Towards a Methodology for the Development of Educational Resources Based on Augmented Reality Technology

Hacia una Metodología de Desarrollo de Recursos Educativos Basada en Tecnología de Realidad Aumentada

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Abstract

Introduction: The teaching development of computerized educational resources and materials is an increasingly common task; However, when these materials require the use of disruptive technologies such as Augmented Reality, the process is complicated, especially when there is no training in the programming area.

Objective: This study aims to generate and make available to teachers, a methodological alternative for the development of computerized educational materials based on Augmented Reality technology.

Method: For the study, a research and development methodology was used through a systematic literature review, for the identification of areas of opportunity around processes for the elaboration of educational materials, then a first methodological proposal was made using verification processes to through the development of two didactic materials, and validation through the expert judgment technique of the Software Engineering area to provide feedback on the methodological proposal built.

Results: The research work generated a methodological framework, which aims to support teachers in the generation of Educational Materials based on Augmented Reality, through a simple and intuitive procedure, without the need to have programming knowledge or, failing that, work with a professional software developer prior to the implementation of high levels of interaction.

Conclusions: According to the empirical verification and evaluation processes, it is possible to affirm that the phases adequately combine the technological and pedagogical aspects for the Development of Educational Materials based on Augmented Reality, regardless of the learning domain. As future work, the authors consider that it is necessary to work on the development of a high-level platform that considers the steps proposed in the implementation phase to provide a tool that assists teachers in the development of the Computerized Educational Materials based on Augmented Reality.

Keywords: Augmented Reality, Educational Resources, Educational Software.

Resumen

Introducción: El desarrollo docente de recursos y materiales educativos informatizados es una tarea cada vez más común; no obstante, cuando estos materiales requieren el uso de tecnologías disruptivas como la Realidad Aumentada, el proceso se complica, sobre todo cuando no se tiene formación en el área de programación.

Objetivo: Este estudio tiene como objetivo generar y poner a disposición de los docentes, una alternativa metodológica para el desarrollo de materiales educativos computarizados basados en la tecnología de Realidad Aumentada.

Metodología: Para el estudio se utilizó una metodología de investigación y desarrollo a través de una revisión sistemática de literatura, para la identificación de áreas de oportunidad en torno a procesos para la elaboración de materiales educativos, luego se realizó una primera propuesta metodológica utilizando procesos de verificación a través del desarrollo de dos materiales didácticos, y la validación mediante la técnica de juicio de expertos del área de Ingeniería del Software para retroalimentar la propuesta metodológica construida.

Resultados: El trabajo de investigación generó un marco metodológico, el cual tiene como objetivo apoyar a los docentes en la generación de Materiales Educativos basados en Realidad Aumentada, mediante un procedimiento sencillo e intuitivo, sin necesidad de poseer conocimientos de programación o en su defecto, trabajar con un desarrollador de software profesional antes de la implementación de los altos niveles de interacción.

Conclusiones: De acuerdo con los procesos de verificación y evaluación empírica, es posible afirmar que las fases combinan adecuadamente los aspectos tecnológicos y pedagógicos para el Desarrollo de Materiales Educativos basados en Realidad Aumentada, independientemente del dominio del aprendizaje. Como trabajos futuros, los autores consideran que es necesario trabajar en el desarrollo de una plataforma de alto nivel que considere los pasos propuestos en la fase de implementación para brindar una herramienta que asista a docentes en el desarrollo de Materiales Educativos Computarizados basados en Realidad Aumentada.

Palabras clave: Realidad Aumentada, Recursos Educativos, Software Educativo.

I. INTRODUCTION

Educational Informatics is a discipline whose purpose is the research and innovation in the information and communication technologies to assist the educational process with the intention to generate positive effects on the students' learning. The educational process formally implemented has been constantly assisted by educational resources and materials of diverse nature. In the last two decades of the last century, it has also been mediated by technological resources that enhance student learning. One of technological elements has been software, particularly the one developed for educational purposes. In this sense, in [1] the author proposed a set of taxonomies on Educational Software, among them, the instructional design (functional, physical and logical designs), the treatment of errors (tutorial, non-tutorial), the internal structure of its engine (linear, branched, flexible) and the one based on the technology that supports it (according to the type of interface, the use of Artificial Intelligence techniques, the support for collaborative work or to the use of Virtual Reality).

In the last two decades, one of the lines of research that has gained momentum in the field of Educational Informatics revolves around the use of Augmented Reality (AR), a technology with a disruptive element to promote learning. AR is an emerging technology that allows users to interact with virtual objects in a real environment [2]. Unlike Virtual Reality (VR) technology in which the user experiences immersion in the virtual environment generated by a software system and interacts with it through peripheral devices, AR extends the individual's interaction capabilities by creating a connection between the real world and digital objects generated with a software system superimposed with objects from the real world or composed with it [3].

With the purpose of identifying areas of opportunity for research, a systematic review of the literature was carried out on primary works in which the use of Augmented Reality technology in educational intervention proposals is reported; one of the main findings regarding the technological aspect, was the fact that only 7% cite the use of some development methodology, as a reference for the software used. In fact, being formal, only one of the three primary studies that identify a methodology corresponds to a recognized one in the field of Software Engineering [4].

This article describes the result of a research project, in which the objective was to generate a Methodological Proposal for the Development of Computerized Educational Materials based on Augmented Reality Technology, which could be used by teachers —without specialized knowledge. in programming—to develop educational materials that would allow them to innovate with their students. The methodology was evaluated by a group of academic experts in the context of Software Engineering.

II. RELATED WORK

In Software Engineering, the methods provide an organized and systematic approach, contributing for the software development process to be a repeatable and success-oriented activity. However, the scope of existing methods varies widely from addressing a single phase of the life cycle to covering the entire software cycle [5]. The various methods proposed by Software Engineering throughout its history have been classified into heuristic methods, formal methods, prototyping methods, and agile methods.

To analyze the way in which the development of a methodological proposal linked to innovative technologies for the development of educational resources is approached, a set of previous works were reviewed, the next four are considered the most significant.

- *Meduc_AR:* an iterative methodology proposed by Cáceres & Tolaba in [6] to develop applications with AR in education, given the observation of the non-existence of a methodology specifically designed for it. The proposal encourages teamwork between developers and the educational establishment. It consists of three phases: (1) Analysis of the problem, (2) Choice of the solution and (3) Evaluation of the application.
- *VGSCL:* a methodology to integrate in the classroom the effective use of educational video games supported by collaborative learning techniques, to used them jointly by teachers and designers of digital games. Likewise, it allows designing the game challenges that correspond to each aspect of the educational content so that, in this way, the teacher

is informed of the student's process in the game and how their performance could influence their educational process [7].

- *MCOV-RA:* a Methodology for the Construction of Virtual Learning Objects based on AR is a mixed approach formed by the AODDEI (Analysis, Obtaining, Design, Development, Evaluation, Implementation) methodology and the Software Engineering based on components (ISBS). The latter complements of the AODDEI make it more versatile, since it allows the use of components for the implementation of AR already developed, which can be reused and applied to meet the proposed objectives in a shorter period [8].
- *GeoPGD:* is a methodology proposed by Arango in [9] for the development of Georeferenced Pervasive Games; it is an adaptation to the pre-production, production, and post-production processes for the generation of digital content. In the pre-production the direct relationship with the conception of the game is considered. Subsequently, in production, the multidisciplinary work is combined and those in charge of game design, carrying out tests at different levels to guarantee quality. Finally, in the post-production, there is room for monitoring, maintenance, and generation of new functionalities to keep people's interest in the game.

The previous proposals with the analysis of some of the traditional methodologies based on the programming paradigms, structured [10], object-oriented [11] and agile [12], established the bases for the development of the methodological proposal next described.

III. METHODOLOGY

The work here reported is the result of a research and development study [13] whose tasks were the following:

(1) Systematic Review of the Literature (SRL). The purpose of this task was to identify, evaluate, and interpret the available research —primary studies— to answer a set of specific research questions about the use of Augmented Reality technology in educational proposals. The findings regarding technological aspects were in reported (Sosa, Aguilar, López & Gómez, 2021).

(2) Design of a Methodological Proposal for the Development of Educational Materials. The second task had the purpose, based on the analysis of previous works as well as on the detected needs in the SRL, of the design of a Methodological proposal for the Development of Computerized Educational Materials based on Augmented Reality Technology. The proposal reported and socialized in specialized events [4].

(3) Empirical verification. For the evaluation of the usability of the methodological proposal a couple of computerized educational resources were implemented using the AR platform "Spark AR Studio". A platform where companies and/or people can create, publish and share AR effects and connect with other developers and creators.

(4) Empirical validation. This task had also the purpose of evaluating the methodological proposal but through the expert judgment technique, in this case experts in academics and around Software Engineering. Through this evaluation, it was obtained feedback on aspects considered as well as some not initially considered, both were incorporated as part of the development methodology.

(5) Methodology for the Development of Computerized Educational Materials. Based on the evaluation processes (verification and validation) of the methodological proposal, this purpose of the last task is to describe the final version of the Methodology for the Development of Computerized Educational Materials based on Augmented Reality (CEM-AR) Technology, which could be used for the development of educational resources, by teachers, in the elaboration of didactic resources for the improvement of the educational process.

IV. EMPIRICAL VERIFICATION

With the purpose of evaluating the use of the methodological proposal to assist the development of Computerized Educational Materials based on AR technology, we proceeded to implement two educational materials for teaching in Secondary Education, in two different domains of knowledge: Biology and Mathematics.

A. Case I: The Nervous System

In this first case, the fulfillment of the tasks in each of the four phases of the methodological proposal is presented in detail. It is oriented to the subject of the brain in the subject of Biology 1. The artifacts generated for the development of the Computerized Educational Material of Case I (e.g., specification of requirements, instructional script, instrument for the evaluation of the resource, and a descriptive video of the use of the resource) are available at:

https://drive.google.com/drive/folders/1eZVA3gzydOQ86-aBscd8hPxOW6vmgl1Z?usp=sharing

Initialization phase:
For first task, the following student characteristics were considered:
(1). Academic level: Secondary
(2). Age: 12 – 14 years
(3). Type of population: Urban
(4). Institution Type: Public

The second task is aimed at mastering the subject, the subject matter is natural sciences, particularly in the subject of Biology. The third task is oriented to the selection criteria of activities, material used in the development stage of the didactic sequence considering the practice activity, because the student can identify the knowledge previously presented in an adequate manner. Finally, in the fourth task, the functionality of the Educational Material was specified, in accordance with what was agreed with the teacher.

Design phase of the learning scenario

The task oriented to the pedagogical design of the Educational material is divided into two subtasks. In the first subtask, the proposed instructional script was used to describe the learning dynamics, and in the second subtask, the type of digital resources necessary for the dynamics. The second task that deals with the technological design, was analyzed and the level of interaction was selected as level 2 (manipulable) appropriate due to the provisions of the third task of the initialization phase. Finally, for the selection of the recognition method, the decision was a static marker in which the student could use the resource for their practice, in both at home and in the classroom.

Implementation Phase

For the implementation phase, the Spark AR Studio platform was selected, because in this platform the AR effects can be created with or without programming knowledge, according to the level of experience of the creator. The platform allows users to import 3D objects, audio files, hi-fi models, and script packages from an AR assets library and a library of free Facebook assets. As for the features that we can be found on the platform, they include: the ability to interact with AR, animate static objects, create textures and materials, and generate effects with understandable and realistic logic. On the other hand, in the tracking function, it can be detected a chosen target, body or hand, with high-fidelity facial tracking; and for specific locations, default experiences can be created.

With the purpose of supporting the creation of educational material three videos were produced: (1) Installation tutorial and use of the basic characteristics of the tool, (2) Tutorial for the creation of educational material at level 1 of interaction, and (3) Tutorial for the improvement of an educational material when going from level 1 to level 2 of interaction. The videos are available at:

https://drive.google.com/drive/folders/1NVXTbjclW9JpSw2uZyzf2JXXlMd1mQFj?usp=sharing

With Spark AR's semantic scene analysis, the AR can become contextually aware, which means the effects will be visually appropriate for the scene. For the second task of the implementation phase, the use of freely distributed software tools for the construction of digital resources was considered. Table 1 lists the tools used to generate the set of required digital resources.

TABLE I

TOOLS FOR THE CREATION OF RESOURCES OF CASE I.

Digital Resource	Support Software
Text	Spark AR
Audio	Mobile Recorder
3D Object	Sketch Fab
Animation	Spark AR

Evaluation phase

In this phase, an expert judgment made the evaluation of the CEM-AR. Subsequently, the selection of the criteria for the evaluation were established in the evaluation guide.

B. Case II: The volume of the Prisms

For the second case, the tasks in each of the phases of the methodology are presented in the same way. In this case, the theme of the volume of the prisms in the subject of Mathematics 1 was selected. The artifacts generated for the development of the Computerized Educational Material of Case II (e.g., requirements specification, instructional script, instrument for the evaluation of the resource, and descriptive video of the use of the resource) are available at:

https://drive.google.com/drive/folders/14ZqH3gekz0mvA9b72l7tIpAFEUgomS5W?usp=sharing

Initialization phase:

For the first task, the following student characteristics were considered:

(1). Academic level: Secondary

(2). Age: 12 – 14 years

(3). Type of population: Urban

(4). Institution Type: Public

Regarding the subject mastery task, the topic addressed is in the area of formal sciences, particularly in the subject of Mathematics 1 at the secondary level.

For the third task, the activity selection criteria, the practice activity considered was as a didactic activity, because the student can identify the knowledge previously presented by the teacher. In addition, this activity will be implemented in the development stage within the didactic sequence. Finally, during the fourth task, the functionality of the Educational Resource was specified in accordance with what was agreed with the teacher.

Design phase of the learning scenario

In the first task that corresponds to the pedagogical design of the CEM-AR, the instructional script was filled out describing the dynamics of learning based on the requirements previously established in the first phase. The second task was oriented to the technological design. The selection of the level of interaction was level 2 (manipulable), it was considered due to the provisions of the third task of the initialization phase. Finally, in the selection of the recognition method, the decision was a static marker for the student to be uses both at home and in the classroom for practice.

Regarding the selection of the level of interaction and the recognition method for the CEM-AR. In the first, a level 1 (basic) interaction was defined because the student visualizes the 3D object with explanations about the prism process by the teacher. In the second, the marker less method was considered because the student can move with the device to observe the dimensions of the prism.

Implementation phase:

As in the first case, the platform selection task for the CEM-AR was developed on the Spark AR platform. In the second task, the use of software tools for the construction of digital resources was considered. Table 2 defines these tools.

Evaluation phase:

In this phase, an expert judgment was used for the evaluation of the CEM-AR. Subsequently, the selection of the criteria that allow evaluating the CEM-AR, which are established in the evaluation guide, continued.

TABLE II

TOOLS FOR THE CREATION OF RESOURCES OF CASE II.

Digital Resource	Support Software
Text	Spark AR
3D Object	Sketch Fab

V. EMPIRICAL VALIDATION

Considering the lessons learned in the verification process, as well as the recommendations collected from a research seminar (organized by the Medellín University), adjustments were made to the methodological proposal and a validation of the methodology was carried out using the judgment technique of experts; this strategy consists of requesting a series of specialist in a particular area for a trial or their opinion regarding a specific aspects [14]. For the procedure, individual aggregation was chosen, which consist in obtaining feedback individually, without the experts being in contact.

The Software Engineering experts who participated in the evaluation process belong to various Educational Institutions of Higher Education, both national and foreign (see Table 3). The comments and recommendations made possible to adjust the methodology, in particular, the way of presenting the phases that it comprises.

TABLE III

NUMBER OF EXPERTS PER EDUCATIONAL INSTITUTION.

UNIVERSITY	#
Autonomous University of Yucatan (Faculty of Mathematics)	3
Autonomous University of Baja California (Mexicali Campus)	1
University of Guadalajara (CUCEI)	1
Higher Technological Institute of Valladolid	1
Mathematics Research Center (Zacatecas Unit)	1
Popular Autonomous University of the State of Puebla.	1
Pontifical Catholic University of Peru (Graduate School)	1
Higher Polytechnic School of Chimborazo (Faculty of Informatics)	2

To identify some of the characteristics of the expertise of the invited researchers, two pieces of information from themselves were recorded; (1) Maximum level of studies and (2) time linked to the area of engineering discipline. Figures 1 and 2 illustrate such characterization.

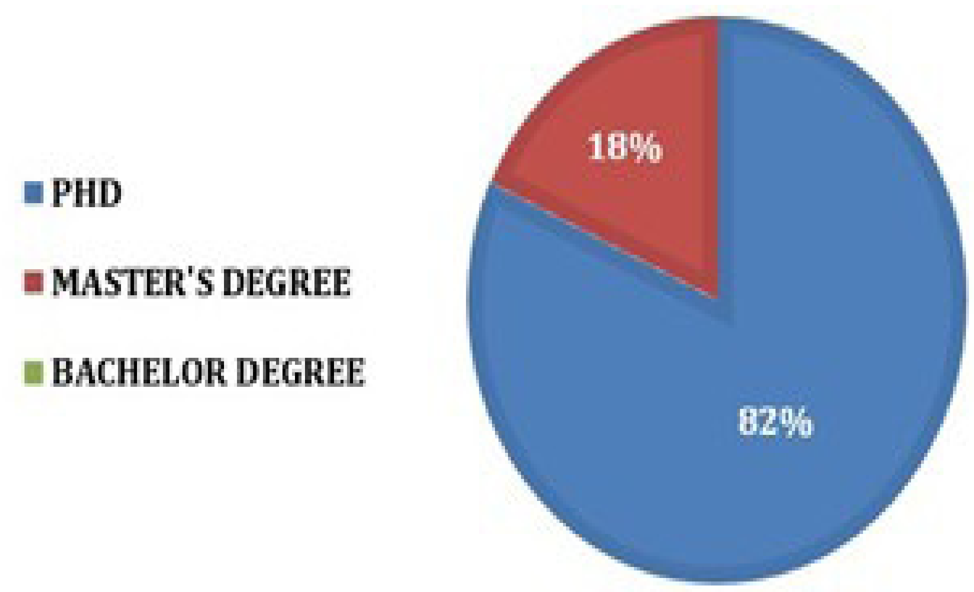

Fig. 1 Level of Studies in SE

Regarding the degree of studies, 9 of the experts have doctoral studies and only two have master studies.

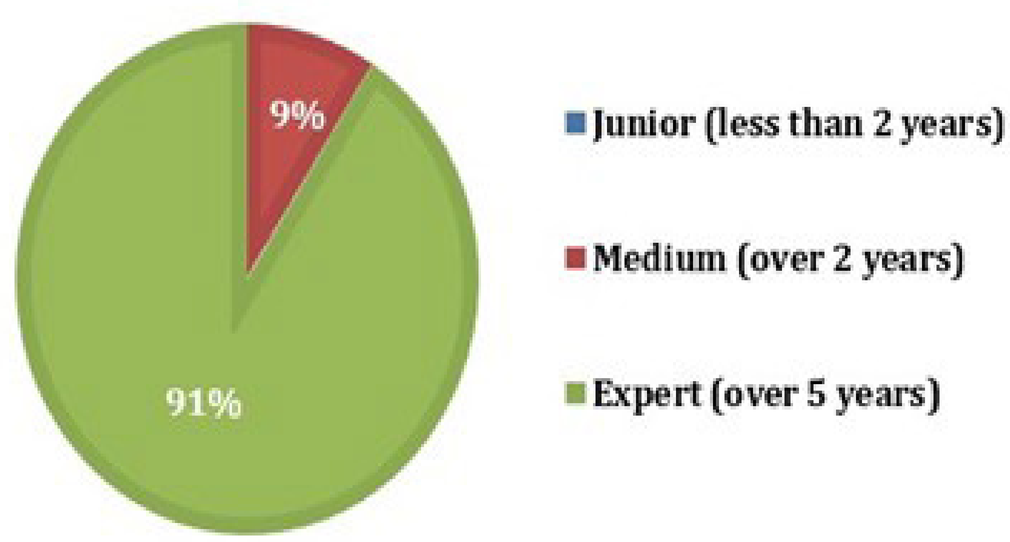

Fig. 2 Expert in the context of SE

Likewise, in relation to the degree of expertise, only one of the respondents has less than five years (but more than two) in the academic area of Software Engineering.

VI. INSTRUMENT FOR VALIDATION

For the evaluation through expert judgment, an instrument was developed to request their opinions related to ambiguity and applicability of the phases considered in the methodological proposal. Table 4 lists the opinions received in % by the experts.

TABLE IV

PERCENTAGE OF THE EXPERTS' OPINIONS

ITEM	Y	N
1. Do you consider the description of the "initialization" phase of the CEM-AR to be ambiguous?	36%	64%
2. Do you consider the description of the "learning scenario design" phase of the CEM-AR to be ambiguous?	18%	82%
3. Do you consider the description of the "implementation" phase of the CEM-AR to be ambiguous?	27%	73%
4. Do you consider the description of the "evaluation" phase of the CEM-AR to be ambiguous?	27%	73%
5. Do you consider the "initialization" phase of the CEM-AR is applicable as specified?	82%	18%
6. Do you consider the "learning scenario design" phase of the CEM-AR to be applicable as specified?	82%	18%

7. Do you consider the "implementation" phase of the CEM-AR is applicable as specified?	89%	11%
8. Do you consider the "evaluation" phase of the CEM-AR is applicable as specified?	91%	9%

The positive opinions received in the case of ambiguity fluctuated between 64% and 82%, and for the aspect of applicability, they fluctuated between 82% and 91%.

A second group of items to collect opinions regarding the completeness of the description of each of the four phases and identified if the considered to require a greater extension, they would propose how to improve such description. The suggestions and/or comments by the experts were considered and evaluated to make modifications to the original proposal. In addition, other research opportunities for future work were noted in the comments of the experts. Among which we can highlight, the design and development of a high-level platform that considers the steps proposed in the implementation phase.

In view of the analysis of the responses and suggestions made by the experts, the following conclusions were reached:

- Most of the experts consider each one of the phases, applicable for the development of the CEM-AR.
- Most of the experts consider the phases as sufficient for the development of CEM-AR.
- Most of the experts would propose the use of this methodology for the development of CEM-AR.
- Most experts offered positive feedback on the methodology.

VII. METHODOLOGY FOR THE DEVELOPMENT OF COMPUTERIZED EDUCATIONAL RESOURCES BASED ON AUGMENTED REALITY TECHNOLOGY

The Methodology for the Development of Computerized Educational Materials Based on Augmented Reality (CEM-AR) consists of four stages that are executed sequentially (as shown in Figure 3), as well as specific elements that must be considered in each one of them for its implementation and correct compliance.

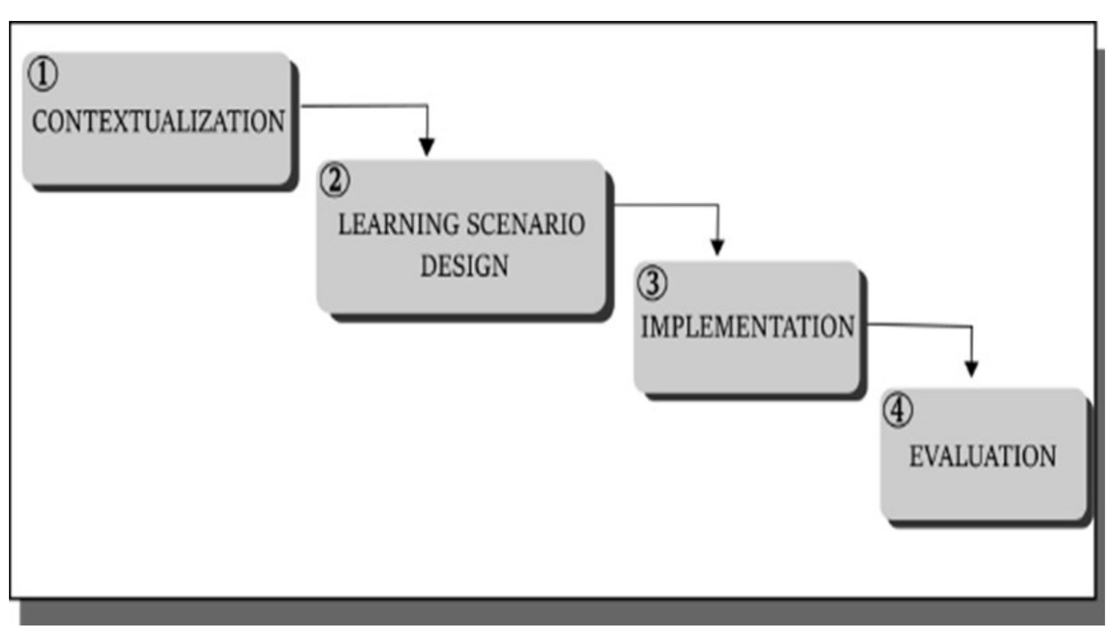

Fig. 3 Phases of the Methodology for the Development of CEM-AR

A. Contextualization Phase

The purpose of this first stage of the methodology is to define the functionalities, characteristics, and restrictions of the CEM-AR to be developed, based on the educational problems observed by the teacher. For this, the phase is integrated by four tasks (see Figure 4).

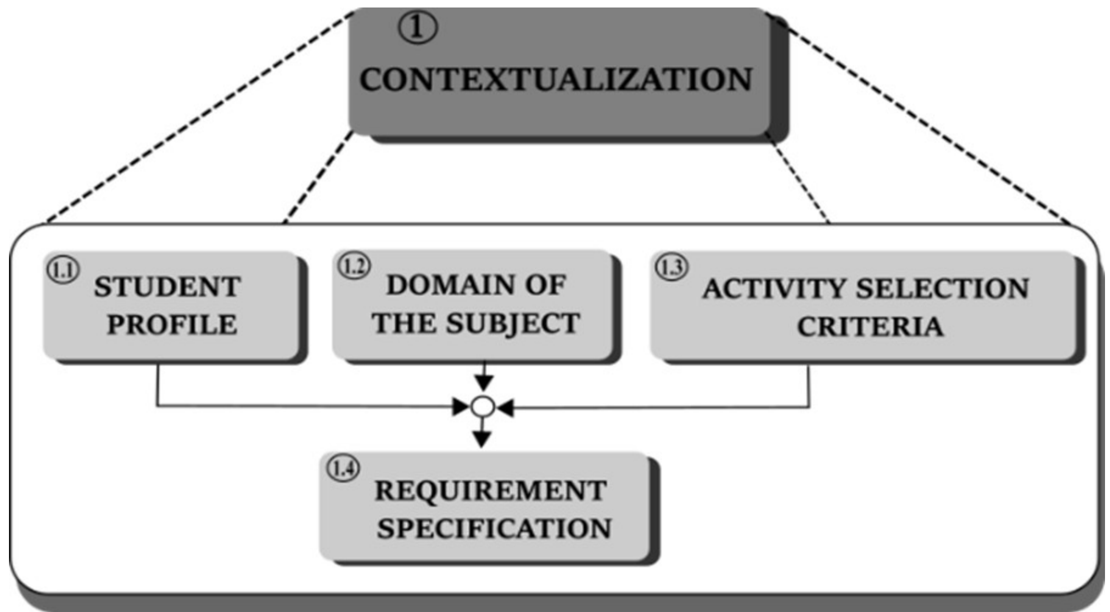

Fig. 4 Tasks for the contextualization phase

The four tasks aim to define:

- *Student profile:* task in which is defined the school level in which the apprentice who will use the CEM-AR is located, and with it the level of the learning complexity to be developed.
- *Mastery of the subject:* task in which the teacher defines the area of science or discipline in which the subject or learning object is located, particularly to identify the dimension of the educational objectives linked to it.
- *Activity selection criteria:* this task defines the type of didactic activity in which the CEM-AR will be used, depending on the stage considered as part of the didactic sequence designed by the teacher.

The activities, according to the moment or stage of the didactic sequence, are the following:

Initiation Stage

- Inductive: activity to attract the attention of the students to lay the foundations for the teaching and learning processes promoted by different activities.
- Diagnostic: to identify the prior knowledge required throughout their school career, as well as social aspects related to the chosen theme.

Development Stage

- Presentation: activity for the presentation of new information to the student; in such a way that it serves as a link between previous and new knowledge, for the generation of significant knowledge.
- Practice: activity or set of activities in which the student is expected to be able to give meaning to the content presented by the teacher. For this, are relevant the cognitive process with the information, as well as its use (put into practice) in some problematic situation. It is desirable that the problematic situation resembles as far as possible a real scenario and not limited to a simple traditional exercise in the school environment.
- Evaluation: activity or set of activities to verify and validate the achievements, difficulties, and deficiencies of students during their learning process. This activity allows to assess the degree to which students have developed their learning on the subject, as well as the difficulties faced during their learning process.
- Feedback: activity that provides the student with feedback regarding their learning achievements. This activity monitors the students' progress, guiding them to continue or to correct the possible difficulties.

Closing Stage

- Integration: through this activity the student manages to re-elaborate the conceptual structure, reorganizing it through interactions generated with the new questions and the information to which he/she had access.

Finally, the fourth task aim to define:

- Specification of requirements: task that defines the functionalities of the CEM-AR based on the three previously performed tasks. The use of the guide is recommended for the preparation of the proposed CEM-AR Specification Document.

B. Design of learning Phase

In this phase is structures the design of the CEM-AR in two tasks (see Figure 5). The first task focuses on pedagogical design and the second on technological design. It is worth mentioning that for the correct accomplishment of the tasks, each one must perform a certain number of specific subtasks, which are:

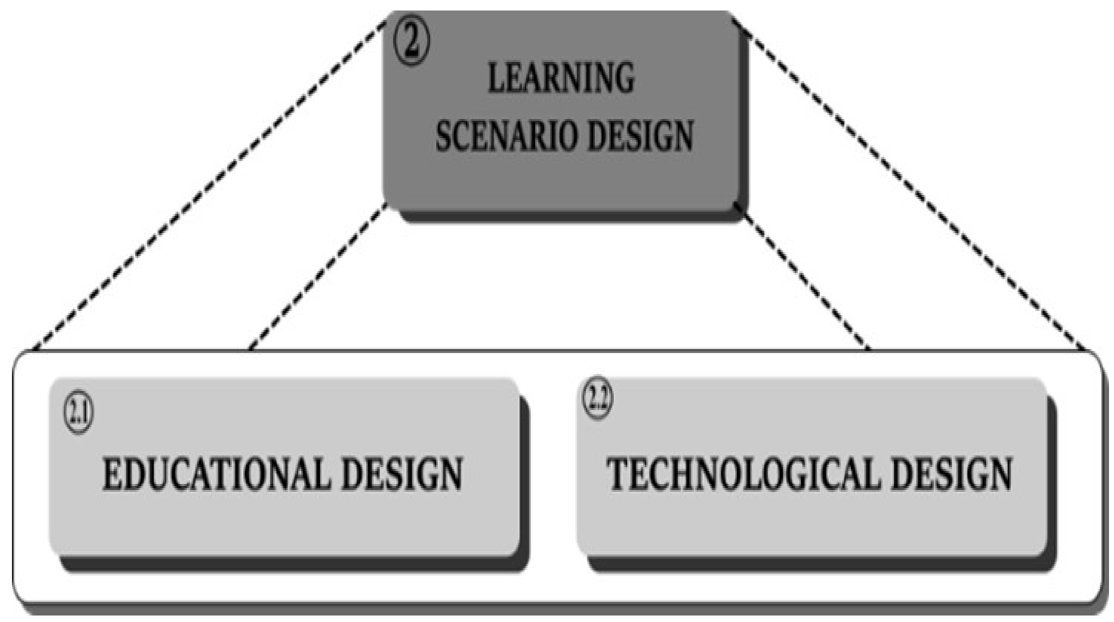

Fig. 5 Tasks for the for the design of learning phase

B1. Pedagogical Design:

A.Script design

Based on the previously defined requirements, a textual description of the learning dynamics is prepared following the proposed structure of the CEM-AR Instructional Script.

B.Design of digital resources

In this subtask the type of digital resource that will be integrated into the CEM-AR is selected. The Digital Resources (DR) that can be used for the integration of a CEM-AR are described in Table 5 and 6. For interaction levels one and two, the use of resources listed in Table 5 is proposed; and the resources listed in Table 6 can be incorporated to generate CEM-AR in the third level of interaction. In the same way, it can be considered as a possible option to use digital resources made by third parties, that is, freely distributed resources available on the internet. However, for this last option it is up to the teacher to consider whether the content is suitable.

TABLE V

RESOURCES FOR INTERACTION LEVELS ONE AND TWO

DR	Description	Activities
Text	It allows generating and visualizing the behavior of a phenomenon or process and/or experimenting with it, based on a configuration selected by the student.	(1) Determine the 3D model(s) that will be used in the theme. (2) Define the parameters to configure. (3) Create the theme script.
Audio	It enables the transmission of information through sound, music, sound effects, words or etc., which bring the student closer to interactive learning due to the identification and recognition of auditory signals that end in comprehension. In addition, it is preserved indefinitely, it is easily accessible and low cost.	(1) Define the audio resource (e.g., sound effect, music, recording). (2) Determine the content (in case it is a recording). (3) Define the duration. (4) Decide the format (e.g., MP3, WAV).

Video	Resource generated by camera or software tools which can be integrated with other resources (text, image, sound, etc.) allowing the student to identify and get involved with the situations that are presented in it. Video can visually present ideas and concepts, enrich digital narratives, and encourage the development of the ability to observe for an easy understanding of reality.	(1) Create the sequence of the theme to be transmitted. (2) Select the scenario (classroom or video tutorial). (3) Define the duration of the video (recommendation between 6 to 10 minutes). (4) Decide the format (e.g., MP4, AVI).
3D Object	Digital resource generated by a computer system that allows visualizing objects with volume, providing a better representation of it, as well as facilitating interaction and exploration by the student.	(1) Define the element(s) to be modeled in 3D according to the theme (e.g., buildings, objects). (2) Define the format (e.g., obj, fbx, dae).
Animation	Resource that allows reproducing a predesigned behavior of a 3D object in its interaction with the environment or with another.	(1) Create the animation script. (2) Define the duration of the animation (time or loop).

TABLE VI

RESOURCES FOR THE THIRD LEVEL OF INTERACTION

DR	Description	Activities
Simulation	Resource that allows generating and visualizing the behavior of a phenomenon or process and/or experimenting with it, based on a configuration selected by the student.	(1) Determine the 3D model(s) that will be used in the theme. 2) Define the parameters to configure. (3) Create the theme script.
Agent	Animated 3D object with autonomous behavior which takes advantage of some properties of human communication, this with the aim of perceiving and acting on its environment and thus, can determine the student's behavior to provide better learning.	(1) Determine the 3D model that will have the agent function. (2) Create the script of the theme to be transmitted.

B2. Technological Design:

A. Select the level of interaction:

Considering the aspects defined in the pedagogical design in relation to the interaction of the CEM-AR, three levels were determined from which the teacher can choose. These levels are:

- *Level 1:* the student can see videos or 3D objects (possibly with audio). At this level, the teacher uses the CEM-AR to promote the acquisition of knowledge through explanations of the phenomena and the processes, as well as the behavior of objects or the systems.
- *Level 2:* the student will be able to manipulate the objects in the environment, as well as to "touch" certain elements of the graphic environment (tap). At this level, the teacher encourages students, in their interaction with the CEM-AR, to understand some features of a phenomenon or process.

- *Level 3:* the student can configure a model about a process or phenomenon from which a visual representation of its behavior is generated (e.g., simulation). At this level, the teacher promotes cognitive dimensions of a higher order.

The development of CEM-AR at levels one and two can be carried out by the teacher using intuitive platforms; in the case of a CEM-AR at level three, multidisciplinary teams and specialized platforms are required.

B. Select the recognition method:

To carry out this task, the results obtained in the SRL are considered, since the recognition methods most cited in the literature are: (1) marker and (2) geolocation. In the same way, the "no marker" method has been considered since it can provide a great contribution to the use of CEM-AR with simultaneous location and mapping (SLAM) technology. For these reasons, they are the options to be chosen by the teacher in our CEM-AR development methodology.

- Marker. It is a static image used by the application running on the mobile device to activate and display the CEM-AR. In the same way, the marker must be unique avoiding the use of free distribution images because they can be used by other projects or applications. It is recommended to create a custom layout to avoid these issues. Some examples can be seen in Figure 4.

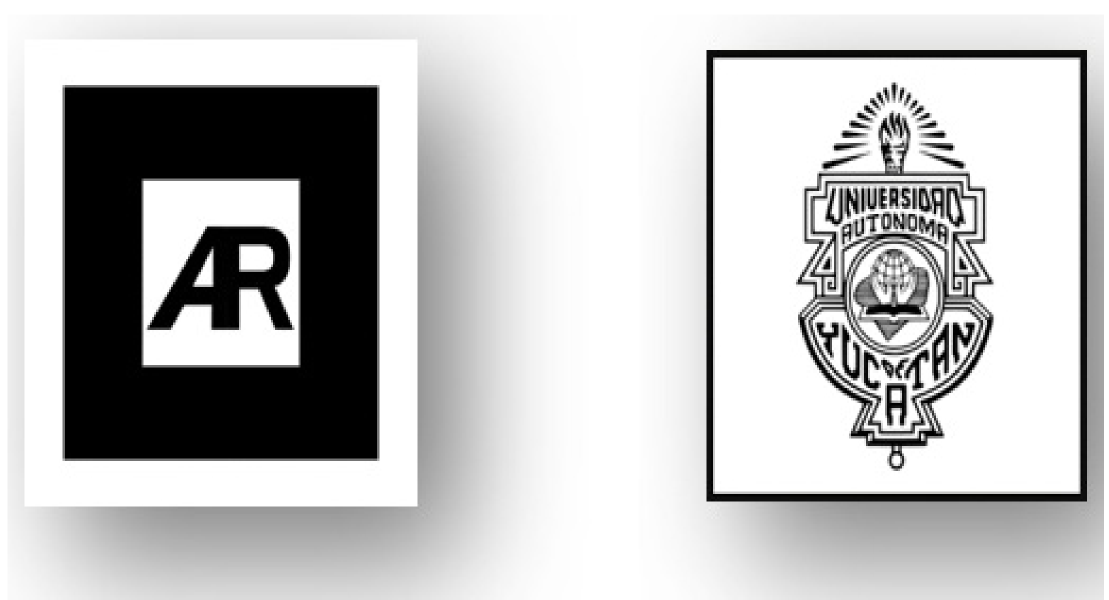

Fig. 6 Examples of markers made with Inkscape

It is worth mentioning that the display of the CEM-AR will be maintained if the mobile device maintains the focus of its camera on the marker.

- No marker. A method that does not require prior knowledge of a user's environment to overlay virtual 3D content. This works with the technology of simultaneous location and mapping (SLAM), it allows to scan the environment and create maps of where to place objects to keep them fixed in one place. This allows the student to move within the environment with the confidence that the 3D content will remain where it was assigned. However, it should be noted that this method relies on flat and textured surfaces for activation.
- Geolocation. Method that through the estimation of the geopositioned (GPS sensor) and orientation (digital compass) of the mobile device allows to visualize the CEM-AR in the real world. This option gives the teacher the possibility of superimposing the digital resources of the CEM-AR in different locations (e.g., buildings, people, places, etc.) in the real world to be found by the students moving around and orienting their camera. Another important point of this method is its low calculation cost and high recognition reliability.

C. Implementation Phase

The third phase is made up of three sequential tasks that begin the development of the CEM-AR with the construction of digital resources and their integration, with the marker previously chosen by the teacher (see Figure 7).

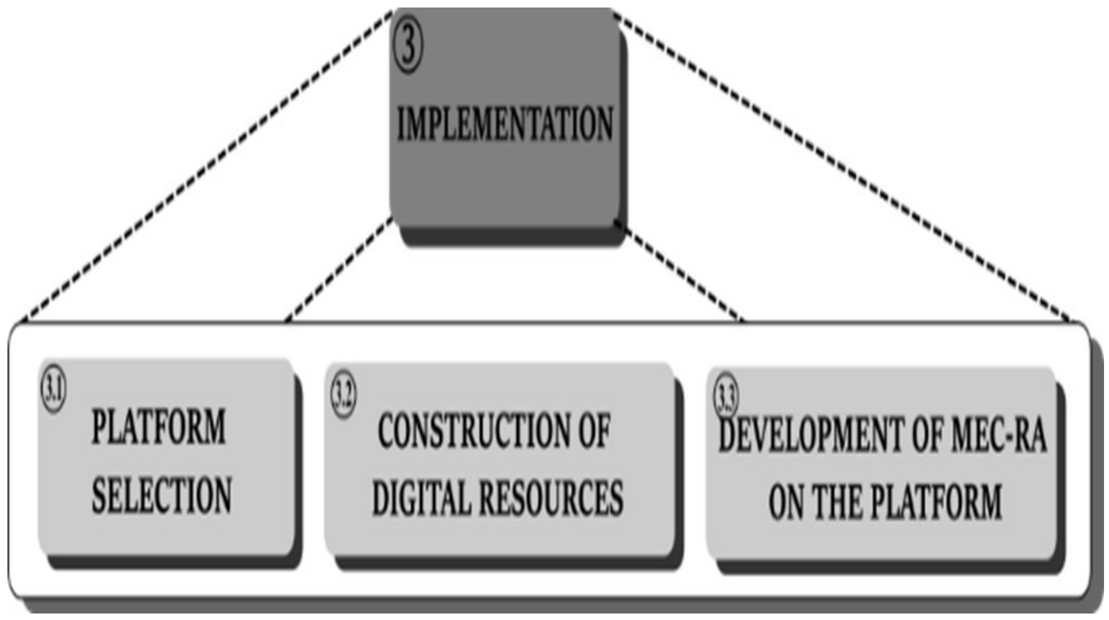

Fig. 7 Tasks for the implementation phase

C1. Platform Selection

In this task the teacher must choose one of two types of platforms that are based on the required level of interaction. These can be:

- High-level platforms: those used to develop a CEM-AR in the first two levels of interaction, that is, it does not require programming knowledge. These have an editor that allows, in a simple and intuitive way, to drag the digital resources (e.g. text, videos, or 3D models) in their environment, manipulate positions, scales and rotations if required, as well as to add the image that will be used as marker for the connection between the real world and the CEM-AR (see Figure 8).

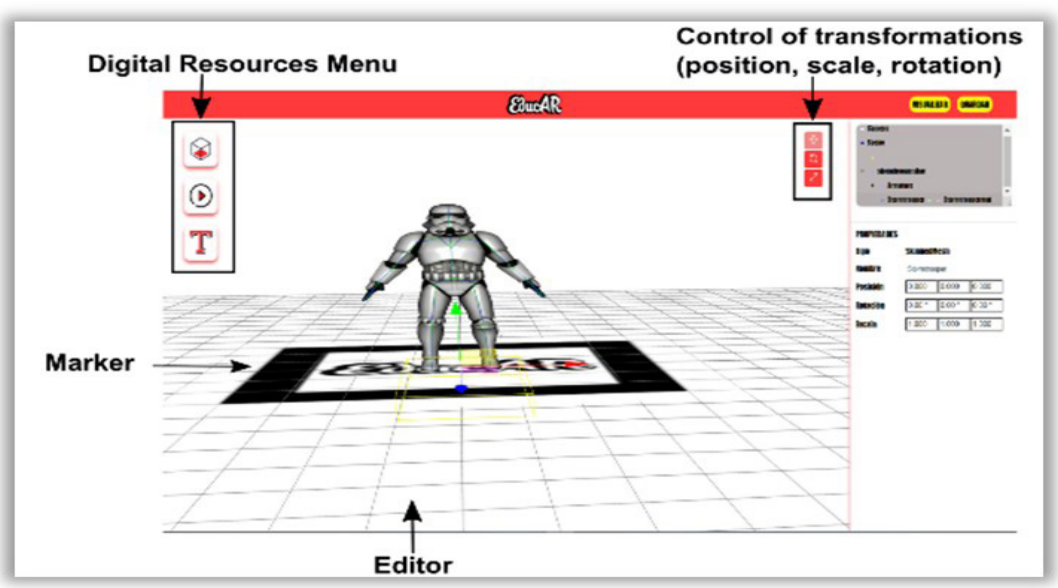

Fig. 8 View of a high-level platform (EducAR)

- Low-level platforms: are those used to develop a CEM-AR at the third level of interaction. These platforms have, in addition to the features of the high-level platforms, a programming interface that allows enhancing the user's interaction with the CEM-AR. On these platforms, the end user can configure the behavior of the digital resources in the CEM-AR by generating specific simulations —previously programmed— or even incorporate interaction capabilities with an intelligent virtual agent (see Figure 9).

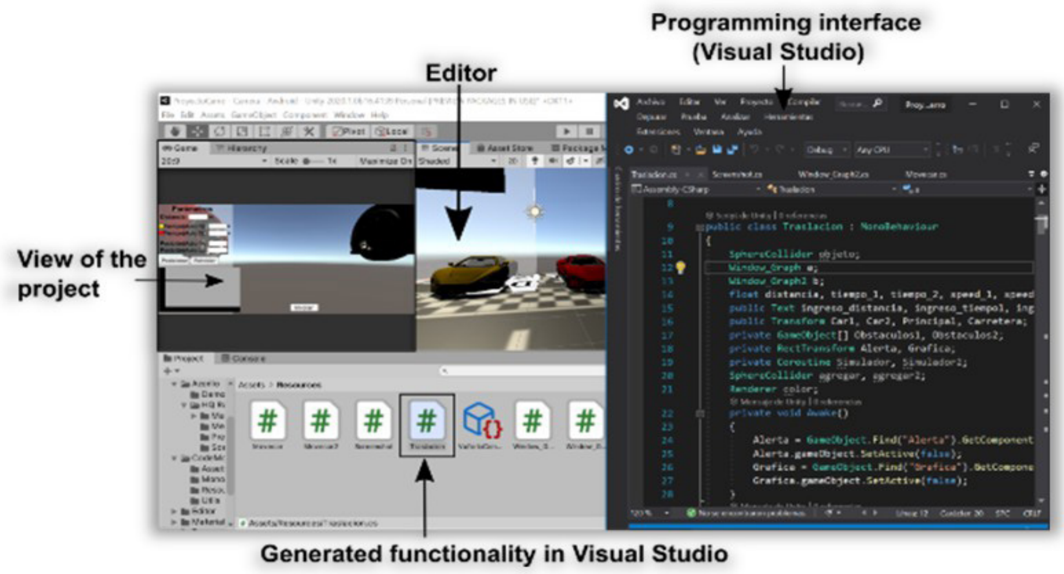

Fig. 9 View of a low-level platform (Unity 3D)

C2. Construction of digital resources

Task in which software tools support the edition and production of digital resources according to the formats established by the selected platform. However, it is worth remembering the possibility of choosing resources made by third parties. However, continuing with the construction of digital resources, the teacher must be supported by professionals around 3D modeling and development for the elaboration of the 3D object, animation, simulation, and the agent due to the complexity of these. Table 7 presents some alternatives for the construction of digital resources.

TABLE VII
ALTERNATIVES FOR DIGITAL RESOURCES

DR	Description
Text	Platform where the CEM-AR will be developed
Audio	Audacity Wavosaur Free Audio Editor
Video	Shotcut Avidemux Adobe Premiere Pro

C3. Development of the CEM-AR on the platform:

In this task, the teacher begins the creation of the CEM-AR on the previously chosen platform, so it will have to be followed a series of steps. However, the steps will only be presented in the case of high-level platforms, because at teacher with no programming knowledge must be adequately guided to develop the CEM-AR. Otherwise, in low-level platforms, the CEM-AR will be developed by a professional programmer and AR technology.

The steps to be followed by the teacher for the construction of a CEM-AR in levels 1 and 2, are the following:

1. Insert the recognition pattern: the teacher must upload the image assigned as a marker in the section on the right side of the platform, named 'Marker'; in this way the image will be displayed in the editor.
2. Insert the digital resources: the teacher inserts the digital resources in the platform editor, the in the resource's menu, click on the button of the resource to be inserted.
3. Adjust the transformations (i.e., position, rotation and scale): having the digital resources in the editor, the position, rotation and scale can be adjusted for the digital resources as they see fit in the transformation control bar.
4. Specify effects (e.g., animation, manipulation, etc.) of the digital resources: this is an exclusive subtask of level 2 of interaction; the teacher have the possibility of adding effects to the digital resources that allow the student to activate them by pressing certain areas of the CEM-AR.

5. Save the scene: once the transformations of the resources have been adjusted, the teacher can click the 'Save' button to store the set of digital resources within the CEM-AR.
6. Generate QR: the teacher can click on the 'Generate' button to assign a QR code to the CEM-AR. The code is scanned by the student to direct it to the CEM-AR within a web browser.

In the case of level 3, since the objects need to have configurable behaviors during the use of the CEM-AR to provide greater interactivity with the student, the support of a professional in the programming area is needed, knowledge and management of programming languages is required. However, it is important to emphasize that even when the programmer has control of the development, the guidelines identified of the teacher has to be followed and reflected in the guide documents. The joint work between these two disciplines will be essential for the successful development of the CEM-AR.

D. Evaluation Phase

The purpose of the evaluation phase is to verify compliance with a set of criteria linked to two critical aspects for the CEM-AR: the pedagogical and the technological ones. A process that integrates two evaluation strategies is then considered. In the first stage, the use of expert judgment, and in the second, a pilot test with students.

The factors considered for the evaluation of the CEM-AR in each of the evaluation stages considered (Expert Judgment and Pilot Test), are the following:

D1. Pedagogical aspect:

- Appropriability: of the degree to which the CEM-AR facilitates the accomplishment of the activity of the didactic sequence.
- Correctness: the degree to which the CEM-AR provides the correct results according to the level of the educational objective.
- Content quality: criteria focused on the evaluation of the content of the CEM-AR, that is, the use of appropriate language which must be clear, precise, related to the subject to which it is addressed and appropriate for the level at which it is addressed.
- Judgment capacity: criterion that evaluates whether the CEM-AR stimulates reflection on the ideas presented and promotes the ability to relate learned concepts with new concepts.
- Motivation: criterion that evaluates the CEM-AR in relation to its ability to attract and maintain the student's interest in learning.

D2. Technological Aspect:

- Format and design: this criterion refers to the fact that the CEM-AR does not contain excessive digital resources, in addition to the fact that such resources have the quality to favor the understanding and assimilation of knowledge.
- Interactivity: criterion that measures the reaction capacity of the CEM-AR before actions carried out by the students, that is, the communication that the CEM-AR will have with the student before the previous and subsequent actions.
- Usability: this criterion helps to measure the ease with which a student interacts with the CEM-AR, in relation to the way of using it (i.e., if it is intuitive, clear, without defective links or that lead to erroneous content).
- Reusability: criterion that refers the possibility of using the CEM-AR several times, either in relation to the content, educational context, or environment.
- User experience: criterion that helps to obtain the positive or negative perspective of the CEM-AR.

It should be noted that, as illustrated in the cases described in the empirical verification section, in both stages of the evaluation process the teacher may select from a list of items provided in the evaluation guide those that he/she considers pertinent, and based on a Likert scale, the opinion of the selected evaluators (experts or users) may be collected. The instructional and evaluation guides, as well as examples of formats for their applicability can be consulted at:

https://drive.google.com/file/d/1aTE8RBtabo6ifAl7qcXbaZkKGfXs2ImK/view?usp=sharing

VIII. CONCLUSIONS AND FUTURE WORK

From the results of the SRL, important information was obtained about the development of applications, materials or educational resources based on AR. Among the findings in the technological field, it was determined that they were designed and/or developed without following a specific methodology, they were usually adapted to traditional methodologies used in Software Engineering. On the other hand, in the educational field it was determined that AR technology must be disruptive in the educational processes. However, it needs to be considered as a core element of the instructional strategy, with a pedagogical support according to the activity and with a variety of means of interaction that promote adequate immersion. From this, it was concluded that it was necessary to design a Methodology for the Development of Educational Materials based on Augmented Reality.

Because there are not many methodologies that consider the technological and pedagogical aspects as essential joint work for the development of applications, resources or educational materials with AR, certain methodological proposals were analyzed and linked to innovative technologies to understand how to approach the development of the methodological proposal. It is important that the phases are be correctly since technology offers new opportunities to immerse to the student, leading to motivation, interest or improvements in academic performance. In terms of Pedagogical perspective, the selection and acquisition of information is provided to be transformed into knowledge for student inside or outside the classroom.

Finally, considering that the methodological framework aims to support teachers to generate Educational Materials based on Augmented Reality in an easy and intuitive way without the need to have previous programming knowledge or otherwise, work with a professional software developer before the implementation of the high levels of interaction. It was proposed to carry out a verification process, for this the proposed methodology was used in the generation of two educational materials, and with this evaluate if the use of the methodology can be used in the development of educational materials in an adequate manner. Secondly, it was proposed to carry out a validation process to evaluate whether the generated artifact corresponds to what is desired (a methodology), in this second case an expert evaluation was used, from which a set of comments and /or suggestions that allowed us to strengthen the phases of the initially proposed methodological framework. According to the results, it was concluded that the phases adequately combine the technological and pedagogical aspects to develop Educational Materials based on Augmented Reality. However, the methodological framework can evolve, so academic knowledge should always be considered for the growth of the development of this type of experiences.

Regarding future work, it was to be consider the suggestions for improvement in the evaluation by expert judgment. It is also necessary to work on the implementation of a training plan which considers a manual for teaches to use the high-level platforms in more detail. Likewise, it is necessary to work on the development of a high-level platform that considers the steps proposed in the implementation phase with the objective of adapting the methodology to provide an ideal complement for the development of the CEM-AR by the teacher in a simpler and more intuitive way. Finally, it is important to consider the evaluation through a pilot test with students and/or teachers, in which the teachers use the methodology for the development of a CEM-AR and the students use the developed materials.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Raúl A. Aguilar-Vera: Conceptualization, Methodology, Writing - Proofreading and editing, Supervision, Project management.

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José L. López-Martínez: Conceptualization, Research, Writing - Original draft.

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