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# CooperAR: supporting the design and implementation of augmented inclusive educational scenarios

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There are sufficiently studied advantages of Augmented Reality (AR) in education. However, studies regarding the impact of AR in educational inclusion are still scarce; particularly, no methodologies that help educational institutions, particularly teachers, in addressing diversity in the classroom using AR are reported. This study describes and evaluates CooperAR, a methodology for co-creating augmented and inclusive educational scenarios, considering three conceptual principles: cooperative learning (CL), universal design for learning (UDL) and co-creation between students and teachers. CooperAR was evaluated under three dimensions, inclusion, cooperation and quality. A quasi-experimental design with a descriptive scope carried out in an educational institution in the South of Colombia, with 63 students pre-organized into two groups. Results demonstrated that CooperAR favors the co-creation of augmented and inclusive educational scenarios among heterogeneous groups, provoking the participation of all students, and evidencing that cooperation is a catalyst for inclusive learning. The evaluation confirms that CooperAR is an effective and innovative methodology that enhances educational inclusion through Augmented Reality. Promoting its adoption in educational settings could help institutions better address the needs of all students, particularly those at risk of exclusion.

KEYWORDS

**educational technology, augmented reality, UDL, cooperative learning, educational inclusion, co-creation**

## 1 Introduction

Diversity in education refers to including diverse social, cultural and personal backgrounds among students and educators, emphasizing the importance of recognizing and respecting differences in race, ethnicity, gender, ability and socio-economic status (Franco Lalama, 2023).

Currently, it is considered a remarkable achievement in many countries that students with or without diverse educational needs might be integrated into the same classroom. However, it is imperative to provide real inclusion, guaranteeing teaching/learning processes wherein students have equal opportunities to participate in a quality education appropriate to their abilities and needs (Pastor, 2012).

According to (Treviranus and Roberts, 2008), inclusion refers to the transformation of learning environments to offer an educational process that considers the needs and preferences of a diverse student body. In this context, the teacher plays essential crucial role in supporting and retaining heterogeneous groups of students with diverse educational needs, which demand the design of open and flexible curricula (Velázquez and Morales, 2018). While this presents significant challenges and requires considerable effort, it ultimately leads to better academic outcomes for students.

The implementation of inclusive educational environments that leverage technologies such as AR has been demonstrated to improve learning experiences for all students, especially those with special needs. Research has shown that AR can effectively visualize abstract concepts, making it a powerful tool in inclusive classrooms, especially in elementary education (Asnawi et al., 2023).

Recently, new approaches that provide fresh design frameworks for creating inclusive educational environments using augmented reality have emerged. These recent studies propose solutions that integrate emerging technologies and pedagogical strategies aimed at student diversity, thereby promoting more accessible and equitable learning (Alvarez-Icaza and Huerta, 2024; Frasnyaigu et al., 2023; Ribeiro et al., 2024). However, findings by Quintero et al. (2019) remain challenging; methodologies that help educational institutions, particularly teachers, address diversity in the classroom using AR are scarcely reported.

Likewise, AR enhancing critical thinking and retention "This technology fosters engagement and comprehension, allowing students from various backgrounds to access and understand complex STEM concepts effectively" (Fetaji et al., 2023).

Therefore, this article introduces the CooperAR methodology as a strategy that addresses the needs of all students by guiding the co-creation of learning scenarios supported by AR, in which both teachers and students become co-creators of augmented content (Quintero et al., 2021).

The methodology follows three key principles: Universal Design for Learning, which reduces classroom barriers caused by rigid strategies; Cooperative Learning, fostering collaboration in diverse groups; and co-creation of content by students and teachers, promoting students as active contributors. Another challenge AR faces as a tool for promoting inclusion is the lack of diverse and comprehensive validation processes in existing studies, which involve more varied samples and methodologies (Castells, 2016; Quintero et al., 2019). To address this, we designed an integrated evaluation method that considers three dimensions, inclusion, cooperation and quality. This approach ensures attention to all students during the execution of the strategy, promotes successful teamwork as a catalyst for inclusion, and supports the verification of the quality of the co-created product by all participants.

Among the products co-created following CooperAR methodology, we also enriched the list of AR applications available to support diversity in educational settings, contributing with AR-mbot, an application to help all students while they learn robotics. AR-mbot was a fundamental part of the strategy and it was the object of evaluation.

This article is structured as follows: Section II presents the analysis of the related works, section III details the CooperAR methodology, section IV describes the evaluation carried out to validate the methodology, section IV reports the results of the evaluation, section V shows the discussion and, finally, section VI reports the conclusions.

## 2 Related works

Research in educational inclusion using AR has had notable advances, primarily as it has facilitated addressing the diverse needs of all students, including those with disabilities (Bacca et al., 2014; Fernández-Batanero et al., 2022; Frasnyaigu et al., 2023; Murniarti et al., 2023; Quintero et al., 2019; Satpathy et al., 2023). Next paragraphs describe relevant recent studies in this research area.

The study by Frasnyaigu et al. (2023), aimed to develop augmented reality (AR) learning tools for using ecosystemic material in an inclusive elementary school classroom. It focused on creating learning resources tailored to children with special needs, following the Bord and Gall model (Gall et al., 2003). The outcome was a design for an AR-based learning tool that helps visualize abstract concepts.

In contrast, Satpathy et al. (2023) establishes a framework for understanding the extent to which augmented reality (AR) and virtual reality (VR) have contributed to building inclusive education in India. The authors conclude that, with the help of AR and VR, transformations occurred in the education system that led to more inclusive education, as evidenced by improved learning, increased motivation to study, greater student participation, authentic learning opportunities, better communication, and additional learning opportunities.

Meanwhile, Mkwizu and Bordoloi (2022) explored AR to support education for girls from an inclusive perspective, finding that AR technologies, particularly mobile AR technologies, should be utilized and applied in women's education to make the learning process fun, interactive and more interesting to students. The study concluded that integrating mobile AR technologies can help address these challenges by creating a more engaging learning environment.

Additionally, Terzieva et al. (2023) conducted a study to analyze the use of augmented reality to support a smart and inclusive education. A Smart Educational System (SES) enables personalized and adaptative learning, supporting inclusive education and mentoring processes. This system employs ontological models and laser projection systems to enhance learning efficiency and participation, achieving satisfactory outcomes in inclusive education.

Similarly, another study aimed to apply Augmented Reality (AR) to improve social responses in students with Autism Spectrum Disorder (ASD), with the potential to extend this tool to a larger group of students and explore additional variables. The study involved 12 students with ASD and used a quasi-experimental design with control and experimental groups. The findings suggest that AR can effectively enhance the social responses of students with ASD, indicating a positive impact of this technology in educational settings (Gilabert-cerdá et al., 2023).

Finally, but not less important, the study by Jindal et al. (2023) overlays historical information tailored to the background and needs of each user, thereby enhancing the design of the user experience. The conclusions emphasize the importance of considering the diverse needs of users when designing technological solutions, particularly in educational settings where AR is used to improve the user experience.

Although advances regarding the use of AR in education have been significant, there are still pressing questions that need to be addressed. Most of the analyzed studies focus on specific populations, benefiting students with hearing limitations and autism. This leads us to conclude that, to truly promote inclusion, it is imperative to diversify the samples of the studied populations. On the other hand, to the best of our knowledge, no methodological frameworks exist to inform or guide the design and development of augmented experiences in inclusive scenarios, especially when it comes to supporting teachers in the design of this type of educational scenario.

In this context, the CooperAR methodology has been designed to guide teachers in creating inclusive educational scenarios supported by AR that address educational problems identified in real educational environments.

The research question guiding this study is: How to support teachers in designing, creating and deploying collaborative learning experiences using AR and Universal Design for Learning to improve the attention to students' diversity in the classroom?

The following section introduces CooperAR as an alternative to address the research question, detailing its principles, participants Actors, use cases, phases, and the concept of evaluation.

## 3 CooperAR methodology

The main objective of CooperAR is to provide methodological guidelines to teachers based on the conceptual frameworks of CL, UDL and co-creation between students and teachers, to facilitate the design and implementation of augmented educational scenarios that address diversity in the classroom. Figure 1 describes the main components of CooperAR.

### 3.1 Conceptual principles

Each framework that supports CooperAR addresses specific methodological and pedagogical issues while teachers co-create educational scenarios that address diversity. In the next paragraphs, cooperative learning (CA), UDL and co-creation between students and teachers are described, emphasizing their contribution in the context of CooperAR.

The UDL is a framework that contributes overcoming the main obstacle to foster expert in educational environments, the creation of inflexible curricula or "one-size-fits-all" approaches (CAST, 2011; Navaitienė and Stasiūnaitienė, 2021).

UDL bases its strategy on supporting the creation of more flexible curricula by addressing three principles in the curriculum design: (1) Provide multiple means of engagement, (2) Provide multiple means of action and expression, and (3) Provide multiple means of representation. Each principle outlines a series of guidelines, with compliance monitored through control points (Meyer et al., 2014).

In CooperAR, designers are guided on which universal design guidelines to apply and when, specifically within an augmented scenario. In particular, AR supports the three UDL principles by offering multiple means to present information to students, promoting multimodality, encouraging students participation in various forms, and enhancing student motivation (Bacca et al., 2018).

On the other hand, CL as an active methodology, supports the second principle of UDL by providing multiple means of action and expression. It promotes inclusion through the use of small, heterogeneous groups of teamwork, where students collaborate to achieve common goals, enhance their learning, and support one another, maximizing mutual support (Garzón, 2020).

Furthermore, CooperAR methodology conceives the definition of co-creation as "a highly-facilitated, team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need" (Roschelle and Penuel, 2006). In CooperAR, co-creation allows teachers and students to collaboratively design and develop an augmented educational resource, incorporating contributions from all participants based on their professional expertise and personal experiences as teachers or students. This approach enables students to become content creators rather than mere consumers, as their preferences, tastes, and input are considered in the creation of educational scenarios, positioning them as co-creators of content.

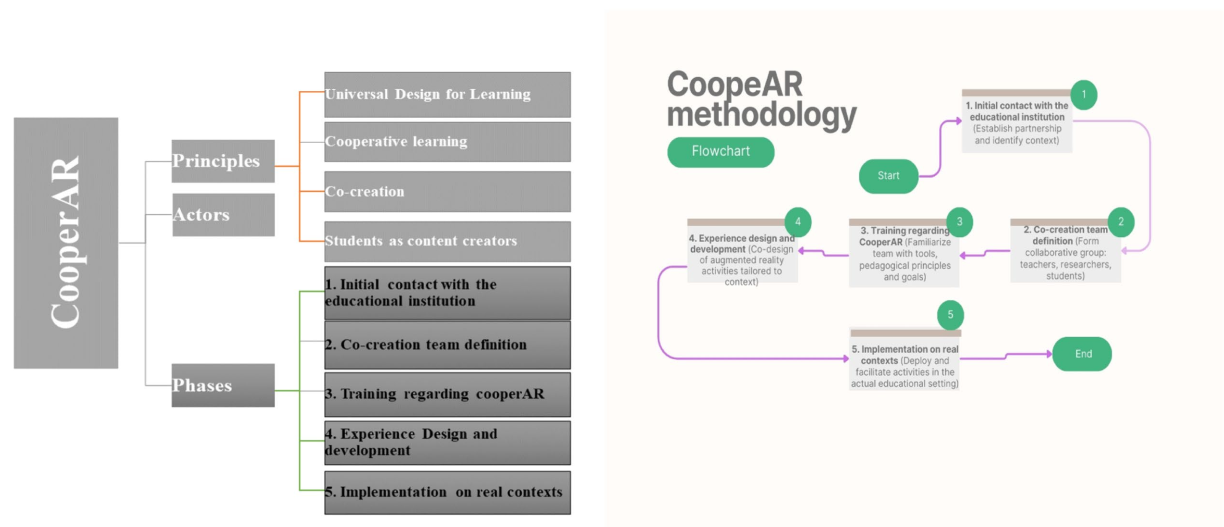


FIGURE 1
Overview of the CooperAR methodology and flowchart.

## 3.2 Actors in CooperAR

CooperAR defines a series of actors who actively participate in the co-creation process: (1) The teachers who face numerous educational challenges in the classroom and co-create augmented and inclusive educational resources to provide a quality experience for their students; (2) The pedagogical or didactic advisor, who is responsible for providing pedagogically support the creation of the didactic experience; (3) The expert in inclusion, who verifies and supports the application of UDL and inclusive practices in the educational scenario; (4) Students, who are selected volunteers that assist in designing the educational resource, offering contributions based on their needs and preferences, and supporting the teacher deploying the created resource; (5) The developer, who is responsible for software programming; (6) The designer, who shapes the graphic designs of the and resource; and finally, (7) The researcher, who leads the development of all methodology phases, ensuring adherence to the principles.

## 3.3 Scenarios of use of the methodology

CooperAR may be used as (1) a methodological strategy to facilitate attention to diversity in the educational context; (2) a strategy to promote cooperation among students to support inclusion; (3) a systematic method of creating augmented educational resources that target specific competencies; (4) a guide for carrying out co-creation experiences with diverse groups of teachers; and (5) a strategy to enhance student motivation.

## 3.4 Phases of CooperAR

The CooperAR methodology consists of a series of stages enriched with templates and annexes to support the systematization of the methodology.

The first stage involves closely relating with the educational institution where the CooperAR methodology will be implemented. This stage is essential because the institutions should understand the methodological process to be followed by teachers and students to create the augmented educational scenarios and encourage the participation of the academic community.

This stage is carried out in two phases: the first involves meeting with the institution's direction to obtain approval for developing the process, and the second involves working with teachers and students to consolidate the co-creation team. In the second stage, called the enlistment of the co-creation teams, the roles of the actors participating in the teams are defined. Actors should be integrated in a multidisciplinary manner, promoting contributions from each team member according to their area of knowledge, experience, and training. The participation of external actors with recognized expertise enriches the co-creation process.

The involvement of students is fundamental in CooperAR; their realities, preferences, motivations, and needs contribute to and enhance the creative process. For this reason, it is essential to encourage their participation through academic incentives such as scholarships and other forms of motivational support.

The third stage corresponds to the training of the co-creation team. In this stage, team members receive guidance on the methodology as well as on Cooperative Learning (CL), Augmented Reality (AR) and co-creation. Topics are tailored based on each member's role within the team.

The fourth stage corresponds to the design and development of the augmented didactic strategy. In this stage, the creation of the educational strategy is carried out with the participation of all team members. This stage is crucial for achieving the methodology's objectives, as it guides participants in applying the principles of CooperAR. The main goal is for the co-creation team to design a didactic strategy that provides a high-quality solution to an educational problem. This strategy will incorporate AR based applications, promote CL, and align with the principles of UDL. Each participant contributes according to their role.

The co-creation team generates ideas to explore solution strategies for the identified educational problem. Subsequently, the process of developing educational content begins, concretizing the didactic approach. During this phase, the graphic content and three-dimensional (3D) models intended for AR are adapted and integrated with the textual content across various sections of the design.

Finally, in the deployment stage, the teacher prepares a real validation scenario and introduces the co-created educational solution to the students. This stage requires careful planning of the learning scenario, with attention to several key aspects: (1) the teacher must be proficient in using both the co-created didactic strategy and associated AR applications; (2) the teacher must effectively utilize tutorials or other support materials related to the applications, ensuring these are provided to the students in either digital or printed form, along with the necessary training; (3) the co-creation team must ensure that the mobile devices to be used are technically prepared in advance; (4) if the strategy involves applications that require AR markers, these must be printed and ready beforehand; (5) the classroom should be carefully prepared, considering adequate lighting to ensure the AR functions work properly; (6) copies of the application tutorials or other support materials must be available for students who need them; (7) students must be thoroughly instructed on how to navigate the applications, including how to enter, exit and manage the menus, to prevent time wastage.

The teacher should also have the support of the co-creation team members, especially if they lack experience with the technology.

During the deployment of the educational scenario, the methodology also recommends controlling the timeline by specifying a detailed schedule for student activities.

## 3.5 Concept of evaluation

The evaluation of CooperAR seeks to verify the methodology facilitates the creation of didactic strategies, including augmented educational resources, that promote educational inclusion by adopting the principles that guide it. In this context, three evaluation dimensions were defined:

Inclusion. The first dimension assesses whether the diverse educational needs of students have been met through the educational strategy generated using the CooperAR methodology.

Cooperation. The second dimension analyses to what extent an educational strategy co-created with the CooperAR methodology fosters cooperative interaction among students.

Quality. The third dimension examines whether the co-created resource meets quality standards in terms of accessibility, usability, reusability, presentation design, and motivation.

Described dimensions ensure an integral evaluation of the educational artifacts generated following the CooperAR methodology, combining the evaluation of the products but also evaluating the process of inclusion itself.

Next, sections detail the evaluation carried out in a real educational setting.

## 4 Evaluation

This study has been developed using a mixed research approach (Hernández-Sampieri et al., 2018). The research design had a descriptive scope, in which different dimensions and variables were measured and evaluated without establishing correlations (Ramos, 2015). It followed a quasi-experimental design, conducted in an educational institution in the South of Colombia, with 63 students, divided into two pre-organized groups, grade 10.1 and grade 10.2 of high school. One group served as the experimental group, while the other acted as the control group, ensuring content equivalence between the two groups (Hernández et al., 2010).

The following sections describe the complete evaluation process, including the development of AR-mBot as an AR application that implements the learning strategy, the context where the evaluation was conducted, the method followed during the evaluation, as well as the results and discussion.

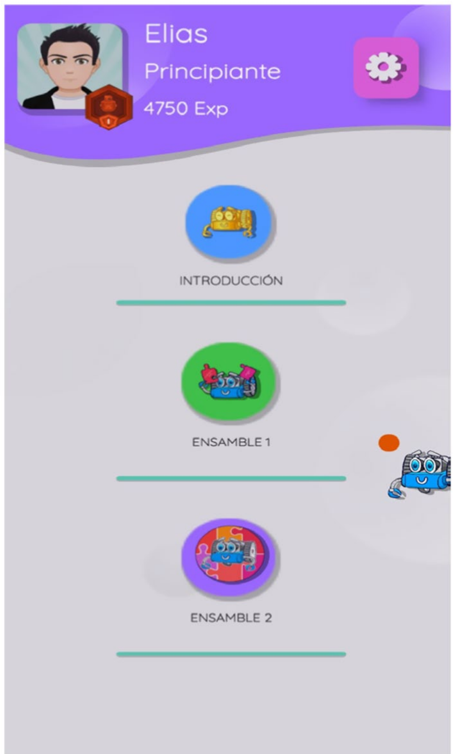


FIGURE 2
AR-mBot application screenshots.

### 4.1 Materials: AR-mBot design

In this study, an educational scenario with AR was co-created with students and teachers, applying the principles and stages of the CooperAR methodology. The evaluation scenario involved developing the AR-mBot application to strengthen computational and algorithmic thinking to solve real problems. Figure 2 presents a screenshot of the AR-mBot application deployment.

The proposed educational scenario integrates AR technology, gamification techniques, and CooperAR principles to create an effective pedagogical tool for teaching robotics. Robotics education, along with other branches of the fourth industrial revolution, has been identified as crucial for enhancing the quality of life of people in developing countries (Serna Gómez et al., 2021). As a result, this educational scenario aims to improve computational and algorithmic thinking skills among primary and secondary school students for effective problem-solving.

The co-creation team consisted of five teachers and ten high school students from an educational institution in Colombia.

AR-mBot is a gamified application designed following the Mechanics, Dynamics, and Aesthetics (MDA) design approach (Kusuma et al., 2018). Each component is described in the next paragraphs.

#### 4.1.1 Mechanics

The mechanics describe the game's components, such as its rules and the actions or tasks that students perform in the gamified scenario (Helmefalk, 2019).

In the AR-mBot application, students must assemble a robot by processing through different levels and lessons. They work in heterogeneous cooperative groups of 4, discovering the robot's parts using AR and motivated by the need to overcome challenges in advance.

The application considers four levels: Introduction, Assembly, Connection, and Programming. In turn, each level contains different lessons and a challenge to overcome. Students' progress from one level to the next by accumulating points and earning prizes.

A new level is activated only after successfully completing the challenge associated with the previous level. However, students can repeat levels as often as needed to improve their performance without incurring penalties. This design accommodates diverse learning needs and styles, encouraging students to improve their results at their own pace.

As students progress through the activities, they unlock a series of trophies that recognize specific achievements. The table below presents each trophy, the criteria to earn it, the level of achievement, and the associated educational competency (Table 1).

Moreover, students can win prizes and points as follows:

*Customization Prizes (Painting):* Students earn a paint bucket each time they successfully complete a challenge in the corresponding levels. These buckets are then used to paint a virtual helper within the application, adding an element of personalization and creativity as a reward for their progress.

*Experience Points:* As the students' progress through each level and successfully complete the proposed challenges, they accumulate experience points. These points are displayed next to the student's

TABLE 1 Progression and achievements in gamified learning with AR.

| Trophy | Criteria to Earn | Achievement Level | Educational Competency |
|---|---|---|---|
| Enthusiast | Completes the introduction of the challenge | Basic | Initiative and participation |
| Assembler | Repeats assembly challenges | Intermediate | Fine motor skills and perseverance |
| Fast assembler | Improves times in assembly challenges | Advanced | Agility and precision |
| Assembly king | Completes all assembly challenges | Expert | Autonomy and goal achievement |
| Fast programmer | Completes programming challenges with improved times | Advanced | Computational thinking |
| Error-free programming | Repeats programming challenges without errors | Advanced | Attention to detail and logic |
| Logic king | Completes all robot programming challenges | Expert | Problem-solving and algorithmic logic |
| AR-mBOT master | Earns all previous trophies | Mastery | Synthesis of learning and excellence |

TABLE 2 Rank by points.

| # | Patch | Rank |
|---|---|---|
| 1 | Beginner | 0–1,999 |
| 2 | Assembler | 2,000–3,499 |
| 3 | Creator | 3,500–4,999 |
| 4 | Humanoid | 5,000–7,499 |
| 5 | Robotic Genius | 7,500 + |

avatar and reward them with an identifying patch, as illustrated in Table 2 and Figure 3.

Two additional features were included in the AR-mBot app: the avatars and the helper "Mr. mBot." The creation of avatars was proposed by the students of the co-creation team, who used an online tool to design a total of 11 avatars incorporated into the AR-mBot application. As a result, each student could choose their avatar when creating his user account.

The students also proposed the inclusion of a helper, Mr. mBot, a robot-like helper assembled during the learning process. This helper supports students when needed during the use of the application. Mr. mBot prompts interaction in two distinct situations: (a) Intrusive: the helper appears with messages when the student has failed more than three times in developing a challenge; it may also automatically appear on the screen to guide the student, and (b) Minimally intrusive: the helper is activated by a notification icon on the right side of the screen, which requires a touch to activate and another touch to hide. Figure 4 shows Mr. mBot delivering a motivational message to a student, which varies according to the module and sub-topic being developed.

### 4.1.2 Dynamics

The dynamics describe the operation of the mechanics to create the interactions between the students (Junior and Silva, 2021). Within cooperative groups, roles and objectives facilitate interaction and share ideas among the group members, allowing for debates on the development of the proposed challenges and mutual support. Students are also required to share, interact, contribute, and assist each other through a forum, adhering to the rules of cooperative work (Paul and Kundu, 2021).

### 4.1.3 Esthetics

Aesthetics concerns the enjoyment within the game, specifically the desirable emotional responses from the player during interactions with the game (Hunicke et al., 2004). For this educational scenario, the aesthetic consists of discovering the parts of the robot and the sensation that AR evokes in each challenge.

Figure 5 illustrates the architecture of the developed application, employing an architectural style based on layers (Rivera Alvarado et al., 2018).

The first layer, called the 'Entry AR-mBot app', serves as the interface layer that presents the application to users. It includes the presentation of all gamified and augmented educational functionalities and interfaces related to the configuration and customization system. This layer is integrated with the camera, playing a crucial role in the input and output of AR data.

The interactivity layer integrates the Unity development engine with Vuforia features to execute the necessary internal AR processes. This layer develops various interactions between the application and the user while supplying the designed resources used in lessons and exercises.

The application features a total of 11 3D models, which operate through markers integrated into the educational robotics module assembly section. Additionally, it includes an animated assistant that provides help when the student needs it or encounters difficulties in progressing through the process.

Each AR object unfolds, providing additional elements for understanding, such as audio, textual information, information in PDF format, and 3D object animation for enhanced student comprehension.

In Figure 6, a 3D AR object representing a part of the educational robotics kit is observed, surrounded by buttons to access additional information. After learning about the components of the robotics kit, the student can review the various educational sections that have been activated, leading to an evaluation where different challenges are presented, with the option to retry. The results are stored in layer three or the storage system.

Layer three, or the data storage layer, manages all the information derived from the user's interaction with the previous two layers. It is specially designed to support the data storage from the gamification process. This includes student identification, the number of trophies, patches, colors and gamification points


FIGURE 3
Types of patches.

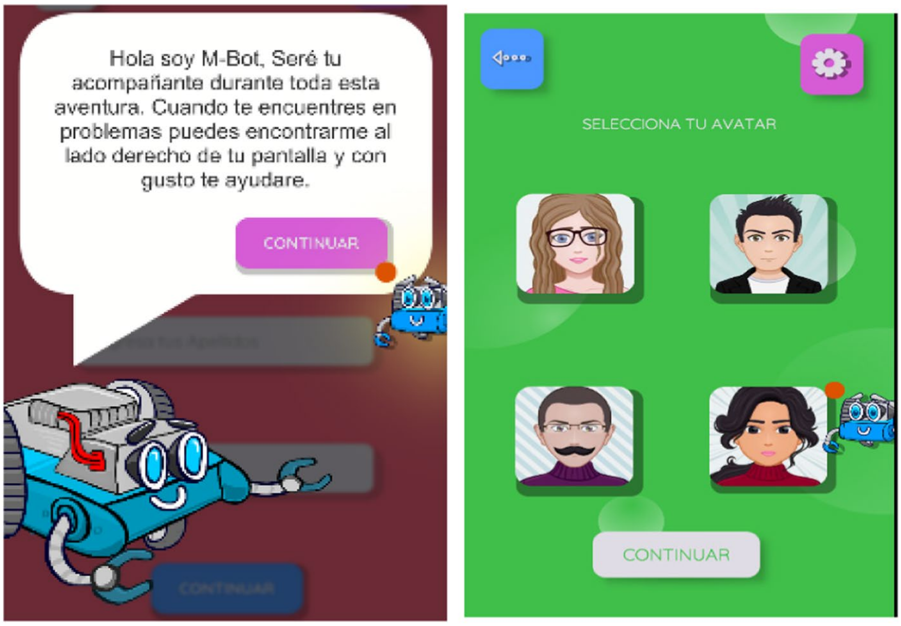


FIGURE 4
Helper Mr. mBot and avatar.

achieved, and progress in the application modules, among other aspects. The collection of this information is crucial for facilitating detailed analysis by the teacher. Initially, the data is stored in the application's local database and later uploaded to the cloud once there is connectivity.

Layer 4 manages the information regarding the student's interactions using the analytics functionalities of Unity (Sarosa et al., 2019). The configuration of the analytics took into account essential aspects for the investigation and the corresponding analysis:

- Student identification number.
- Workgroup number.
- Extracts from the challenges: time, number of attempts, and errors.
- Number of trophies, patches, colors, and gamification points achieved.
- Number of times the student used the audio cues in the application.
- Number of times the student asked for the help of Mr. mBot.

## 4.2 Evaluation context

### 4.2.1 The Luis Carlos Galán school

The CooperAR methodology was implemented and evaluated in an educational institution in the South of Colombia called Luis Carlos Galán School. In this context, to provide evidence on the current situation regarding the processes of attention to diversity in the educational institution where the research was developed, the instrument Themis (Azorín et al., 2019) was applied to teachers of the institution and published in the following repository: https://acortar.link/0vYNih.

The Themis instrument is a diagnostic tool that identifies the strengths and weaknesses of the institution in terms of response to diversity while encouraging reflection among educators (Azorín et al., 2019). Themis measures three dimensions: (1) Contexts, which refers to the circumstances surrounding the schools; (2) Resources, which evaluates the resources schools have available for inclusion and is divided into three categories: personal, institutional and local; and finally, (3) Processes, which pertains to presence, participation and achievement.

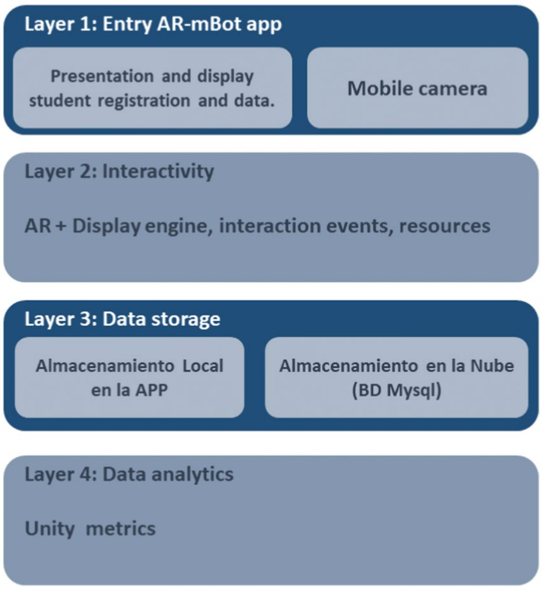


FIGURE 5
Architecture of AR-mBot.


FIGURE 6
Unfolded 3D model.

Themis questionnaire has a total of 65 Likert-type questions. The first 23 questions evaluate dimension A (Contexts), from questions 24–43 the dimension B (Resources) is evaluated and from questions 44–65 the dimension C (Processes). The results of the instrument application are presented below.

Figure 7 shows the results corresponding to dimension A (Contexts), dimension B (Resources), and dimension c (Processes).

Dimension A analyzes the socioeconomic situation of the institution, cultural diversity, educational policy, leadership, inclusion values, prevention, teacher-student relationship, family-school relationship, learning processes, and academic community participation.

The questions that received a score of less than 3 points on the Likert scale are shown in Table 3.

Less scored questions reflect the lack of collaborative work of the school to guarantee inclusion at different levels. These results support the importance of the CooperAR implementation.

Figure 7 shows the results obtained concerning dimension B; it allows for estimating the level of training of human resources, the physical resources available, and the material and technological resources available in the educational institution.

The questions that received a score of less than 3 points on the Likert scale are shown in Table 4.

Lowest-scoring questions reflect limitations regarding teachers' professional development on inclusion, lack of adequate equipment to support inclusion, and limited relationships with families as leading actors in the inclusive process. This finding highlights the importance of implementing CooperAR at the institution.

In addition, Figure 7 shows the results of dimension C, through it the variety of methodologies, the formation of heterogeneous groups, the organization of educational processes, educational support processes, evaluation, and transition processes between stages or educational levels are analyzed.

The results of the less-scored questions are shown in Table 5, particularly those questions with results that are more related to the main inclusion principles.

Results show that in this school, most teachers do not apply various teaching strategies and methodologies that favor educational inclusion for all students. For instance, active methodologies and heterogeneous work groups are not actively used in the classroom.

The result of the diagnosis shows the importance for the school of implementing the CooperAR methodology, which can facilitate teachers' adoption of emerging technologies such as AR and also support attention to all students.

### 4.2.2 Participants

A total of 63 students comprised the two groups selected from the tenth grade of high school of the educational institution in southern Colombia that participated in the evaluation. Among them, 33 (52%) were men, and 30 (48%) were women. According to the data of the Integrated Registration System of Colombia (SIMAT) (Toro, 2013), all the participants belong to the lowest socioeconomic stratum; seven belong to indigenous groups, two are afro-descendants, three are migrants, and five are victims of the armed conflict in Colombia.

Among the participants, there was a student with low vision and one with moderate intellectual disability, both diagnosed. Nine students were also reported as having poor academic performance, and a total of nine students indicated they were failing classes, experiencing academic delays, or repeating a grade. Informed consent was requested signed by the student's parents because participants in the study were minors.

The consent of the Luis Carlos Galán School's ethics committee regarding the study's research design is available at the project repository, section permissions: https://acortar.link/0vYNih.

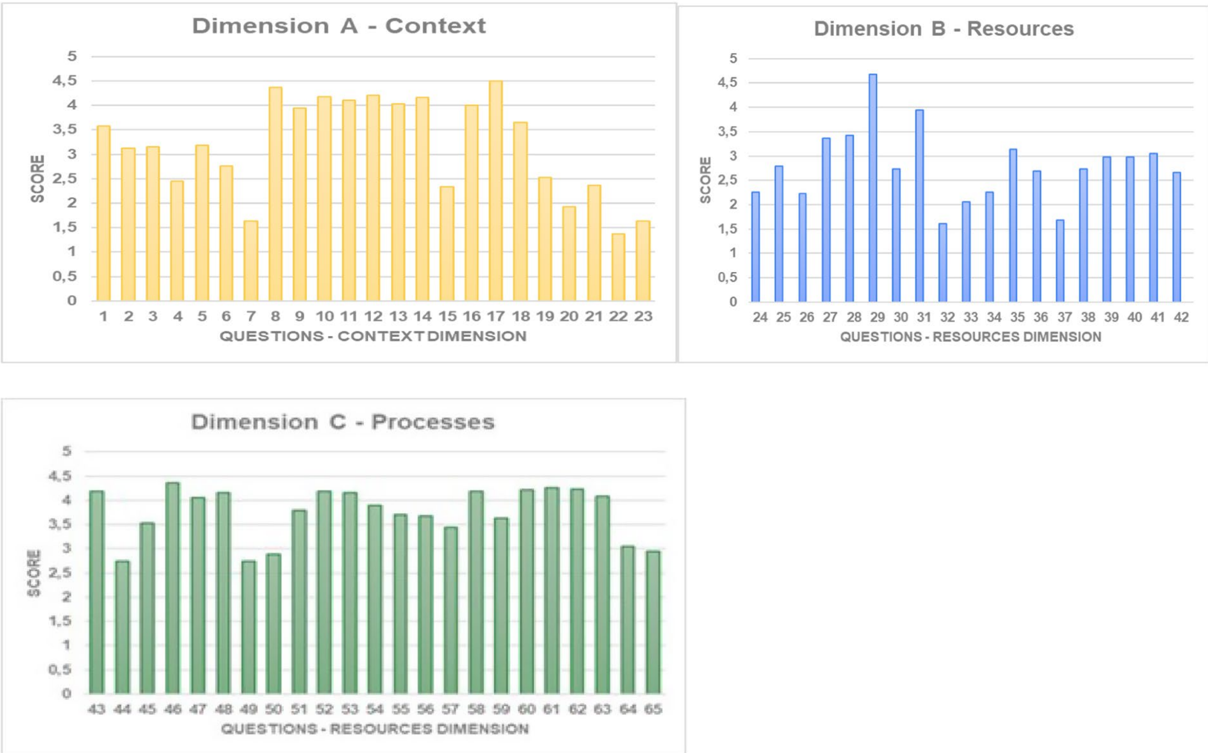


FIGURE 7
Results.

TABLE 3 Less scored questions on context dimension.

| Questions... |
|---|
| 4. I believe that the response to diversity measures under current legislation responds to the needs of the students at my school |
| 6. The Senior Leadership Team considers the opinions of others when making decisions |
| 7. The Senior Leadership Team promotes the development of inclusive practices |
| 19. Some volunteers collaborate in the education process (former students, retired individuals, families and others) |
| 20. During the school year, I carry out activities with associations that cooperate with the school (those devoted to disabilities or other purposes) |
| 21. The local authorities are receptive to requests to get involved in campaigns or to provide services within the school |
| 22. The school is twinned with another school (regional, national or abroad) |
| 23. The school collaborates with other schools in the area |

## 4.3 Instruments

In this study, several instruments were considered to support the evaluation of the three dimensions defined in CooperAR.

The first dimension is related to the inclusion capacity of the co-created scenario, understood as the measure of adoption of the UDL principles. This was verified using an instrument designed specifically for this study, which is based on the rubric proposed by Spooner et al. (2007). Specifically, the instrument evaluates a correct definition of the educational objectives, the description of the course profile, the design of methods and materials, and the design of the evaluation in accordance with following the universal design for learning design. This instrument was completed by three teachers with training in attention to diversity. The instrument is available in the project repository: https://acortar.link/0vYNih.

The analysis of the metrics reported by Unity regarding the gamification process was conducted to provide quantitative results of the impact of gamification in the processes of educational inclusion.

To measure the degree of cooperation between the groups formed during the educational intervention, the students answered a questionnaire proposed and validated by Fernandez et al. (2017). This questionnaire measures five dimensions of collaborative learning: (a) Social skills, (b) Group processing, (c) Positive interdependence, (d) Promote interaction, and (e) Individual responsibility. It consists of 20 items (4 items per dimension). Each item was evaluated using a Likert-type scale where 1 corresponds

TABLE 4 Less scored questions on resources dimension.

| Questions |
|---|
| 24. I take part in ongoing training in response to diversity (Courses, Seminars, Conferences) |
| 25. I collaborate in teaching innovation projects for improved inclusion |
| 26. The staff at the school includes enough specialists/auxiliary workers to attend to its student diversity |
| 30. I enjoy a wide range of teaching resources that respond to all my students' characteristics |
| 32. All the classrooms are technologically equipped (beamer, projector, computer, smart board) |
| 33. The computer rooms are equipped with enough computers for the number of students |
| 34. Students who need alternative means to access the curriculum, information and communication have these available |
| 36. The school's equipment and furniture are adapted to students" need |
| 37. The school offers out-of-school activities (theatre, cinema, choir, dancing, radio, press) |
| 38. The school offers out-of-school sports activities |
| 40. The school organizes out-of-school activities for families (Workshops, Schools for parents) |
| 42. The school manages the community/district resources effectively |

TABLE 5 Less scored questions on resources dimension.

| Questions |
|---|
| 44. I plan my teaching by taking all the students into account |
| 49. I use various methodological strategies throughout my teaching (e.g., project work, workstations, research work, cooperative learning) |
| 50. I set up heterogeneous work groups in the classroom |
| 64. The school provides students and families with information about the transit from one educational stage to the next |
| 65. The school runs activities to familiarize students with their next school (e.g., a visit to the primary/secondary/vocational school or university) |

to strongly disagree and 5 to strongly agree. Cronbach's Alpha coefficient ($\alpha = 0.992$) indicates an adequate reliability of the questionnaire. The instrument is available in the project repository at the following https://acortar.link/0vYNih.

With the purpose to enrich the quantitative results regarding cooperation, the students were asked to write a storytelling in an open format but guided by some questions as mechanism to count with qualitative data which could explain the quantitative results.

To measure the quality of the AR applications, the checklist published and validated by Guimarães and Valeria (2014), which includes usability, efficiency and satisfaction heuristics, was used. This instrument was completed by a group of five engineers with experience in developing educational applications with AR and by the teachers of the co-creation team. The instrument is available in the project repository at the following link: https://acortar.link/0vYNih.

The quality of an AR application is also determined by the quality of the immersion of the participant during the experience. For this reason, to measure the stimuli and cognitive reactions inherent to the immersive technology in the students of the experimental group, the Tinmer instrument published by Sandoval and Badilla (2021) was applied. It corresponds to a validated questionnaire with a Cronbach's Alpha coefficient of 0.85. The instrument has 18 questions that measure variables such as interactivity, presence and flow, using a Likert scale from 1 to 5, where 1 correspond to totally disagrees and 5 to totally agree. The interactivity variable is related to the stimulus through 3D augmented reality objects, where the student can see, move, rotate, zoom in, zoom out and access complementary information; the presence variable allows measuring cognitive reactions such as the sensation of immersion with AR, while the flow variable assesses how the student perceives the interaction. The instrument is available in the project repository at the following https://acortar.link/0vYNih.

## 4.4 Methods

In this section, both experimental and control interventions will be explained.

Grade 10.2 of the school was considered the experimental group, while 10.1 served as the control group for the purposes of conducting the respective comparative study (Ross and Morrison, 2003). Since both groups were in the same grade, they were homogenous in terms of basic competencies.

### 4.4.1 Experimental method

The dynamics of the experimental group were as follows. Initially, heterogeneous cooperative sub-groups were created (Pujolàs Maset et al., 2013), based on literature regarding cooperative work (Bertucci et al., 2012). Each Sub-groups consisted of four students.

Initially, the group of students was characterized according to the orientations of Table 6.

Based on the characterization of Table 6, the teacher who was familiar with the students, organized the heterogeneous groups by assigning two students categorized in typology 1, one from typology 2, and another from typology 3 to each group.

TABLE 6 Characterization of students.

| Typology 1 | Typology 2 | Typology 3 |
|---|---|---|
| Students ready to offer help to others.<br>High academic performance.<br>More motivated.<br>Those with the best teamwork skills. | The rest of the students | Students who may need help, considering their educational needs. |

TABLE 7 Evaluation experts about UDL adoption.

| Dimensions | Result |
|---|---|
| 1. Learning goals | Very high |
| 2. Course Profile | Very high |
| 3. Design of methods and materials | Very high |
| 4. Evaluation design | High |

Initially, training on the application and use of AR-mBot markers was provided to the experimental group to ensure that the students were familiar with the application before the intervention.

The educational intervention was organized in eight sessions of 40 min. Due to the pandemic caused by COVID-19 (Ratten, 2020), each group met at one of its member's home, under strict biosecurity measures. The researcher had the opportunity to observe each session in person.

During the intervention, the students used the AR-mBot app as part of the computational thinking development topic. Learning was supported through the use of robotics kits purchased by the school for educational purposes.

Students utilized tablets provided by the school, which had the AR-mBot app installed. Additionally, printed AR markers were available each session.

The cooperative groups worked on the proposed programming challenges, supported by examples from the application; everyone was required to contribute with achieving the proposed objectives in each programming challenge.

Once the intervention was over, the students received the guiding questions to write their Storytelling (Hafiza and Halimah, 2010) about their experience. Likewise, the students completed a digital questionnaire on cooperative learning and an instrument to measure cognitive reactions.

Student interactions were recorded in the AR-mBot application throughout the intervention.

### 4.4.2 Control method

On the other hand, the control group was divided into subgroups freely; that is, the students chose their co-workers, indicating that the groups should consist of a maximum of four members. The students had a work schedule and a tutorial designed by the teacher. The tutorial was similar to the one given to the students who used the AR-mBot application, but it did not include augmented elements.

As in the experimental group, each subgroup worked each session at one of its members' homes; the researcher had the opportunity to conduct participant observation of the sessions. At the end of the intervention, the students answered the cooperative work questionnaire. It is important to note that biosafety protocols were adopted for all groups during the work sessions.

To ensure baseline equivalence between the experimental and control groups, the following measures were implemented:

Predefined structure: The division of the experimental group was based on cooperative work organization criteria aligned with student typology and characteristics, as outlined in Table 6. This approach minimizes the risk of initial self-selection bias.

Partial randomization: Although the groups were pre-established, their assignment as "experimental" or "control" was randomized to neutralize potential unmeasured external factors.

## 4.5 Data analysis

In this study, a quantitative analysis of the data collected was carried out using the SPSS v26 tool (Arkkelin, 2014), the results are described in the next section.

## 4.6 Results

The results of the educational intervention are shown below according to the evaluated dimensions, inclusion, cooperation and quality.

### 4.6.1 Inclusion dimension

#### 4.6.1.1 Adoption of the UDL principles

Table 7 shows the results of the evaluation made by the experts in educational inclusion, who determined the level of adoption of UDL in the co-created educational scenario.

Three of the evaluated dimensions in Table 7 show very high values, while on one-dimension shows a high value. These results indicate that the learning goals were well defined in the learning scenario, communicated effectively to the students, and met through the design of the augmented experience. The evaluation of the course profile indicates it allowed for the identification of the needs, weaknesses, and preferences of the diverse student population.

On the other hand, the evaluation of the design of methods and materials shows that the learning experience provided a variety of didactic methods that adequately addressed the needs and preferences of the students. Finally, the evaluation design criteria received a score lower than the other dimensions, suggesting the need to strengthen this area by offering evaluation and feedback processes that are more appropriate to the variability of students.

#### 4.6.1.2 Gamification to support inclusion

Table 8 shows the metrics reported by Unity in the execution of the AR-mBot app concerning the implemented gamification process. Table 8 presents selected events designed as variables.

The results of Table 9 indicate that most students progressed and improved across all app levels. The findings show that they achieved the highest number of patches, trophies and colors designed. On the other hand, Table 9 shows the results of the subgroup of students at risk of exclusion.

TABLE 8 Results of gamification for all students.

| Events | Averaged results (n = 30) | | |
|---|---|---|---|
| | Time | Attempts | Fails |
| Challenges | 3.80 min | 3 | 3 |
| Sections (Levels) | 6 of 6 | | |
| Using help | 5 times | | |
| Use of audio | 5 | | |

| Incentives | Amount achieved |
|---|---|
| Patches | 4 of 5 |
| Trophies | 4 of 7 |
| Colors | 10 of 12 |

TABLE 9 Results of students at exclusion risk.

| Events | Averaged results (*N* = 30) | | |
|---|---|---|---|
| | Time | Attempts | Fails |
| AR challenge | 4.30 | 3 | 1 |
| Sections | 6 of 6 | | |
| Use of help | 8 | | |
| Use of audio | 7 | | |

| Incentives | Amount achieved |
|---|---|
| Patches | 4 of 5 |
| Trophies | 4 of 7 |
| Colors | 9 of 12 |

TABLE 10 Cooperation questionnaire results.

| Dimension | Control | | Experimental | |
|---|---|---|---|---|
| | Mean | Std dev. | Mean | Std dev. |
| 1. Social skills | 3,16 | 0,88 | 4,4 | 0,65 |
| 2. Group processing | 3,24 | 1,02 | 4,4 | 0,66 |
| 3. Positive interdependence | 3,25 | 1,07 | 4,5 | 0,64 |
| 4. Promotional interaction | 2,98 | 0,98 | 4,4 | 0,62 |
| 5. Social responsibility | 3,2 | 1 | 4,51 | 0,62 |

TABLE 11 Mann–Whitney *U* test results.

| Dimension | Result |
|---|---|
| 1. Social skills | $U = 15{,}825$, $p < 0.01$ |
| 2. Group processing | $U = 9{,}020$, $p < 0.01$ |
| 3. Positive interdependence | $U = 8{,}650$, $p < 0.01$ |
| 4. Promotional interaction | $U = 14{,}675$, $p < 0.01$ |
| 5. Social responsibility | $U = 6{,}525$, $p < 0.01$ |

TABLE 12 Storytelling records.

| What do you think about this learning experience? | Records | % |
|---|---|---|
| Exciting | 5 | 16% |
| Very creative | 4 | 14% |
| Challenging | 8 | 26% |
| Unforgettable | 9 | 30% |
| Easy and attractive | 4 | 14% |
| Isolated | 0 | 0 |
| TOTAL | 30 | |

According to the results in Table 9, the subgroup of students at risk of exclusion also could overcome all levels of the app along with the challenges. The average number of times these students repeated a challenge, the number of attempts, and the number of fails were similar compared to results for the group as a whole. This result reveals that gamification is a good strategy to support student variability.

### 4.6.2 Cooperation dimension

#### 4.6.2.1 Collaborative learning questionnaire

Table 10 shows the descriptive results for each evaluated dimension of cooperation by both control and experimental group.

Since data does not follow a normal distribution, the non-parametric Mann–Whitney *U* test was used to assess whether there were significant differences between the means of the two groups. Table 11 show the results for each dimension.

Consequently, in all the dimensions analyzed, significant differences were evidenced, with higher levels in the experimental group than in the control group. This allows us to conclude that experimental intervention favors cooperative work.

#### 4.6.2.2 Results of the storytelling

In this section, the analysis of two questions, which guided students in the creation of their storytelling, is detailed. The first question was, what do you think about this learning experience? each student answered this question, and their responses were recorded in their created stories. The content analysis of the students' answers was carried out, categorizing students' responses on a set of categories which are summarized in Table 12.

The answers allow us to conclude that the experience was, above all, unforgettable and challenging for the students but also exciting, creative, easy, and attractive.

All the students expressed positive thoughts about their experiences, and none reported any adverse situations in group work.

Moreover, the students, professor, or researcher reported no instances of isolated students during the experience.

Regarding collaborative work, the students were asked the following question: what would you highlight about cooperative work? This question also allows them to analyze the contribution of the cooperative work. Result can be seen in Table 13.

A high percentage of the students confirmed that they could work successfully with the support of their peers, the group reached the

TABLE 13 Summary of the cooperative work according to storytelling.

| ¿What would you highlight about cooperative work? | YES | NO | LITTLE |
|---|---|---|---|
| Support from teammates? | 27 | 1 | 2 |
| Did the group work to guarantee the achievement of the objectives? | 28 | | 2 |
| Was there isolation from groupmates? | | 30 | |
| Everyone learned | 28 | | 2 |

TABLE 14 Results of the quality questionnaire by experts.

| Ítem | Experts | | | | | Mean |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| 1 | 4 | 5 | 5 | 4 | 5 | 4,6 |
| 2 | 4 | 4 | 5 | 4 | 5 | 4,4 |
| 3 | 4 | 5 | 4 | 4 | 4 | 4,2 |
| 4 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 6 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 7 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 8 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 9 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 10 | 4 | 5 | 4 | 4 | 4 | 4,2 |
| 11 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 12 | 4 | 5 | 4 | 4 | 4 | 4,2 |
| 13 | 4 | 5 | 4 | 4 | 5 | 4,4 |
| 14 | 3 | 3 | 4 | 3 | 3 | 3,2 |
| 15 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 16 | 4 | 5 | 4 | 5 | 5 | 4,6 |
| 17 | 4 | 4 | 4 | 5 | 5 | 4,4 |
| 18 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 19 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 20 | 4 | 5 | 4 | 4 | 4 | 4,2 |
| 21 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 22 | 4 | 4 | 4 | 5 | 5 | 4,4 |

TABLE 15 Results of the teacher's quality questionnaire.

| Ítem | Professors | | | | | Mean |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| 1 | 4 | 4 | 5 | 5 | 5 | 4,6 |
| 2 | 5 | 5 | 4 | 5 | 5 | 4,8 |
| 3 | 4 | 4 | 4 | 3 | 3 | 3,6 |
| 4 | 5 | 5 | 4 | 5 | 5 | 4,8 |
| 5 | 5 | 5 | 4 | 5 | 5 | 4,8 |
| 6 | 4 | 5 | 4 | 5 | 5 | 4,6 |
| 7 | 5 | 4 | 5 | 5 | 5 | 4,8 |
| 8 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 9 | 4 | 5 | 4 | 5 | 5 | 4,6 |
| 10 | 4 | 4 | 3 | 4 | 4 | 3,8 |
| 11 | 5 | 5 | 5 | 5 | 5 | 5,0 |
| 12 | 4 | 4 | 5 | 4 | 4 | 4,2 |
| 13 | 4 | 5 | 5 | 4 | 4 | 4,4 |
| 14 | 4 | 4 | 4 | 4 | 4 | 4,0 |
| 15 | 5 | 4 | 5 | 5 | 5 | 4,8 |
| 16 | 4 | 5 | 5 | 4 | 4 | 4,4 |
| 17 | 4 | 5 | 4 | 4 | 4 | 4,2 |
| 18 | 5 | 5 | 4 | 5 | 5 | 4,8 |
| 19 | 3 | 3 | 3 | 3 | 3 | 3,0 |
| 20 | 4 | 4 | 5 | 4 | 4 | 4,2 |
| 21 | 4 | 5 | 5 | 5 | 5 | 4,8 |
| 22 | 5 | 4 | 4 | 5 | 5 | 4,6 |

TABLE 16 Timer questionnaire results.

| Variable | Average by question | | | | | | |
|---|---|---|---|---|---|---|---|
| Interactivity | Item | 1 | 2 | 3 | 4 | 5 | 6 |
| | Mean | 4,60 | 4,67 | 4,53 | 4,63 | 4,57 | 4,57 |
| Presence | Item | 7 | 8 | 9 | 10 | 11 | 12 |
| | Mean | 4,23 | 4,57 | 4,50 | 4,27 | 4,13 | 3,77 |
| Flow | Item | 13 | 14 | 15 | 16 | 17 | 18 |
| | Mean | 4,87 | 4,20 | 4,27 | 4,00 | 4,30 | 4,43 |

academic objective, and that no one felt isolated from any peer within the cooperative group.

## 4.6.3 Quality dimension

### 4.6.3.1 Results of the quality questionnaire

As mentioned, a group of experts in AR programming, external to this project, applied a quality questionnaire designed by Guimarães and Valeria (2014). The results of the questionnaire allow us to measure usability, efficiency and satisfaction regarding the AR-mBot app using heuristics.

The results shown in Table 14 present the experts' evaluation, with an average score of 4.6. The heuristic related to error prevention received the lowest score; it refers to the fact that if a user selects an incorrect marker, an error message should appear.

For its part, the evaluation by the five teachers of the co-creation team shown in Table 15 reflects an average score of 4.4 over 5, the lowest score corresponds to the help heuristic.

The errors and observations reported by the evaluators were considered to improve the application.

### 4.6.3.2 Results of Tinmer questionnaire

Table 16 shows the quantitative results for the 3 dimensions evaluated through the Tinmer questionnaire.

The values for the mean in the three variables indicate that students positively value the feeling of immersion provided by the AR-mBot app and have a favorable perception of both the design of the proposed interactions and their flow.

## 5 Discussion

Results presented in the previous sections show that the CooperAR methodology encourages teamwork through co-creation, guiding the actors in the development of tasks for the design of augmented didactic strategy that address the variability of needs and educational preferences of the students.

For validation purposes, the development of a mobile application has been presented, created following the guidelines and principles of the CooperAR methodology, where different actors such as teachers, professionals, and students contributed their experience by co-creating a tool that successfully addresses diversity in the classroom, and meets the educational needs identified in the context.

The quantitative results of the inclusion dimension reveal that the adoption of the UDL contributed to the success of the educational purpose in terms of inclusion, offering greater possibilities for the presentation of information, action, expression and participation for the student. The design of the educational experiences by the co-creation groups promoted the contribution of the different actors in the process, enriching the educational experience.

Likewise, the quantitative data showed that gamification supported the motivation and interest of the students, becoming an excellent didactic strategy for addressing diversity. It generated less marginalization and greater participation, thus supporting both the social and individual aspects of the students. The results successfully demonstrate that augmented reality, combined with methods such as gamification, acts as a catalyst for educational inclusion, ensuring the achievement of positive outcomes for all students.

Moreover, the adequate planning of cooperative work by the teacher, supported by augmented reality showed better results in the experimental group compared to the control group. These findings indicate that AR generates a positive impact, fostering interest in participating and engaging with educational activities. This eliminates barriers between students and the learning strategy; all students are drawn to the use of AR regardless of their diverse needs, and they feel supported by their peers to overcoming academic challenges.

The high quality of the products generated under the CooperAR methodology is reflected not only in the academic results of the students, but also through evaluations conducted by experts and teachers. This supports the conclusion that the CooperAR methodological process is effective for generating relevant artifacts to be used in educational settings, facilitating the involvement of key stakeholders in the learning process.

Finally, the documentation of CooperAR permits its replicability in diverse contexts. We anticipate that the broader implementation of this technology could have significant implications in terms of accessibility, active student engagement, and overall improvements in educational outcomes within the educational context. However, it is necessary to address implementation challenges such as device availability and adequate teacher training to ensure an effective and successful implementation of augmented reality as a catalyst for more inclusive education.

Threats to Internal Validity and Their Mitigation:

1 Selection bias: The lack of full randomization (due to the predefined administrative grouping) could introduce undetected differences. To address this, covariates were included in an ANCOVA model, adjusting post-intervention outcomes for baseline variables.
2 Effect of heterogeneous grouping vs. self-selection: The formation of heterogeneous subgroups (experimental group) compared to self-selected teams (control group) might interact with preexisting group dynamics (e.g., social affinities). This was monitored through observational records of interactions during activities, with no disruptive patterns identified.
3 Differential maturation: A mid-intervention test was administered to both groups to rule out that final differences stemmed from unequal learning rates unrelated to the intervention.

Acknowledged limitation: While statistical equivalence was confirmed for measured variables, the risk of unobserved confounders (e.g., learning styles not assessed in the diagnostic) remains. This is noted as a study limitation, and future research is suggested to adopt full randomization or a quasi-experimental design with propensity score matching.

## 6 Conclusion

Emerging technologies have revealed new educational scenarios that provide diverse learning opportunities to students; one of these technologies is augmented reality (AR). However, teachers often find designing and developing AR applications to be complex, and sometimes unattainable due to methodological and technical barriers.

This article introduces the CooperAR methodology as a strategy aimed at facilitating the generation of educational scenarios that address diversity. It leverages three relevant conceptual frameworks: CL, UDL, and co-creation, considering the real possibilities within schools and, the benefits of AR to enhance inclusion.

The CooperAR methodology has been validated in a school in Southern Colombia, through a quantitative approach design with descriptive scope, which included the co-creation of an educational scenario by professors, experts and students. This scenario involved developing a mobile application to facilitate the teaching of educational robotics, promoting the acquisition of computational thinking skills among students.

The evaluation of the CooperAR methodology focused on three dimensions: inclusion, cooperation, and quality.

The results indicate CooperAR effectively promotes inclusion by stimulating the participation among all students, including those with academic challenges or other individual educational needs. Additionally, CooperAR enhances cooperation, contributing to the successful completion of all activities and challenges by all students, and enables diverse teams to produce high-quality educational artifacts.

Furthermore, gamification has proven to be an excellent inclusive didactic strategy. It supports compliance with UDL guidelines by incorporating various forms of representation, action and student engagement through the designed dynamics, mechanics, and aesthetics. The analysis of the gamification metrics confirmed that all students met the academic objectives related to the proposed topics.

These findings are particularly significant considering the study was conducted during the Covid-19 pandemic, a time characterized by widespread demotivation and reduced participation in the learning process. The high levels of engagement and compliance with the proposed activities underscore the effectiveness of the CooperAR methodology in fostering a productive learning environment.

In conclusion, the findings suggest that the CooperAR methodology is an efficient and innovative approach to promoting educational inclusion through the use of Augmented Reality (AR). Its implementation should be encouraged within educational settings to enhance the learning experiences of all students.

## 6.1 Limitations of this study

The findings of this study are contextualized within a specific area of knowledge and a particular sample with unique conditions regarding the use of technologies. This specificity may limit the generalizability of the results. Future research should aim to expand the evaluation of the CooperAR methodology to other communities that possess different characteristics and conditions to enhance the robustness of the findings.

It is acknowledged that the role of the teacher-researcher as the sole implementer of the intervention may represent a potential source of bias, both in the delivery of activities and in the interpretation of the results. To mitigate this risk, a structured instructional plan with standardized instruments was employed, and all phases of the process were carefully documented. This approach supports the replicability of the study in similar educational contexts.

Additionally, the potential novelty effect associated with the use of emerging technologies such as augmented reality and programmable robots is considered. This effect may lead to a temporary increase in motivation or performance due solely to the introduction of a new and engaging tool. While this does not invalidate the findings, it does limit their generalizability over time. Therefore, follow-up evaluations or longitudinal studies are recommended to assess the sustainability of the observed impact once the use of the technology becomes normalized in the educational environment.

# Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

# Author contributions

JQ: Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JC: Investigation, Resources, Writing – review & editing. SB: Writing – review & editing, Formal analysis, Methodology, Supervision.

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# Conflict of interest

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

# Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

# Publisher's note



# References

Alvarez-Icaza, I., and Huerta, O. (2024). Augmented intelligence for open education: bridging the digital gap with inclusive design methods. *Front. Educ.* 9, 1–6. doi: 10.3389/feduc.2024.1337932

Arkkelin, D.. (2014). Using SPSS to understand research and data analysis. En psychology curricular materials 2014 Valparaiso. Available online at: http://scholar.valpo.edu/psych_oerhttp://scholar.valpo.edu/psych_oer/1%0Ahttp://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.139.2050&rep=rep1&type=pdf (Accessed November 20, 2023).

Asnawi, A., Sahudra, T. M., Ramadhani, D., Kenedi, A. K., Aosi, G., Wardhana, M. R., et al. (2023). Development of Digital Diagnostic Test Instruments for Differentiated Learning Process in Elementary Schools. *J. Penelit. Pendidikan IPA* 9, 460–466. doi: 10.29303/jppipa.v9ispecialissue.6125

Azorín, C. M., Ainscow, M., Arnaiz, P., and Goldrick, S. (2019). A tool for teacher reflection on the response to diversity in schools. *PRO* 23, 11–36. doi: 10.30827/profesorado.v23i1.9142

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., and Kinshuk (2014). Augmented reality trends in education: a systematic review of research and applications. *Educ. Technol. Soc.* 17, 133–149.

Bacca, J., Baldiris, S., Fabregat, R., and Kinshuk (2018). Insights into the factors influencing student motivation in Augmented Reality learning experiences in Vocational Education and Training. *Front. Psychol.* 9, 1–13. doi: 10.3389/fpsyg.2018.01486

Bertucci, A., Johnson, D., Johnson, R., and Conte, S. (2012). Influence of Group Processing on Achievement and Perception of Social and Academic Support in Elementary Inexperienced Cooperative Learning Groups. *J. Educ. Res.* 105, 329–335. doi: 10.1080/00220671.2011.627396

CAST. (2011). Universal design for learning guidelines. CAST. Available online at: https://udlguidelines.cast.org/ (Accessed November 17, 2023).

Castells, M. (2016). El impacto de las tic en la educación. En Josep M. Mominó y Carles Sigalés (Ed.), Editorial UOC (Primera ed). Universitat Oberta of Catalunya

Fernandez, J., Cecchini, J., Méndez, A., Méndez, D., and Prieto, J. (2017). Diseño y validación de un cuestionario de medición del aprendizaje cooperativo en contextos educativos. *Anal. Psicol.* 33, 680–688. doi: 10.6018/analesps.33.3.251321

Fernández-Batanero, J. M., Montenegro-Rueda, M., and Fernández-Cerero, J. (2022). Use of Augmented Reality for Students with Educational Needs: A Systematic Review (2016–2021). *Societies* 12:36. doi: 10.3390/soc12020036

Fetaji, B., Fetaji, M., Asilkan, O., and Ebibi, M. (2023). Examining the Role of Virtual Reality, Augmented Reality, and Artificial Intelligence in Adapting STEM Education for Next-Generation Inclusion. *Int. J. Emerg. Knowledge Stud.* 2, 876–883. doi: 10.70333/ijeks-02-12-025

Franco Lalama, M. M. (2023). Attention to Diversity with Love and Respect. Inclusive, Equitable and Quality Education At Io. *TECHNO review* 15, 13–20. doi: 10.37467/revtechno.v15.5033

Frasnyaigu, R., Mulyahati, B., and Aprilia, R. (2023). Design of augmented reality (ar) learning media in ecosystem meteri in elementary school inclusion classroom. *J. Penelit. Pendidikan IPA* 9, 8539–8545. doi: 10.29303/jppipa.v9i10.5298

Gall, M., Gall, J., and Bord, W. (2003). Educational Research: An Introduction (8.a ed.).

Garzón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educ. Res. Rev.* 31:100334. doi: 10.1016/j.edurev.2020.100334Kinshuk, Baldiris, S., Gutiérrez, J., & Pavón, J

Gilabert-cerdá, A., Lledó, G. L., Lorenzo-lledó, A., Carreres, A. L., and Pérez-vázquez, E. (2023). Augmented Reality Promotes Social Responses in Autism Spectrum Disorder Subjects. *Educ. New Develop.* 2, 424–428. doi: 10.36315/2023v2end096

Guimarães, M., and Valeria, F. (2014). A checklist to evaluate augmented reality applications. Proceedings −2014 16th Symposium on Virtual and Augmented Reality, SVR 2014, 45–52

Hafiza, A., and Halimah, B. Z. (2010). Digital storytelling design with Augmented Reality technology for remedial students in learning Bahasa Melayu. *Global Learn Asia Pacific* 2010, 3558–3563. http://www.editlib.org/p/34436

Helmefalk, M. (2019). An interdisciplinary perspective on gamification: Mechanics, psychological mediators and outcomes. *Int. J. Serious Games* 6, 3–26. doi: 10.17083/ijsg.v6i1.262

Hernández, R., Fernández, C., and Baptista, P. (2010). Metodología de la investigación (Interamericana Editores S.A. (ed.); Primera Ed). Available online at: https://www.uv.mx/personal/cbustamante/files/2011/06/Metodologia-de-la-InvestigaciÃ³n_Sampieri.pdf (Accessed October 15, 2023).

Hernández-Sampieri, R., Fernández, C., and Baptista, M.del. (2018). Metodología de la investigación (S. A. D. C. McGRAW-HILL/INTERAMERICANA EDITORES)

Hunicke, R., Leblanc, M., and Zubek, R. (2004). MDA: A formal approach to game design and game research. AAAI Workshop-Technical Report, WS-04-04, 1–5.

Jindal, P., Park, A. J., and Hwang, E. (2023). "Augmented Reality Campus Exploration Application Incorporating Equity, Diversity, and Inclusion" in 2023 15th International Conference on Computer and Automation Engineering (ICCAE), 81–86.

Junior, R., and Silva, F. (2021). Redefining the mda framework—the pursuit of a game design ontology. *Information (Switzerland)* 12, 1–19. doi: 10.3390/info12100395

Kusuma, G. P., Wigati, E. K., Utomo, Y., and Putera Suryapranata, L. K. (2018). Analysis of gamification models in education using MDA framework. *Procedia Comput. Sci.* 135, 385–392. doi: 10.1016/j.procs.2018.08.187

Meyer, A., Rose, D., and Gordon, D. (2014). Universal Design for Learning: Theory and practice (Edición pr, Vol. 91). Available online at: http://castpublishing.org/books-media/udl-theory-and-practice/ (Accessed October 12, 2023).

Mkwizu, K., and Bordoloi, R. (2022). Augmented reality and education for girls: an inclusive approach. En Proceedings of the tenth pan-commonwealth forum on open learning, 14–16

Murniarti, E., Prayitno, H., Wibowo, G. A., Suparmi, and Rochmah, E. Y. (2023). Implementing augmented reality in inclusive education: experiments and potential. *Int. J. Sci. Soc.* 5, 60–72. doi: 10.54783/ijsoc.v5i4.765

Navaitienė, J., and Stasiūnaitienė, E. (2021). Improving inclusive learning and educational equity (Educationa)

Pastor, C. A. (2012). Aportaciones del Diseño Universal para el Aprendizaje y de los materiales digitales en el logro de una enseñanza accesible. *Strength Materials* 11, 658–662. doi: 10.1007/BF00770118

Paul, A., and Kundu, D. (2021). Collaborative learning. *Int. J. English Learn. Teach. Skills* 3, 2567–2576. doi: 10.15864/Ijelts.3408

Pujolàs Maset, P., Lago, J., and Naranjo, M. (2013). Aprendizaje cooperativo y apoyo a la mejora de las prácticas inclusivas. *Revista Educ. Educ.* 11, 207–218.

Quintero, J., Baldiris, S., Cerón, J., Garzón, J., Burgos, D., and Vélez, G. (2021). CooperAR: promoting educational inclusion through augmented reality. *Int. Conf. Advanc. Learn. Technol.* 3, 311–313. doi: 10.1109/ICALT52272.2021.00100

Quintero, J., Baldiris, S., Rubira, R., Cerón, J., and Velez, G. (2019). Augmented reality in educational inclusion. a systematic review on the last decade. *Front. Psychol.* 10, 1–14. doi: 10.3389/fpsyg.2019.01835

Ramos, C. A. (2015). Los paradigmas de la investigación científica. *Avances Psicol.* 23, 9–17. doi: 10.33539/avpsicol.2015.v23n1.167

Ratten, V. (2020). Coronavirus (Covid-19) and the entrepreneurship education community. *J. Enterpris. Commun.* 14, 753–764. doi: 10.1108/JEC-06-2020-0121

Ribeiro, Pedro, Nele, Wild, and Christian, R. (2024). Digital augmentation in special needs reading: enhancing inclusiveness: exploring a digitally augmented reading system in special needs education. IDC '24: Proceedings of the 23rd Annual ACM.

Rivera Alvarado, L. A., Lopez Dominguez, E., Hernandez Velazquez, Y., Dominguez Isidro, S., and Excelente Toledo, C. B. (2018). Layered software architecture for the development of mobile learning objects with augmented reality. *IEEE Access* 6, 57897–57909. doi: 10.1109/ACCESS.2018.2873976

Roschelle, J., and Penuel, W. (2006). Co-design of innovations with teachers: Definition and dynamics. *Comput. Sci.*, 606–612.

Ross, S., and Morrison, G. (2003). Experimental research methods. En Research on educational communications (Número January 2003). *Edn: 2nd*. AECT.

Sandoval, F., and Badilla, M. G. (2021). Measuring stimulation and cognitive reactions in middle schoolers after using immersive technology: Design and validation of the TINMER questionnaire. *Comput. Educ.* 166:104157. doi: 10.1016/j.compedu.2021.104157

Sarosa, M., Chalim, A., Suhari, S., Sari, Z., and Hakim, H. B. (2019). Developing augmented reality based application for character education using unity with Vuforia SDK. Annual Conference of. *Sci. Technol.* 1375:012035. doi: 10.1088/1742-6596/1375/1/012035

Satpathy, Ipseeta, Patnaik, B. C. M., Baral, S. K., and Islam, M. (2023). Inclusive education through augmented reality (AR) and virtual reality (VR) in India. En B. Richa Goel, Sukanta Kumar Baral, Tapas Mishra and Vishal Jain (Ed.), Augmented and virtual reality in industry 5.0 147–162

Serna Gómez, J. H., Díaz-Piraquive, F. N., de Muriel-Perea, Y. J., and Díaz Peláez, A. (2021). Advances, Opportunities, and Challenges in the Digital Transformation of HEIs in Latin America. En D. Burgos and J. Branch (Eds.), Radical Solutions for Digital Transformation in Latin American Universities (pp. 55–75). Springer, Singapore

Spooner, F., Baker, J. N., Harris, A. A., Ahlgrim-Delzell, L., and Browder, D. M. (2007). Effects of Training in Universal Design for Learning on Lesson Plan Development. *Remedial Spec. Educ.* 28, 108–116. doi: 10.1177/07419325070280020101

Terzieva, V. T., Ilchev, S., Ivanova, T., Todorova, K., and Savov, T. (2023). Technologies for Intelligent and Inclusive Education. En Scopus (Ed.), Advances in educational technologies and instructional design book series, 208–238.

Toro, P. L. (2013). Cuando se vive el desarraigo. Educación y desplazamiento forzado: una mirada desde el Distrito de Aguablanca, Cali. *Revista Científica Guillermo de Ockham* 11, 35–51. doi: 10.21500/22563202.608

Treviranus, J., and Roberts, V. (2008). Meeting the Learning Needs of all Learners Through IT. *Int. Handbook Inform. Technol. Primary Secondary Educ.* 20, 789–801. doi: 10.1007/978-0-387-73315-9_46

Velázquez, F., and Morales, G. (2018). Augmented Reality and Mobile Devices: A Binominal Methodological Resource for Inclusive Education (SDG4). *Example Secondary Educ. Sustain.* 10, 1–14. doi: 10.3390/su10103446