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Information and Communication Technologies in Education 4.0 Paradigm: A Systematic Mapping Study

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Abstract. Industry 4.0 technologies are being applied in the teaching and learning process, called Education 4.0. However, there is no specification of what is being considered when developing technologies for education in the 4.0 context. Therefore, we performed a Systematic Mapping Study to investigate the information and communication technologies (ICTs) proposed to Education 4.0. From a search in four search engines, 81 articles had data extracted. The results elucidated aspects considered as Education 4.0, such as contextualized learning and student-centered learning. Besides, some applied ICTs are not in agreement with the ICTs considered as 4.0 in the literature, the focus on ICTs to engineering education and to be applied to higher education. As implications of the results obtained, it is necessary to understand why some ICTs are not aligned with 4.0 literature and apply these ICTs in knowledge areas beyond STEM.

Keywords: industry 4.0, information and communication technologies, 21st century abilities, active methodologies, educational technologies, 4.0 technologies.

1. Introduction

In recent years, it was observed a growing academic interest in what is being called Education 4.0, a defined term, according to several authors (Almeida and Simoes, 2019; Bongomin *et al.*, 2020; Keser and Semerci, 2019; Silva *et al.*, 2021), based on alignments with perspectives such as Industry 4.0 and Economy 4.0. To understand the historical transformations that underlie Industry 4.0 perspectives, it is necessary to understand that Industry 1.0 was linked to steam engines, with slower development processes linked to bodywork and the introduction of machinery. Industry 2.0 was related to the industrial revolution, having as important points the use of electricity and a faster pace of development. In Industry 3.0, a relationship with information and communication technologies (ICT) was verified, increasing the pace of development of work and the economy itself (Bongomin *et al.*, 2020; Ciolacu *et al.*, 2017).

Thus, we arrived at Industry 4.0, which is also understood from ICT, but significantly deepening these relationships. Thus, Industry 4.0 involves nanotechnology, biotechnology, three-dimensional printing, artificial intelligence, robotics, the internet of things, quantum computing, among others (Hussin, 2018). Although this discussion is relevant to educational contexts, it is necessary to understand the relationships in these spheres in greater depth, especially the influences of an Industry 4.0 for educational processes and vice versa. Likewise, it is necessary to verify which ICT are being developed for education in the 4.0 paradigm.

It is essential, in this context, to understand that education has its interests and goes beyond the barriers of training for simple labor in any industrial or economic configuration. There is an intrinsic relationship between Education 4.0 and the so-called Industry 4.0 and Economy 4.0, as a discourse present in research in this field. When seeking to comprehend the roots and the main arguments that differentiate this perspective from others, such as Education 3.0, it is also necessary to trace history in this regard. According to (Dematrini and Benussi, 2017), Education 1.0 is understood as a paradigm that considers the teacher as a centralizer and the student in a passive perspective during a very focused school institution and on traditional teaching and learning methods.

Education 2.0, in turn, would be a breaking point, as there is a considerable change in the relationships between teachers and students, with the student taking a more active role in the process through approaches such as project-based learning, for example. Some authors comment that this perspective is in line with Web 2.0, beginning the use of technologies in Computer Based Training (Keser and Semerci, 2019). Relations between institutions expand, but there is still a direct affiliation between students and educational institutions. In the Education 3.0 paradigm, we have involvement of concepts such as Virtual Learning and Social Networks, with the roles of teachers and students even more modified (Keser and Semerci, 2019). It is understood here that the student dominates their educational process. At the same time, the teacher is a leader in the collaborative construction of knowledge, which makes room for broader relationships between students and institutions (Dematrini and Benussi, 2017).

Finally, the 4.0 paradigm aims to deepen the relationship of the educational process with Industry 4.0 technologies (Keser and Semerci, 2019). In this way, the relationship between teachers and students is even more dispersed, even involving mediating systems based on Artificial Intelligence. Thus, greater autonomy is sought on the part of the student, something that even reflects in their relationship with institutions, making them less and less relevant. In Education 4.0, a learning process that is highly mediated by ICT and adapted to the needs and interests of the student in real-time stands out (Dematrini and Benussi, 2017). Education 1.0, 2.0, and 3.0 paradigms are not necessarily aligned with industrial perspectives, involving broader discussions, such as civic education, for example, which do not have a specific focus linked to Industry and Economy as is the case with Education 4.0 (Dematrini and Benussi, 2017; Keser and Semerci, 2019).

Besides, no studies broadly map ICTs in Education 4.0 since the ICTs began to be developed based on the term Education 4.0. The literature reviews already developed on Education 4.0 have other focuses besides ICTs, such as blended learning and social networks (Sanjeev and Natrajan, 2021) or active methodologies (Silva *et al.*, 2021). This research's main point of differentiation concerns an analysis of Education 4.0 focusing on understanding the relations between education, technology, and computing. Therefore, our study aims to:

- Analyze scientific publications to characterize ICT implemented, taking into account the Education 4.0 paradigm, through a Systematic Mapping Study (SMS) method (Petersen *et al.*, 2015).

Thus, we seek to visualize how computing has been understanding this field of study and developing artifacts that seek to align with the expectations of Education 4.0. The presented review sought to bring the point of view of Computer Science researchers, specifically in Informatics in Education, in the context of primary sources available in three digital libraries (ACM Digital Library, IEEE Xplore, and Springer Link) and one indexing (Scopus). The remain of this paper is organized as follows: Section 2 shows the background of Education 4.0 and the main concepts that involve the term. Then, Section 3 presents the method applied to carry out the SMS. Finally, in Section 4, results and discussions of extracted data are presented, and in Section 5, conclusions are presented with some gaps in the studies and possibilities for future work.

2. Background

Bongomin *et al.* (2020) explain that Industry 4.0 differs in "speed, scale, complexity, and transformative power" concerning previous paradigms. The term Industry 4.0 was defined by the German Federal Ministry of Education and Research in Germany, and it is a strategy to position Germany as a developed manufacturing country that starts to look at emerging technologies (Kagermann *et al.*, 2013). Moreover, the German idea is to understand the technology as development potential through cyber-physical systems, implementing Internet of Things and Services related to the concept of Smart Factories (Kagermann *et al.*, 2013).

We bring this definition, as it is necessary to highlight the strong relationship between Industry 4.0 and Education 4.0 by the literature discussing this theme. Thus, the term Education 4.0 arises from the demands of the 4th Industrial Revolution, or Industry 4.0. Furthermore, Education 4.0 is linked to the need for differentiated training, as current training will be out of step with the jobs that will emerge over the next few years (WEF, 2016). When discussions about Education 4.0 began to emerge in 2016, the top skills to be achieved by the year 2020, identified by WEF (2016), were: complex problem solving; critical thinking; creativity; people management; coordinating with others; emotional intelligence; judgment and decision making; service orientation; negotiation; cognitive flexibility (Hussin, 2018).

The 2020 version of the report (WEF, 2020) points to a considerable acceleration in changes in work profiles due to the economic recession resulting from the COVID-19 pandemic, something that can be seen with an increase in the use of computer technologies in work, requiring even more significant retraining. In this sense, the World Economic Forum updates skills for the years 2020–2025, as pointed out by employers as growing in prominence, for critical thinking and analysis; problem-solving; selfmanagement; working with people; management and communication of activities; technology use and development; core literacies; physical abilities.

We observed that one of the central spectrums of Education 4.0 is the wide use of ICT tools in educational contexts. These are considered essential innovations to implement this paradigm since the term Education 4.0 has been used to discuss the construction of skills linked to this new industry configuration (Bongomin *et al.*, 2020). Concerning ICT linked to the Industry 4.0 and Education 4.0 paradigms, the authors Bongomin *et al.* (2020) and Keser and Semerci (2019) show an analysis of several works that demonstrate that there is still no consolidation on the subject. While Bongomin *et al.* (2020) found 35 technologies in 70 works, they highlighted 13 that appeared most frequently, namely: Internet of Things (IoT); Big Data; 3D Printing; Cloud Computing; Autonomous Robots; Virtual and Augmented Reality; Cyber-Physical System (CPS); Artificial Intelligence (AI); Smart Sensors; Simulation; Nanotechnology; Drones; Biotechnology. On the other hand, Keser and Semerci (2019) bring a set of 16 technologies, nine according to the list of Bongomin *et al.* (2020) and seven new ones: Smart Robots and Machines, Mixed Reality, Data Analytics, Digital Twins, Quantum Computing, Radio Frequency Identification Technologies, and Smart Spaces.

Almeida and Simoes (2019) mentioned that Education 4.0 is based on the "concept of learning by doing, in which students are encouraged to learn and discover different things in unique ways, based on experimentation." In this way, to achieve the skills concerning ICT, active methodologies are depth explored in Education 4.0. These methodologies aim to centralize the student's role in the educational process and collaboratively construct knowledge. Silva *et al.* (2021) define active methodologies as educational practices that allow students to relate reflection, questioning, and searching for knowledge based on its application in authentic contexts. Thus, they bring greater dynamism and interactivity in skills related to Education 4.0. Santana and Lopes (2020) and Silva *et al.* (2021) point out some examples of active methodologies, such as Project-Based Learning, Collaborative-Based Learning, Problem-Based Learning, Blended Learning, Flipped Classroom, Simulation-Based Learning, Digital Game-Based Learning, and Creative Learning.

Based on these definitions of Education 4.0, our SMS seeks to understand, from the ICTs developed and applied in the 4.0 context, which Industry 4.0 technologies pointed out by Keser and Semerci (2019) and Bongomin *et al.* (2020) are also being applied in Education 4.0. Moreover, we seek to understand whether aspects, such as the development of skills and competencies, are considered when developing ICT for Education 4.0 and other aspects that may also be present in the 4.0 paradigm and are not mentioned in the literature. Furthermore, to comprehend if the active methodologies, mentioned by Santana and Lopes (2020) and Silva *et al.* (2021), are used in the development and application of ICT in the educational process.

3. Methods

The SMS protocol is based on the guidelines proposed by Kitchenham and Charters (2007) and Petersen *et al.* (2015). An SMS aims to present a broad context of primary studies in a given area, identifying evidence about that topic, as discussed by Kitchenham and Charters (2007). The main objective of this research was developed based on the GQM (Goal-Question-Metric) paradigm (Basili and Rombach, 1988) and is described as **Analyze** scientific publications **for the purpose of** characterize **in relation to** ICT that have been implemented taking into account the Education 4.0 paradigm **from the point of view** of computer science researchers, specifically in the field of informatics in education **in the context of** primary sources available in search engines.

We seek to select search engines with significant impact and popularity in computing and consider search engines' efficiency and the good number of returned articles. The following search engines were selected: ACM Digital Library, IEEE Xplore, Scopus, and SpringerLink. We considered only the articles that were written in the English language. The Fig. 1 summarize the articles' selection process. To define the search string, we considered that the term Education 4.0 appeared recently, and it still includes little scientific research on search engines. Therefore, we have decided to use only the term "Education 4.0" in the initial searches of the mapping, trying to reach the most significant possible number of scientific articles.

Despite the recent emergence of the term Education 4.0, no time limit has been set to collect articles on search engines. Therefore, the search was carried out until the end of the first semester of 2020, June 30. A total of 1090 articles were returned from the initial search, eight from ACM Digital Library, 478 from IEEE Xplore, 385 from Scopus, and 219 from SpringerLink. The information of the articles, such as title, year of publication, authors, the venue of publication, summary, and keywords, were collected and organized in an electronic spreadsheet.

To select relevant papers after our initial search, we defined inclusion and exclusion criteria based on our main objective, as shown in Fig. 1. Then, the articles went through two filters. The first filter aimed to read the papers' title, abstract, and keywords, evaluating selection or exclusion based on the criteria defined above. Two researchers carried out the first filter process, requiring that at least one researcher approve each article for the second filter for a more complete and definitive evaluation. Finally, we applied the Kappa statistical test to assess the degree of agreement between the two researchers. The value obtained was 0.92, indicating an almost perfect agreement, which varies between -1 and +1, where a negative value indicates total disagreement and 1 represents a perfect agreement (McHugh, 2012).

From the initial 1090 articles, 298 were selected for analysis in the second filter, representing three from ACM Digital Library, 103 from IEEE Xplore, 157 from Scopus, and 35 from SpringerLink. A complete reading of the papers was performed in the second filter, evaluating selection or exclusion based on the same criteria. In the second filter, the same two researchers performed the process, and both needed to agree on the inclusion or exclusion of articles. After full reading, 81 articles were selected for

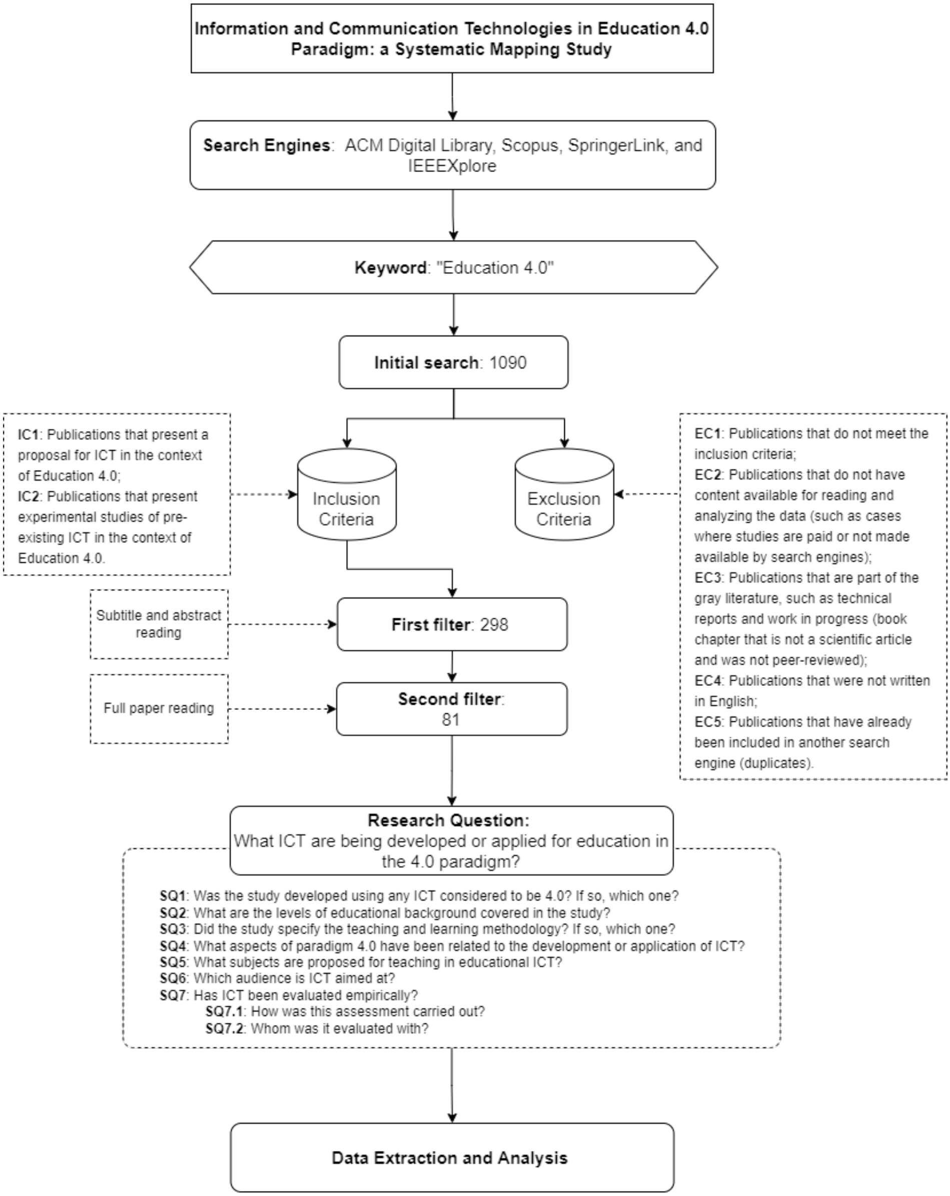

Fig. 1. Articles selection process.

data extraction and analysis, representing one from ACM Digital Library, 20 from IEEE Xplore, 55 from Scopus, and five from SpringerLink.

Based on our objective, we seek to understand how ICT have been developed and applied in Education 4.0, which educational content and levels are being met by the articles, which active methodologies are being utilized, and which 4.0 aspects have been considered in the proposals. Therefore, we have as the main research question (RQ): *What ICT are being developed or applied for education in the 4.0 paradigm*? Several sub-questions (SQ) were defined to answer the main research question and to understand in detail each of the technologies implemented or applied in the 4.0 paradigm, as can be seen in Table 1.

Table 1

SMS sub-questions

Sub-questions	Objective
SQ1. Was the study developed using any ICT considered to be 4.0? If so, which one?	Based on the review article from Bongomin *et al.* (2020) and the research of Keser and Semerci (2019) that identified industry 4.0 key technologies, we expected to find those technologies: internet of things, big data, 3D printing, cloud computing, autonomous robots, virtual and augmented reality, cyberphysical system, artificial intelligence, smart sensors and places, simulation, nanotechnology, drones, biotechnology, blockchain, industrial internet of things, smart factory and intelligent factory, digital twin.
SQ2. What are the levels of educational background covered in the study?	With this sub-question, the educational levels that the technologies were taking into consideration were categorized, such as primary education, as elementary school, secondary education, as high school and technical high school, terciary education, as undergraduate and postgraduate, and special education.
SQ3. Did the study specify the teaching and learning methodology? If so, which one?	Understanding the methodologies applied in the studies is relevant because the Education 4.0 paradigm is aligned with a specific perspective, in this case, the active methodologies. Thus, we sought to quantify and identify whether these approaches are being adopted in the studies. Some of the expected responses were mobile learning, hybrid learning, e-learning, flipped classroom, among others.
SQ4. What aspects of paradigm 4.0 have been related to the development or application of ICT?	We sought to understand which aspects the authors considered as 4.0 when discussing the term and which direction the paradigm is taking. Among the responses we expected were skills and abilities, the application of ICT, digitalization, and personalization and adaptation of learning.
SQ5. What subjects are proposed for teaching in educational ICT?	It was possible to visualize the contents taught by the educational ICT developed or applied in the articles from this question. Expected answers included math, languages, sciences, computing, and engineering.
SQ6. Which audience is ICT aimed at?	With this question, the objective was to understand the public of the ICT, considering the existing roles in the educational environment, such as students, teachers, and school administrators. We considered the target audience as the final audience of educational ICT.
SQ7. Has ICT been evaluated empirically?	We understood whether ICT was being evaluated in concrete situations, with possible yes or no answers from this sub-question.
SQ7.1. How was this assessment carried out?	We sought to understand how the assessment was applied, whether in the school context, residential environments, companies, and how the technology was evaluated.
SQ7.2. Whom was it evaluated with?	We aimed to understand the public which the ICT was evaluated with, not necessarily being the same target audience for whom the technology was built, which may be roles present in the educational routine, such as students, teachers, and school administrators, or other roles, such as specialists and researchers.

3.1. *Threats to Validity*

As Ampatzoglou *et al.* (2019) mentioned, several threats to validity can occur in an SMS. Among the most common, they cite the construction of the search string, which in this mapping we sought to mitigate by using only the term Education 4.0, without adding other terms with logical connectors, which could slightly restrict the search and the return of articles that would fit the scope of the research. Another common threat to validity is the study inclusion/exclusion bias. We seek to mitigate this threat by carrying out the inclusion and exclusion process by two researchers, who hold weekly meetings to discuss each article, especially those with no agreement with the applied criterion.

Another threat that is quite common in studies is data extraction bias, which was mitigated by defining possible answers to each question in the protocol before the extraction. Moreover, we sought to define mainly quantitative research questions, facilitating data extraction. Furthermore, another threat to validity that we sought to mitigate is the selection of digital libraries. To avoid this problem, we selected libraries that are known and widely used in the field of computer science and related.

4. Results and Discussion

This section presents and discusses the SMS results. Initially, the general results are presented, such as the distribution between the proceedings and journals, the researchers' countries of origin, and the years of publications. Next, the main research question (RQ) is discussed, followed by the sub-questions (SQs). From 81 articles with extracted data, 30 were published in scientific journals, 48 were published in event proceedings, and three were published as book chapters. In total, 55 different journals and conferences are part of this mapping, with 36 conferences proceedings and 19 journals and a book, Engineering Education 4.0, which had the three publications mentioned above.

Regarding the conferences, The Journal of Physics: Conference Series (N = 8 publications) is the publication venue with the most significant number of articles represented in this SMS. Moreover, IEEE International Symposium for Design and Technology in Electronic Packaging (N = 4), IEEE Global Engineering Education Conference (N = 2), and IEEE International Conference on Industrial Informatics (N = 2) are the conferences with more than one publication each. Furthermore, regarding the journals, Procedia Manufacturing (N = 6), International Journal of Innovation, Creativity and Change (N = 3), Sustainability (N = 3), International Journal of Scientific and Technology Research (N = 2), and Universal Journal of Educational Research (N = 2) are the journals that appear more than once.

Regarding the countries of origin of the articles, considering the authors' affiliations, 30 countries are represented in the selected works, covering four continents (America, Asia, Europe, and Oceania), as seen in Fig. 2. First, Indonesia is the most represented country in research with 28.40% articles (N = 23), representing articles with only researchers from the country and partnerships between researchers from two

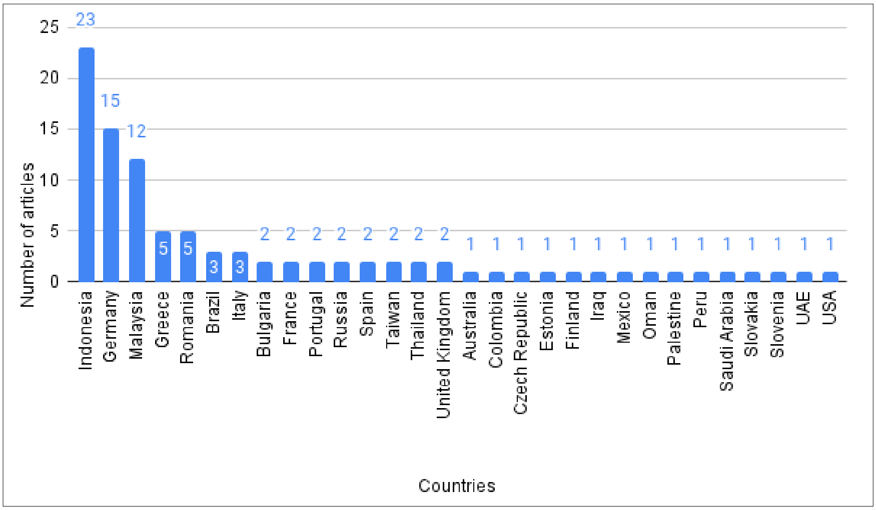

Fig. 2. Countries covered in the SMS.

or more countries. Then Germany appears with 18.52% articles (N = 15), Malaysia with 14.82% articles (N = 12), and Greece and Romania with 6.18% (N = 5) each, completing the five countries with the most publications in the area. The large number of countries represented is very relevant, showing the theme's importance in recent years and the need to understand which paths Education 4.0 is taking in the world panorama of education.

Regarding the years of publication of the articles, despite not having restricted the years' category in the initial searches, only articles from 2016 and beyond met the inclusion criteria (Fig. 3). Thus, there were six publications in 2016, four in 2017,

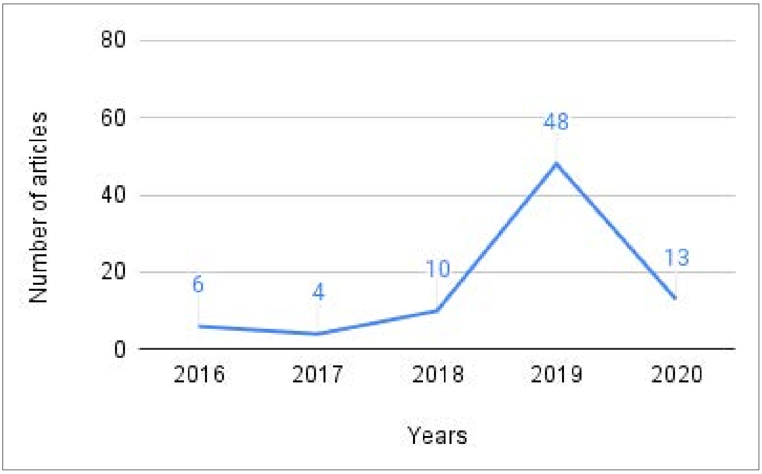

Fig. 3. Number of publications per year.

and 10 in 2018. After the stability of the first three years, in 2019, 48 articles were selected. In 2020, 13 articles were selected and, despite the lower number in comparison to 2019, it is necessary to consider two aspects: articles were selected until the first semester of 2020, and it is possible that this number has grown in the second semester, and also taking into account the COVID-19 pandemic context, which has impacted the whole world and possibly delayed publications that would be published in 2020, 1st semester.

4.1. *RQ – What ICT are Being Developed or Applied for Education in the 4.0 Paradigm?*

In the RQ, we sought to understand which ICT are being associated with the Education 4.0 paradigm. We identified a variety of 77 ICT in 90 occurrences. It is noteworthy that data extraction from these technologies is strictly linked to the researchers' reported data. Thus, although there are possible technologies similar to each other, only those with the same term were grouped and classified as the same technology.

We verified seven main categories during data extraction. The categories were created based on the presentation and discussion of the results, which means that the technology does not necessarily belong exclusively to the group associated or that there cannot be other possible groups of ICT based on similarities. The seven categories detailed below are Learning Systems, Laboratories and Factories, Simulation-related Technologies, Artificial Intelligence, Multimedia, Internet of Things, and Robotics. Besides these categorizations, some technologies did not fit it and are presented individually. In cases where studies involved more than one category, we categorized the technology with the central role in the study.

The most popular category involves **Learning Systems**, with 23 occurrences in the papers. More specifically, the mapped technologies are (with the number of occurrences of each technology in parentheses): Adaptive Learning System (2); Edmodo (2); Kahoot! (2); Moodle (2); Android-based Learning Application (1); Software Twine (1); Schoology (1); Learning System (1); Learning Management System (1); Smart Hybrid Learning System (1); Technology-based Learning System (1); Mathematica (1); Web-Based e-Learning Tool Confirm-A (1); Smartphone Apps EduKits 4.0 (1); Padlet (1); Quizizz (1); Virtual Learning Environment Supported by a Remote Laboratory (1); Mobile Learning Ku App (1); and Learning System Structure (1).

Next, technologies related to **Laboratories and Factories** were identified, with a total of 18 occurrences, namely: Learning Factory (4); Digital Manufacturing Laboratory (2); Teaching Factory (2); Remote Laboratory in Virtual Reality Environments (1); Training Laboratory (1); 3D Factory Simulation (1); Industry 4.0 Technologies Laboratory (1); Power Electronics Experiments Laboratory (1); Remote Laboratory (1); Electro-Pneumatic Laboratory (1); Virtual Learning Factory (1); Web-based Virtual Laboratory (1); and Remote and Virtual Labs (1).

Fourteen occurrences of **Simulation-related Technologies** were identified: Minecraft (3); Simulation Game (2); Augmented Reality Application (1); 3D Simulation

Application (1); Integrated System for Simulation (1); Virtual Reality-Based Training Methods (1); 360-Degree Videos to Virtual Reality Simulation (1); 3D Animation-based Augmented Reality Technology (1); Digital Learning Environments in Virtual and Augmented Reality (1); Tools to Develop Digital Twin Technology (1); and Twin Version of an RFID-measuring-chamber (1).

Technologies with **Artificial Intelligence** connection appeared in eight articles and are classified as Machine Learning Techniques (1); Decision Support System (1); Adaptive User Interface (1); Model for Graduation Course Evaluation (1); Chatbot (1); App Orai (1); Advanced Correction and Validation System (1); and Learning Analytics Technologies (1).

Some researches sought the development or application of **Multimedia**, with seven occurrences in total: E-modules (1); E-handouts (1); Project-based multimedia learning media (1); Android-based Instructional Media (1); App Goodnote (1); instructional iBook iBakery (1); and Development of Music Videos (1).

Technologies related to **Internet of Things** were four occurrences: IoT System (2); Wearable Devices Framework (1); and Ontology for a Smart System with Internet of Things Based Architecture (1). Finally, topics related to **Robotics** are linked to three occurrences, being the technologies: Collaborative Robots (1); Automated Guided Vehicle (1); and LEGO Mindstorms (1).

Moreover, other technologies were also developed or applied to the 4.0 paradigm and could not be fitted in the categories mentioned above: Programming Tool (1); Workbench-scale Systems (1); Cloud Platform (1); Virtual Business Projects Model (1); Computerized Testlet Instrument (1); Computational Programs on Molecular Modeling and Visualization (1); Engine for Virtual Electrical Engineering Equipment (1); Software Study Plan (1); Instructional Model to Meeting Integration (1); Framework to a Manufacturing System (1); CATIA Software (1); Procast Software (1); and 3D Printing Technologies (1).

Technologies related to Simulation, Artificial Intelligence, Internet of Things, and Robotics are strongly connected to 4.0 concepts presented and discussed in the literature of the area (Bongomin *et al.*, 2020; Keser and Semerci, 2019). Some examples found in the SMS are: in Simulation, an Augmented Reality application to support the teaching of geometry in an elementary school (Cazzolla *et al.*, 2019); in Artificial Intelligence, the app Orai, which provides English audio models, some speaking exercises with immediate actionable feedback (Ibrahim *et al.*, 2019); in Internet of Things, a system to monitor student physiological signals (through different sensors) in real-time, without distracting them in their learning activity, to study their behavior and response to learning conditions (Ciolacu *et al.*, 2019b); in Robotics, a Laboratory of Industry 4.0 with a collaborative robot and automated guided vehicle (Poór *et al.*, 2019).

These ICT are commonly cited as examples of the development of Industry 4.0 and demonstrate the impact and importance they have on the educational process considered as 4.0. However, despite mapping technologies traditionally categorized as 4.0, several technologies have not been classified within the ICT traditionally debated in the 4.0 context. For example, Learning Systems, which usually function as learning management systems, have been present since other paradigms, such as 3.0. An example is the use of Schoology, a learning management system, to promote blended learning (Roqobih *et al.*, 2019).

Others ICT were previously developed and widely used not only in the 4.0 context, such as Moodle (Fitri and Zahari, 2019; Mulyani *et al.*, 2019), Kahoot! (Madzlana, 2019; Nurhadianti, 2020), and Edmodo (Cholifah *et al.*, 2019; Tania *et al.*, 2020), but were applied based on the 4.0 context, according to the authors. Moreover, there are technologies implemented by the authors of the articles to be applied in the 4.0 context. One of them is ALMo-DML, an adaptive learning approach that considers both the cognitive and engagement states of the students and intervenes with the learning automatically (Hamid *et al.*, 2019), and Confirm-A, a web-based E-Learning tool for primary and secondary school students to have additional practices for all subjects required in the major examination (Sulaiman *et al.*, 2018).

Factories and laboratories are ICT that were not mentioned in the works of Bongomin *et al.* (2020) and Keser and Semerci (2019) as belonging to the educational and industrial 4.0 contexts. However, they still significantly impact the technologies developed and applied in this SMS, mainly in engineering and manufacturing, with the Learning Factory and Virtual Learning Factory being the most present technology (Gualtieri *et al.*, 2018; Lang *et al.*, 2018; Mourtzis *et al.*, 2019b; Salah *et al.*, 2019; Zarte *et al.*, 2019).

The ICTs presented in this section are an abstraction of the data extracted from the articles. In the following subsections (4.1.1 to 4.1.7), the research sub-questions are presented and discussed, seeking to understand better the objectives and paths these ICTs are considering within the 4.0 paradigm.

4.2. *ICT Considered as 4.0 (SQ1 – Was the Study Developed Using Any ICT Considered to be 4.0? If so, Which One?)*

We sought to understand with SQ1 which were the most used technologies and, when it comes to Education 4.0, if there is the application of one of these technologies. Fig. 4 illustrates the technologies considered 4.0 that returned in the data extraction. We point out that each article can describe the use of none, one or many ICT.

Based on the results, we observed that 34.57% of studies (N = 28) do not apply ICT considered 4.0, as discussed in Keser and Semerci (2019) and Bongomin *et al.* (2020). Of the studies that applied any of the 4.0 technologies, Simulation was the most applied technology, with 25.93% of studies total (N = 21). Robotics and Virtual Reality were the second most applied technologies, in 17.29% of studies each (N = 14). Cloud Computing (12.35%, N = 10) and Augmented Reality (11.12%, N = 9) were the subsequent technologies most frequently used. In sequence, Artificial Intelligence (9.88%, N = 8), Internet of Things (9.88%, N = 8), Cyber-Physical Systems (6.18%, N = 5), Biotechnology (3.71%, N = 3), Digital Twins (3.71%, N = 3), 3D printing (2.47%, N = 2), Smart city/Smart systems (2.47%, N = 2), Smart Factory/Intelligent Factory (2.47%, N = 2), Big Data (1.24%, N = 1), and Industrial Internet of Things (1.24%, N = 1).

As examples of the technologies with the most occurrences (Simulation), we point out game-based approaches: a simulation game called Christmas Tree Production Game

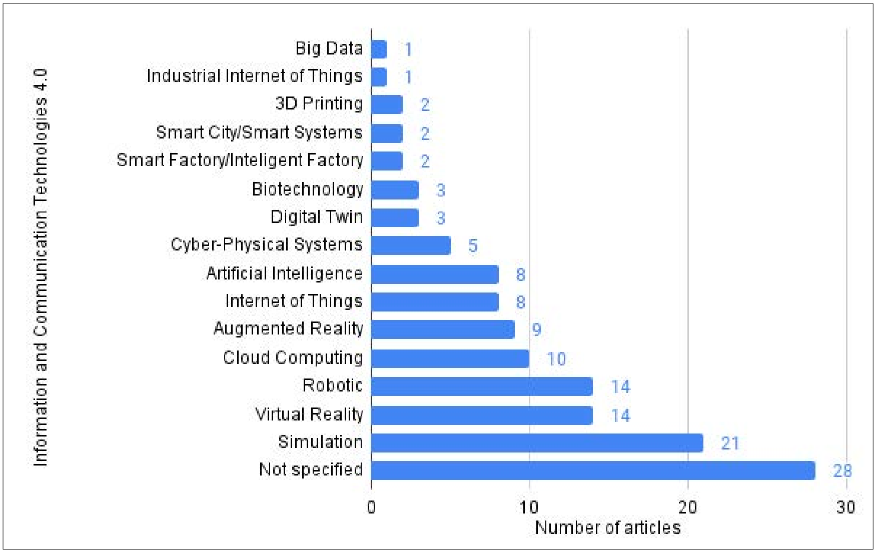

Fig. 4. ICT considered as 4.0.

(Zarte and Pechmann, 2017); a digital educational game called BeeCEO, focused on a digital business process simulation software where users can practice the business process theory through simulation (Limantara *et al.*, 2019); and virtual learning environments within the game Minecraft (Janßen *et al.*, 2016; Plumanns *et al.* 2016; Schuster *et al.*, 2016).

Virtual Reality and Robotics have the second most occurrence. Some papers mix them in their approach, such as a twin version of an RFID-Measuring-Chamber and a learning management system, to automatically store video recordings and experiment specific data of the real experiment (Höehner *et al.*, 2019); a remote and virtual lab for mechanical engineering education with a focus on manufacturing technology, with conceptualization and implementation of a tele-operative material characterization along with a remote lab for incremental tube forming, through a Massive Open Online Course (Grodotzki *et al.*, 2018); and a remote laboratory in virtual reality environment, using direct and inverse kinematics control schemes in order to enable the control of two cooperating six-axis robots (Hoffmann *et al.*, 2016).

In total, 15 different ICT were mapped in our study, a number lower than the lists proposed by Bongomin *et al.* (2020) and Keser and Semerci (2019). Technologies like Nanotechnology, Drones, Mixed Reality, Quantum Computing, and Radio Frequency Identification Technologies were not identified in our SMS, besides those technologies being part of the literature related to ICT from Industry 4.0 applied in Education 4.0. On the other hand, 28 studies did not point to any of these technologies, demonstrating no consensus on which technologies are under the concept of Education and Industry 4.0, a topic with open discussion.

4.3. *Levels of Education (SQ2 – What are the Levels of Educational Background Covered in the Study?)*

As shown in Fig. 5, 74.08% of studies (N = 60) were carried out in tertiary education, especially with undergraduate students and professors, and 7,41% of studies (N = 6) in the postgraduate. Secondary education appears with 12,35% of studies (N = 10), with 1 study representing the technical high school and 9 representing the regular high school. Primary education, with 2,47% of studies (N = 2), and special education, with 1,24% of studies (N = 1), were also backgrounds for applying or developing 4.0 ICT, but in a lesser amount than those oriented to undergraduates. It is noteworthy that some of the content proposed for teaching with ICT, such as engineering, automation, and manufacturing, naturally focuses on teaching at the undergraduate level (Liljaniemi and Paavilainen, 2020; Mourtzis *et al.*, 2020).

Education with the support of 4.0 technologies has a low presence at primary and secondary educational levels, showing that the impact and focus of Education 4.0 are on tertiary education. This context of research and application found reinforces the idea that Education 4.0 is aligned with the training of labor for Industry 4.0, searching for specific qualifications. Reflecting on the educational discussions of the previous paradigms points out this specific alignment, which leaves aside broader aspects of the human formation, which is taken into account in the previous paradigms. Therefore, there is a space for exploring and deepening the 4.0 paradigm at basic levels of education.

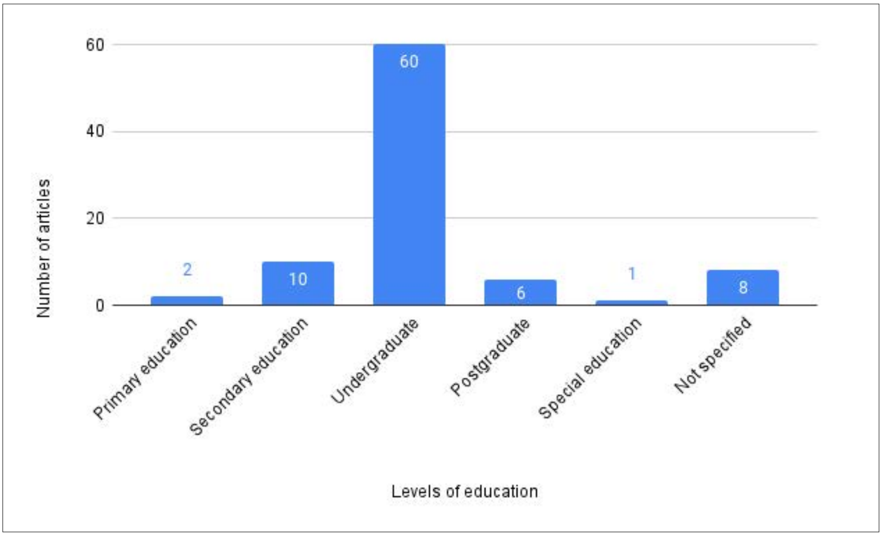

Fig. 5. Educational levels where technologies were applied.

4.4. *Methodologies (SQ3 – Did the Study Specify the Teaching and Learning Methodology? If so, Which One?)*

It is valid that we understand in which teaching and learning strategies the ICT are being applied, especially active methodologies, considered an important aspect of the 4.0 context where, according to Silva *et al.* (2021), make students participate in the educational process, promoting the development of 21st-century skills. Therefore, we map all the methodologies presented by the papers, whether active or not. Fig. 6 brings the results of this subquestion and, of the 81 extracted articles, 43 did not specify which methodology they applied in the teaching and learning process, representing 53.1% of the total. There is a wide variety of applied methodologies among the specified research, with 19 different methodologies cited. The most present methodologies in the studies were: hybrid learning (11.12%, N = 9); blended learning (8.65%, N = 7); e-learning (7.41%, N = 6); mobile learning (6.18%, N = 5); project-based learning (4.94%, N = 4); and problem-based learning (4.94%, N = 4).

As Santana and Lopes (2020) and Silva *et al.* (2021) mentioned, the active methodologies that were presented by the authors and found in this SMS were Project-Based Learning, Collaborative-Based Learning, Problem-Based Learning, Challenge-Based Learning, Blended Learning, Flipped Classroom, Case-Based Learning, and Digital Game-Based Learning. In addition, Santana and Lopes (2020) and Silva *et al.* (2021) still mention Team-Based Learning and Competency-Based Learning, enterprise-centered learning, scenario-based learning, simulation-based learning, inquiry-based learning, design thinking, problem-based corporate learning, creative learning, assisted learning. However, there was no occurrence of these active methodologies in the works of this SMS.

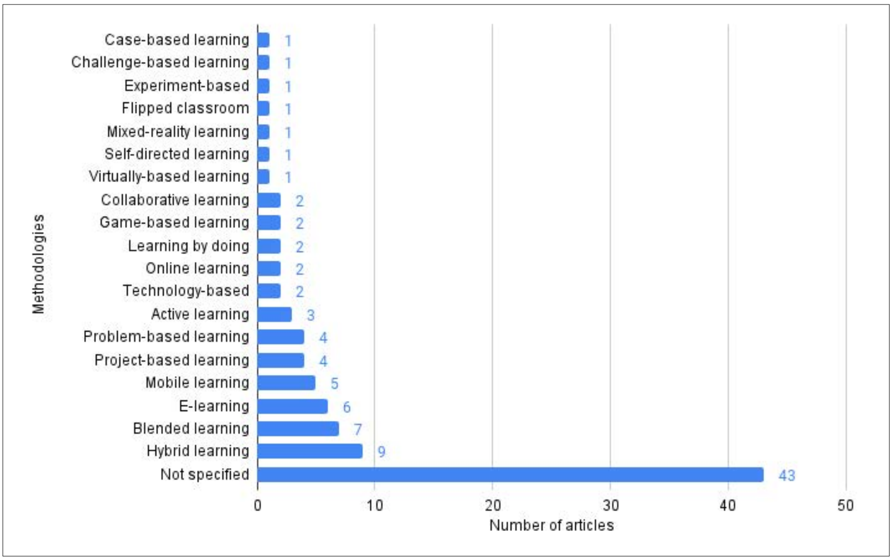

Fig. 6. Educational methodologies considered in the studies.

In addition, other methodologies were extracted from the studies and are not mentioned in the literature (Santana and Lopes, 2020; Silva *et al.*, 2021), specifically Active Learning, E-learning, Experiment-based Learning, Hybrid Learning, Learning by doing, Mixed-reality learning, Mobile Learning, Online Learning, Self-Directed Learning, Technology-Based Learning, and Virtually-Based Learning. Thus, it highlights a wide variety of methodologies being applied in the context of Education 4.0.

From the comparison between the data extracted from this SMS with the studies by Santana and Lopes (2020) and Silva *et al.* (2021), it is possible to observe that this is a field that is still under development, with no traditional conceptions about active methodologies in the 4.0 context. Whereas Education 4.0 seeks disruptive strategies in educational contexts, studies must specify the educational methodology strategy applied, considering that just 46.9% did it. There must be an evolution from what was considered 1.0, 2.0, and 3.0 so that the application of the 4.0 context can be in line with the changes expected by the theory, taking into account that it is relevant that the application of educational technology in the classroom can overcome the traditional teaching method.

4.5. *Education 4.0 Aspects (SQ4 – What Aspects of Paradigm 4.0 Have Been Related to the Development or Application of ICT?)*

We list 26 aspects, shown in Fig. 7, from what the researchers considered as paradigm 4.0, based on the discussions presented in the extracted articles. None of the articles presented more than 4 of the 26 aspects in the same study. There are, therefore, several strands that contemplate different views of the Education 4.0 paradigm. Based on this, we have grouped aspects into six different groups, namely: aspects of ICT, aspects of industry 4.0, aspects centered on the student, aspects of contextualized education, aspects of skills, and other aspects.

The most frequent aspect group was **ICT**, appearing 53 times in the papers, including the most present aspect among all: the use of technology itself, with 33 appearances in the papers collected. In addition, aspects of ICT include Digitalization (N = 13), Internet of Things (N = 2), Immersive Learning (N = 2), The Use of Artificial Intelligence (N = 1), E-Assessment (N = 1), and Virtual Learning (N = 1).

Understandably, this group of aspects is the most frequently found in the works, considering the objectives of the SMS and the inclusion and exclusion criteria defined for the selection of articles. We point out digitization, which is an aspect that has been accentuated mainly after the beginning of the COVID19 pandemic. The physical processes of the traditional classroom are migrating to virtual processes, with the use of virtual teaching environments, hybrid teaching, virtual learning, and other teaching methods and technologies, which are a change from the traditional classroom configuration.

The second most frequent group of aspects is **Skills**, which includes the aspects of abilities and skills (second most present aspect in papers in general, N = 21) and competence improvement (N = 1). Several subgroups exist within abilities and skills, such

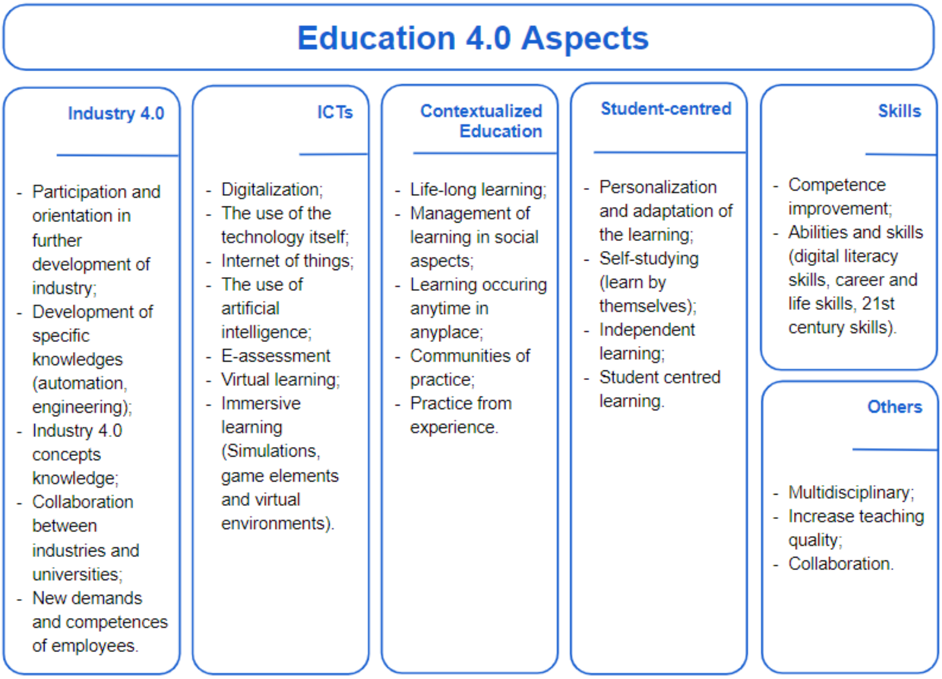

Fig. 7. Education 4.0 aspects.

as digital literacy skills, career and life skills, and 21stcentury skills. Problem-solving and critical thinking are skills often mentioned as necessary for developing the 4.0 paradigm.

Another group is the **Student-centered Aspects**, which tend to debate the student's independence, such as student-centered learning (N = 5), personalization and adaptation of the learning (N = 5, selfstudying (N = 4), and independent learning (N = 1). This group of aspects supports the idea that the student is increasingly at the center of the teaching and learning process. However, there must be a person in charge to support this student and help him/her make pedagogical decisions in his/her educational process. Aspects such as collaboration can be related to Student-centered Aspects to propose this independence consciously and responsibly.

The fourth group of aspects is those closely linked to **Industry 4.0**, such as Industry 4.0 concepts knowledge (N = 6), development of specific knowledge, in this case, automation and engineering (N = 3), participation and orientation in the further development of industry (N = 1), collaboration between universities and industry (N = 1) and new demands and competencies of employees (N = 1). There is still a strong relationship between Industry 4.0 and its needs with Education 4.0. It is essential to rethink which trajectories paradigm 4.0 seeks to follow. It is necessary that, in addition to industry concepts and the need for labor, Education 4.0 must also be broad and seek to educate citizens with diverse knowledge and skills.

The fifth group of aspects, **Contextualized Education**, encompasses aspects of life-long Learning (N = 3), practice from experience (N = 2), Learning occurring anytime in anyplace (N = 1), management of learning in social aspects (N = 1), and communities of practice (N = 1). These aspects indicate the importance of contextualizing learning from the experiences of students and teachers. There is also a need to consider the teaching beyond the classroom, students' relationships, and routine. Furthermore, **other aspects** are not strongly correlated with the groups defined here, but that were mentioned in the articles: collaboration (N = 3), multidisciplinary (N = 1), and increase teaching quality (N = 1). These are general aspects that can be associated with different groups of aspects.

4.6. *Subjects (SQ5 – What Subjects are Proposed for Teaching in Educational ICT?)*

The area of study most present in research was engineering, with 30.87% of articles (N = 25) sought to teach engineering and related subtopics. There is a great diversity of other areas covered in the articles, however, with smaller number of occurrence, such as: the teaching of languages (9.88%, N = 8); automation (7.41%, N = 8); mathematics (7.41%, N = 6); manufacturing (6.18%, N = 5); chemistry (4.94%, N = 4); computer science (3.71%, N = 3); logistics (2.47%, N = 2); and personal development (2.47%, N = 2). All areas of knowledge covered are shown in Fig. 8.

Considering Education 4.0 as a broad and generic educational paradigm, other areas besides STEM (Science, Technology, Engineering, Mathematics) should be contemplated and studied in this context. If Education 4.0 is considered as a successor of the paradigms 1.0, 2.0, and 3.0, it is valid that the studies developed in educational paradigm 4.0 have a greater engagement in other knowledge areas besides those directly related to Industry 4.0 or labor formation, such as humanities, educational and pedagogical related topics.

Although STEM-related topics are dominant, some studies point out for relating different topic formation, such as iBakery, autistic user-friendly courseware which provides a set of instructions needed in baking activity as a form of iBook (Shahbodin *et al.*, 2019); Software Twine applied to forensic and crime science, which lets one create branching narratives, that is, stories for which readers can choose what to do (Thompson, 2020); and project-based multimedia learning media applied to fashion design education, the presentation of information in the form of text, images and sound integrated (Ampera, 2020).

When linking subjects to the 4.0 ICT, we can see relationships between those technologies and specific areas of study. In particular, the ones related to engineering, automation, and manufacturing areas, such as Robotics, Cyber-physical Systems, and Digital Twin (Gualtieri *et al.*, 2018; Höehner *et al.*, 2019; Liljaniemi and Paavilainen, 2020; Martin *et al.*, 2018; Mourtzis *et al.*, 2018; Prieto *et al.*, 2019; Zarte *et al.*, 2019). Therefore, it is worth understanding if there is a greater affinity between 4.0 computational technologies and specific subjects, comprehending the reasons and impacts.

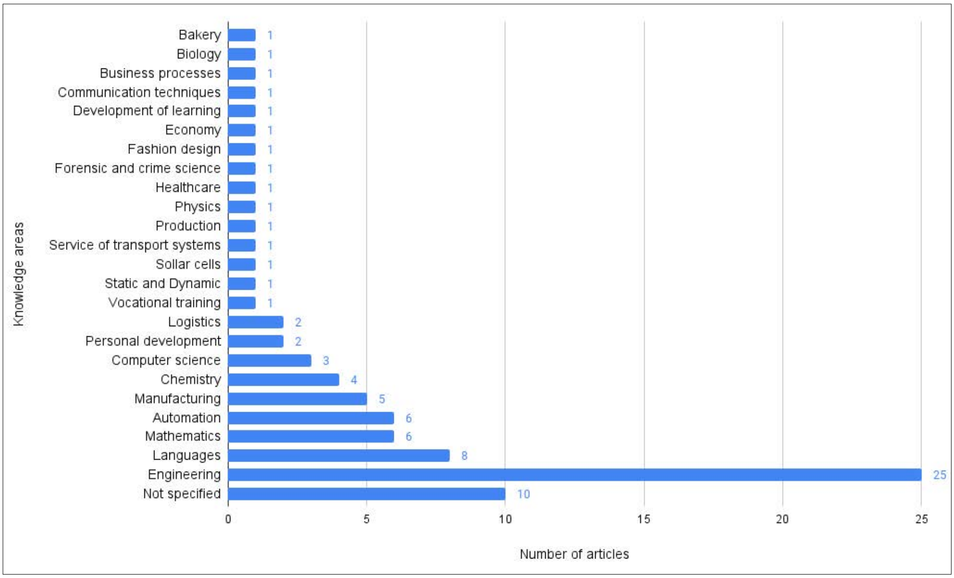

Fig. 8. Subjects proposed for teaching and learning.

4.7. *Target Audience (SQ6 – Which Audience is ICT Aimed at?)*

Among the selected articles, 86.42% (N = 70) developed or applied 4.0 ICT for students. Moreover, 8.65% of articles (N = 7) were geared towards teachers and students, 3.71% (N = 3) were focused on teachers, and 1.24% (N = 1) on course coordinators, as seen in Fig. 9. Therefore, few studies seek to solve problems of teachers, coordinators, and teaching administrators from the development or application of ICT in the 4.0 context.

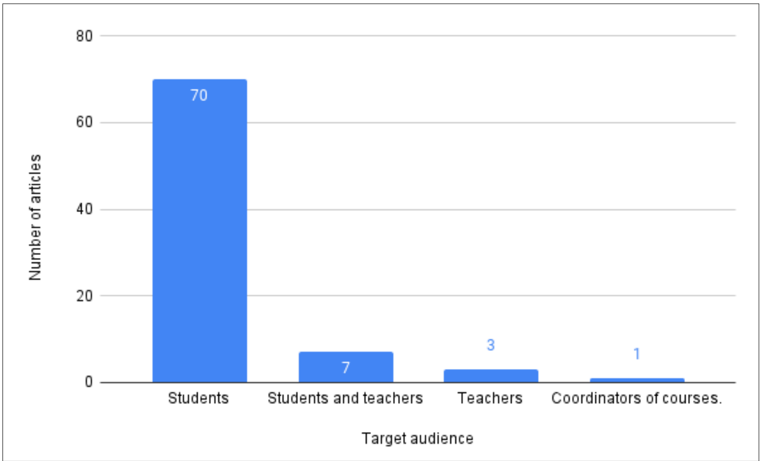

Fig. 9. The Target Audience of ICTs.

Even though there is a conceptual assumption of Education 4.0 that centers on the student, the other profiles remain involved. In the case of the teachers, although they are not the centralizer of the educational process, they still actively act as advisors or facilitators for groups of students. It is essential to study these relationships in the 4.0 paradigm, as there is a gap to be explored in studies related to teachers and other teaching professionals.

4.8. *ICT Evaluations (SQ7 – Has ICT Been Evaluated Empirically?)*

Among the extracted articles, 67.9% (N = 55) empirically evaluated the technologies, while 32.1% (N = 26) only presented the development of the application. Of the articles that performed empirical evaluation, an average of 72.05 people evaluated the ICT. Among the public that evaluated these ICT, students participated in 45 of the 55 evaluations (81.82%), teachers participated in 10 (18.19%), specialists participated in 6 (10.91%), 1 course coordinator participated in one (1.82%), and one study did not specify the target audience (1.82%).

Considering the recent creation of the term Education 4.0 and the rapid growth that the studies had since 2019, the ICT applied in the 4.0 context must be evaluated and analyzed simultaneously with the development of the paradigm. This analysis can lead to a robust study base on which educational research needs to be supported to understand the unfolding of applied methodologies and technologies.

4.9. *Implications*

From the results obtained in the RQ and SQ, it can be seen that the ICTs applied in Education 4.0 are not entirely aligned with the ICTs applied in Industry 4.0. Even though they are not considered Industry 4.0 ICT, learning systems are the most popular Education 4.0. These are technologies already present in other educational paradigms (Keser and Semerci, 2019), and it is necessary to understand if these ICTs are being updated to the 4.0 aspects. Of particular note is the work of (Roqobih *et al.*, 2019), who uses the learning management system Schoology to promote blended learning. Even using a learning system, the work seeks to promote an active methodology, which is considered part of Education 4.0 (Silva *et al.*, 2021).

Regarding educational methodologies, a relevant number of articles do not specify the methodology, 43 of the 81 papers, representing more than half of the articles with extracted data. The developed and applied ICT must be aligned with the educational aspects. It is difficult to understand if the solution developed or applied obtains the expected success and helps solve the proposed educational problems without an educational methodology definition.

This way, it also becomes difficult to understand how the aspects, concepts, and proposes of the Education 4.0 are related to the researches, considering that methodologies are an intrinsic part of any educational paradigm. Therefore, it is essential to link the methodologies, the technologies, the aspects, and the people related to the process. Using technology without a significant goal makes it difficult to solve society's educational problems.

Considering that Education 4.0 is a recent term in the education area, it is essential to understand which paths Education 4.0 is taking and which destination the paradigm seeks to reach. From this SMS, we collected five groups of aspects that can help define the educational paradigm 4.0: Industry 4.0, ICTs, Contextualized Education, Student-centered, and Skills. It is essential to highlight that the aspects collected were those the authors associated with the term Education 4.0. Also, it is crucial to consider that the analyzed studies started from the perspective of the ICT developed and applied in Education 4.0.

From the aspects collected in this SMS, we observed that ICTs are considered the central aspect of the work developed in the 4.0 context for education. However, other aspects, such as Skills, Industry 4.0, Student-centered, and Contextualized Education, can be explored. Therefore, when developing research on Education 4.0, it is relevant to step back and analyze the existing aspects of the paradigm to contextualize new ICT related to Education 4.0, seeking continuity of research in the area.

In general, when we characterize the ICTs developed in Education 4.0 context, it is possible to verify that most technologies are being applied in tertiary education, representing 74.08% of the mapped studies. Furthermore, most articles seek engineering education regarding the content taught, representing 30.87% of the total, which may be related to the high rate of ICT with a focus on application in higher education. Also, the target audience of the ICTs developed seeks to help students, representing 86.42% of the articles. There is, therefore, a focus on developing ICT in Education 4.0 to assist engineering students in tertiary education

5. Conclusions

We sought to understand the 4.0 paradigm from the ICTs developed and applied to education in this context. Based on a Systematic Mapping Study, 1090 articles were analyzed and evaluated by two researchers. Based on inclusion and exclusion criteria, the articles initially went through a filter, when the researchers read the title and abstract, and a second filter with a complete reading of the articles. A total of 81 articles were selected for extraction and discussion of results. We observed that ICTs had been proposed related to the concept of Education 4.0 since 2016, with a more expressive growth in 2019. Researches are being carried out in 30 countries, covering four continents, with greater expressiveness in Indonesia, Germany, Malaysia, Romania, and Greece.

This study has limitations, considering the threats that could not be mitigated, which could influence our research results. It should be noted: (i) the search engines were defined by the researchers, and there may be other search engines that contained articles relevant to this SMS that were not mapped; (ii) other techniques were not used in the recovery of articles, such as snowballing; (iii) lack of sufficient information in papers to be extracted. However, the definition of popular search engines in the field of informatics in education and the peer-review process help to reduce the limitations of our SMS.

According to the results and the implications, we noticed several study gaps in ICTs for Education 4.0. First, there are research gaps when we consider the areas of knowledge and the educational levels, as seen:

- Few studies are designed for elementary and high school. Therefore, there is a possibility of developing ICT for these educational levels.
- The knowledge area that ICT supports could encompass other areas of knowledge besides STEM, such as health sciences, education, and humanities.
- There are few researches developed to solve the problems of teachers, coordinators, and teaching administrators, enabling the development of ICT to support these audiences.

Besides, some gaps evidence that potential studies must be explored to understand the goals and impacts that 4.0 ICT can achieve in education. The gap to be explored:

- There is a need to explore what is the impact of some technologies mentioned in the Industry 4.0 literature (Bongomin *et al.*, 2020; Keser and Semerci, 2019) (e.g., drones and mixed reality) on Education 4.0 since no articles on these technologies were identified in this SMS.

Moreover, 28 studies did not apply the usual 4.0 ICTs described in the Industry 4.0 literature (Bongomin *et al.*, 2020; Keser and Semerci, 2019), which brings new questions about the reasons these ICTs were applied and defined as Education 4.0. Therefore, as a gap:

- It is necessary to understand if the ICTs developed for Education 4.0 are taking a different path than the ICTs of Industry 4.0 and the differences and impacts that can occur from this possible differentiation, such as the evolution of the paradigm incorporating new technologies and approaches.

When aspects of Education 4.0 are discussed, it is essential to highlight that researchers consider the use of ICT itself as an aspect of Education 4.0. Therefore, considering the objectives of this SMS, the most common aspect found was that related to ICTs, which encompasses concepts such as digitization and internet of things. Therefore, as a research gap we have:

- Develop ICT based on other mapped aspects, such as student-centered and contextualized education.
- Understand the union between all the mapped aspects of Education 4.0 and how they can be developed together from an ICT.

As future works, we hope to understand the relationship between Education 4.0 and technologies that have not been previously described in the literature, especially learning management systems. Learning systems were the most applied ICT in the mapped works, even though they are already present in previous educational paradigms. Therefore, we will seek to understand if the aspects identified, such as contextualized and student-focused education, are present in the studies of the area and, if they are not, integrate the aspects and objectives of Education 4.0 with these systems to comprehend the impact of Education 4.0 to the educational process.

Acknowledgments

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Note: The references marked with "*" (asterisk) are the articles selected in our SMS.

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