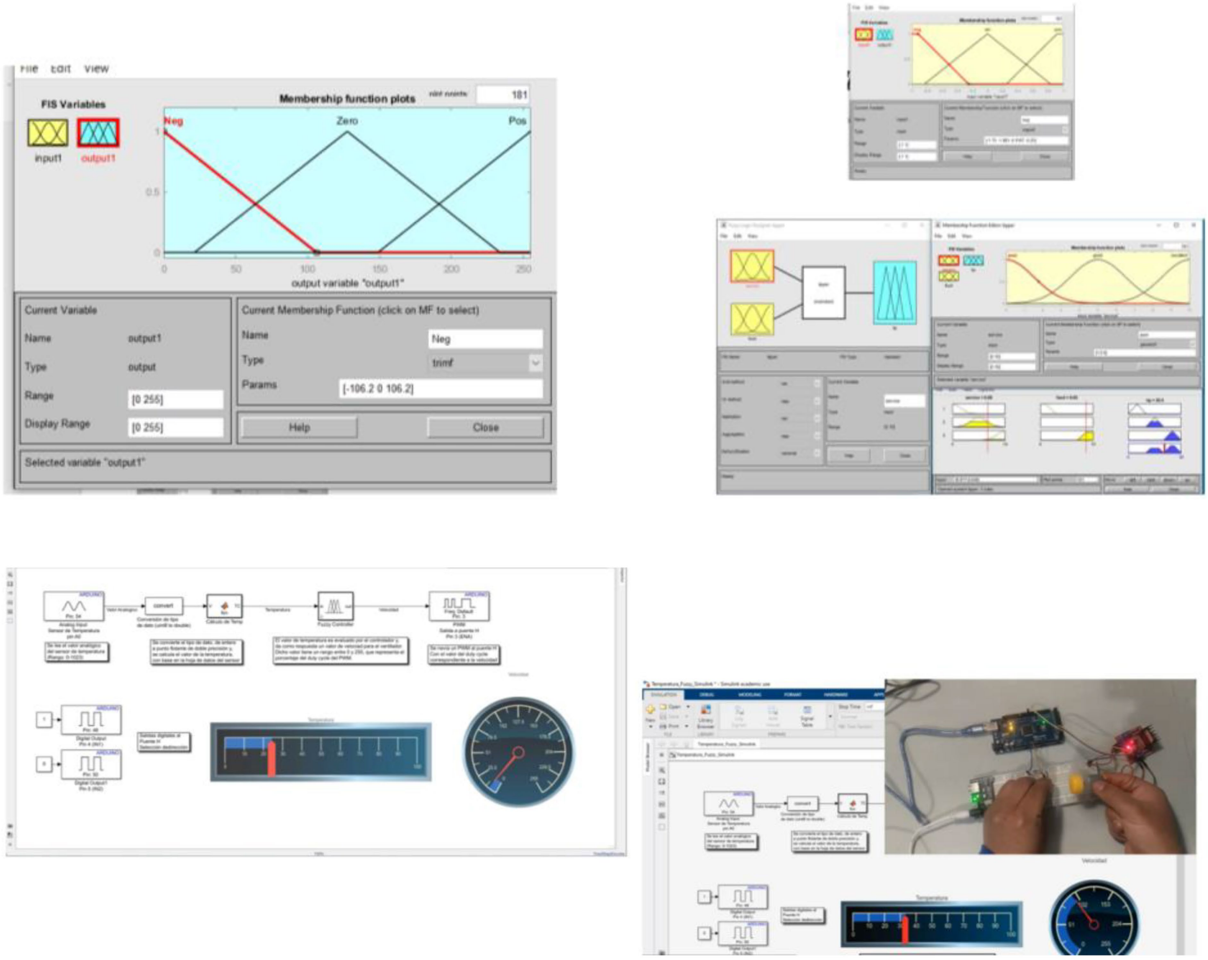


FIGURE 12
Fuzzy logic controller programmed using the fuzzy logic editor of MATLAB.

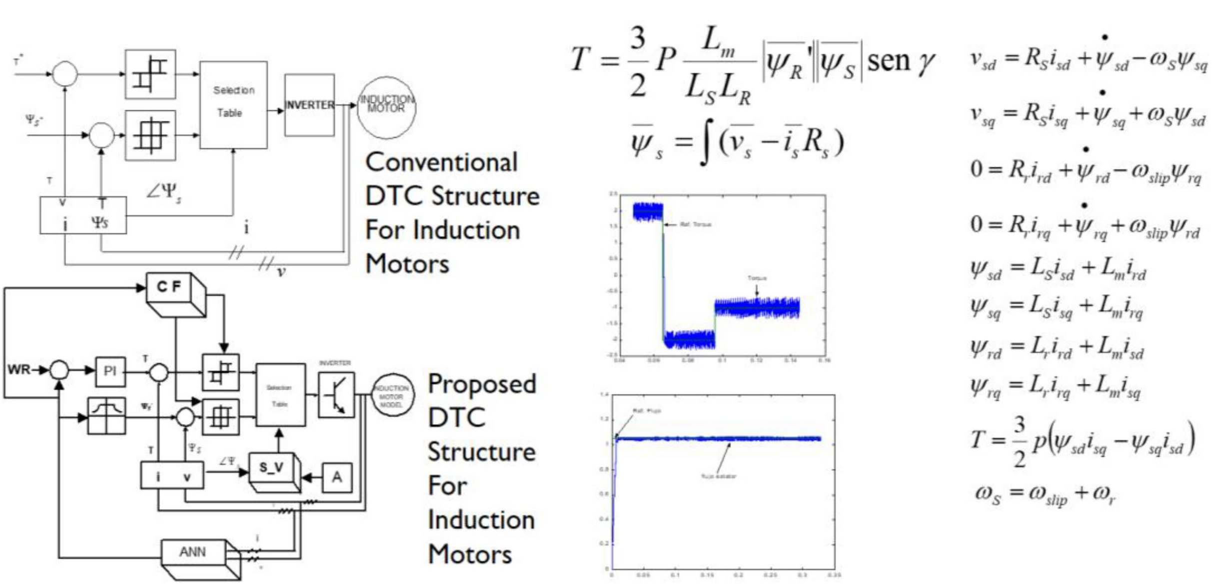


FIGURE 13
Conventional structure of a DTC scheme.

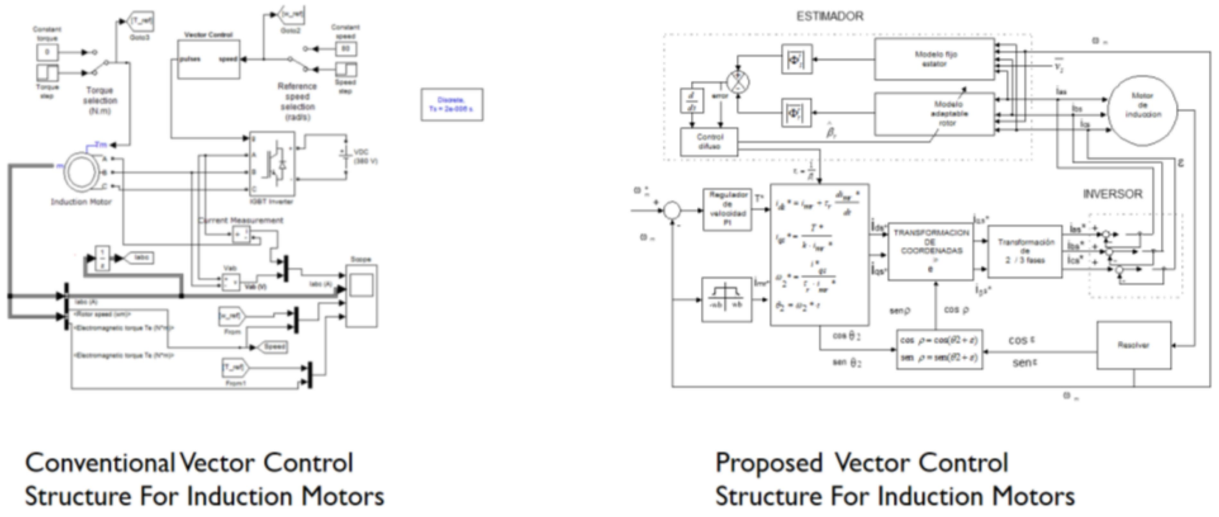


FIGURE 14
Conventional vector control and proposed control topology.

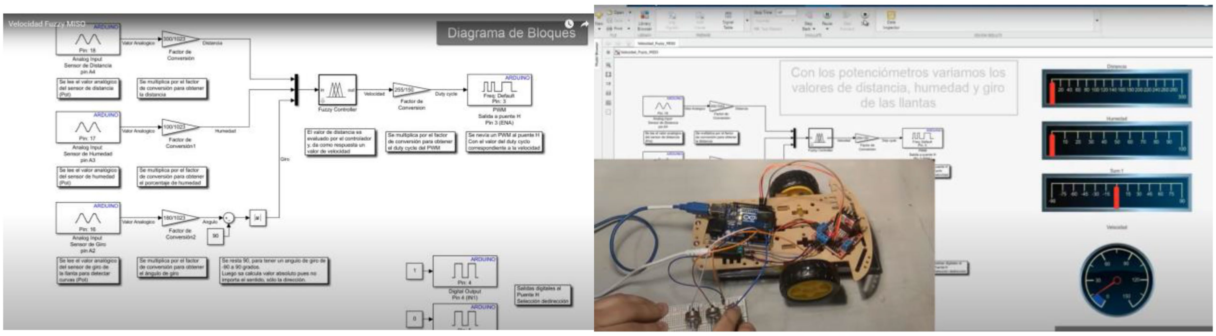


FIGURE 15
Electric vehicle rapid prototype using a fuzzy logic controller.

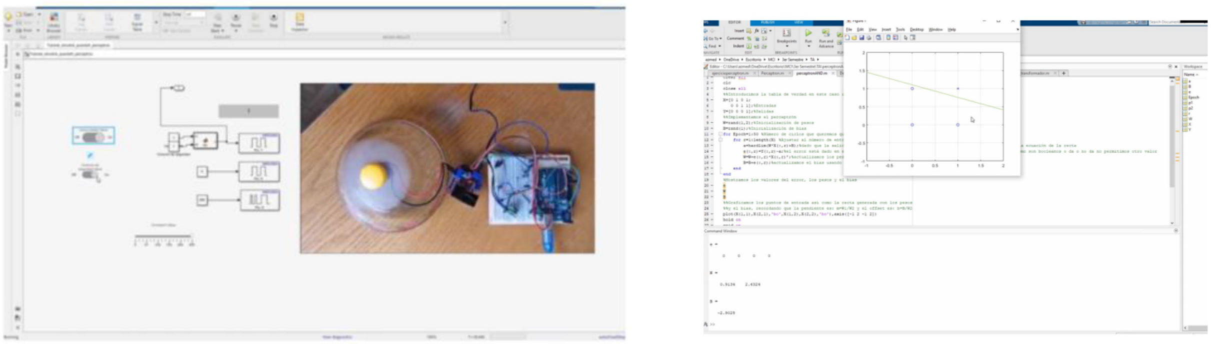

FIGURE 16
The basic structure of a perceptron programmed using MATLAB.

Mamdani-type fuzzy logic controller designed for parking, and Figure 16 illustrates a perceptron that is the primary element in a neural network topology. An artificial neural network controller (based on a multilayer structure) designed to avoid obstacles during navigation is presented in Figure 17. The fuzzy logic and neural network controller are created using a primary hardware platform of DC motors, so the students only validate the specific operation of the electric vehicle.

However, the DC drive can be changed to an AC drive when a DTC or vector control is implemented since these techniques mimic the performance of DC drives using two channels, one for the torque and the other for the flux. Figure 18 illustrates how students can move from the rapid prototype to the complete functional prototype of an electric bicycle. This electric bicycle was

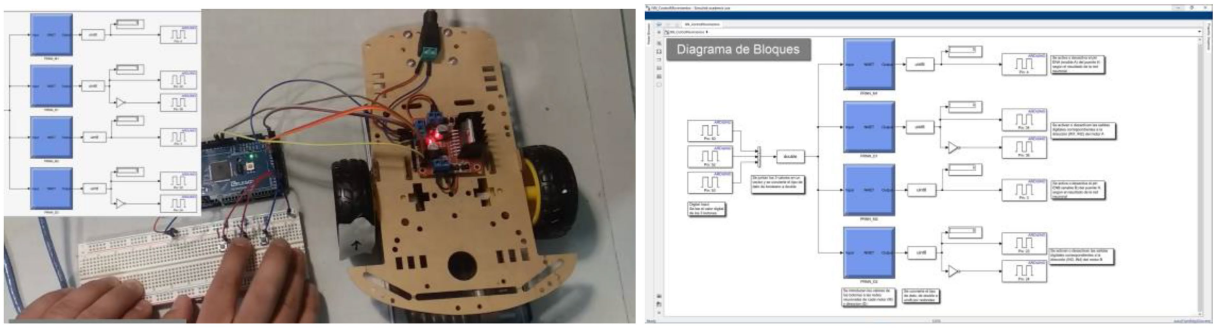


FIGURE 17
Artificial neural network controller for an electric vehicle (rapid prototype).

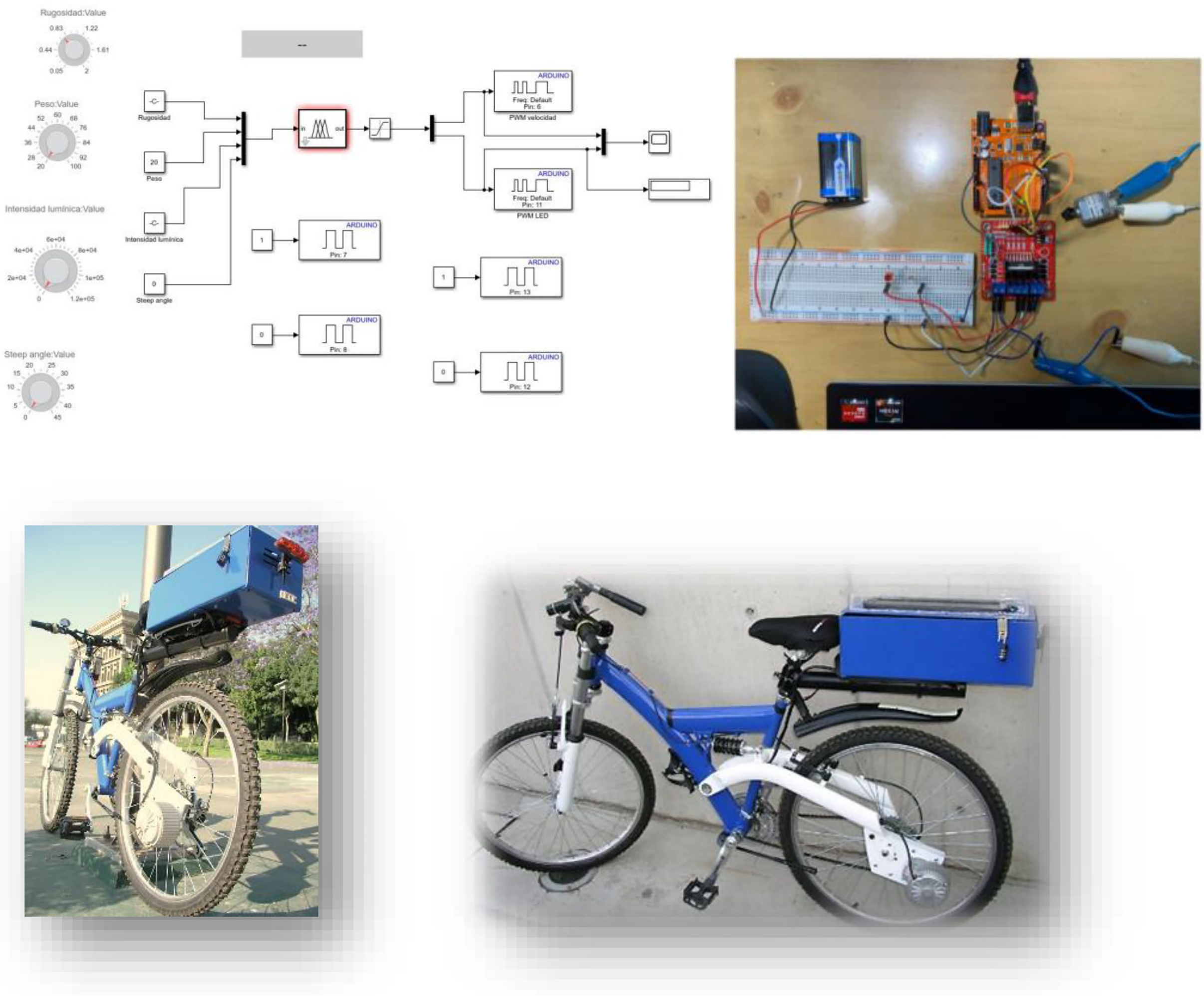


FIGURE 18
Electric bicycle from a rapid prototype to a functional prototype.

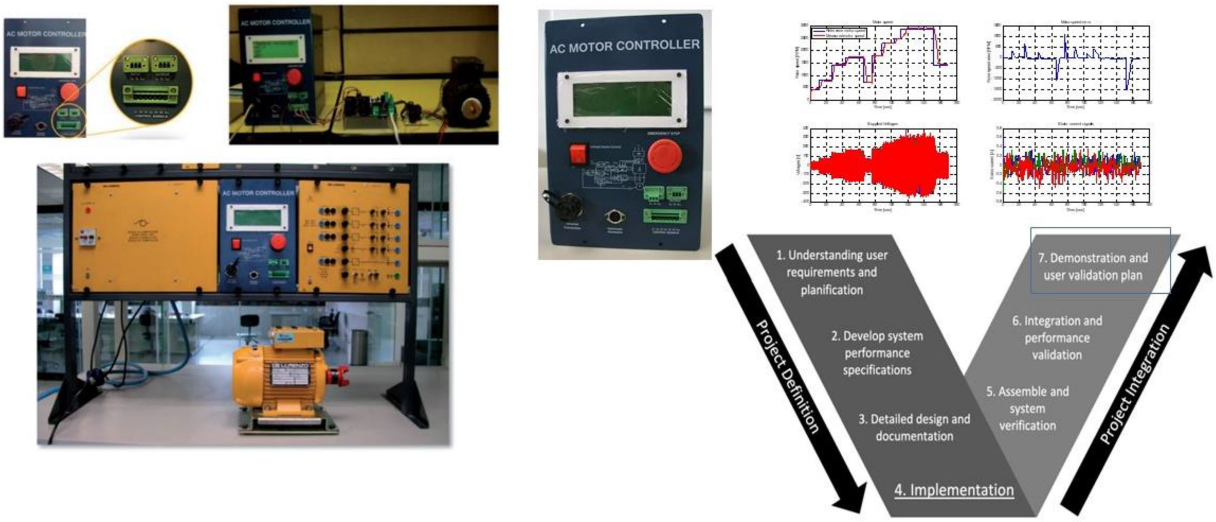


FIGURE 19
Field oriented controller for induction motors functional prototype.

FIGURE 20
Prototype's evolution using the end-user feedback.

developed using solar panels to charge the battery pack in the DC drive. Students assessed different control topologies in the Arduino board and created a functional prototype. These project assessments determine the progress level in the V model as a reference so students can realize how far they are from producing a commercial product. It is essential to mention that some projects achieve only the first stages in the V model. Nevertheless, the students understand, define, and propose a solution for a real complex problem that could be implemented. Figure 19 shows a field-oriented controller for an induction motor that achieves the last stage in the V model. It is important to mention that there are some drawbacks when the hardware is implemented. These drawbacks are explained below. Figure 20 illustrates the evolution of an educational training module to teach electric drives. It is essential to observe how the prototypes are changing according to the end user's feedback, so the final version of the prototype achieves all the end user's requirements.

To implement low-cost hardware systems, students have to break down a whole system into basic components to detect fault conditions or improve performance, but they are unfamiliar with breaking down a whole system. Moreover, the selection of specific hardware components for solving an application is unclear when the curse starts.

Besides, some students are unfamiliar with digital systems, so advanced digital systems cannot be taught at the beginning of the course. This is the main reason that Arduino is a good starting point regarding digital systems. In addition, real-time simulation is evaluated in the power electronics section, so students have to learn about FPGAs and DSPs. This course only gives information for understanding the essential information about advanced digital systems, but it does not cover all the technological and practical issues about advanced digital systems.

There is a general introduction about the hardware at the beginning of the course, but the students must independently deal with more advanced problems. The professor has to deal with a short period of time to cover the material, so additional activities are crucial in this curse; additionally, specific homework is assigned to students with less knowledge about digital systems.

The experimental examples have a time limit of 2 h, so some students require more time because they have to detect fault conditions. However, at the end of the course, all the students can finish the experimental exercises in time. If low-cost hardware is implemented as an embedded system, the memory and processing time could be limited in the implementation. However, they can be replaced to implement advanced electric drives. In addition, a sample of 95 students who took the course answered the survey presented in Table 2. It is essential to mention that the survey results show that students accepted and adopted the course of this electric drive. Moreover, the course helps develop their career goals. Finally, Figure 20 shows the general results obtained in the course. It is essential to comment that there are some limitations from the previous advanced digital systems knowledge since the students did not take a course on this topic previously. Thus, during the course, specific topics are covered. Besides, the percentage of students that get a final grade equal to 60/100 is low compared to students that get a grade of 85/100 points; the minimum grade to pass the course is equal to 70/100. Similarly, the number of students that course previous electric machines and control system topics is high (see Figure 21). The grades and feedback regarding the written report were evaluated based on the following elements (Scoles et al., 2000; Gibson, 2001; Ihsan et al., 2012): general appearance, title page, table of content, figures and tables, section heading, subheadings, introductions, development, conclusions, and references.

TABLE 2 Evaluation survey regarding the electric drives course.

| Question | Students' response |
|---|---|
| Considering your development in your career goals, does this course fulfill your expectations and needs to achieve these goals? | 84% yes it does<br>10% no it does not<br>6% not sure |
| What is this course job-related with your personal and professional? | 88% yes it is<br>2% no it is not<br>10% not sure |
| Was the course material up-to-date according to your needs? | 95% yes it was<br>5% no it was not<br>0% not sure |
| Was the content of the course challenging and interesting based on the topic of the electric drive? | 99% yes it was<br>1% no it was not<br>0% not sure |
| Were the learning outcomes of the course clearly defined during the course? | 100% yes they were<br>0% no they were not<br>0% not sure |
| Would you recommend this course to other students? | 90% yes they would<br>5% no they would not<br>5% not sure |
| Do you use time effectively to solve theoretical and experimental endeavors? | 88% yes they do<br>10% No they do not<br>2% Not sure |
| Do you cooperate actively with all the members of the team? | 98% yes they do<br>0% no they do not<br>2% not sure |
| Do you successfully face tasks that require significant research? | 90% yes, they do<br>1% no. they do not<br>9% not sure |
| Were you able to complete individual tasks without assistance from assistance and teammates? | 85% yes, they were<br>15% no, they were not<br>0% not sure |
| Do students develop and use effective interdisciplinary communication skills during the course? | 80% yes, they do<br>9% no they do not<br>11% not sure |
| Can students explain how electric drive topology can be designed and installed in industrial applications? | 85% yes, they can<br>10% no, they cannot<br>5% not sure |
| Do students gain confidence as students and professionals in studying and evaluating research and advances in electric drives in industrial applications? | 90% yes, they do<br>1% no, they do not<br>9% not sure |
| Overall how do you rate this course? | 94% excellent<br>5% regular<br>1% not good enough |

## Conclusion

This undergraduate course structure allows students to propose original solutions to complex problems and develop transversal and multidisciplinary competencies using complex thinking in electric drives. Moreover, this course confronts the students with real scenarios where they have to create rapid prototypes to assess ideas to improve the performance of electric drives in several applications. Thus, the students can get feedback from end-users. The students begin this undergraduate course by developing basic DC motor models. Finally, they can create a rapid electric vehicle prototype and assess the results. Besides, they can connect the experimental results to gain valuable experience in creating practical electric drives.

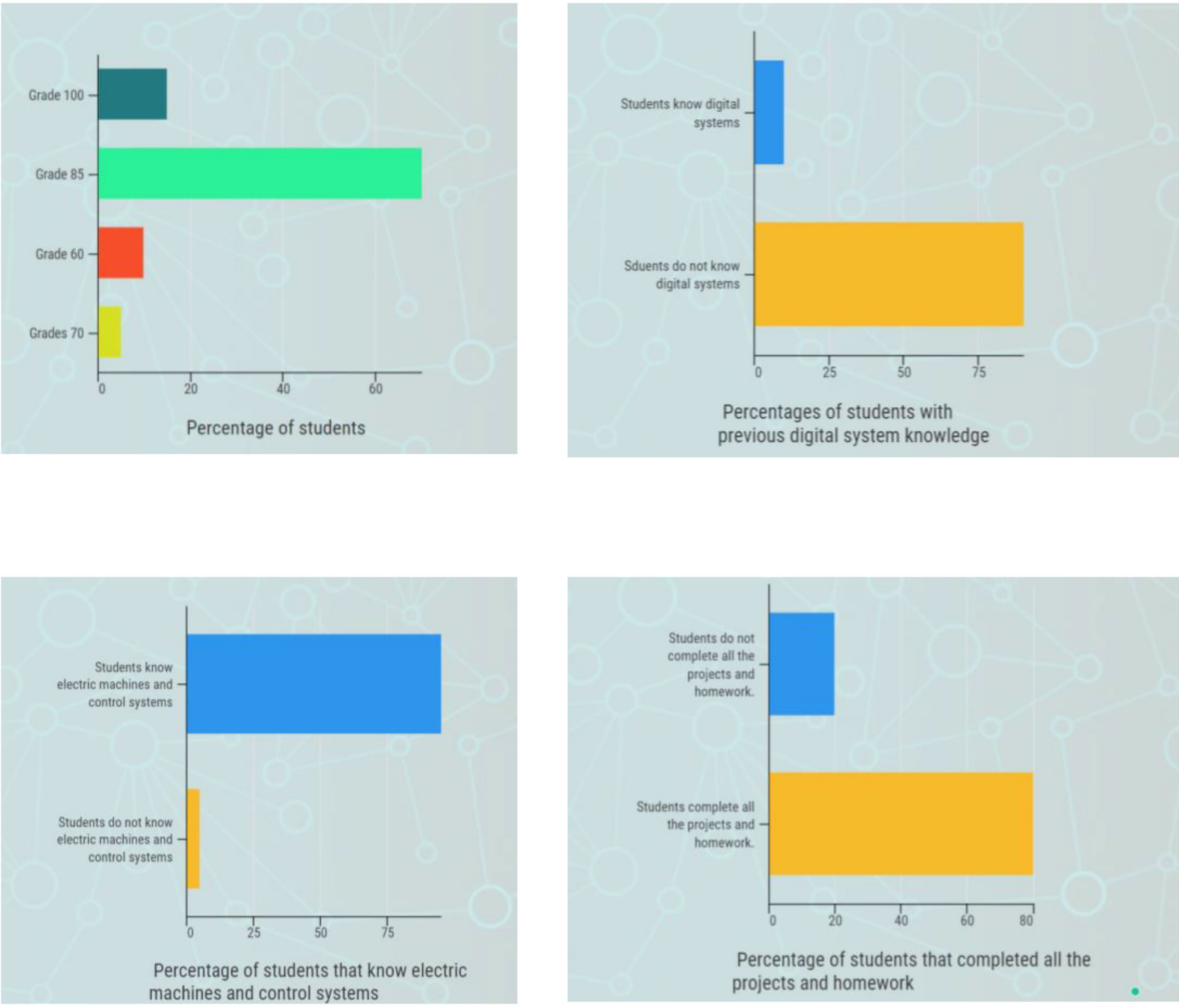


FIGURE 21
General assess of the electric drive course.

This paper shows how students can learn not only theoretical concepts of electric drives but also propose solutions to real complex problems and combine information from industry and academia using the Tec 21 Educational Model and the V model. In this structure, industry partners provide real problems to students in each course section to resolve as challenges. Thus, students must develop and propose innovative solutions to improve the performance of electric drive applications. The students become familiar with industrial problems and how the industry tries to solve them. The students begin with theoretical concepts and move to practical results using MATLAB, Simulink, and OPAL-RT, which are excellent educational tools. Initially, some students do not know how to program in MATLAB and Simulink, but they can learn those quickly. These educational tools are used with Arduino during the entire course.

This course is accepted by students and also improved their knowledge about practical and theoretical issues regarding electric drives. Since electric drives are extremely useful technology, they can apply their gained knowledge to solve practical problems in several areas. Besides, the students can construct a solution and validate it using rapid prototyping based on model V and Tec 21 model. Thus, the proposed structure helps them to develop and organize a practical solution.

This educational proposal could be implemented in engineering courses to increase students' practical knowledge. This course is not designed to substitute for a laboratory course in electric drives; it is a new approach at Tecnologico de Monterrey for teaching theory and its applications in undergraduate programs.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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## Conflict of interest

BM was employed by company National Instruments. MA was employed by ABB.

The remaining 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.

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