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TOPICAL REVIEW

E-Learning Ecosystems for People With Autism Spectrum Disorder: A Systematic Review

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ABSTRACT E-Learning Ecosystems (ELE) offer excellent opportunities to manage teaching activities by incorporating state-of-the-art technologies, practices, and professional support, as well as learning and assessment resources that can be adaptive. Therefore, it can help people with disabilities or conditions such as Autism Spectrum Disorder (ASD) to develop skills. However, some technological factors prevent this population's implementation of support scenarios and hinder the proper learning process. This paper systematically reviews relevant studies on E-Learning Ecosystems for people with ASD, identifying the influence of Information and Communication Technologies (ICT) on forming ELE and the technological barriers that affect their development and appropriate use on people with ASD. This work conducted a systematic review using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, including a search of five scientific literature databases from 2017 to 2022. The main aspects identified were 1) a shortage in design guides for the implementation of e-learning ecosystems adapted for people with ASD, 2) technological barriers that prevent the development of ELE, and 3) recommendations that help to mitigate the limitations of this field. In addition, the authors identified that the skills with the most significant focus of interest were social, communicative, and cognitive. The most implemented technologies include virtual and augmented reality or mobile applications. Most studies involved children with ASD between 8 and 15 years, followed by works with children between 5 to 8 years. Very few researches linked adults with ASD. Very few studies mention the ASD level of the participants, but most highlight the positive results of implementing ICT in training processes.

INDEX TERMS Adaptive learning systems, autism spectrum disorder, disability, e-learning, e-learning ecosystem, inclusive education, information and communication technologies.

I. INTRODUCTION

Disabilities arise when individuals with health conditions live in inaccessible environments that limit their full development. The World Health Organization (WHO) has reported that more than one billion people worldwide have a disability [1]. One of the disabilities whose prevalence is increasing is Autism spectrum disorder (ASD). ASD is a neurodevelopmental condition that affects people who suffer from it throughout their lives [2]. This disorder is prevalent in developed countries, at approximately 1.85% (1 in 54 people) [3], and it is four times more common in boys than in girls [4], [5]. People with this syndrome are mainly affected by three aspects, known as the Triad of Impairments [6]: social relationships, communication, and behavior [7]. It is possible to summarize these characteristics as: a) constant difficulty in social interaction and reciprocal communication with others and b) limited and repetitive patterns of behavior, interests, or actions [8]. Other features of this population are the following: a) sensory hypersensitivity, b) excess or lack of interest or attention in objects and activities, and c) difficulty expressing feelings or understanding those of others [3], [8]. All these aspects have a significant influence on the learning process of these people [9].

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Information and Communication Technologies (ICT) and the Internet have become fundamental support for education [10]. In the educational context, ICT promote student motivation and creativity [11] and allow individuals with exceptional learning needs to adapt and perform satisfactorily within a school environment [12]. In addition, ICT encourage the design of online learning environments [13].

One of the essential characteristics of online learning systems is adaptability [14]. This attribute allows customization based on various parameters, such as learning styles, prior knowledge, user profiles, previous cognitive skills, preferences, and special needs [14]. Therefore, adaptability offers an excellent opportunity to facilitate access to education, especially for people with special learning needs seeking to improve their functional skills. The concept of Assistive Technology (AT) emerged to articulate ICT in the comprehensive support process for disabled people, where devices or services are linked [15]. Including AT and adaptability in educational systems is the way to go [16].

People with disabilities not only face health problems associated with their condition but also tend to experience low academic performance, fewer job opportunities, and a higher rate of poverty than people without disabilities [1].

The presence of informal or not regulated learning resources has increased due, among other reasons, to the needs of people with such difficulties. In the future, the lack of quality education might impact their job opportunities and ability to be self-sufficient and maintain an independent life.

ICT are essential to support inclusion since the Internet provides information and access to knowledge anytime, anywhere [17].

Educational technologies support education for people with disabilities, projecting an advance in their academic performance, developing social and communication skills, training to solve everyday situations, and increasing their participation in the workforce [18], [19].

For people with ASD, human-computer interaction represents a safe and pleasant environment that minimizes distractions. It allows educators and developers to focus on a specific aspect of development and increase usability for a more significant number of users [7]. In addition, the inclusion of technology adds a more striking interaction component compared to a human pair from a person with ASD [20].

This paper studies the E-Learning Ecosystem, a relevant term that has gained popularity in the last two decades, especially in the educational context. An E-Learning Ecosystem is the set of all essential elements to implement an e-learning system [21], [22].

This metaphor relates the attributes of a biological ecosystem with a technological system that supports the management of the educational process in a particular context. Under this concept, combining biotic factors (organisms) with abiotic factors inside an e-learning system and analyzing them is possible [22]. The organisms correspond to the people involved: teachers, students, tutors, parents, instructional designers, developmental pediatricians, and pedagogy and psychology professionals. In contrast, abiotic factors include software, hardware components, educational technologies, and connection infrastructure [23].

The dimensions identified within an e-learning ecosystem are a) the virtual learning community, which includes the actors within the learning process and can be related to the term biodiversity; b) the technological tools, pedagogical principles, and content management, which can be related to the species; and c) regulatory elements, such as government policies, curricula and characteristics of the e-learning system (related to the habitat) [22].

According to [24], [25], [26], and [27], among the technologies with the best results in the treatment or intervention of people with ASD are: a) the implementation of special input devices (e.g., touch screens, smartphones, sensors, laptops, or smart glasses), b) Artificial Intelligence -based systems, c) serious games, d) extended reality, and e) robots.

The developers of these learning environments and researchers must study the target audience, especially if they have a disability. For this, it is pertinent to deepen the analysis of his interaction with a broader environment [17]. In this sense, several studies have compared the Teaching/Learning system to an ecological system [28]. Although the focus is on the student, these works' researchers also analyze the different interactions with the environment and the elements involved in the educational process [17].

There are three characteristics of a Learning Ecosystem: dynamic (constantly changing), diverse (variety of resources), and including support systems (learning). These should be adaptive so they can be adjusted to the needs of the individual [29].

However, suppose developers do not appropriately design learning resources. In that case, these elements cannot be used efficiently by people with conditions such as ASD and, in some cases, even produce frustration and blockages in the individual [30]. Therefore, the authors in [25] suggest further research on evaluating ICT architectures and devices to determine their relevance within the clinical context in treating people with ASD.

Consequently, in the present work, the researchers have been motivated to study how ICT influence these ecosystems' formation and how ecosystems should be structured when aimed at people with ASD. The authors have concluded from previous research that test scenarios applied in studies implementing ICT in educational or clinical contexts for people with ASD are limited only to a particular aspect.

Another conclusion obtained from the deepening of the ecological approach is that it facilitates the holistic understanding of the system and its integral perception since it allows identifying the elements that compose it, their relationships with each other, and the impact they generate. It needs to include the participating individuals, the environment where it is carried out, and the ecosystems involved [22].

Based on the above, the authors have carried out a literature review, supported by the Preferred Reporting Items for

TABLE 1. Research questions statement and motivations.

ID	Research question statement	Motivation
RQ1	Within an educational context, which design elements of the technological components stand out to cater to the unique needs of people with ASD?	To analyze the appropriate design approach for developing software applications for people with ASD.
RQ2	How do Learning Ecologies influence the formation of e-learning environments for people with ASD?	To examine how e-learning ecosystems for people with ASD are developing.
RQ3	Which technologies are being applied within the e-learning ecosystems for people with ASD?	To identify the technological approaches contributing to this population's formation of e-learning ecosystems.
RQ4	Are there any technical barriers that prevent the proper development and application of E-Learning Ecosystems for people with ASD?	To identify the prevalence of limitations in developing e-Learning Ecosystems for people with ASD.

Systematic Reviews and Meta-Analyses (PRISMA) methodology [31], to analyze:

1) The design elements that stand out in a technology-based educational context for people with special needs, such as ASD.
2) The influence of ICT in the development of learning ecosystems.
3) The most common Information and Communication Technologies in educational support for people with ASD.
4) The technological barriers affecting the development and use of e-learning ecosystems for people with ASD.

The main objective of this work is to contribute to the educational field based on information technologies for people with ASD. For this, the researchers incorporated the ecological approach in studying e-learning systems that support people with this condition. The remainder of the paper includes the following sections: SECTION II shows the methodology used in the systematic review. SECTION III presents the main findings of this study. SECTION IV presents the discussion of the results. Finally, SECTION V includes the conclusions.

II. METHOD

The present review used the PRISMA methodology [31] to collect and organize the information. The procedure consisted of listing and structuring the challenges faced by people with ASD in the educational field. Then, identifying the essential elements to be implemented in the design of e-learning resources to achieve the learning goals of this population.

The steps followed during the systematic review of the literature, recommended by [32], are the following: 1) to formulate the questions that will guide the review; 2) to set keywords and to start the literature search; 3) to select and evaluate studies; and 4) to analyze and synthesize the findings.

A. RESEARCH QUESTIONS

TABLE 1 presents four research questions to cover the topics of interest in this study. There is also a brief description of the reasons that encouraged this work.

TABLE 2. Used strings in search engines.

Specific topics	Total	Selected
Autism and ("Information and communication technology" or ICT)	7.163	9
Autism and E-learning	2.117	12
Autism and ("online learning" or "virtual learning")	4.460	9
TOTAL	**13.740**	**30**

B. LITERATURE SEARCH

1) DATA SOURCES

The research included a search in five specialized electronic databases: IEEE-Xplore, Scopus, Science Direct, Springer Link, and Taylor & Francis. In the review, the researchers abstracted vital elements of the studies, such as the title, the summary, and the keywords of sources, such as articles from magazines and reports of conferences. The authors identified the most critical topics to be covered to answer the questions that guide the research.

2) SEARCH STRINGS

The descriptors used in this search combined the word "Autism" with the logical operator "and". These terms were: "Information and communication technology" (or "ICT"), "e-learning", "online learning", and "virtual learning". To organize and summarize the information, **TABLE 2** shows the combined keywords used in the search during this work.

The term "Learning Ecologies" or "Learning Ecosystems" was not included in the search strings. The found reports of studies on online learning systems for people with ASD were analyzed holistically, identifying the abiotic and biotic elements constituting an e-learning ecosystem in this context.

In addition, the ecological model was applied in the educational field and aimed at people with disabilities in a general way. These findings generated motivation to develop this work without finding evidence of studies that addressed the term Learning Ecosystems specifically focused on people with ASD.

C. STUDY SELECTION

The initial search in the five electronic databases collected 13.740 studies between 1969 and 2022. **FIGURE 1** shows

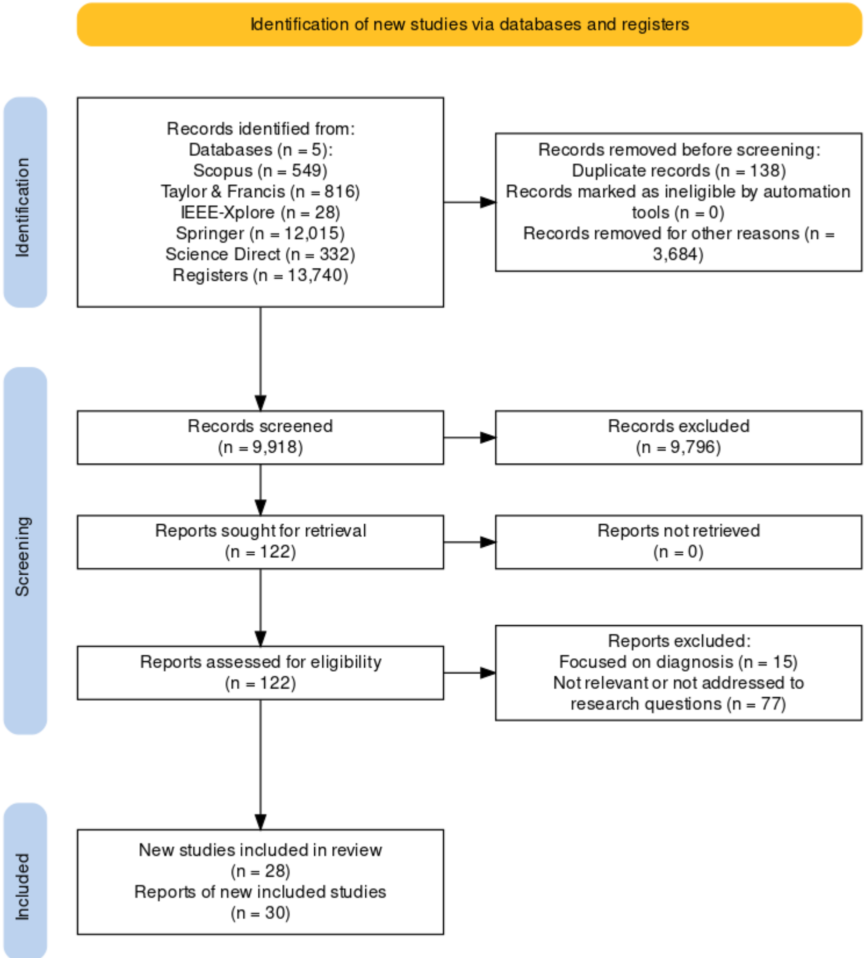

FIGURE 1. **PRISMA 2020 flow diagram for the Systematic Review - Shortlisting studies and included reports.**

a flowchart of the developed systematic review based on the PRISMA 2020 statement [31] to guide the search. According to this diagram, the methodology develops 3 phases within the search process: 1) initial **identification** of the studies extracted from the selected databases using terms associated with the topics of interest. In this phase, researchers excluded duplicate reports and those blocked records. At this point, the review had omitted a total of 3,822 records. 2) in the **screening**, the selection was limited to studies published within the last decade. The criteria also include studies written in English and published in journals or conference papers. Additionally, the authors checked the title and keywords. Subsequently, we examined the abstract of the articles on the eligible list, reducing it to 122 reports; so far, the review had removed a total of 9796 records 3) Finally, in the included step, we could find 30 works that met the pre-established inclusion and quality criteria.

To generate **FIGURE 1**, the authors used the R package with the Shiny online application,[1] designed for creating PRISMA 2020 flowcharts.

[1] https://www.eshackathon.org/software/PRISMA2020.html

The inclusion criteria used in the selection process of the papers were:

- Studies written in English.
- Studies published in 2017 or later.
- Studies from peer-reviewed journals or conferences.
- The research focused on supporting the learning process of people with ASD, mediated by internet-based educational technologies.
- The work provides answers to one or more of the research questions.
- The study area had to be related to Computer Science or Engineering.

1) QUALITY ASSESSMENT

To assess the quality criteria (QC) within the study selection process, the authors established the following questions:

- QC1: Have the objectives been clearly stated?
- QC2: Has the context of the problem been described concisely?
- QC3: Is the methodology used appropriately for the research carried out?
- QC4: Are the research findings accurately stated?

TABLE 3. Year and type of publication of the primary studies.

Year/ Type of publication	2017	2018	2019	2020	2021	2022	Total
Journal	3	4	4	3	3	3	**20**
Conference	1	2	3	2	1	1	**10**
Total	**4**	**6**	**7**	**5**	**4**	**4**	**30**

- QC5: Are the objectives connected to the conclusions?
- QC6: Does an added value to the researched field stands out?

The review included studies that fully complied with the six proposed quality criteria.

D. DATA EXTRACTION

The authors generated a template to carry out this process to extract some relevant data from the selected studies. These characteristics were: a) reference, b) year of publication, c) type of publication, d) skills targeted, e) technological approach, f) age range of the target population, and g) main contributions. The reader can locate the findings obtained from these characteristics in the results section.

III. RESULTS

Learning ecosystems are part of the second-generation e-learnings, where their applications focus more on the needs of learners [21]. According to [21], e-learning ecosystems comprise three main elements: a) infrastructure, b) content providers, and c) consultants. These include adaptive hypermedia resources, peer support in learning, ICT search to improve the process, and online dissemination. Based on the information in the publications, **TABLE 3** shows the years of publication of the 30 primary studies, classified according to type (Research journal or article derived from a conference).

TABLE 3 highlights a progressive interest in online learning environments for people with ASD.

TABLE 4 shows the findings resulting from the analysis of the primary studies.

FIGURE 2 presents a general map of the most relevant keywords found in the papers from the search carried out in the Scopus database. The authors made this graph with the VOSviewer application. The image shows 6 clusters, with the most significant weights related to e-learning and autism. Some featured nodes (red ones) correspond to virtual reality, adaptive learning systems, diseases, virtual learning environments, mobile applications, educational robots, and assistive technologies. Blue nodes correspond to trends related to disability and some technologies implemented to support this population, including ICT, artificial intelligence, and mobile technology. In contrast, yellow and green nodes represent health and social science issues.

Although the focus of the selected studies was broad, the skills that most frequently presented as the central axis of research were: social skills (N = 10), communication skills (N = 8), and cognitive skills oriented toward STEM areas (N = 7), emotional skills (N = 3) and visual attention (N = 3). Other skills investigated were those related to job-related skills, motor skills, behavioral skills, and the use of public transport.

RQ1. Within an educational context, which design elements of the technological components stand out to cater to the unique needs of people with ASD?

A. VISUAL COMPONENT

As highlighted by the authors of [6], [35], [42], and [60], visual elements (videos and pictures) are of great importance for people with ASD due to mainly having a visual learning style. As for the colors, it is preferable to use bright colors that attract attention and maintain a considerable contrast between the background and the texts or images displayed [35], [43]. Reference [16] also, suggest using a few colors and real pictures to maintain the users' attention.

The graphic component also includes animations. In this context, a study [58] showed that children with ASD respond better regarding eye fixation to the presentation of cartoons in a social environment than natural stimuli.

Some techniques that have been successful in the intervention of people with ASD and that also highlight the use of visual elements are TEACCH (Treatment and Education of Autism and Related Communication-handicapped Children) and PECS (Picture Exchange Communication System) [35], [40], [42].

Regarding verbalizing information, using specific, simple, literal, consistent, and easy-to-follow instructions is relevant [40]. This work suggested avoiding changing the position, size, or color of the signs displayed to fulfill the same task.

As previously mentioned, a weakness of people with ASD relates to sensory hypersensitivity. This frailty includes irritation towards certain sounds, such as computer voices. Therefore, using human agents in the generated prompts or messages is advisable, avoiding loud noises [38], [43].

Children with ASD may refuse to use hearing aids or other items that make sounds uncomfortable or intense. Hence, an alternative is to use good-quality sound devices and wearables to capture and track participant responses [40], [43].

B. EVALUATIVE COMPONENT

Another design aspect that allows more satisfactory results in the training of people with ASD is to present situations of progressive difficulty [50] so that they can feel motivated to reach different milestones within their learning [38], [40].

Additionally, using supervision features is also recommended [34]. This approach allows monitoring the development of activities and behavior associated with them in terms of performance and response by the application users [6]. In addition to the correct answers, it is convenient to include the time of attention or concentration devoted to a particular activity as evaluation criteria and the number of

TABLE 4. Skills targeted, technological approach, participants' age range, and main contributions summary from (N=30) primary studies.

ID	Refer.	Year	Type of publication	Skills targeted	Technological approach	Participants Age range	Main contributions
1	[6]	2018	Conference	Social skills	Mobile Application	Five children (four boys and one girl) between the ages of 8 to 12	Developing a video modeling mobile application
2	[16]	2021	Conference	Social and communication skills	Mobile Application	Children aged 5 to 15 years old.	This work proposed the Squizzy assistive technology mobile application for children with ASD. The authors implemented the Scrum methodology.
3	[33]	2022	Conference	Self-advocacy development and social skills	Digital Biomarkers and robots	61 children between 3 and 6 years	The DREAM project made it possible to build predictive models to monitor children with ASD regarding three essential skills: imitation, joint attention and taking turns, and analyzing behavioral traits, such as facial expressions, gaze, and body movements. The main objective was to train children with social skills.
4	[34]	2022	Journal	Physics concepts (Dynamics, Electricity, or Magnetism)	E-learning platform / Service-learning	Eight teenagers and nine adults with ASD	This document describes the transformation process from the previous Service Learning (SL) to the current e-SL, incorporating corporate ICT. The authors developed an e-learning platform. They organized the participants in this experience into four groups, where four projects aimed at people with ASD were created (2 physics, one engineering, and another recycling).
5	[35]	2022	Journal	**Not specified**	Architecture model IoT	15 children 5 to 12 years old	The authors identified 12 design and development requirements for ICT tools for children with ASD. They also corroborated the correspondence of these requirements with the Model of Persuasive Education based on Multiple Agents (MAPE). Finally, they proposed a framework based on the Internet of Things (IoT) that allows monitoring of the learning performance of children with ASD.
6	[36]	2019	Journal	Social skills	Social Robots	42 children with ASD. Average age: 7.94	The researchers developed an experiment that analyzes the joint attention of children with ASD when interacting with a robot. They included metrics to analyze the participants' responses to certain robot behaviors, such as body movement, gaze direction and magnitude, and kinetic energy.
7	[37]	2017	Journal	Personal and social skills	Web application	Seven children. Age between 30 and 72 months and one low-functioning child ten years old.	The authors implemented an open-source web application to monitor learning in autistic children, where authors combine educational analysis tools with behavior analysis programs (ABA)
8	[38]	2018	Journal	**Not specified**	Immersive Virtual Reality	**They did not test**	The authors describe the challenges and design issues of Virtual Reality applications developed for training people with ASD. Although this report refers to a literature review, they reach relevant findings regarding design guidelines.
9	[39]	2020	Conference	Cognitive (Learn science and engineering concepts)	Virtual Reality (VR)/Augmented Reality (AR)	Eight teenagers from grades 6 to 12.	They created an information-centric model to explain how to design and build Virtual Learning Environments (VLEs). Also, they implement a VLE to teach concepts in density, assembly, manufacturing, path planning, and robotics.
10	[40]	2022	Journal	Vocabulary learning	Mobile learning game	Seven children aged between 5 and 10 years. Two instructors and five parents	This work shows a mobile learning game's design, implementation, and evaluation. In addition, compare two learning approaches in learning games: advancing difficulty levels gradually (classical) and the dynamic difficulty adjustment (DDA) system, where the application adapted the difficulty level according to the player's abilities.

TABLE 4. ***(Continued.)*** **Skills targeted, technological approach, participants' age range, and main contributions summary from (N=30) primary studies.**

ID	Refer.	Year	Type of publication	Skills targeted	Technological approach	Participants Age range	Main contributions
11	[41]	2020	Journal	Mathematics and emotion recognition and regulation	E-learning model	Children with ASD aged 8 to 14	This work proposed an e-learning model for mathematics learning that integrates an emotion recognition classifier and an emotion regulation method.
12	[42]	2020	Journal	Empathy development	Mobile Application	Stakeholders of autistic children (parents, teachers, therapists, social workers)	The authors developed a mobile application to exercise empathy in children with ASD, implementing design thinking. Experts who constantly interact with people with ASD evaluated the application regarding acceptability and usability.
13	[43]	2021	Journal	Motor skills	Mobile Application	Six children with mild to severe ASD aged between 4 and 11 years	Provides foundations for developing sonification technology as part of the intervention in children with autism.
14	[44]	2018	Journal	Social, communicative, and emotional skills	3D Collaborative Virtual Learning Environments	They did not test	This work analyzed the current approach to 3D CVLEs and the challenges of implementing it in people with ASD.
15	[45]	2017	Journal	Social initiation and collaborative behaviors	Virtual environment	Male children between the ages of 10 to 14.	The authors documented the construction of a full-body multi-user interaction system aimed at children with ASD to promote social initiation and collaborative behaviors.
16	[46]	2019	Conference	Cognitive / STEM Learning	Virtual Reality	45 medical residents and students	This paper proposed a cyber-human framework for immersive learning. It focused on orthopedic surgery for medical residents and science learning for children with ASD.
17	[47]	2020	Journal	Emotional and social skills	Immersive Virtual Reality	14 children with high-functioning ASD, aged between 8 and 15 years	Development of a Virtual Reality Environment in a school context included designing realistic and customizable avatars.
18	[48]	2017	Conference	Communication (vocabulary training and sentence training)	Mobile Application	Children between 5 to 8 years	Implementing a mobile application contributes to developing communication skills, including sentence structuring, vocabulary building, and pronunciation training.
19	[49]	2019	Journal	Communication skills	Serious Games	Five children between 6 to 10 years	The authors developed a serious game to improve the receptive identification of vocabulary items for children with ASD.
20	[50]	2018	Conference	Visual performance skills	Model-Driven Engineering approach Mobile Learning Game	Collective validation sessions with ASD experts	In this project, the authors developed an adaptive learning game, where dynamic scenarios are supported, focused on helping young children with Autistic Syndrome Disorder to learn and generalize visual performance skills.
21	[51]	2018	Journal	Behavioral skills	Robotic	Eight children with ASD, between 3 to 7 years (47 to 93 months)	It presents a technological framework that integrates multiple visual cues (facial and expression recognition, gaze estimation, and head pose estimation) to determine behavioral trends during ASD treatment with the intervention of a humanoid robot.

TABLE 4. ***(Continued.)*** **Skills targeted, technological approach, participants' age range, and main contributions summary from (N=30) primary studies.**

ID	Refer.	Year	Type of publication	Skills targeted	Technological approach	Participants Age range	Main contributions
22	[52]	2018	Journal	Social and communication skills	Virtual Reality	Three groups: 6-8 years old, 9-10 years old, and 11-12 years old.	This work implemented the concept of autonomous virtual humans exercising basic social skills such as greeting, establishing a conversation, listening, and taking turns.
23	[53]	2021	Journal	Social skills	Virtual Learning Environments (VLEs)	Three children with ASD, between 11 to 14 years old.	This research allowed them to describe a cloud-based system for creating Virtual Reality Learning Environment applications focused on courses for young people with ASD.
24	[54]	2019	Conference	Using public transportation	Immersive Learning Intervention (Virtual Reality)	Adults	Design and evaluation of an immersive intervention training program (called Virtuoso) focused on using public transport, aimed at adults with ASD.
25	[55]	2019	Journal	Linguistic and mathematical basics skills	Mobile Application	Children with ASD between 5 to 13 years	They developed a mobile app focused on teaching autistic Arabic children the linguistic and mathematical basics and improving their social skills. One hundred autistic children participated in three age ranges and three autism types (mild, moderate, and severe).
26	[56]	2019	Conference	Cognitive abilities	Virtual Reality	Five male children, aged between 4 and 8	The authors developed a virtual reality platform to support learning. They compared electroencephalography (EEG) signals flashcards and the virtual reality learning tool.
27	[57]	2017	Journal	Gesture-based communication and other life skills	Virtual Reality	A small group of children with ASD. The age range is not specified	They developed a game based on an augmented reality environment to improve gestures and their understanding of the requirements of specific tasks in children with ASD.
28	[58]	2020	Conference	Visual attention characteristics	Eye-tracking	23 Autistic children aged 3-6	This research incorporated eye-tracking technology to study the visual attention characteristics of children with ASD through the display of cartoons and natural social stimuli.
29	[59]	2019	Journal	Ability to use public transport	Spherical video-based virtual reality (SVVR) Mobile App	5 Autistic adults aged 23-34	The study delved into the literature on the implementation of VR for people with ASD and the implementation and evaluation of a virtual reality mobile application based on a spherical video to train adults with ASD in public transport. The assessment focused on usability, feasibility, user experience, and relevance.
30	[60]	2021	Journal	Eye attention	Virtual Reality	110 children with ASD, aged 2-10	In this study, the authors implemented an assistant application for children with ASD involving interactive art.

times the participants correctly follow verbal or non-verbal prompts [6], [43]. Other assessment criteria suggested by [45] are related to participants' attitudes during the execution of activities. These can be measured through collaborative

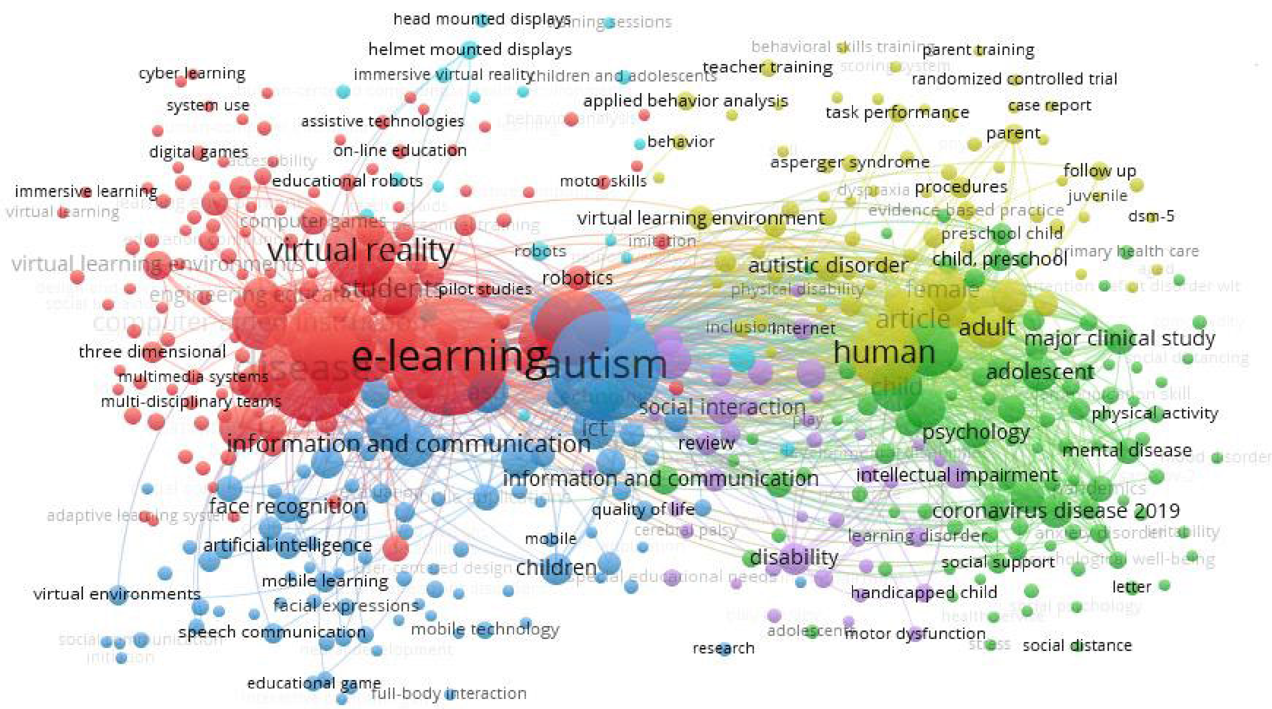

FIGURE 2. Map based on bibliographic data that reflects trends in keywords – Network visualization.

actions and motivation reflected in the activity level or effective interactions [47].

Considering that people with ASD have difficulties maintaining visual contact, e-learning systems should evaluate the percentage of time and time that they remained visually connected with the technological tool during its execution [47].

C. INSTRUCTIONAL COMPONENT

The authors in [35] and [39] suggest using affirmative words or positive reinforcements as a motivational mechanism when obtaining a good result in an activity. For example, saying that a ''Good job'' has been done or emitting motivational sounds such as clapping [40]. In the same way, researchers suggest avoiding negative language because children with ASD can interpret it as offensive or discouraging. Another good design practice mentioned by these authors is to project the progress achieved so that users can visualize how many tasks they have completed and how many are left.

RQ2 How do Learning Ecologies influence the formation of e-learning environments for people with ASD?

Within the elements of learning ecologies, the technological component stands out. Therefore, technological advancements have fostered the generation of e-learning environments for people with ASD [34]. Within these advances, the evolution of touch technology stands out, which facilitates navigation for people with this condition and can be implemented on easily accessible mobile devices such as tablets and smartphones [6], [16], [40]. This type of device favors portability due to its small size and intuitive use [16].

Implementing learning technologies within therapies for people with ASD offers multiple advantages. These include but are not limited to decreased anxiety regarding group work or face-to-face settings [16] and faster and more enjoyable interventions. Other related aspects are the generation of controlled scenarios, the possibility of implementing repetitive and predictive tasks [35], [39], ease of use for caregivers, simplicity in customization, and the possibility of monitoring progress. Also, it is relevant to have the opportunity of giving immediate feedback with recommendations [53], [55] and cost reduction by being able to use open-source software [37].

In addition, sensors might help collect valuable information on everything in the learning environment and its interaction with the user in real-time [56].

One technological element that includes the implementation of sensors is eye tracking in response to certain stimuli. The authors in [58] proposed adding parameters such as the duration of ocular fixation and the time to the first fixation.

Another influential factor is the joint work of different specialties around the same objective: to improve the living conditions and daily performance of people with ASD. This interest has promoted the surge of many studies involving professionals from different disciplines, such as doctors, psychologists, teachers, therapists, social workers, engineers, computer scientists, and designers [16], [39], [42], [43].

Bearing that the socio-economic, cultural, and educational conditions of the family and immediate environment of children with ASD greatly influence their performance and progress, studies such as [60] highlight the importance of involving the microsystem in the therapeutic and educational process of people who live with them.

The researchers in [35], [50], [54], and [55] consider it is essential to involve different actors that are part of a learning ecosystem for people with ASD, such as autism experts, parents of children with this condition, and Computer Science researchers who develop technology for education.

The experts in the context of ASD contribute substantially to the different processes of design, construction, and validation of the systems created for learning [46]. Therefore, all agents that coexist around a person with ASD get involved in creating and validating technological tools for education.

The participation of experts and caregivers in the development of e-learning systems supports significant progress in increasing social, communication, and behavioral skills in people with ASD. Joint reinforcement work is necessary at home, in educational institutions, and during visits with health specialists [40].

One of the difficulties that people with ASD face is related to their communication and use of language. Speech recognition and text-to-speech conversion are two tools that gain value in applications that develop these skills. Libraries that meet these needs are commonly incorporated [55].

Among the different objectives pursued by the implementation of technology-based learning environments, three stand out: a) the assistance approach to facing daily life; b) the rehabilitation approach, where therapists and psychologists are supported [59]; and c) the educational approach [40].

RQ3 Which technologies are being applied within the e-learning ecosystems for people with ASD?

The development of mobile applications is one of the fields of technological interest that has successfully supported the learning and communication process of people with ASD [6], [16], [40], [55]. These kinds of applications that include striking visual elements support teachers and therapists in encouraging the learning process of children with ASD [16], [55].

Alternatively, using social robots in treating people with ASD has multiple advantages [51], such as they can be programmed to create simple and predictable behavior within a social interaction scenario. They allow the inclusion of humanoid elements to generate elements of non-verbal communication. They enable the inclusion of design in the physical figure to be shown, being able to represent people, animals, or fictional characters [36].

Another technology widely used in the treatment of people with ASD is Virtual Reality [33], [52], [54], [56], [59]. Among the main reasons for their acceptance, they can provide safe, personalized, and monitoring environments. Virtual reality also allows multiple repetitions as part of training. They generate real-time messages and reports due to perceived stimuli or behavior. Besides, Virtual Reality enables scenario simulation to avoid the actual transfer [56], [59]. In addition, Virtual Reality simplifies the production of stimuli and controls the degree of experience that users can have [57], [59].

Finally, it is worth highlighting a line in developing educational applications for people with ASD. These are serious games [40], [49]. Serious games allow training and development of skills entertainingly. This tool can playfully capture the users' attention but with a didactic approach and a clear learning objective.

RQ4. Are there any technical barriers that prevent the proper development and application of E-Learning Ecosystems for people with ASD?

Research has not explored much about customizing design elements in virtual or augmented reality technologies. That is, to propose distinctive and personal aspects of the user, such as how to use hair, clothing, or physical appearance [38].

The tools that apply these technologies must be more flexible in the virtual environments and participants [47].

Another shortcoming of technological developments for people with ASD is the lack of generalization [47]. For example, the intensity of the contrast in the visual effects or proposing a variety of environments would significantly advance in increasing educational inclusion for this population [38]. However, the spectrum makes it challenging to characterize the entire population.

Software architectures for implementing cloud-based applications that support the learning or treatment of people with ASD require improving immersion in learning with high-speed networks [53].

Even though the persisting challenges faced by people with ASD, there is an absence of research to cover this topic. It includes challenges of a social, behavioral, and communicative nature. One of the least explored areas, according to [41], is academic emotion regulation interventions and, among them, the development of empathy [42].

Although the repetition of tasks is a crucial component in the learning process, it is also vital to emphasize the generation of dynamic responses. These responses generate similarities to human interaction, thus promoting the necessary confidence to achieve an approach to real social situations. Applying this strategy also allows for avoiding the opposite effect of producing dependency and total preference for digital media [44]. On the other hand, according to [48], existing educational technologies make it difficult to monitor individual performance.

In the case of specialized Serious Games, there has been a growing interest in the design of frameworks in recent years. However, there is an evident lack in the approach for children with ASD [49].

Regarding how to evaluate the results obtained by people with ASD during an ICT-mediated behavioral analysis, it is common for therapists to provide qualitative evaluations based on observations [55]. The above shows a need to deploy quantitative assessments with technological applications and tools [51].

IV. DISCUSSION AND ANALYSIS

This research carried out a systematic review to cover a general picture of the trends in online applications aimed at the educational needs of people with ASD at different times. The study was directed toward applications of ecosystem frameworks. Here, the technological environment of proposals prevailed and included issues such as the social circle around the patients with ASD condition. These aspects might interfere with their learning process. It can also influence the design of the tools, along with the technological, pedagogical, and therapeutic infrastructure.

For this purpose, the primary studies paid particular attention to the design guides, both in the graphic environment and at the instructional and evaluative levels. In contrast, the main elements that make up a learning ecosystem for people with ASD were identified at the abiotic and biotic levels. The abiotic ones include educational technologies, knowledge management, software, and hardware infrastructure. Conversely, the biotic group comprises parents, teachers, tutors, instructional designers, psychologists, pediatric developmental specialists, and exceptional pedagogy professionals. Based on these components, how they influence an educational system based on technology aimed at people with this condition was analyzed.

This review also broke down the educational technologies that have been a trend in recent years. Among the most outstanding technologies are Virtual Reality, Mobile Applications, Robots, and Serious Games. It is essential to highlight the use of sensors in some studies. Especially those that implemented Augmented Reality and Virtual Reality to capture information related to the focused visual attention of users, both in duration and location. The evaluation of these variables is of great interest to researchers since one of the characteristics of people with ASD is their difficulty in maintaining eye contact, which affects the rate of concentration and permanence in an activity for long periods.

A. MOTIVATIONS

ASD has been on the rise and requires special attention. Many families today live with a person with this condition, which lasts a lifetime [61]. However, early intervention has proven to support significantly developing skills and reducing the severity of some symptoms [33], [44].

In addition, the implementation of ICT in support of people with ASD is an area that has aroused the interest of researchers due to the multiple technologies that can benefit the learning process and the support that can be provided to tutors, teachers, parents, and other people who accompany this population, who try daily and who also suffer from the difficulties that arise [48].

This work arises from the need to provide support to developers of technological tools for people with ASD through the identification of limitations that affect this field of study and that represent a research opportunity. Once the rules, tendencies, and little-explored abilities have been detected, it is advisable to continue working until more excellent coverage, inclusion, and support are achieved for people with ASD and their closest social environment.

It should be noted that this work represents support for researchers and developers of e-learning applications for people with ASD. As a differentiating factor, compared to other works that have implemented systematic searches, this study wanted to involve elements of learning ecosystems: technology, actors involved, required infrastructure, and pedagogical models. In addition, an in-depth investigation was sought into the technological barriers that hinder the implementation of these technologies, managing to identify the focus of most excellent attention for future work in this area. Finally, the research contribution highlights the trend in technologies implemented, skills promoted, and age range of participants with ASD in the studies. This information represents a common thread that can guide new work, especially in those little-explored aspects that require more intervention.

B. CHALLENGES

Considering the breadth of the autistic spectrum, the difficulty of covering the target population in all its levels of severity in the same study is evident. Several analyzed studies expressed it in their limitations, as in [6], which state that only medium-functioning ASD was considered (not low-functioning or high-functioning ASD).

Other limitations mentioned in the primary studies related to:

- Lack of generalization. They suggest validations with a larger population and in different contexts to generalize metrics. In addition, the experiment is highly controlled, limiting the possible answers given by children [36]. The sample taken by [37] and [41] was small. In addition, in [37], the selection was also non-homogeneous. The findings do not allow generalization of the population with the autistic spectrum in preschool age. In [47], it is impossible to generalize the results due to the lack of analysis. This evaluation is related to the durability of the acquired skills in the long term. Also, the time applied to the study and the heterogeneity of the participants.
- Duration of the experimental tests. Due to the special educational needs of people with ASD, it is suggested to dedicate enough time so that users can have enough interactions with the learning environment [39], [43]. References [45] suggest that long-term evaluation of the system in a classroom or group therapy setting should be considered to assess its effectiveness as an intervention tool. In the case of [46], the tests applied to children with ASD were under development, and only a previous evaluation was developed that showed potentially positive results.
- Participants' age. Focusing on the recognition and regulation of emotions, the authors suggest a study involving participants older than the chosen one since adolescence is where more emotional changes occur [41].
- Sensor hypersensitivity. Children with low-functioning ASDs may not feel comfortable using sensors [57].

C. RECOMMENDATIONS

Through the review, it was possible to detect the most frequent limitations in the works oriented to the development of mobile applications, web, or that incorporate educational technologies to support the learning of people with ASD. This material represents an opportunity for improvement and a strong work focus for researchers who wish to overcome the mentioned challenges.

The difficulties affect not only people with ASD but also those closest to them, including parents, healthcare providers, relatives, developers, and caregivers.

It is essential to generate development guides that include both the pedagogical and technological components and consider the characterization of individuals with ASD, to implement adaptive systems that are increasingly efficient and easy to use.

V. LIMITATIONS OF THIS RESEARCH

The term learning ecosystems, being novel, has not been specifically involved in studies oriented to developing online applications for people with ASD. However, the analysis considered the components of this term. The selected primary studies are limited to compliance with mentioned parameters: inclusion criteria, research questions that guide the study, keywords (widely used), and quality criteria.

VI. CONCLUSION

This study is motivated by the desire to contribute to formulating learning ecosystems for people with ASD. This population presents many characteristics that hinder the development of skills related to communication, emotion management, social interaction, and concentration. All these factors might directly affect the learning process.

Experts in different areas agree on the importance of early intervention to minimize the deficiencies mentioned. In addition, they highlight the vital role that learning technologies play in this context.

However, different factors, mainly technological, threaten the successful adaptation of these ecosystems. Among the findings, lack of generalization is one of the most challenging factors to counteract. It is related to several causes, such as the size and heterogeneity of the population sample, the intervention duration, and the complexity of the skills to develop, among others.

Another factor that affects the proper implementation of these ecosystems is the lack of design guidelines, especially related to adaptation models to the educational needs of people with ASD.

The primary motivation of this work is to provide relevant information for developers and specialists in constructing and implementing learning ecosystems for people with ASD. The learning from the trends in educational technologies skills little intervened, and shortcomings of the applications. The last ones are susceptible to reduction and the opening to a more general vision of the components necessary to include in a system of this nature.

The development of teaching and learning activities from an ecological perspective shows the interaction of individuals with ASD with the different elements of their environment. This work identifies the unresolved limitations that make it impossible to develop virtual learning communities; work must continue to enable enriching learning processes for people with ASD.

The studies' researchers highlight their concern about providing optimal technological tools which allow a significant inclusion of people with ASD and improve their daily functionality. In addition, they seek to provide the means to generate meaningful support in the monitoring and intervention process for their caregivers, educators, and therapists.

Besides, the researchers highlight the importance of generating guides for constructing e-learning systems and adapting them to the needs of people with ASD due to this condition's complexity.

Other significant findings are related to the skills directed in studies. Most of the works focused on developing social and communicative skills, while very few studies focus their efforts on recognizing and regulating emotions in people with ASD. On the other hand, the vast majority of studies aimed at the intervention of children with ASD between 8 to 15 years, and very few focus on support for adults. On average, the works involved 21.6 people in their study cases, within an interval of 5 to 110 participants. However, it is essential to clarify that only 50% of the studies indicated the exact number of participants with ASD. Nine works had less than 10 participants, and only two exceeded 50.

A. FUTURE WORK

For future works, the authors propose different action fields:

1) Participants: there is a low proportion of research involving adolescents and adults with ASD. Therefore, the authors consider guiding future works toward this population essential.

2) ASD severity level: very few works specified this level, and fewer studies focused their research on people with a low-level functioning within the spectrum. Consequently, the authors suggest addressing the different severity levels, especially those requiring very substantial support.

3) Design guidelines: given the shortage in the approach of design guides, future works could be aimed at establishing conceptual and technological design models of electronic learning systems for people with ASD, involving parents, therapists, psychologists, pedagogues, development specialists, caregivers, caregivers, and teachers.

4) Adaptive Systems: the authors suggest deepening adaptation objectives and techniques in e-learning systems according to the educational needs of people with ASD.

5) Characterization of people with ASD: to implement adaptive e-learning systems, developers must design powerful instruments of characterization associated with the user's profile and their condition or adaptable mechanisms within their applications.

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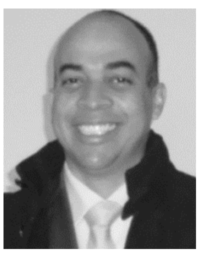

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