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An Approach to Developing Learning Objects with Augmented Reality Content

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Abstract. Augmented reality (AR) has become widely available to the general public. Diverse real-life AR applications, ranging from entertainment to learning, have been created. In this context, this paper describes a systematic approach to creating learning objects with an AR content. This approach yields seven steps to guide the developer: (i) requirements; (ii) design; (iii) implementation; (iv) evaluation; (v) packaging; (vi) distribution; and (vii) learning evaluation. To evaluate the proposed approach, a case study was carried out. We carried out the development and evaluation of learning objects with AR content in an elementary school. We also conducted a usability test with specialists and an experiment with 40 students, on the usage of a learning object with an AR content. The delivered lecture was compared with the use of learning objects with multimedia content (the traditional type). Post and pre-test evaluations were conducted to record the students' learning; these indicated that the proposed learning objects are more effective than the traditional type and can play a significant role in improving students' grades. As a result, we claim that the proposed approach efficiently guides the development of learning objects with AR content. Using the approach presented here, it was possible to conclude the following: (i) it can guide the developer to create learning objects with AR content; (ii) it can integrate learning objects into learning object repositories.

Keywords: Augmented Reality · Learning objects · Software development

1 Introduction

It is now becoming increasingly common for teachers take advantage of digital technologies in educational practices; this can be favorable to the learning process, bringing new possibilities and new challenges. Learning Objects (LO) [1] are an example of a

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digital technology tool that can be used in this new educational context. According to the Institute of Electrical and Electronic Engineers' Learning Technology Standards Committee[1], LO are "any entity, digital or non-digital that can be used, re-used or referenced during technology-supported learning". These objects can provide learning support for teachers through sets of didactic educational materials [2–5], of which main features are discoverability, reusability and interoperability.

Traditionally, digital LO use multimedia (loMU) content such as text, audio, images, animations and video. However, the recent advances in immersive and interactive technologies have driven several promising [7] resources which are capable of providing new ways to create LO; these have already become easily available to the general public, such as augmented reality (AR). AR enables users to interact with 3D objects embedded into the real world, while users keep their perception of the real world during an activity [6]. AR applications can be deployed on commodities platforms that users already have purchased for general purposes: desktops, tablets, smartphones, laptops with built-in cameras or specific devices. Moreover, it is also available devices such as Microsoft's HoloLens and Magic Leap's display.

The aim of this study is to improve traditional LO with the usage of AR (loAR), which can extend learners' interaction with and perception of their content, creating new possibilities such as different visual views. Rather than just adding extra data to the real world, AR can modify the way that learning takes place. However, the creation of models to facilitate their development is necessary in order to make their use feasible. We propose an approach to assisting the development of loAR which is an extension of its incremental development [19]. It covers the key stages of specification, modeling, implementation, evaluation, packing, distribution and learning efficiency, and was tested using a case study in an elementary school. Beyond its interesting content, the success of a loAR depends on factors such as usability and user acceptance. In the case study, we then carried a usability test with a group of three specialists [8] that allowed us to improve the object before use by the children. A controlled experimental lecture with 20 students was conducted with a loMU and other with 20 with a loRA. Post- and pre-testing were also conducted to record the students' learning.

The major contributions made by this paper are: an approach to developing loRA; a case study illustrating our approach; and a loRA for teaching animal classification. The remainder of this paper is organized as follows. Section 2 presents our approach, created to develop loAR with quality and practicality. Section 3 describes the experiment to evaluate the approach, which involved a case study carried out on the teaching of animal classification. Finally, Sect. 4 presents our conclusions.

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[1] http://grouper.ieee.org/groups/ltsc/wg12/.

2 An Approach to Developing and Evaluating Learning Objects Based on Augmented Reality

Computational technologies are increasingly present in various educational contexts. These have modified current teaching methods and created new alternatives [9–12]. However, the efficient and effective use of these depends, among many factors, on a simple process of software development. AR has created diverse opportunities to improve the teaching-learning process [13–17], but it has several specific features that make their development and adoption difficult, such as environment illumination and object tracking. These features are not considered during conventional software development [18].

This approach extends the process of incremental development [19], which proposes that a detailed study of analysis and design is carried out before coding, so that when the code is produced, it matches the requirements. Moreover, incremental development promotes the creation of a new version for each solution evaluated by the user. This concept was maintained because LO are always subject to modifications according to the evaluation/needs of the teacher. Thus, it is expected that the loAR are capable of promoting the construction of other LO by changing their content or even their structure.

2.1 Requirements

The requirements specification is defined as the process by which the user's needs are identified, outlining a way to find a correct definition of the system to be elaborated [20], that is, defining what will be done rather than how it will be done. This phase requires the identification of stakeholders, the solution of ambiguities, the clear definition of requirements, and the promotion of communication among those involved. We propose to create a document with the following content: (1) the user's definition, which involves the acquisition and analysis of a user profile, such as education, age, gender and previous technological knowledge; (2) functional requirements, which define the actions that the loAR will be able to execute; and (3) non-functional requirements which consist of aspects that do not directly involve the user or software. For example, the physical position of the user related to capturing a marker image, and the characteristics of the physical environment (i.e. illumination, physical area and background).

Specific techniques can be used for the elicitation of requirements, such as interviews with users, questionnaires, and visits to the physical environment [21]. In our context, the participation of users, such as the teacher and the person in charge of the computational laboratory, is essential so that their needs can be correctly met. Only in this way is it possible to determine how the loAR will be applied. The use or otherwise of markers and user mobility are examples of specific AR demands that should be highlighted in this phase.

2.2 Design

The design phase describes how the application will be built [22]. It therefore establishes which hardware will be used for input and output, the types of markers, the development tools adopted, virtual objects (3D, images, textures and others) and supported platforms such as mobile, web and desktop. Although there are several points in common between most applications and AR applications, there are some striking differences; for example, AR applications generally do not use a database. The following design considerations:

- Physical environment design: most AR applications use a camera. Consequently, the illumination of the physical environment directly interferes with the tracking of objects in the scene. Thus, aspects such as this and others (i.e. ergonomic and locomotion) should be considered;
- Hardware design: an interactive AR application requires about 30 frames/second. In addition, the computer performance must be compatible. It is also essential to specify the camera adopted. Other aspects should also be evaluated to specify the equipment to be used, such as the user's mobility;
- Interaction considerations: this defines the interaction between users and virtual objects, and interaction with the environment. This project is a specific requirement of AR applications. For example, it is necessary to define whether the application is a marker or markerless solution. Our case study uses a marker solution; it was designed for children, and we therefore had to define an appropriate marker size to fit in a child's hand. The application can support diverse kinds of interaction, such as marker, mouse or a 3D mouse. This project also includes user feedback, which defines output resources such as sound;
- Visualization: most AR applications overlay 3D objects on the real world. This design aspect must consider the visual output resources that will be used, such as a mobile phone, where the user can be moving, or a desktop computer, where the user is stationary while the application is running;
- 3D virtual models: it is necessary to define the 3D objects necessary to build the AR application. This also includes textures and animations. This aspect must be based on the application goals of the teacher education plan, following the educational strategies associated with the potential and limitations of the tools; and
- The design of use: this defines how the AR application, in the format of a LO or otherwise, will be used by the teacher. For example, the project may aim only to present 3D objects with different perspectives, or to illustrate a process. If the application is used in the format of a LO, then the environment responsible for importing and displaying it (i.e. Moodle, Blackboard, Edmodo, Skillsoft, Desire2Learn and Schoology) must also be defined. The didactic strategy and the complementary didactic material must also be designed.

To promote LO reuse, a decoupling structure from the applications is desirable; this gives ease of adding new features and/or content. The results of this phase will be used by developers and other people, such as the teacher, modelers, designers and the laboratory manager, to perform their respective activities.

2.3 Implementation

There are several tools for the construction of AR applications (i.e. Vuforia[2] and Flaras[3]). Each has its own strengths, which allow the development of a variety of solutions, with or without markers, for various software platforms (IOS, Android and Windows Mobile) and with the support of several types of 3D models. An important point that distinguishes them is their ease of use. Some of these tools (such as Flaras) are targeted at end-users, which allows the teachers themselves to develop applications. However, tools such as these offer very limited features, for example only providing markers. On the other hand, low-level tools (i.e. ARToolkit[4]) require programming and a longer development time, but also provide flexibility; for example, it is possible to change the object detection algorithm.

loAR has as its content 3D models, sounds, and textures. There are several repositories, paid and otherwise, that provide ready-made objects. If the object is not ready-made, it is necessary to construct it using modeling tools such as Blender, 3D Studio and Maya; in the case of textures, tools such as Photoshop and Gimp can be used. This phase also requires other design considerations, among them, if applicable, the adequacy of the laboratory (computational resources and environment). Also, a user manual may be necessary, which may include pedagogical strategies for using the loAR.

2.4 Evaluation

The evaluation of an AR application aims to verify whether it satisfies the specified requirements. Since AR applications also rely on specific equipment such as cameras and markers, this phase is also required to validate these resources. As AR technology is new and supports unconventional types of interaction and visualization, quality analysis becomes important, especially concerning usability (that is, aspects of the user interface that may result in ease of use and a good fit for end users). Usability evaluation allows experts to make a judgment about the quality of use of a software application, and identify any problems [23–25]. A usability inspection is a low-cost evaluation method that is applied by experts, and can be applied when the application is ready.

Nielsen [26] has presented general usability metrics to determine items such as the visibility of the system status and error prevention in the use of the application. These heuristics are general and do not consider new concepts such as the use of markers and the addition of 3D objects. Kostaras and Xenos [27] have outlined guidelines for AR applications; they identified the strengths and weaknesses of making assessments through interviews, questionnaires, inspections, or usability testing. Zainuddin, Zaman, and Ahmad [28] have presented an evaluation of AR applications for deaf people. Martins, Kirner, and Kirner [29] have proposed a questionnaire to evaluate the usability of AR applications in the educational context. This phase should not be underestimated,

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2 https://www.vuforia.com/.

3 http://ckirner.com/flaras2/.

4 https://artoolkit.org/.

since the results help in the improvement of the application and, consequently, in the achievement of the objectives. Following the proposed approach, the process can return to the requirements phase if necessary. It is therefore expected that users will be satisfied with the AR application at the end of this phase.

2.5 Packaging

The packaging process encompasses an aspect of use which is based on the reuse of the LO. The phase is therefore optional, since reuse is not a requirement. However, the packaging and distribution of a loRA allows others to contribute to its evolution, increasing its lifespan.

Since loAR are digital resources that contribute to the teaching/learning process, they are composed of the AR application itself and several complementary files, such as presentation slides and exercises. The design phase therefore also takes into consideration the educational strategy which results in the creation of these materials. Initially, the packager receives as input the files (AR application and complementary materials); the metadata file is then generated and included, and finally, the LO is generated in a compact format according to the LO adopted (i.e. SCORM, Ariadne, IMS, IEE_LTSC or other).

2.6 Distribution

The possibility of reuse by end-users (students, teachers and tutors) motivates the distribution of the LO. However, for this to happen, in addition to allowing adaptation according to the aims of the developer, an adequate storage method is required that makes it easy to find, thus making it accessible [30–32]. BIOE, CESTA, LabVirt and RIVED are examples of LO repositories on the internet. They store the LO and offer search tools based on the metadata of the objects; these contain information about them, for example the relevant discipline. Repositories are the most appropriate databases for organizing, classifying and storing LO.

Storage of LO outside of repositories creates difficulties in locating them, since the search engines are not able to find them. This problem may trigger duplication of work, whereby someone unaware of the existence of an LO that meets their needs reconstructs the object. In addition to being stored in repositories, LO can reside in other places such as in a virtual learning environment, a web page, or even a shared folder on a local server.

2.7 Learning Evaluation

To determine whether a loAR creates gains, it is necessary to evaluate whether it has brought benefits to the teaching/learning process. There is thus a need to collect, analyze and quantify or qualify the results according to a predetermined quality format. There are three ways to assess a teaching/learning context: (1) summative assessment, which aims to measure student growth after instruction, and which occurs at the end of the teaching and learning process; (2) formative, which occurs during instruction in a didactic unit or a school term; and (3) diagnosis, which evaluates the conceptual and procedural knowledge that the learner dominate in a given discipline. This work proposes the use of diagnostic evaluation, since it allows the possibility of comparative pre- and post-testing to establish the evolution of the learner.

The diagnostic evaluation consists of a survey, projection, and retrospection of a learner's development situation, using elements to verify what and how he or she has learned. Thus, this evaluation makes it possible to verify to what extent previous knowledge existed and what are the difficulties. This is required to be done at the beginning of each cycle of use of the target loAR; thus, it is possible to know how much significant learning occurred during the process.

The diagnostic evaluation procedure applied to loAR should be performed as follows: pre- and post-tests should be used to measure the knowledge acquired by participants through the use of the object. The pre-test is a set of questions asked of the participants before using the loRA to determine their knowledge level about the content that will be taught. After using a loRA, learners should take a post-test with the same questions asked previously, or questions with the same level of difficulty. By comparing the pre-test scores with the post-test scores, it is possible to find out whether or not the use of the LO was successful. This phase is the final one in the construction cycle of loAR.

3 Using a Learning Object to Teach Animal Classification

To validate our approach, we carried out a case study in an elementary school classroom at Itajubá (Minas Gerais, Brazil). The class had 40 students, aged 9–10 years old. The test was performed with LO for all students; half of them with loAR, and the other half with loMU. Although the proposed approach is tailored to create a loAR, it is also can be used to develop a loMU. The difference is that the loAR uses 3D models, while the loMU uses 2D images and videos.

The requirement-gathering process used was an interview. We asked open questions to the teacher and to the school's lab coordinator. The questions concerned the difficulties faced by the students, interesting subjects, computational resources used, and which subjects would benefit from the insertion of 3D visualization.

3.1 Case Study: Requirements

During the interview, the teacher stated that students faced difficulties in understanding the classes of animals (in the field of biology). These difficulties were related to the visualization of the characteristics of each class, and especially when it was necessary to count the animals' legs. The teacher presented the textbook used to illustrate this subject [34]. Thus, we proposed the development of a loAR to assist learners in understanding the classes of animals.

The main points of the user's definition were: (1) the LO must be able to be used by users aged 9–10 years old, regardless of gender; and (2) the solution must be able to be used by users with lower levels of expertise or technical skills. The main functional requirements were: (1) the loAR should be able to recognize the marker and present the associated content (sound, 3D image). The loMU should present only 2D images, text and videos to the children; (2) the animals should be classified and presented in classes; and (3) the loAR should allow the children to rotate the visualized animals freely. The main non-functional requirements were: (1) the environment must be illuminated; (2) the application design must use a colorful and flashy interface; (3) the markers must fit the children's hands; (4) a web-based application would be desirable; and (5) the interaction will be based on fiducial markers and mouse.

These points played an important role during the development of the LO (loAR and loMU), as they were the basic criteria for decision making on the design alternatives and implementation.

3.2 Case Study: Design

In the design stage, a computational description was produced, describing in detail what the application would do:

- Physical environment design: recent technological advances allow AR applications to be run in commodities labs. The school lab had 20 computers, distributed with an adequate space between them, and was well illuminated;
- Hardware design: each computer in the local lab was equipped with Windows 7, internet access, headphones, webcam, and web browser;
- Interaction: a standard marker and mouse were used to provide user interactions to generate changes to the loAR state. We adjusted the marker size to fit the children's hands. When a child pointed the marker at the camera, and after the marker was recognized, the 3D animal was shown by the application. The children used the mouse to interact with the loMU;
- Visualization: this project considered aspects such as the children's attention and motivation; colorful and childlike images were used, which were pleasing and attractive to them. It was decided that the images in the background of the screen would have a theme of approachable and child-friendly images, including the classes of the animals, simple and colorful menus, and text with large lettering which was rounded and colored. Figure 1 presents an example of the web page design;

Fig. 1. Visualization

- 3D virtual models: taking the defined pedagogical strategy into consideration, we selected 3D animals, images, and sound from open repositories; and
- Design of use: the animal classification content was designed to run on learning management systems (LMS) as a LO.

3.3 Case Study: Implementation

Two websites were implemented using HTML, one to receive the loAR and another the loMU, and the pre- and post-test forms. The AR content was implemented using Flaras. Figure 2 depicts the website with the loAR.

Fig. 2. Learning object with AR content (loAR)-a 3D dog over a fiducial marker.

Figure 3 depicts the website with the loMU.

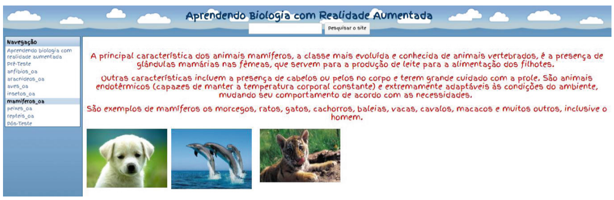

Fig. 3. Learning object with multimedia content (loMU).

This phase also required the assembly and preparation of the computer lab. Twenty computers were prepared. We carried out a performance test to check the children's interaction with the application.

3.4 Case Study: Evaluation

A questionnaire was prepared for our LO (loAR and loMU) usability inspection, which was carried out by three experts. Nielsen [24, 26] proposed a heuristics approach, which was adapted here. The following aspects were evaluated: (1) effectiveness: the user's ability to interact with the system to achieve its goal; (2) efficiency: the resources (time, labor and materials involved) required for the user to interact with the system and achieve its goal; (3) satisfaction: how far the user is satisfied with the system. This expresses how the system affects the user's emotions and feelings.

The severity degrees used were: strongly disagree (1); disagree (2); neither agree nor disagree (3); agree (4); strongly agree (5). The following tables have the ratings of the three experts, as well as their remarks when relevant. Table 1 represents the analysis regarding the effectiveness aspect. Although the LOs were working, the experts pointed some problems (i.e., buttons not working and designed properly, and animal sounds very low). These problems were fixed before the tests with the children.

Table 1. Verifying the effectiveness.

Checklist	Severity degree	Experts' comments
I know what is going on during the interaction	3;5;3	There are buttons that will not be used by the children in the menu below; -; The user does not know that they have to click on the animal to hear the explanation
If I put more than one marker on the interface, then I can specify one	2;4;2	I do not think so - we only select one marker at a time; -; The application works with one marker
It is possible to perform "redo" and "undo" easily	5;1;5	Yes. There is a button for this; The reset buttons did not work; No need to return
The purpose of the application is achieved	4;3;4	No. I could not even hear the explanation of each animal; The audio did not work; A child will feel lost while using it alone. If it is explained orally, it works. Despite the low audio, it fulfills the aim

Table 2 shows the evaluations regarding the LO efficiency. In general, the LO reached the aim. Almost all of the experts' comments were taken into account and fixed in the version used by the children. However, we did not alter some features; for example, although the scale of all the animals was altered, we did not add animation to reproduce behavior consistent with the real world.

Table 3 measures the experts' satisfaction. This can be considered as good for these tests. They provided important suggestions for improving the LO before the final test (i.e. the help was incomplete).

The results clearly showed that the LO were not ready. It was therefore necessary to fix these problems before the next phase. For example, the sizes of 3D objects were changed and the sound volume adjusted.

Table 2. Verifying the efficiency.

Checklist	Severity degree	Experts' comments
Load time of virtual objects is satisfactory	3;4;1	The child will be annoyed at having to activate the camera for each animal; The application took more than five seconds to load the amphibians; Sometimes it takes time to load
The virtual objects are well positioned in the scene (position, texture, scale)	4;4;5	The 3D objects should be apparent on the same scale; -; -
Animation behavior is consistent with the real world	5;2;3	-; Animals in the real world do not spin around; There is no animation regarding behavior
Actions/feedback are standardized	5;3;3	-; Audio is associated with each animal; The application does not warn about clicking on the animal
The application prevents errors (for example, the application warns when the user has shown a wrong marker)	3;2;4	The application does not work with another marker; Sometimes the 3D object got stuck, and the page had to be reloaded, and the user is not alerted; -
It's easy to remember how the application works	5;5;4	Yes, because there are few steps; -; The menu features are difficult to memorize
The learning curve is low	4;3;2	The actions are explained in the help, but it should show messages in each page to improve the learning curve; It is easy to learn, but requires training; Easy to learn after an explanation
An experienced user can use the application optimally (for example, by not watching the introductory videos)	4;5;3	There is no necessary optimization for experienced users; -; There is no optimization for experienced users
It's easy to position the marker for the camera to detect	5;4;3	-; Illumination interferes in marker detection; There are some tracking problems
The user is instructed on what to do during the interaction	3;1;4	The user does not know which subpage he/she is on; No; There is no link to download the marker anywhere
The application requires the fulfillment of specific requirements (camera, position, lighting and others)	5;1;4	The requirements are simple to fulfill; The application requires non-conventional resources; Some specific requirements are necessary to the application work
The tracking system is stable	5;3;4	Yes; The mammal did not work; Depends on the illumination
If the application detects more than one marker in the scene, it continues to function normally	5;4;5	Yes; There is a small delay; Yes

Table 3. Verifying satisfaction.

Checklist	Severity degree	Experts' comments
The number of virtual objects in the scene is appropriate	5;3;5	Yes. Only one animal is shown at a time, not overloading the child; More than one animal could be presented for each animal class; -
The number of interaction options is satisfactory (marker, keyboard, mouse, joystick)	5;3;3	-; There are a lot of buttons on the menu; The object has a predefined rotation movement that cannot be changed
The help offered is satisfactory (video, text, audio)	1;3;3	No. The help is a bit confusing and lacking in information. For example, there are two markers to be printed, but only one is spoken. Which one should be used?; The help is incomplete; The help does not clarify its use, nor the features of the buttons
I am satisfied with the interaction solution	5;3;5	-; The marker should be an appropriate size to fit in the children's hands, or it should stay on the table
I am satisfied with the freedom of movement during interaction	5;2;2	-; Having to hold the marker all the time is uncomfortable; You cannot scale an object to see it more closely

3.5 Case Study: Packaging

The LOs developed were packed into SCORM format using the tool created by Guimarães et al. [33]. This tool receives the application files as input and adds files according to the SCORM format. The packing process does not alter the application content; however, it adds files such as the metadata file imsmanifest.xml, which describes LO items (i.e. it contains links to every piece of content within the LO and a logical grouping of its component parts). As output, it generates a single ZIP file. The content of the whole application is self-contained within the ZIP file.

To validate the LO objects files, we used the Cloud Repository[5] which is an online learning tool focused on storing and distributing e-learning content. If a LO stored in this repository is altered, all LMSs are automatically updated. This repository also tracks how much of the LO content is being used, regardless of which LMS it is stored in.

3.6 Case Study: Distribution

This case study was carried out internally on the school network in which the project was applied; it was not imported and distributed via a repository. However, the LOs were ready to be inserted into the main existing LO repositories.

[5] http://scorm.com/scorm-solved/scorm-cloud-features/.

3.7 Case Study: Learning Evaluation

To evaluate the benefits of using loAR to teach and learn animal classes, we carried out a randomized experiment. More formally, we set out to answer the following research question (**RQ**): Are learning objects with AR content (loAR) a more effective approach to teach animal classes than learning objects with multimedia content (loMU)? The RQ outlines the issue addressed by this study and was used as the basis to formulate our hypotheses.

- **Hypothesis formulation:** we formalized our RQ into hypotheses so that statistical tests could be carried out.
- **Null hypothesis, H_0:** there is no significant difference in efficiency between the two LO (measured in terms of the children's scores), which can be formalized as follows:
- $H_0 = \mu_{loAR} = \mu_{loMU}$
- **Alternative hypothesis, H_1:** there is a significant difference in efficiency between the two LO, which can be formalized as follows:
- $H_1 = \mu_{loAR} \neq \mu_{loMU}$

Our experiment was broken down into four steps. These steps are listed in chronological order in Table 4.

Table 4. Learning evaluation stages.

Step	Description	Time
Pre-test	All students answered seven questions about animal classes	15 min.
Division of class	The class was divided into two groups of twenty students randomly	Free
Learning phase	Group A: this group went to the laboratory and was taught with the loMU Group B: this group went to the laboratory and was taught with the loAR	Group A: 30 min. Group B: 30 min.
Post–test	All students answered seven questions about animal classes	15 min.

The pre-test stage consisted of an activity similar to a questionnaire in the book [34] used by the teacher. The activity consisted of one question with five alternatives for each animal class (Table 5). The questionnaire was scored from 1 to 7.

Immediately afterwards, the class was divided randomly into two groups of 20 each (Group A and Group B), and we started the lecture (30 min). Group A worked with the loMU and Group B with the loAR. Each student used a computer, and they were guided by a teacher to access the website with the LO and to navigate to it.

Figure 4 shows the scores of the children in Group A in the pre- and post-tests. The change between the results of the post-test and the pre-test was 20%, and the average hits jumped from 3.6 hits to 5 hits (Table 6); 75% of students had progressed between the first test and the second.

Table 5. Pre-test questionnaire.

Question	Alternatives
1. Which animal class does the dog belong to?	()mammals ()amphibians ()reptiles ()birds ()fish
2. Which of these animals belongs to the reptile class?	()eagle ()salamander, ()swordfish, ()snake ()giraffe
3. How many legs does an insect have?	()four ()six ()eight ()ten ()twelve
4. Which of these animals is an arachnid?	()ant ()scorpion ()ladybug ()mouse () starfish
5. Which animal class does the frog belong to?	()insects ()amphibians ()reptiles ()birds ()fish
6. Which of these animals belongs to the fish class?	()dolphin ()tilapia ()bat ()platypus ()whale
7. The duck is a …	()insect ()amphibian ()reptile ()bird ()fish

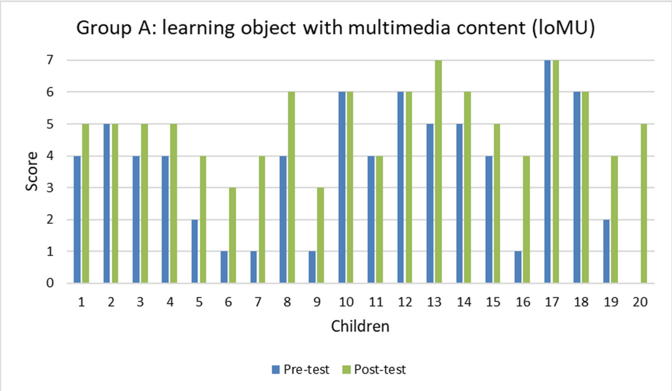

Fig. 4. Pre- and post-test scores obtained by Group A using loMU.

Table 6. Summary of the scores obtained by Group A using loMU.

	Group A: loMU	
	Pre-test	Post-test
Median	4.00	5.00
Mean	3.60	5.00
Std	2.06	1.16
Max	7	7
Min	0	3

Figure 5 shows the scores of the children in Group B in the pre- and post-tests. The change between the results of the post-test and the pre-test was 36%, and the average hits jumped from 3.2 hits to 5.7 hits (Table 7); 90% of students progressed between the first test and the second.

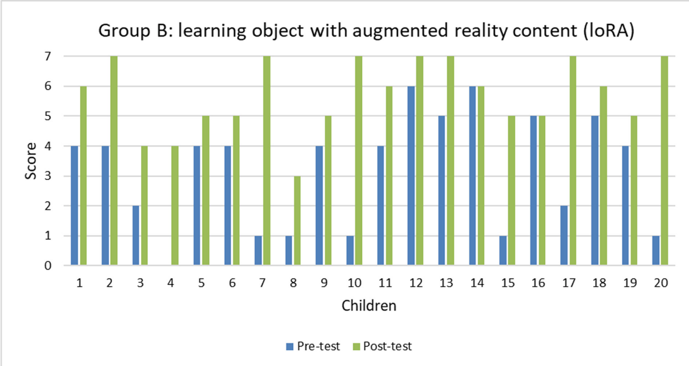

Fig. 5. Pre- and post-test scores obtained by Group B using loRA.

Table 7. Summary of the scores obtained by Group B using loRA.

	Group B: loRA	
	Pre-test	Post-test
Median	3.8	6.0
Mean	3.2	5.7
Std	1.88	1.21
Max	6	7
Min	1	3

In both cases, the standard deviation decreased after the use of the LO, indicating that its use can increase the learning process. However, in general, the children using the loMU increased their scores by 20%, while the children using loRA increased by 36%. Moreover, in the question about arachnids and insects (Question 3) the children using the loMU increased their scores by 0%, while the children using the loRA increased their scores by 45%, indicating that loAR can be of valuable assistance in subjects that require a depth view to understand the subject. In this case, it assisted the children to count the legs.

The p-value for the loMU was 0.000134602, while the p-value for loRA was 0.0000199 762496490467; the p-value for both was 1.9263E-08. (significance level 0.05), rejecting the null hypothesis. That means that the tests were significant; that is, the change in the children's scores between the pre- and post-tests was not random.

The children's teacher reported that the experiment motivated the students, especially those who did not usually pay attention during traditional classes based on the book. Although she was already aware of AR, she was surprised by the positive student involvement. The students did not have any difficulty in manipulating the marker. They become anxious to have another class with AR content.

4 Concluding Remarks

There is interest in LO that facilitate the teaching-learning process. However, an effective use of loAR that is affordable and easy to develop must be provided. This research presented a development approach tailored to create loAR with quality and practicality. As result, we expected to improve traditional LO with the usage of AR, extending learners' interaction with and perception of their content, creating new possibilities such as different visual views. Rather than just adding extra data to the real world, AR can modify the way that learning takes place

The approach presented extends the process of incremental development, a traditional software model, remodeling the concepts and adding several new steps. To test our approach, we carried out a case study which aimed to teach animal classification to children. We were able to create and validate a loAR. Moreover, our results indicate that using loAR to introduce children to animal classification can be an effective resource. During the post-test, that is, after being exposed to animal classification through a loAR, the children's scores were improved.

Although the approach presented here is an innovative work, it has limitations. These provide directions for future work in terms of extensions, experimental validations, variations and enhancements. In order to evaluate the approach differently, an experiment could be conducted in other contexts, but with some characteristics that are different from those presented in this work. For example, the development phase could be carried out using another development tool (e.g. Unity, SmartAR). The packing and distribution phases also could be validated with other tools. Finally, new experiments could also be carried out with other groups.

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