Towards the Revolution and Democratization of Education: A Framework to Overcome Challenges and Explore Opportunities through Industry 4.0

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Abstract. Education 4.0 (E4) aims to improve the teaching-learning process and democratize access to quality education by using Industry 4.0 technologies in educational environments. The main objective of this article is to propose a framework containing a package of policies and initiatives for the drivers of society (industry, government, and academia) to develop E4. The framework was elaborated through systematic review based on good practices, challenges, and opportunities of E4, which were systematized considering the technical-scientific literature and the authors' experience. The main scientific contribution of this work is the creation of a new block of knowledge about E4 that expands and at the same time deepens the existing literature and can support new research and foster initiatives on the subject. Its main applied contribution is to increase access to quality education through the development of E4.

Keywords: Education 4.0, Industry 4.0, Technical-Scientific Scenario, Development Framework, Triple Helix.

1. Introduction

Quality and accessible education for all is the fourth Sustainable Development Goal (SDG) of the United Nations (UN) and has been highlighted in international agendas in recent decades. Education is crucial to promote the improvement of social and economic conditions, especially for people living in extreme poverty (UN, 2020). To achieve SDG 4, Information and Communication Technologies (ICT) are important tools that can be used to democratize and expand access to quality education (UNES-CO, 2017). One of the indicators proposed by the UN to measure the performance of this SDG is related to the percentage of people who have the skills to use ICT (UNESCO, 2018).

The use of ICT has enabled advances of various orders and driven changes in industry toward the era of the Fourth Industrial Revolution or Industry 4.0 (I4). I4 is characterized by the evolution in the interaction among electronic devices, machines, and people. It integrates the technologies developed to support real-time decision-making through Cyber-Physical Systems (CPS), Internet of Things (IoT), Cloud Computing (CC), Big Data (BD), etc. This revolution is transforming the job market and demanding professionals with new skills and competencies (Benešová and Tupa, 2017; Lee *et al.*, 2015; Xu *et al.*, 2018).

For preparing qualified professionals for these demands and provide higher quality education, initiatives to reformulate the teaching models have been proposed using I4 technologies and different pedagogical approaches. These reformulations are originating a real revolution in education, called Education 4.0 (E4) (Almeida and Simoes, 2019; Martín-Gutiérrez *et al.*, 2015; Mian *et al.*, 2020). The E4 uses I4 technologies and collaborative, flexible, and personalized pedagogical approaches to update teaching methods. It brings together elements such as gamification, flipped classroom, among others, to engage and qualify students, increasing the effectiveness of teaching-learning (Ab Rahman *et al.*, 2019; Chang and Hwang, 2018; Popenici and Kerr, 2017).

The integration of technologies into education is considered promising by academia and governments of several countries. However, the results of the Programme for International Student Assessment (PISA) conducted with 15-year-old students in 2018 in 79 countries indicated a lack of infrastructure, support, and quality Internet access at participating educational institutions. In OECD (Organisation for Economic Co-operation and Development) countries, only 65% of principals believe that their teachers have sufficient skills to integrate ICT into the teaching-learning process. Although most OECD countries are developed, have high-income economies and high Human Development Index, only 50% of the schools consider they have adequate technical support and online learning platform (OECD, 2020). Therefore, the education scenario in countries not belonging to this organization should probably present much lower results.

Due to intense global demand for increased access to quality education and technological advances, the World Economic Forum (2020) produced the School of the Future report to propose an E4 model and present some of its successful initiatives. The study by Bonfield *et al.* (2020) discussed and highlighted the importance of using E4 approaches in the teaching-learning process at universities in the UK, Australia, and Singapore. The study by Mian *et al.* (2020) identified the challenges and opportunities of I4 teaching at universities and proposed recommendations for developing University 4.0.

However, it is important to conduct more studies that propose solutions to overcome the technological challenges of E4, because of its great potential to democratize and improve education. This work deepens the above-mentioned studies and makes it possible to fill scientific gaps related to the need to integrate I4 technologies with education (Akçayır and Akçayır, 2017; Arpaci, 2017; Huang *et al.*, 2016b) and identification and solution of the main challenges related to this integration (Skryabin *et al.*, 2015; Tashkandi and Al-Jabri, 2015; Yilmaz, 2016).
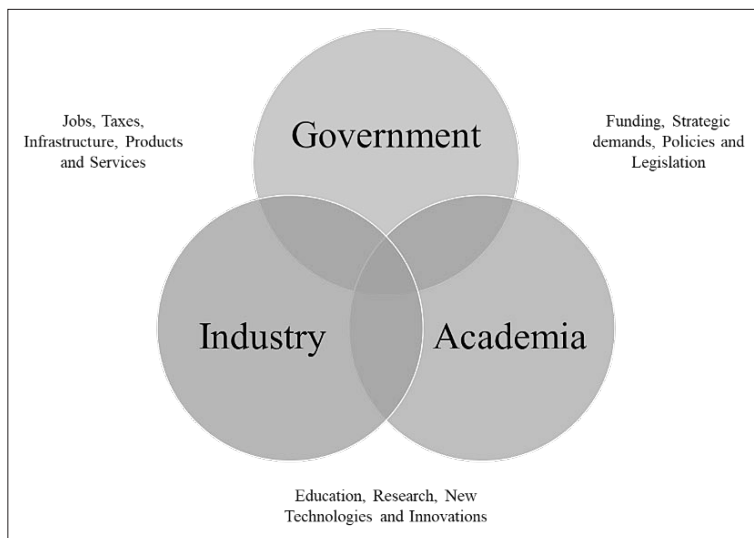
Fig. 1. Triple Helix Model.
Adapted from Kimatu (2015).

Several challenges directly influence the use of ICT in education, such as lack of infrastructure and technological support in the teaching environment, the difficulty of teachers in using them, and deficiency of appropriate educational platforms and software (Gil-Flores *et al.*, 2017; Wei *et al.*, 2015). These challenges are complex and should be addressed collaboratively by the main actors in society (industry, government, and academia) represented by Triple Helix and illustrated in Fig. 1 (Daniel, 2015; Ghavifekr and Rosdy, 2015; Kimatu, 2015).

The Triple Helix model proposes a continuous interaction among agents that compose it to accompany the evolution of technologies and respond to society's global challenges (Galan-Muros and Davey, 2019). The results of these interactions are derived from factors that influence how individuals use and interact with technologies in practice, leading to the emergence of new structures and advanced technologies (Orlikowski, 2000). To support all transformations, policies and innovations must be frequently proposed to society's actors (Hussenot, 2008). In this way, the Triple Helix agents proactively contribute to socioeconomic development through the creation of policies and partnerships, training of professionals, research and development (R&D), innovations, and technological infrastructure (Gachie, 2020; Razorenov and Vodenko, 2020).

The agent industry is responsible for providing innovative products and services for the education area and increasingly demands better qualified professionals in I4 technologies, which can be developed through E4 (Benešová and Tupa, 2017; Kimatu, 2015). The government, for its part, must create and propose policies that regulate the interactions of sectors of society, encouraging and financing the improvement of teaching methods, increasing the level of schooling of its population, and improving teachers' formation (Lim *et al.*, 2020b). Academia is responsible for education its students to deal with the

new technological demands of I4 and develop products and innovations from scientific research to overcome the challenges of I4 in society and industry (Mian *et al.*, 2020).

In this context, the research question that guided the development of this work arises: in what way is it possible to improve the teaching-learning relationship and increase access to education through the technologies of Industry 4.0? To answer this question, this article proposes a framework containing a package of policies and initiatives that can be adopted by industry, governments, and academia for the development of E4, in order to improve the teaching-learning process at all levels of education and democratize access to quality education.

The results of this work contribute scientifically to the creation of a new block of knowledge that deepens and expands the existing literature on E4, creating new bases for future work on the theme. The major applied contribution of this work is to enable the increased access to quality education through the proposal of policies and initiatives that enable E4 development by the principal agents of society.

After this introductory section, this paper is organized as follows: Section 2 provides the literature review; Section 3 describes the research method used in the development of this work and its stages; Section 4 presents the technical-scientific scenario; Section 5 identifies the challenges and opportunities of E4 development; Section 6 proposes E4 development framework; Section 7 offers the conclusion, and finally, the references and appendix are presented.

2. Literature Review

Industrial revolutions were movements in which different production methods and processes were inserted into organizations, increasing their competitiveness and improving their productivity. By 2020, four industrial revolutions had emerged in history. The first one contemplated the beginning of manufacturing and the use of steam machines to replace handicraft activity. The second represented mass manufacturing, using assembly lines and electric power. The third characterized the advance of electronics, which made possible the automation of industrial processes and the use of robots (Ghobakhloo, 2018; Pereira and Romero, 2017; Rojko, 2017).

Unlike the first three industrial revolutions, I4 emerged from a strategic plan by the German government in partnership with academia and industry to make its industrial organizations more autonomous, flexible, and collaborative. The goal of I4 is to increase competitiveness by meeting the variations in market demand and to reduce environmental impact. To achieve this, information is made available in real-time to improve decision-making through the implementation of various technologies such as IoT, BD, CC, AI, etc. However, I4 presents several challenges to be implemented and consolidated (Dalenogare *et al.*, 2018; Hofmann and Rüsch, 2017; Wang *et al.*, 2016).

One of the main challenges is related to the demand for professionals with new technical and socioemotional skills such as digital, interpersonal, technology, and innovation skills (Benešová and Tupa, 2017; Pereira and Romero, 2017; WEF, 2020). To overcome this challenge, education has a fundamental role to train better qualified professionals
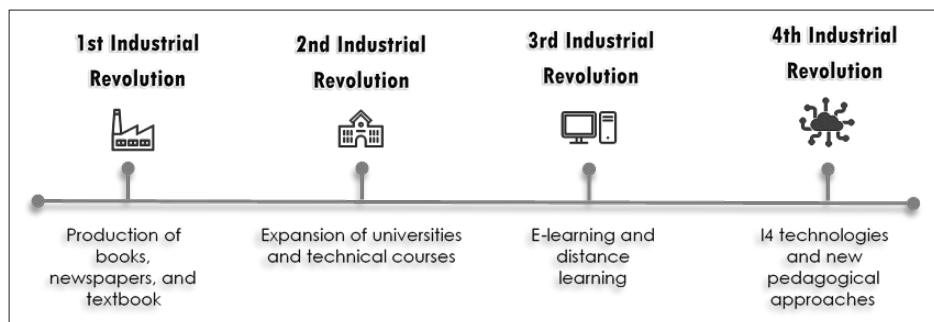
Fig. 2. Industrial revolutions and education.
Based on Bonfield *et al.* (2020), Li (2020), Yusuf *et al.* (2020).

and provide improvements in people's quality of life (Alvarenga *et al.*, 2021). In this sense, E4 is being proposed to support I4 and social change through the integration of technologies in the teaching-learning process and the use of new pedagogical approaches (Hariharasudan and Kot, 2018).

E4 is the result of the evolution of educational systems aimed at supporting socio-economic development (Koul and Nayar, 2021). This interaction between education and industry is recurrent and has happened throughout the other industrial revolutions, as illustrated in Fig. 2. In the first revolution, knowledge was expanded and disseminated through new universities, books, and newspapers. In the second revolution, education mainly contributed by training engineers and technicians for industry and increasing the supply of higher education courses (Li, 2020). The invention of computers and the emergence of the Internet during the third industrial revolution enabled the creation of e-learning and the popularization of distance learning courses (Yusuf *et al.*, 2020). The fourth revolution enables the use of technologies such as AI, BD, and CC in teaching environments to enhance the teaching-learning process and support I4 (Bonfield *et al.*, 2020).

Therefore, the proposed new model of education called E4 comprehends two complementary areas. The first one aims to develop students' skills and competences, training them according to the needs of the factories that use I4 technologies, and to this, has used new teaching approaches. The second aims at the insertion of I4 technologies in educational environments as a tool for improving the teaching-learning process (Bonfield *et al.*, 2020; Hariharasudan and Kot, 2018; Reis *et al.*, 2020). Several I4 technologies can be used in teaching environments to motivate students and support teachers. Among them are AR, VR, CC, BD e AI (Huang *et al.*, 2016b; Shiau and Chau, 2016; Wei *et al.*, 2015).

AR enables animated virtual objects to be viewed in the real environment through tablets or smartphones. This technology allows the improvement of the teaching-learning process and increased collaboration and motivation of students. It can be used to simulations of practical activities in various areas such as physics, engineering, and architecture (Akçayır and Akçayır, 2017; Batista *et al.*, 2020; Huang *et al.*, 2016b).

VR provides the immersion of students in a virtual environment for teaching more interactively. It can be used to simulate experimental practices that are difficult to repli-

cate due to security and cost issues. This technology can be applied at all levels of education, such as the training of doctors, pilots, and teaching science to children. However, VR needs the development of more software to expand and facilitate its use by teachers and students (Alhalabi, 2016; Jensen and Konradsen, 2018; Takala *et al.*, 2016).

CC is becoming increasingly used in teaching platforms for providing networked file storage and management services. This technology allows users to simply access its content anytime and anywhere. Examples of cloud applications are Google Apps, Dropbox, and OneDrive. CC brings ease of use and access to documents, increase in collaboration among students, and reduction in hardware costs and IT support. Its main challenge is the security of data sharing and the need for a high-speed Internet connection for its operation (González-Martínez *et al.*, 2015; Sabi *et al.*, 2016; Shiau and Chau, 2016).

BD is one of the I4 technologies that allow the analysis of large amounts of data in various areas of society. In education, BD can be used to analyze standards in academic performance throughout the school term and discover students at risk of failure and enable teachers to conduct personalized actions in teaching for these students. However, the application of this tool has a high implementation cost and can become complex when the data are decentralized and in different formats (Almohammadi *et al.*, 2017; Daniel, 2015; Huda *et al.*, 2017).

AI is an I4 technology widely applied to analyze data and perform the decision-making process. In teaching, this solution complements the role of teachers and assists students in the teaching-learning process. The AI allows teachers to customize the content for each student from the analysis of their strengths and weaknesses. This technology also enables students' questions to be quickly resolved through intelligent virtual assistants in educational environments (Almohammadi *et al.*, 2017; Popenici and Kerr, 2017; Terzopoulos and Satratzemi, 2020).

These I4 technologies have been increasingly used in education at all levels (elementary, upper, secondary, and postsecondary). However, for native digital students, that is who was born in a connected and digital society, it is greater acceptance of these innovations. When this type of student is immersed in an environment with technologies, the engagement with the content taught is better and their performance improves. Even for students who are not digital natives, the use of technologies in the classroom is relevant to improve the teaching-learning process, making it more interactive and attractive (Ghavifekr and Rosdy, 2015; Huang *et al.*, 2016a).

Teachers play a key role in driving the transformation of education and encouraging the use of technologies in the teaching-learning process. Therefore, their digital skills and competencies must be developed through teacher education programs, training, and public policies (Burns and Gottschalk, 2020). Several frameworks are mapping and bringing together the skills that should be developed in teachers, such as DigCompEdu. DigComEdu covers 22 competencies divided into 6 main areas that teachers should possess to implement ICT in teaching (Lucas *et al.*, 2021). These are professional engagement, digital resources, teaching and learning, assessment, empowering learners, facilitating learners' digital competence. The goal of this framework is to enable teachers to be able to select and apply technologies in teaching environments, engaging students through personalized and inclusive learning (Redecker, 2017).

3. Research Method

This work was developed from a systematic review of technical-scientific literature on Education 4.0. The systematic literature review is a research method based on the critical analysis of literature that allows the identification of the most relevant and recent studies and initiatives on the subject. The literature review must comprise several sources of data to be relevant and effective (Cronin *et al.*, 2008). In this study, content analyses of the main technical and academic publications on E4 were conducted. Among the publications analyzed, there are industrial initiatives, patents, law texts, policies, business and government reports, and scientific articles.

Thus, the technical-scientific scenario was mapped in the E4 area composed of the policies, initiatives, and innovations of the 4 countries that highlighted both in the development of technologies and the publication of articles on E4. The technical-scientific scenario served as a benchmark for the authors of the study, who compiled, analyzed, and adapted the good practices in the teaching environments of these countries considering their experiences and the literature to propose an E4 development framework. The study was conducted according to the flow of activities presented in Fig. 3.
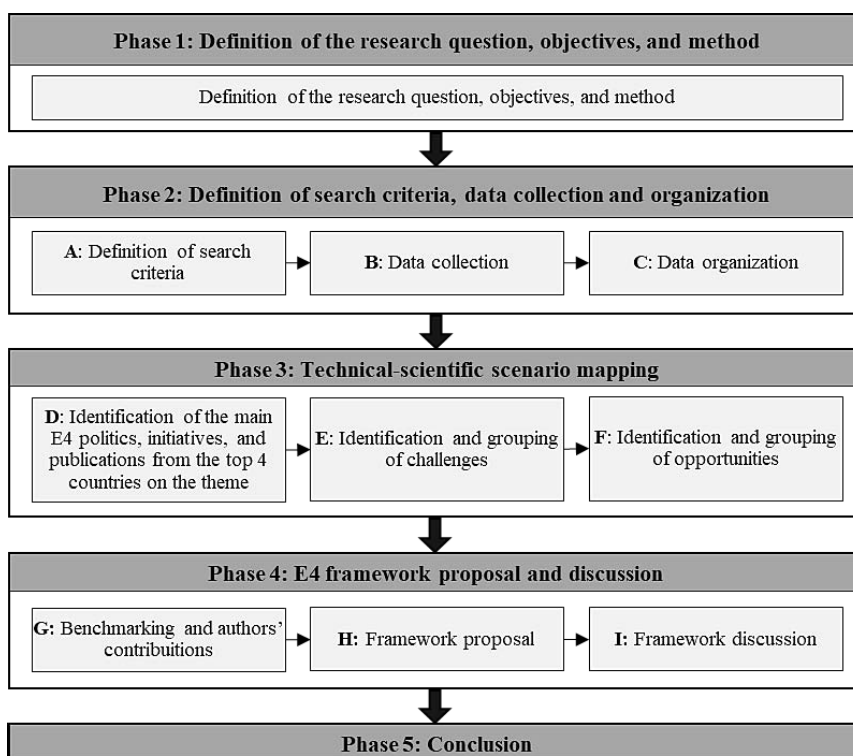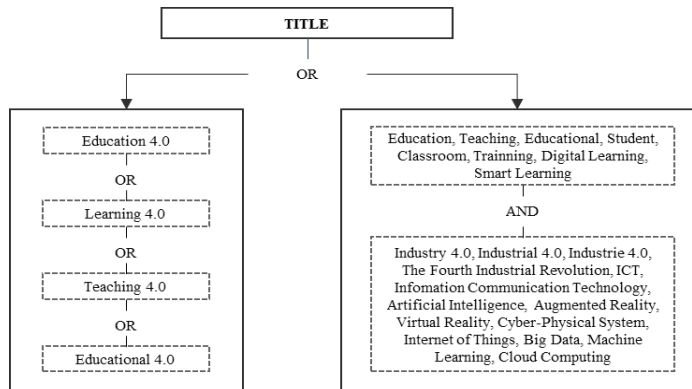

Fig. 3. Research activity flow.

The work was divided into five phases: definition of the research question, objectives, and method; definition of search criteria, data collection and organization; technical-scientific scenario mapping; E4 framework proposal and discussion; and conclusion. Table 1 details each of these phases and their stages.

Table 1

Research phases and stages

Phases	Stages	Description
Phase 1: Definition of the research question, objectives, and method	Definition of the research question, objectives, and method	The research question to be answered by the study, the objectives, and the method to conduct this work were defined.
Phase 2: Definition of search criteria, data collection, and organization	A: Definition of search criteria	The criteria for technical and scientific data search were defined. The Orbit Intelligence platform was chosen for the search of technical data and analysis of patents since it encompasses the largest patent repositories filed by companies and universities around the world (Vincent *et al.*, 2017). The patents studied must have been registered between 2010 and 2020 to represent the trends and innovations of the theme.
		The Scopus database was chosen to search for the scientific data. It is one of the most comprehensive scientific databases and allows access to papers published on the subject around the world. The articles studied were published in the last five years (2015–2020) in the English language, which is the most used in the scientific environment (Mongeon and Paul-Hus, 2016; Reis *et al.*, 2017). This period was chosen because the studies published in the last five years consolidate and expand previous works in the literature and represent real and current practices on the subject.
		Two sets of keywords were used in the search, as explained in the following figure. The first set was composed of the word "Education 4.0" and its synonyms ("Learning 4.0", "Teaching 4.0", and "Educational 4.0"). The second set was composed of words related to I4 and its technologies ("Industry 4.0", "ICT", "Big Data" etc.) combined with words related to teaching ("Education", "Teaching", "Educational" etc.). Articles must contain words from the first set or the second in their titles. Thus, it was possible to include studies on the use of I4 technologies to improve the teaching-learning process, which characterizes E4.

Table 1 – continued from previous page

Phases	Stages	Description
	B: Data collection	Information from 4273 patents and 1973 scientific papers that met the search criteria was collected. Among these articles, the 30 most cited were selected for the analysis of their contents and identification of the challenges and opportunities for E4 development. The 30 articles most cited are presented in Appendix A.
	C: Data organization	The data collected were organized and the main countries in the E4 technical-scientific scenario were selected based on the relationship between the two criteria: h-index and number of registered patents. At first, the 10 countries with the highest number of registered patents were selected and ranked, indicating for the technical scenario of the subject, those with important R&D teams of technologies and innovations on E4. Then, the 10 countries with the highest h-index in the subject studied were ranked from the data collected in step B. This index quantifies the productivity and relevance of published studies and is, therefore, a good indicator of scientific production capacity (number of publications) and importance (citations) of works published in these countries (Hirsch, 2005). Thus, the averages of the positions of the countries that were present in both rankings were calculated. The countries were arranged in ascending order according to the calculated average. So, the final ranking of the prominent countries includes both the technical and scientific scenarios. The first four countries in this ranking (United States, China, Taiwan, and South Korea) together cover more than 80% of the number of patents returned from the search, indicating significant innovations on the subject. For this reason, they were selected for the qualitative analysis of their main industrial, governmental, and academic initiatives. Then, the three companies that registered the most patents on E4 and the three authors and universities with the highest h-index in the theme of each country were selected to be analyzed in the next stage.
Phase 3: Technical-scientific scenario mapping	D: Identification of the main E4 politics, initiatives, and articles from the top 4 countries on the theme	The main policies and initiatives in E4 of companies, governments, and academia belonging to the countries identified in step C were mapped, to support the work and provide a benchmark to the authors. In each country, the analysis of the main initiatives of the three companies that have registered most patents on the subject was conducted. Their initiatives were identified through the analysis of the content of their business reports, patent texts, and official websites. Then, the relevant government policies in the E4 area were identified in the four outstanding countries in the technical-scientific scenario. They were mapped from the analysis of texts of laws, official websites, and scientific articles dealing with the theme. Finally, the initiatives and articles of the authors and universities highlighted in the theme selected in step C were systematically analyzed to identify their objectives, methods, and main contributions to the development of E4.
	E: Identification and systema-tization of challenges	Content analysis was conducted on the 30 most cited and selected articles in step B of this work. The objectives, methods, contributions, and challenges for the E4 development of each study were identified and systematized from its analysis. They were then grouped according to their similarities and discussed.
	F: Identification and systema-tization of opportunities	The same procedure of step E was conducted but focused on identifying the scientific opportunities for E4 development. After that, these clusters were discussed.

Table 1 – continued from previous page

Phases	Stages	Description
Phase 4: E4 framework proposal and discussion	G: Benchmarking and authors' contributions	The policies and initiatives mapped in the technical-scientific scenario and the challenges and opportunities to E4 development were analyzed by considering the literature and experience of the authors of this study. Policies and initiatives were expanded and adapted to the areas of Triple Helix sectors through a benchmarking process of the good practices identified in the E4 scenario. The policies implemented by the countries studied to modernize their education systems were appropriate to the industrial and academic sectors as suggestions for practices for the development of E4. The scientific and technical advances developed at universities, researchers, and companies were used as a benchmark to propose broader initiatives and research topics to promote the use of I4 technologies in teaching and overcome the challenges of E4.
	H: Framework proposal	The elements of the framework were proposed considering the analysis performed in step G of this work. The framework was elaborated with proposals for policies and initiatives that can be adopted by industry, governments, and academia to develop E4, to improve the teaching-learning process at all levels of education and democratize access to quality education.
	I: Framework discussion	The policies and initiatives of the framework were discussed in the light of the literature to provide scientific robustness to the results and allow a full understanding of the proposal.
Phase 5: Conclusion	Conclusion	The fulfillment of the objectives proposed in this work and the main scientific and applied contributions of its results were highlighted, besides its limitations and suggestions for future works.

Thus, the research phases and steps described in Table 1 allowed the mapping of the most relevant policies and initiatives of the main institutions of the E4 technical-scientific scenario and the identification of the main scientific challenges and opportunities of the theme. As shown in Fig. 4, the analysis of the technical-scientific scenario and the authors' contributions of this research assist the proposal E4 development framework.
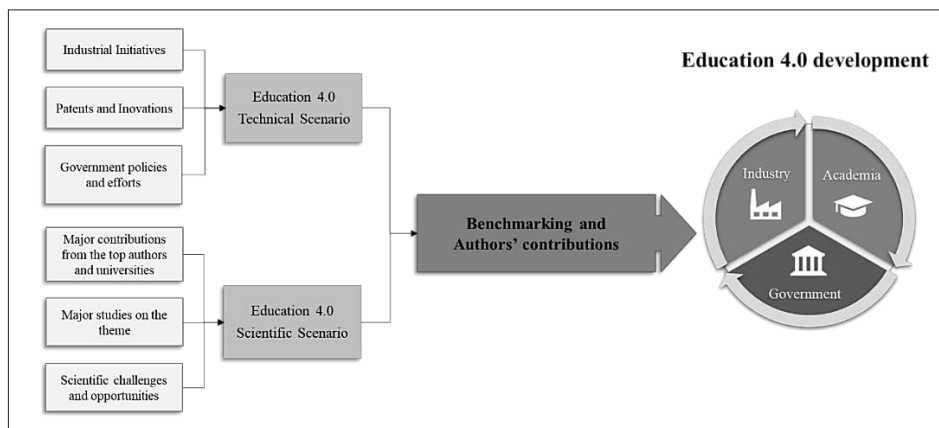

Fig. 4. E4 development framework.

Table 2

Top Countries in Education 4.0

N	Country	Patents	H – Index
1	United States	260	22
2	China	3360	12
3	Taiwan	18	15
4	South Korea	493	9

4. Technical-Scientific Scenario

The countries that are contributing to the development of E4 were selected for the elaboration of the technical-scientific scenario. They have the highest h-index and are the ones that have filed the most patents on the subject from 2015 to 2020 according to Scopus and Orbit Intelligence bases, respectively. The countries selected were the United States, China, Taiwan, and South Korea, as shown in Table 2. Their main industrial, governmental, and academic initiatives will be analyzed and presented in the next topics.

4.1. *United States*

The United States is the third country regarding the number of patents filed (260) and has the largest h-index on the subject (22). The American government has been investing in the development and application of new teaching practices and tools in its educational system since the 1990s. Therefore, the country is at the forefront of E4 and is house to leading companies and universities in the development of technologies and research in the area.

4.1.1. *Industry*

The companies that have the most patents published in the US are Samsung Electronics (47), Lincoln Electric Global (24), and IBM (8). They are recognized for developing I4 technologies for education and for using them in their training and qualification.

Samsung develops educational technologies such as mobile devices, e-learning platforms, digital flipchart, and projects in partnership with schools and universities to support and enhance digital learning (Samsung, 2013). In one of its successful partnerships with the College of Business at Colorado State University (CSU), Samsung has created a television structure to reinvent distance learning so that remote students can be viewed and interact with students and teachers in real-time. In this way, the project increases the engagement and collaboration among students to improve learning and expand the ability of educational institutions to train new professionals for the job market (CSU, 2019; Haynes, 2019).

Lincoln Electric Global is a company that manufactures welding products and offers training to companies and new welders at its education institute (Lincoln, 2017).

Among the products and services marketed by the company are the robotic training and simulation tool with VR. The simulation technology allows a mobile and safe teaching environment for welding practice. The tool provides a real-time report with feedback activity analysis data, supporting teachers and students in the teaching-learning process (Lincoln Electric, 2018).

IBM is an information technology company that develops and markets products and services such as CC, AI, and Machine Learning. The company created P-TECH in partnership with academia and other industries to provide free teaching and internship in the areas of STEM (Science, Technology, Engineering, and Mathematics) for needy people (IBM, 2020). P-TECH also has an online teaching platform with free courses and certifications for developing of technical skills and technologies such as Blockchain, Data Science, and AI (P-TECH, 2020).

4.1.2. *Government*

In the governmental sphere, the Every Student Succeeds Act aims to ensure that every graduate student has access to digital learning and this end, allocates financial resources to projects that promote and implement blended learning and digital learning (U.S. Department of Education, 2019). The Nation Science Foundation (NSF) is also an important source of research funding for developing of educational technologies (NSF, 2020a). NSF funds science and engineering projects such as "Smart Advanced Manufacturing Education in the Silicon Valley", which proposes to develop a program with new courses to meet the demands of well-qualified I4 professionals, focusing on areas such as the Internet of Things, Prototyping, and Automation (NSF, 2020b).

4.1.3. *Academia*

The main academic initiatives in the country were analyzed based on the most prominent authors and universities on the subject. David F. Cihak, Don D. McMahon, Nassir Navab, Timothy Green, and Abbie Brown have used and innovatively study emerging technologies in teaching in their articles.

The authors David F. Cihak and Don D. McMahon have contributed with studies to improve teaching with emerging technologies such as mobile devices, AR, and VR in schools and training courses for people with disabilities (University of Tennessee, 2012; Washington State University, 2020). These technologies are used to teach science, encourage the practice of physical exercise and support the development of professional skills of students to enter the job market (Washington State University, 2016). Nassir Navab and his research team called Computer Assisted Medical Procedures (CAMP) use AR, VR, robotics, and machine learning combined with medicine, engineering, and medical solution providers to develop mechanisms for teaching anatomy and assisting physicians in surgery more accurately (CAMP, 2014). Tim Green and Abbie Brown contributed by identifying the best mobile device software that can be used to implement AR in classrooms. Among them, Aurasma software is distinguished for its functionality and was applied in the teaching of history and geography in basic education to increase student engagement in the teaching-learning process (Green *et al.*, 2017).

The American universities University of Illinois at Urbana-Champaign (UIUC), University of Arizona (UA), and NC State University (NCSU) have excelled in publishing studies on E4 and in applying and developing innovative teaching techniques and tools.

UIUC has developed studies on the application of BD, data science, and machine learning techniques in the evaluation of learning in digital teaching environments and the prediction of student behavior (Cope and Kalantzis, 2015; Paquette and Baker, 2019). Such techniques allow the analysis of the results of new technologies quickly, accurately, and safely. At UIUC, studies on the responsible use of BD in Art teaching were also developed (Duncum, 2018), and the use of VR and simulation in archaeology teaching (Shackelford *et al.*, 2019). The use of VR has favored the students' cognitive learning by allowing interaction with the study environment, which has made teaching more dynamic and practical.

The UA has developed studies on the use of VR and BD in the teaching of medicine and foreign languages (Iserson, 2018). VR has proven to be an important ally in teaching and learning skull-based lateral surgeries and clinical testing procedures by simulating 3D environments where students could practice these activities (Barber *et al.*, 2020). Studies were also conducted on the application of artificial intelligence in teaching Braille to the visually impaired, where students improved their learning performance (McCarthy *et al.*, 2016); and the application of new ICT in teaching reading and spelling (Schneider *et al.*, 2015).

NCSU studied the application of AR in teaching topography, engineering, and veterinary medicine. The use of this technology helped students in the three-dimensional understanding of topics such as topographic mapping studies and dog neuroanatomy, proving the multidisciplinary potential of its application. This technology has considtheerably increased student engagement and performance (Akbulut *et al.*, 2018; Christ *et al.*, 2018; McNeal *et al.*, 2020; Soltis *et al.*, 2020). NCSU studies also identified that VR, mobile learning, interactive learning environments, and e-learning technologies are the most widely used in the area of AR for education (Karakus *et al.*, 2019).

4.2. *China*

China is the country with the highest number of registered patents (3360) and is the third country in the h-index classification (12) on the subject. The country has been recognized for developing technologies and patents, its policies to modernize teaching, and the publication of important scientific studies in E4.

4.2.1. *Industry*

The main technical initiatives of the country were analyzed according to the companies that most deposited patents on the theme in the period studied. They are Shangai Yixue Education (18), Gansu Pugongying (18), and State Grid Corporation (16).

Shangai Yixue Education is the first company to specialize in adaptive learning with AI in China (Squirrel AI Learning, 2017). The company provides personalized educa-

tion, blending face-to-face and online teaching with I4 emerging technologies. Its AI system simulates teachers and provides a personalized teaching plan based on an intelligent algorithm for capturing and mining students' learning data in real-time and accurately identify their difficulties, setting their priorities in underperformance subject (Squirrel AI Learning, 2020).

Gansu Pugongying Information Technology is a technology developer company and seeks the improvement of hardware to enable software advances in teaching. Its inventions contribute to increasing the efficiency and useful life of the equipment that uses online teaching technologies with AI (Xuecheng, 2019).

State Grid Corporation of China is an electrical energy transmission and distribution company that develops simulation systems using technologies such as AR, VR, drones, and 3D software for training of its professionals in high power equipment. Their systems are safe and cost-effective solutions for teaching practices that are difficult to implement and replicate (Shengli *et al.*, 2019; State Grid Corporation, 2017; Yan *et al.*, 2016).

4.2.2. *Government*

To boost education at all its levels, the Chinese government launched the long-term "China Education Modernization 2035" plan and the short-term "Implementation Plan to Accelerate the Promotion of Education Modernization (2018–2022). The Chinese government emphasizes the importance of integrating education systems with information technologies, using tools such as AI, DB, simulations, and AR to improve and innovate in teaching and training new professionals. The government also plans an annual increase in the budget for funding projects to modernize education and promote research exchanges abroad, encouraging international collaboration among universities to create research centers in I4 technologies and intelligent campuses (Australian Government, 2020; Shuo, 2019).

4.2.3. *Academia*

The main academic initiatives in the country were analyzed based on authors and universities of prominence in the subject. The authors Cher Ping Lim, Di Wu, and Danhui Zhang have studied the use of ICT and their benefits for the teaching-learning process.

Cher Ping Lim has investigated and analyzed the use of virtual games and ICT to improve the teaching and training of new teachers. Its research uses case studies in universities and schools in Asian countries that have integrated ICT into teaching to identify challenges and propose innovative strategies for curricular upgrades (Lim *et al.*, 2015, 2020a). Di Wu has researched to investigate the effects of integrating ICT, online platforms, and CC into education and assess the benefits and challenges of their application in rural and urban areas (Shi *et al.*, 2014; Wu *et al.*, 2019a).

Danhui Zhang verified a positive relationship between the use of ICT in teaching and student performance in subjects such as mathematics, science, and reading upon studying the results of international exams such as PISA and PIRLS (Progress in International Reading Literacy Study) (Skryabin *et al.*, 2015; Zhang and Liu, 2016).

Chinese universities Beijing Normal University (BNU), East China Normal University (ECNU), and University of Science and Technology Liaoning (USTL) highlighted as the most published studies on Education 4.0. Their main contributions in the area are described in the following.

BNU has conducted studies on the impact of ICT use in teaching reading, mathematics, and science in China. The university studied the use of VR in the education of students with autism (Hu and Han, 2019) and in teaching problem-solving skills to elementary school students (Wu *et al.*, 2019b). This technology enables greater immersion and interaction in the learning process, proving useful in special education. BNU studies have also identified an increase in student learning gains from the use of AR technologies in teaching abstract concepts of statistics, probability, and mathematics (Cai *et al.*, 2020a, 2020b). The university has also developed an e-learning model based on elastic cloud computing. This technology allows the construction of computer architectures for distance learning with less investment in infrastructure, which facilitates the implementation of these initiatives (Zhang and Zhu, 2017).

ECNU studies on the application of VR in face-to-face learning environments have identified an increase in the sense of students' presence and the relevance of visual processing in children's learning, revealing the importance of the use of new virtual technologies in curricula and teaching materials for these students (Huang *et al.*, 2020; Liu *et al.*, 2020). As a way to better instruct pedagogy graduates on these technologies, ECNU developed for its pedagogy course the subject "Modern Education Technology," in which the main skills and competencies necessary for the use of ICT in teaching-learning are addressed (Lim *et al.*, 2015).

USTL studied the implementation of flipped classrooms and micro-lecture in VR teaching. These pedagogical approaches allowed teachers to understand the difficulties their students faced during the learning process and what were their different study habits and behaviors. Such findings allowed the adaptation of teachers' teaching styles according to their students' needs, which encouraged engagement during classes and improved learning performance (Ji and Han, 2019). The university conducted studies on the use of VR in teaching graphic design and folk art. This technology stimulated students' enthusiasm, creativity, motivation, and sensitivity during class by simulating painting activities (Li, 2017). The university also applied CC to dance teaching by offering a multimedia system with videos and images during the classes (Li, 2016).

4.3. *Taiwan and South Korea*

Taiwan has great prominence in the scientific scenario with the third-largest h-index on the subject (15), however, it is the eighth country with the number of patents filed (18). On the other hand, South Korea has great prominence in the technical scenario and is the second country with the highest number of patents filed (493), however, it has a lower prominence in the scientific scenario and is in the tenth position of the ranking according to the h-index in the theme (9). Thus, the initiatives of both countries will be explored together for a better framework proposal.

4.3.1. *Industry*

The main technical initiatives of the countries were analyzed based on the companies that have filed the most patents. In Taiwan, Dianshi Jingwei Technology (1) and South Korea, Samsung Electronics (88), Total Soft Bank (5) were selected and analyzed.

Dianshi Jingwei Technology has developed a smart and personalized teaching environment based on AI, BD, and CC in its line of software and hardware called OKAY Smart Classroom. This environment has scoring reports with the evolution of student learning in subjects and mobile devices that enable learning anytime and anywhere (Okay Smart Education, 2017, 2020).

Samsung Electronics, now analyzing its performance in Korea, created the Smart School program that offers a high-tech teaching system with interactive whiteboards, tablets, laptops, and personalized teaching for needy schools in remote areas intending to reduce the digital education gap (Samsung, 2020b). The company also has programs in other countries like Samsung OneWeek in which its professionals voluntarily dedicate five days of their vacation to teach IT and develop digital skills of students in needy schools and remote communities (Samsung, 2020c). In addition, the Samsung Innovation Campus program aims to develop the skills required by I4, offering training in IoT, BD, CC, and programming for young people from 14 to 18 years old (Samsung, 2020a)

Total Soft Bank is a company of innovative software solutions for port logistics that uses technologies such as AR and VR to create training products for industries and educational institutions. Its products simulate training environments, using VR for crane control operations and teach technical design with 3D parts visualization and AR (Total Soft Bank, 2008, 2018).

4.3.2. *Government*

In the government sphere, the Taiwanese Ministry of Education (MoE) has been conducting constant reforms in education intending to stimulate the creation of advanced digital learning environments and promote the use of e-learning in the country's educational systems (MoE of Taiwan, 2012). The Education Cloud is a platform developed with CC and BD by MoE, increasing learning about digital technologies and providing technical resources to teachers and students (Yang and Huang, 2016). MoE created the "Digital Application Promotion Project for Remote Areas" program to develop the use of digital technologies and provide funding to build digital environments in remote areas of the country through the volunteer work of academics and private sector professionals in order to improve the social and economic conditions of the place (MoE of Taiwan, 2020).

The Korea Education and Research Information Service (KERIS) is an institution of the Korean Ministry of Education that aims the development of education with the integration of ICT for improving education due to the demands of I4 (KERIS, 2020a). Its projects use AI, DB, and CC to improve elementary school, support the development of educational policies, distance training for teachers, and library digitization (KERIS, 2020b). KERIS also has an e-learning platform intended for higher education, which contains free videos and class materials on various topics, including I4 to encourage knowledge sharing (KOCW, 2015; Lim *et al.*, 2019).

4.3.3. *Academia*

The main academic initiatives in Taiwan were analyzed based on the authors and universities of prominence in E4. Gwo-Jen Hwang, Ying Shao Hsu, Chin Chung Tsai used learning technologies to improve student performance in elementary and high school subjects.

Gwo-Jen Hwang has research focused on combining AI, mobile learning, AR, and VR with flipped classroom approaches and digital games. He has developed a practical activity with VR for teaching Electromagnetism on a flipped classroom platform to increase the interest and motivation of his students in educational content (Chang and Hwang, 2018; Hwang *et al.*, 2016). Ying Shao Hsu uses AR to develop technological tools and software that promote interest in STEM (Science, Technology, Engineer e Math). In one of his studies, a cardiac surgery simulation tool developed by engineers and doctors of Taiwanese universities was used in the teaching of sciences and it was found an increase in the students' understanding of the importance of the relationship among the areas of STEM (Hsu *et al.*, 2017). Akeem Pedro, C.S. Park, and Q.T. Le have developed VR technologies for teaching construction methods because workers in this industry are often affected by accidents, injuries, and fatalities because of lack of experience and adequate training. These technologies made the learning environment safer and allowed practical experiences in the topic (Le *et al.*, 2015; Pedro *et al.*, 2016; Pham *et al.*, 2018).

The National Taiwan University of Science and Technology (NTUST) and the National Taiwan Normal University (NTNU) of Taiwan and the Ewha Womans University (EWU) of South Korea have been distinguished by conducting important studies on E4.

NTUST studies have identified the great potential in combining AR with building information modeling (BIM) for the teaching and practice of architecture and civil engineering (Diao and Shih, 2019) and the use of this technology in teaching layout design, allowing students to develop building interior design activities interacting with 3D environments (Chang *et al.*, 2020b). The university has also applied VR in teaching childbirth practices to undergraduate nursing students. The research found that the application of this technology reduced students' anxiety during classes and allowed for better practical learning (Chang *et al.*, 2019).

NTNU studied the use of AR in geography classes about climate and in physical education classes in the development of motor skills (Chang *et al.*, 2020a; Hsiao *et al.*, 2016). This technology was also applied in the teaching of elementary school children, where a collaborative 3D environment was developed in which each student could create their own stories and relate to others. The results of this application have shown that increased reality can facilitate the development of children in group work (Hsu, 2019). The university also proposed and applied a pedagogical framework called Learner-Immersed Virtual Interactive Expedition (LIVIE) in the teaching of geography. LIVIE is based on the use of VR simulations that allow students to explore 3D environments of the locations being studied (Jong *et al.*, 2020).

EWU has developed a machine learning prediction system on the evasion of students from South Korean higher education. This technology allows those responsible for educational institutions to act in advance in cases where the student presents a risk

of abandonment (Chung and Lee, 2019). The university has also conducted studies on the use of AR in teaching creative skills for writing and story-retelling and in STEM educational programs from the inquiry learning model, an active learning approach (Ahn and Choi, 2015, 2016).

5. Scientific Challenges and Opportunities for E4 Development

In this topic, the challenges, and scientific opportunities of E4 development are presented and analyzed. The main challenges of E4 correspond to the difficulties and barriers that are hindering its development and implementation in educational institutions in several countries. They have been identified and systematized based on the 30 most cited articles in the scientific literature and grouped into clusters as presented in Table 3.

The first challenge highlights the lack of adequate technological resources for the use of ICT by students and teachers. I4 technologies require the availability of adequate resources and technological infrastructure for their operation. Electronic devices such as computers and tablets need to be in good working order to be used by students and teachers through a quality Internet connection and with technical support available for maintenance and upgrades of hardware and software. In some remote areas and poorer countries, the digital divide is severe, and some educational institutions do not have computers and an Internet connection (Asamoah, 2021; Lim *et al.*, 2020a; Nikolopoulou *et al.*, 2019; Southgate *et al.*, 2019).

The second challenge highlights that in addition to providing adequate technological infrastructure, the success of integrating ICT into teaching depends directly on their acceptance by teachers and principals of the educational institutions. However, many of them have resistance to change and reject the use of technologies in the teaching-learning process, impacting the development and deployment of E4. This may be related to the lack of training that teachers receive during and after their formation. In E4, teachers should have technical and pedagogical skills to use ICT in teaching with autonomy (Gil-Flores *et al.*, 2017; Hämäläinen *et al.*, 2021; Liesa-Orús *et al.*, 2020).

Table 3

The challenges of E4

Challenges	Article
Lack of technological infrastructure in good conditions of use and with technical support	Asamoah (2021), Cao *et al.* (2020), Lim *et al.* (2020a), Nikolopoulou *et al.* (2019), Qasem *et al.* (2019), Ghavifekr and Rosdy (2015), Skryabin *et al.* (2015), Southgate *et al.* (2019), Wei *et al.* (2015)
The resistance of teachers and principal in using I4 technologies in teaching	Hämäläinen *et al.* (2021), Qasem *et al.* (2019), Gil-Flores *et al.* (2017), Scherer *et al.* (2015)
Absence of legislation and data protection and privacy mechanisms in the use of this information	Fischer *et al.* (2020), Qasem *et al.* (2019), Daniel (2015), González-Martínez *et al.* (2015), Reyes (2015)

The third challenge results from the creation and exploitation of data through I4 technologies. There is a great concern with the security of the information shared and especially with privacy in its analysis. Ethical conflicts are under debate to identify who is accessing the data, such as location, tracking, and performance of students and teachers and for what purpose they are used at E4. The technologies used must be secure in order to ensure that the data and information stored on students, teachers, and employees of the educational institutions are not accessed and disclosed by third parties (Fischer *et al.*, 2020; Qasem *et al.*, 2019).

Scientific opportunities are important topics that can be explored for advancing E4 literature and the development of its practices. They have been systematized and then grouped according to their similarities, originating the clusters presented in Table 4.

The first cluster of opportunities identified was about the development of approaches for inserting E4 in teacher training. Teachers are one of the main responsible for the application of new technologies and E4 approaches in the classroom. However, the complexity of some ICT and the lack of digital skills make their use difficult. The main factors that influence the use of E4 technologies by teachers are their skills, knowledge, and perception of the usefulness of these technologies (Gil-Flores *et al.*, 2017; Scherer *et al.*, 2015). Therefore, it is of high relevance that teachers are properly trained and motivated to engage in its use (Valtonen *et al.*, 2015).

The second cluster refers to the need to map the important skills and competences for professionals to work in I4 and introduce them in the curricular grids. The rapid development of new technologies and accelerated globalization, combined with global challenges in the social, economic, and environmental spheres, created a scenario of great uncertainty, that requires students and professionals a new set of skills to face the 21st-century adversities. Among the current most valued skills are creativity, resil-

Table 4

Clusters of scientific opportunities in E4

Cluster	Article
Create approaches for inserting E4 in teacher training	Benešová and Tupa (2017), Ghavifekr and Rosdy (2015), Gil-Flores *et al.* (2017), Gupta *et al.* (2015), Scherer *et al.* (2015), Valtonen *et al.* (2015), Wei *et al.* (2015)
Map the important skills and competencies for professionals to work in I4 and introduce them in the curricula	Benešová and Tupa (2017), Gil-Flores *et al.* (2017), Gupta *et al.* (2015)
Propose solutions for integration of technology and teaching approaches in the E4	Akçayir *et al.* (2016), Alhalabi (2016), Almohammadi *et al.* (2017), Arpaci (2017), Huang *et al.* (2016a), Huda *et al.* (2017), Jensen and Konradsen (2018), Le *et al.* (2015), Lu and Liu (2015), Sabi *et al.* (2016), Shiau and Chau (2016), Tashkandi and Al-Jabri (2015), Yilmaz (2016)
Investigate the impacts and challenges of integrating technologies of the I4 into education	Akçayir *et al.* (2016), Alhalabi (2016), Chang and Hwang (2018), Daniel (2015), González-Martínez *et al.* (2015), Huang *et al.* (2016b), Hwang *et al.* (2016) Martín-Gutiérrez *et al.* (2015) Skryabin *et al.* (2015), Tashkandi and Al-Jabri (2015), Yilmaz (2016)

ience, critical thinking, problem-solving, communication, collaboration, and knowledge of technologies. Thus, learning environments should use technologies and teaching approaches that allow students to develop the skills and competencies demanded by modern society. Therefore, they must be identified and inserted in the curricula of schools and universities (Huda *et al.*, 2017; OECD, 2018; Valtonen *et al.*, 2015).

The third cluster emphasizes the need to propose solutions for technologies and teaching methods integrating into E4. Many studies have proven that integrating I4 technologies with education improves student learning and facilitates teaching. ICT, for example, have been used in several countries as a way to make knowledge available to students inside and outside the classroom and to integrate communities of professionals so that they can share good practices in teaching-learning and improve the quality of education (Gil-Flores *et al.*, 2017; Skryabin *et al.*, 2015; Valtonen *et al.*, 2015).

 Technologies such as AR and VR allow students to interact with representations of reality in 3D environments and simulate abstract concepts, facilitating learning and improving students' academic performance (Alhalabi, 2016; Chang and Hwang, 2018; Le *et al.*, 2015; Wei *et al.*, 2015). Therefore, the development of technologies with applicability in different subjects is a great opportunity that can be explored scientifically for developing E4.

The fourth cluster refers to the importance of studies that measure the impacts of the use of E4 technologies in the classroom, helping map the areas with the greatest potential for the application of these technologies and studies that identify the main challenges facing them. Measuring the gains from these applications can guide investments in technologies and support the expansion of their applications to different teaching topics (Hwang *et al.*, 2016; Martín-Gutiérrez *et al.*, 2015; Yilmaz, 2016). Identification of E4's development challenges can drive the search for solutions to facilitate your applications (Akçayir *et al.*, 2016; Tashkandi and Al-Jabri, 2015).

6. Framework for E4 Development

In this work, industrial, governmental, and academic initiatives, patents, laws, scientific articles, and challenges and scientific opportunities of E4 were identified and analyzed. This information was used as a benchmark, in other words, compiled, adapted, and expanded considering the experience of the authors to support the proposition of the E4 development framework for Triple Helix agents. The framework is designed for industry, governments, and academia to overcome challenges, explore opportunities, and adopt E4 reference policies and initiatives. Its proposals are segmented into different themes, called domains for each Triple Helix agent, and are summarized in Table 5.

The initiatives proposed in the framework related to the Industry were divided into domains Training and Technology. In Training, the realization of partnerships among companies, universities, and schools is proposed to qualify students according to the skills required by I4 from the modernization of curricula and internships, helping the development of future professionals. Training in companies can be offered through online

Table 5

E4 development framework

Agents	Domains	Politics and Initiatives	Triple Helix Integration
Industry	Training	Create online-training platforms for internal and outsourced employees	Industry and Academia
		Use E4 tools in training for activities that provide risks to worker safety or that are difficult to implement and replicate	Industry and Academia
		Partner with universities and schools to modernize curricula and conduct internships to develop the skills required by I4 in future professionals	Industry, Government and Academia
	Technology	Partner with universities and schools for the development and commercialization of E4 technologies	Industry and Academia
		Develop and commercialize educational platforms to enable personalized and adaptive education	Industry, Government and Academia
Government	Politics and Legislation	Develop a national policy with guidelines, objectives, and action plans for the modernization of education based on E4, which includes activities of training of people, educational management, and development of infrastructure	Industry, Government and Academia
		Develop legislation to ensure access to quality education with the development of students' digital skills	Government and Academia
	Education	Boost the use of E4 approaches and technologies at all levels of education	Government and Academia
		Create centers that support public and private universities to develop online learning platforms based on E4	Government and Academia
	Economy	Create technological infrastructure for E4 development in public education	Government and Academia
		Support financially the development of projects and research centers on E4 technologies	Industry, Government and Academia
		Create financing programs and partnerships with companies to capacitate future professionals in I4 technologies	Industry, Government and Academia
Academia	Education	Develop approaches for inserting E4 in teacher training	Government and Academia
		Use E4 technologies to include students with disabilities in schools, universities, and the job market	Industry, Government and Academia
		Use E4 in educational approaches to teach STEM areas	Government and Academia
		Include and to offer blended learning in their courses and programs	Academia
	Research	Investigate the impacts and challenges of integrating I4 technologies into education	Academia
		Propose solutions for integration of I4 technologies to teaching	Industry, Government and Academia
		Map the skills and competencies needed for professionals to work in I4 and introduce them in the curricula	Industry, Government and Academia

teaching platforms to train their employees, including on I4 technologies. In addition, companies can commercialize these courses and provide consulting services to other organizations that wish to use I4 technologies. The training can be offered through E4

technologies such as RV, AR, and simulation. The benefits of using these technologies in training that offers worker safety risks or that are difficult to implement and reproduce are highlighted (Mian *et al.*, 2020; Pedro *et al.*, 2016).

In the Technology domain, the development and commercialization of educational platforms that use AI and DB tools to enable personalized and adaptive education are proposed. These technologies are useful to support teachers in the teaching-learning process through chatbots, virtual assistants, and by providing intelligent reports on students' academic performance. It is also proposed that companies partner with universities to research and develop effective hardware and software for E4 (Almohammadi *et al.*, 2017; Huda *et al.*, 2017).

The politics and initiatives proposed on the framework for Government are divided into the areas of Politics and Legislation, Education, and Economy. The proposals for Politics and Legislation are important to promote and encourage E4 from the creation of guidelines, objectives, and action plans for modernizing education. Access to computers, tablets, and interactive whiteboards in classrooms should be expanded. Also, legislation should ensure access to quality education and the development of digital skills of students to meet the demands for professionals trained to work at I4 (Benešová and Tupa, 2017).

In the Education domain, the use of E4 technologies is proposed to engage and motivate students in the teaching-learning process at all levels of education. It is also proposed to create centers that support the development of online teaching platforms with technologies such as DB, AI, CC for monitoring academic performance and sharing educational activities between teachers and students (Popenici and Kerr, 2017).

In the Economy domain, the allocation of financial resources to purchase computers, tablets and provide adequate Internet access is proposed for enabling the implementation of E4 at all levels of public education. In addition, it is necessary to encourage the creation of research centers at universities in partnership with companies and other countries for developing E4 technologies and the training of future professionals in I4 technologies (Wu *et al.*, 2019a).

The initiatives proposed in the framework for Academia are divided into Education and Research domains. In Education, the development of methodologies for inserting E4 into the training of teachers is proposed, so that they can use it in teaching environments. It should be employed in courses and programs to provide greater inclusion of students in schools and the labor market, including students with disabilities from greater autonomy and better qualification. Besides, E4 should be implemented to increase student engagement in the subjects, especially STEM. Schools should include and offer blended learning in their courses and programs (Gil-Flores *et al.*, 2017; Hsu *et al.*, 2017; Smith *et al.*, 2017).

In the Research domain, studies to take advantage of scientific opportunities and to overcome the E4 challenges identified in this work are suggested. It is also essential to propose an increasing number of solutions for integrating I4 technologies into education and to investigate the impacts of this integration, being a necessary mapping of skills and competencies necessary for professionals to work in I4 and to introduce them in the curricular grids (Akçayır and Akçayır, 2017; Gupta *et al.*, 2015).

Thus, the policies and initiatives of the proposed framework also must be conducted through constant interactions among Triple Helix agents. The government-academia interaction must promote and foster the development of E4 through the formation of research centers, the creation of policies for modernizing teaching, and teacher training to improve the quality of teaching. The government-industry interaction must provide funding and technological infrastructure for E4 and create partnerships to create training programs at I4. Finally, the industry-academia relationship must promote the continuous development of research and innovation, commercialization of technologies on the subject, and provision of the infrastructure necessary for E4 development in the teaching environments.

7. Conclusion

The fourth SDG established by the UN aims to ensure greater access to quality education, in consideration of education is crucial for developing society and must not be restricted to geographical or social barriers. The proposed E4 development framework aims to improve the teaching-learning process, making it more interactive, personalized, and accessible through the implementation of policies and initiatives for Triple Helix agents.

The main theoretical-scientific contribution of this work is the creation of a new block of knowledge that deepens and extends the existing literature, introducing good practices, challenges, and opportunities mapped in the technical-scientific scenario and the proposal of the framework containing a package of policies and initiatives. Thus, this work will support further studies on the theme based on the scientific challenges and opportunities for E4 development identified and the proposed framework.

The major applied contribution of this work is to enable the increase in access to quality education, modernization of the teaching-learning process, and improvement of the professionals' qualification demanded by I4. To that end, policies, and initiatives for E4 development were proposed to be adopted by Triple Helix agents, aiming to increase the engagement and motivation of students with the content taught through the integration of I4 technologies with teaching. In addition, the use of ICT and the Internet in teaching allows students from remote areas or those without financial resources for face-to-face courses to have access to effective online courses that enable adaptive, personalized, and student-centered learning.

Although the countries of technical and scientific prominence in the subject have been studied, the results of this article are limited to the experiences analyzed and the search criteria used. Obviously, if more countries and other databases were considered, other relevant policies and initiatives could be identified to support the authors in the elaboration of the proposed framework. Therefore, it is proposed that future studies use different search criteria to identify other countries with policies and initiatives that could be added to the framework for Triple Helix agents. Future studies could select countries considering the number of patents per capita in the technical scenario and the number of citations in the scientific scenario. In addition, exploratory studies and surveys could be conducted to identify the benefits and challenges of implementing E4 in developed and developing countries.

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APPENDIX A
The most cited articles from 2015 to 2020

Article Name	Authors	Year	Journal
Advantages and challenges associated with augmented reality for education: A systematic review of the literature	Akçayır and Akçayır	2017	Educational Research Review
Big Data and analytics in higher education: Opportunities and challenges	Daniel	2015	British Journal of Educational Technology
Cloud computing and education: A state-of-the-art survey	González-Martínez *et al.*	2015	Computers and Education
Augmented reality to promote collaborative and autonomous learning in higher education	Martín-Gutiérrez *et al.*	2015	Computers in Human Behavior
Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories	Akçayir *et al.*	2016	Computers in Human Behavior
Conceptualizing a model for adoption of cloud computing in education	Sabi *et al.*	2016	International Journal of Information Management
Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment	Huang *et al.*	2016	Computers and Education
Educational magic toys developed with augmented reality technology for early childhood education	Yilmaz	2016	Computers in Human Behavior
Understanding behavioral intention to use a cloud computing classroom: A multiple model comparison approach	Shiau and Chau	2016	Information and Management
Teaching based on augmented reality for a technical creative design course	Wei *et al.*	2015	Computers and Education
Requirements for Education and Qualification of People in Industry 4.0	Benešová and Tupa	2017	Procedia Manufacturing
Factors that explain the use of ICT in secondary-education classrooms: The role of teacher characteristics and school infrastructure	Gil-Flores *et al.*	2017	Computers in Human Behavior
Teaching and learning with technology: Effectiveness of ICT integration in schools	Ghavifekr and Rosdy	2015	International Journal of Research in Education and Science
Antecedents and consequences of cloud computing adoption in education to achieve knowledge management	Arpaci	2017	Computers in Human Behavior
Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations	Hwang *et al.*	2016	Interactive Learning Environments
The impact of authentic learning experiences with ICT on pre-service teachers' intentions to use ICT for teaching and learning	Valtonen *et al.*	2015	Computers and Education
Exploring adaptive teaching competencies in big data era	Huda *et al.*	2017	International Journal of Emerging Technologies in Learning
Integrating augmented reality technology to enhance children's learning in marine education	Lu and Liu	2015	Environmental Education Research

Table continued from previous page

Article Name	Authors	Year	Journal
A review of the use of virtual reality head-mounted displays in education and training	Jensen and Konradsen	2018	Education and Information Technologies
A Social Virtual Reality Based Construction Safety Education System for Experiential Learning	Le *et al.*	2015	Journal of Intelligent and Robotic Systems: Theory and Applications
How the ICT development level and usage influence student achievement in reading, mathematics, and science	Skryabin *et al.*	2015	Computers and Education
Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection-based display systems	Huang *et al.*	2016	Interactive Learning Environments
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