ISSN: 2444-250X | ISSN-e: 2444-2887

Expanding the virtual universe of university students. Educational use of augmented reality and contributions of Rafodiun Project

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Abstract

Augmented reality is an emerging technology that is increasingly being integrated into the educational system. In addition, numerous investigations highlight its benefits for learning such as: mixed reality recreation, real-time integration, incorporation of information from different sources (video, 3D, audio, web pages, etc.). In this sense, this work presents the results of the Rafodiun Project (Augmented Reality to Increase Training. Design, Production and Evaluation of Augmented Reality Programs for University Training), financed by the Ministry of Economy and Competitiveness of the Government of Spain in 2017. In it, it is intended to analyze the educational possibilities that augmented reality can have for university training contexts. This analysis is carried out from different perspectives, both technological-instrumental, educational, design of training environments, and of students as augmented reality content producers. The results demonstrate the possibilities and potential that augmented reality offers for the learning of students and university professors (men and women) in different areas. In the same way, predictive models of the acceptance of this technology in the classroom (technology acceptance model [TAM]) are consolidated. Based on the previous lines, the applicability of augmented reality in the university classroom is discussed, as well as the necessary training of teachers in creating, editing and modifying objects and materials in augmented reality.

Keywords: augmented reality; higher education; emerging technologies; digital competence; teacher training; educative technology; technology acceptance model (TAM).

Received: 13-02-2022 | Accepted: 02-06-2022 | Published: 07-09-2022

Citation: Barroso-Osuna, J. and Palacios-Rodríguez, A. (2022). Expanding the virtual universe of university students. Educational use of augmented reality and contributions of Rafodiun Project. *Tecnología, Ciencia y Educación*, *23*, 137-154. https://doi.org/10.51302/tce.2022.874

ISSN: 2444-250X | ISSN-e: 2444-2887

Ampliando el universo virtual del alumnado universitario. Uso educativo de la realidad aumentada y aportaciones del Proyecto Rafodiun

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Extracto

La realidad aumentada es una tecnología emergente que se está integrando cada vez más en el sistema educativo. Además, numerosas investigaciones destacan sus beneficios para el aprendizaje en realidad mixta, integración en tiempo real, incorporación de información de diferentes fuentes (vídeo, 3D, audio, páginas web, etc.). En este sentido, este trabajo presenta los resultados del Proyecto Rafodiun (Realidad Aumentada para Aumentar la Formación. Diseño, Producción y Evaluación de Programas de Realidad Aumentada para la Formación Universitaria), financiado por el Ministerio de Economía y Competitividad del Gobierno de España en el año 2017. En él se pretende analizar las posibilidades educativas que puede tener la realidad aumentada para contextos de formación universitaria. Este análisis se efectúa desde diferentes perspectivas tanto tecnológicas-instrumentales como educativas, de diseño de entornos formativos y del alumnado como productor de contenidos en realidad aumentada. Los resultados demuestran las posibilidades y potencialidades que ofrece la realidad aumentada para el aprendizaje del alumnado y del profesorado universitario (hombres y mujeres) en diferentes áreas. De la misma forma, se consolidan modelos predictivos de la aceptación de esta tecnología en el aula (*technology acceptance model* [TAM]). En función de las líneas anteriores, se discute la aplicabilidad de la realidad aumentada en el aula universitaria, así como la necesaria formación del profesorado en creación, edición y modificación de objetos y materiales en realidad aumentada.

Palabras clave: realidad aumentada; enseñanza universitaria; tecnologías emergentes; competencia digital; formación del profesorado; tecnología educativa; *technology acceptance model* (TAM).

Recibido: 13-02-2022 | Aceptado: 02-06-2022 | Publicado: 07-09-2022

Cómo citar: Barroso-Osuna, J. y Palacios-Rodríguez, A. (2022). Ampliando el universo virtual del alumnado universitario. Uso educativo de la realidad aumentada y aportaciones del Proyecto Rafodiun. *Tecnología, Ciencia y Educación*, *23*, 137-154. https://doi.org/10.51302/tce.2022.874

Summary

Note: Proyecto «Rafodiun (Realidad Aumentada para Aumentar la Formación. Diseño, Producción y Evaluación de Programas de Realidad Aumentada para la Formación Universitaria)», financiado por el Ministerio de Economía y Competitividad (EDU2014-57446-P), actual Ministerio de Economía, Industria y Competitividad.

1. Introduction

The augmented reality is a technology that facilitates the combination of digital information and physical information in real time through different technological supports, such as tablets and smartphones (Cabero Almenara and Barroso Osuna, 2016; Cabero Almenara and García Jiménez, 2016; Johnson *et al.*, 2016).

We can consider augmented reality among the so-called emerging technologies, contextualized by Sosa-Jiménez *et al.* (2018) as those «resources, artifacts, tools, concepts and innovations, associated with the digital, that have the disruptive power to transform or generate changes in the processes where they are used regardless of whether these are new or old technologies» (p. 129). We are facing a technology that, due to what was previously mentioned, presents great possibilities in the educational field (Cabero Almenara *et al.*, 2018; Yip *et al.*, 2019), by substantially increasing and reducing the possibilities of access to information. We must bear in mind that this technology allows access to information using mobile devices, the use of which is fully standardized among university students in the Ibero-American context (Vázquez Cano and Sevillano-García, 2018).

As far as its defining characteristics are concerned, they can be specified as: being a mixed reality, integrated in real time, incorporating information from different sources (video, 3D, audio, web pages, etc.), being interactive and offering different levels of interaction and enriches or alters the information of the physical reality where it is integrated.

Regarding their educational possibilities, according to the indications of different authors, they can be grouped into the following: a) exclusively present the relevant information, eliminating that which may hinder its acquisition by the student; b) enrich the information of reality to make it more understandable; c) being able to observe an object from different points of view, selecting the moment and position of observation by the student; d) can be used at different levels of education; e) enhances ubiquitous learning; f) favors the development of active learning; g) creates highly motivating training scenarios for students as they experience and interact with virtual and auditory elements; h) create safe «artificial» scenarios for students, such as laboratories or simulators, where they can carry out their teaching practices; i) enrich printed materials for students with additional information in different media; j) can be used in different subjects and disciplines; k) encourage students to become producers of learning objects in augmented reality; l) can improve divergent processing; and m) the subject remains in the real world and therefore does not lose contextualization (Barba Vera *et al.*, 2015; Cabero Almenara and Barroso Osuna, 2016; Cubillo Arribas *et al.*, 2014; Fonseca Escudero *et al.*, 2016 Han *et al.*, 2015; Jeřábek *et al.*, 2014; Prendes Espinosa, 2015; Roda-Segarra *et al.*, 2022; Santos *et al.*, 2016).

Although the vast majority of research on the educational use of augmented reality is of a recent nature, in recent times different works have been carried out that have provided different findings to justify its incorporation into educational practice. Thus, some have focused on analyzing the degree of satisfaction that students showed after participating in training experiences with learning objects in augmented reality (Barroso Osuna and Gallego Pérez, 2017; Cabero Almenara *et al.*, 2016; Fonseca Escudero *et al.*, 2016; George Reyes, 2020; Han *et al.*, 2015; Hsu *et al.*, 2017; Joo Nagata *et al.*, 2017; Marín-Díaz and Sampedro-Requena, 2020; Pérez-López, 2015; Rodríguez Hernández *et al.*, 2016). In this sense, the results are conclusive: students show high levels of satisfaction when they participate in this type of experience. This is independent of the level of studies at which the experience was carried out and of the curricular contents on which it dealt.

To a certain extent related to what was mentioned above, research has tended to indicate that carrying out experiences in augmented reality increases student motivation (Barba Vera *et al.*, 2015; Bicen and Bal, 2016; Cheng, 2017; Chiang *et al.*, 2014; López-Belmonte *et al.*, 2019; Marín-Díaz and Sampedro-Requena, 2020; Nielsen *et al.*, 2016). This is explained by different reasons that range from the possibility it offers to represent content in various ways, enriching books and notes with audiovisual and multimedia documents, specifying information, and allowing students to interact with objects. This has been found in students at different educational levels: kindergarten and nursery school (Han *et al.*, 2015), primary school (Pérez-López and Contero, 2013), and university students (Barba Vera *et al.*, 2015; Barroso Osuna and Gallego Pérez, 2017).

On the other hand, different studies have shown that the use of learning objects in augmented reality improves the intelligence and spatial abilities of students (Lee *et al.*, 2016), spatial orientation (Carbonell Carrera and Bermejo Asensio, 2017), and visual comprehension (Álvarez-Marín *et al.*, 2017; López-Cortés *et al.*, 2021).

Regarding the improvement obtained in student performance, the results found vary between those that indicate their improvement (Álvarez-Marín *et al.*, 2017; Lin *et al.*, 2013; Pedraza Caballero and Valbuena Duarte, 2014; Santos *et al.*, 2016; Toledo Morales and Sánchez García, 2017), and those who indicate that it is not affected or that learning decreases (Hofmann and Mosemghvdlishvili, 2014; Pérez-López, 2015; Santos *et al.*, 2016). This is explained by several reasons: the worse performance of augmented reality applications on mobile phones currently available, since some of them require a lot of capacity, the existing Wi-Fi connectivity in educational centers, and the cognitive disorientation suffered by certain subjects when interacting with objects in augmented reality.

One of the possibilities of incorporating augmented reality in training is in the form of books and notes enriched with augmented reality objects, which consists of specific parts of traditional physical books being used as an interface or bookmarks to augment their contents virtually. Books and notes on different investigations have been carried out that have indicated that students perceive them with less cognitive load, greater motivation, and more

positive attitudes when they have had experiences of interaction with this type of material and improved performance (Cheng, 2017; Ferrer Torregrosa *et al.*, 2016; Martín-Gutiérrez, 2015; Nadolny, 2016; Villalustre Martínez, 2020).

It should also be noted that, within the educational uses of augmented reality, the possibility that it offers in tele-training and e-learning teaching situations is beginning to be contemplated (Reinoso, 2016). To conclude, indicate two limitations for its incorporation in the teaching-learning processes: the lack of conceptual references and theoretical justification and the lack of research (Alkhattabi, 2017; Bower *et al.*, 2014; Cabero-Almenara *et al.*, 2020, 2021; Nielsen *et al.*, 2016; Saidin *et al.*, 2015).

In any case, even acknowledging the lack of theoretical coverage to justify its incorporation of technologies, proposals for its use are being carried out based on the idea that incorporation solutions cannot reside in a single educational paradigm, but rather a mixture of pedagogical approaches (Bower *et al.*, 2014; Rasimah *et al.*, 2011; Tarng and Ou, 2012). In this sense, constructivist learning, situated learning, inductive learning, and game-based learning. On the other hand, the theory of variation initially formulated by Mazur (1997) suggests that enriching learning situations are those that put the student in a situation where he must experiment or analyze to change his initial conception, can provide clues and suggestions for its educational use.

It would be good to end this section by pointing out the two elements of Cuendet (2013):

- The proposed augmented reality system should be flexible enough for the teacher to adapt it to the needs of their students.
- The implemented augmented reality system should consider the restrictions present in the educational context to which it is applied.

2. Objetives of Rafodiun

Augmented Reality to Increase Training. Design, Production and Evaluation of Augmented Reality Programs for University Training (Rafodiun) is a project financed by the Ministry of Economy and Competitiveness (EDU2014-57446-P) that pursues the following main objectives:

- Evaluate the possibilities and potential offered by different software used for the creation of technological environments under the augmented reality architecture to be used in university training contexts.
- Design and produce different contents in augmented reality format to be applied in contexts of university education in different curricular areas and evaluate its possibilities for student performance.

- Know the degree of motivation and level of satisfaction that arouses in university students the fact of participating in training experiences supported by augmented reality.
- Know the educational possibilities that allow the student to become a producer of training experiences supported by augmented reality.
- Investigate the technical, curricular, and organizational difficulties that augmented reality could have to be applied to university training contexts.

In summary, the aim is to analyze the educational possibilities that augmented reality can have for university training contexts. This analysis is carried out from different perspectives, both technological-instrumental, educational, design of training environments, and the student as producer of augmented reality content.

To achieve the above objectives, different types of research are carried out, which are presented below.

3. Method and results

3.1. Analysis of the possibilities and potential offered by different types of software

For the analysis of the possibilities and potential offered by different types of software to produce objects in augmented reality, an «expert judgment» is carried out. For their selection, a series of previous premises are carried out, such as: having professional experience in fields related to educational technology and the application of information and communication technologies to educational contexts; have work experience in the field of educational production of educational resources in general, and in augmented reality learning objects in particular; belong to research groups in educational technology; be from different Spanish and Latin American universities; have previously collaborated in other research projects or in publications that would allow a prior assessment of their seriousness and professionalism; and have some link with the Rafodiun project. For their selection, two steps were followed: first, a massive selection was made considering the aforementioned criteria. Second, the so-called «coefficient of expert competence» is obtained (Cabero Almenara and Barroso Osuna, 2013).

The evaluation is carried out by means of a questionnaire presented by the main existing software and regarding which they were asked about a series of dimensions:

- The degree of technical knowledge that they consider that a user must have to manage the program, in a scale of 0 (no need to have knowledge) to 10 (to have strong technological knowledge).

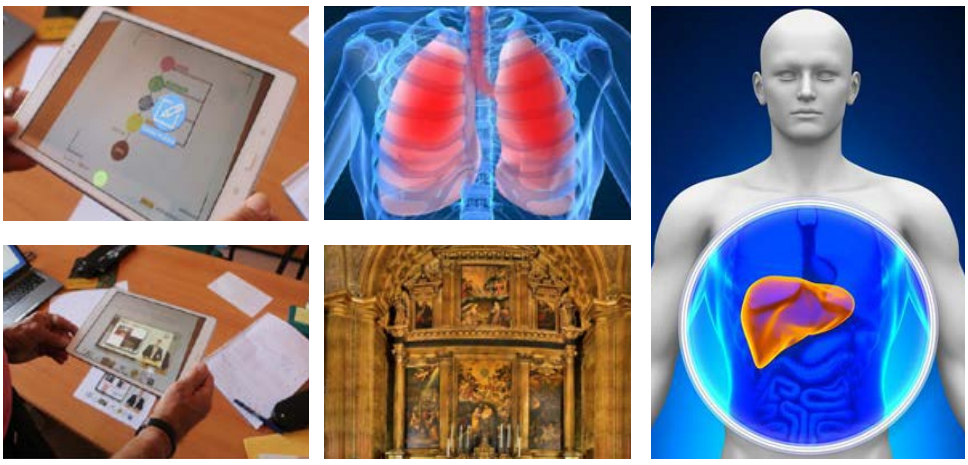
- Accessibility/ease of navigation and getting around the program on a scale of 0 (easy to navigate) to 10 (very complicated to handle),
- The possibility of incorporating different materials (videos, printed documents, 3D, etc.) offered by the program on a scale of 0 (allow very few types of materials) to 10 (allows wide range of materials).
- The ease of use by teachers and students of the program for the production of learning objects offered by the program on a scale of 0 (very difficult to use) to 10 (very easy to use).

The questionnaire is built with the Google Forms tool, and is administered via the internet. It was answered by 220 experts, of which, applying the aforementioned coefficient, 104 remained, who were the only ones who obtained scores of 0.8 or higher.

3.2. Design and produce different contents in augmented reality

To achieve this goal, different types of learning objects are built for different disciplines and areas of knowledge, ranging from medicine, pedagogy, musical expression, fine arts, and architecture, and which belonged to curricular content that was taught in subjects of these disciplines. These objects can be seen at the following address: https://grupotecnologiaeducativa.es/proyectorafodiun/index.php/objetos-en-ra. In figure 1, some of them are presented.

Figure 1. **Images of different objects produced in augmented reality**



Source: https://grupotecnologiaeducativa.es/proyectorafodiun/index.php/objetos-en-ra

To produce these objects, different computer programs are used, some of which we present in table 1, indicating at the same time the functions assigned to them.

Table 1. **Programs used to produce the objects**

Software	What is it for
Metaio Creator	Augmented reality programming.
Metaio SDK	Augmented reality software development kit.
Eclipse	Java development environment. Export apk for Android.
Xcode	Java development environment. Export ipa for iOS. Upload to the app store.
Adobe After Effects	Video and sound postproduction. Chroma and key light.
Photoshop	Image postproduction. Graphics. Photomerge. 3D textured.
Macromedia Fireworks	Image postproduction. Graphics.
FFmpeg	Programming on the codec for exporting 3g2 videos. Augment reality.
Microsoft PowerPoint	Buttons in video format with transition effects.
Notepad ++	Professional text editor for code retouching.
Metaio Toolbox	3D based marker extraction.
Autocatch	Photogrammetry.
Artec-Studio	3D scan.
Astrum	Windows installer creator.

Source: own elaboration.

With these objects, different studies are carried out, measuring the different variables with the instruments presented in table 2.

Table 2. **Information collection instruments**

Variable	Evaluation instrument
Academic performance.	*Ad hoc* instrument, with multiple choice test construction, and used under the pretest-posttest modality.
Technology acceptance level.	TAM model (Davis, 1989).
Motivation.	Instructional material motivational survey (IMMS) (Keller, 2010).
Evaluation of augmented reality objects by students.	*Ad hoc* instrument with Likert-type construction.

Source: own elaboration.

The reliability of the instruments is obtained through the application of Cronbach's alpha statistic, reaching the values that we present below: TAM model (0.942), IMMS (0.940), and assessment of augmented reality objects by students. Values that, according to the proposals of different authors (Mateo Andrés, 2004; O'Dwyer and Bernauer, 2014), can be considered high or very high.

The design used for the analysis of the degree of acceptance of the technology by the student, the design that we used was generated from the TAM model generated by Davis (1989), the model indicates that the attitude or predisposition that we have regarding the intention of the use of a technology is fixed by two variables: the perceived usefulness and perceived ease of use, with repercussions on the intention of its use by the student. This allows us to contrast different such as the following:

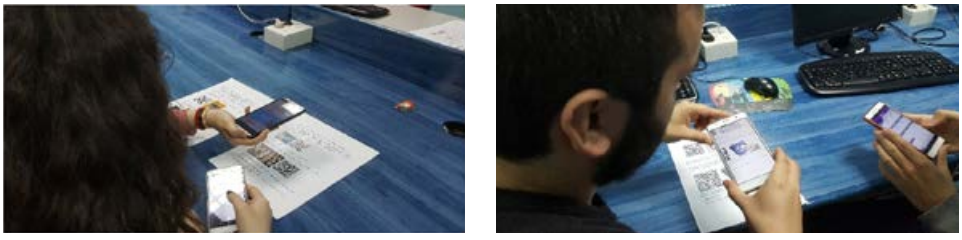
- **H1-H2-H3.** The perception of the technical quality of the augmented reality object produced can positively and significantly affect the perception of enjoyment, the perception of ease and the technical quality of using augmented reality learning objects.
- **H4-H5-H6.** The gender of the subject can positively and significantly affect the perception of enjoyment, the perception of ease and the technical quality of using learning objects in augmented reality.
- **H7-H8-H10.** The perception of ease of use can positively and significantly affect the perception of enjoyment, the perceived usefulness, and the attitudes of use of learning objects in augmented reality.

- **H9-H14-H15-H16.** The perceived usefulness of using learning objects in augmented reality can positively and significantly affect the perception of enjoyment, the attitude towards use, the intentions of use and the academic performance achieved by students in the use of objects. Learning in augmented reality.
- **H11-H12-H13.** The perception of enjoyment can positively and significantly affect the attitudes of using learning objects in augmented reality, the intentions of use and the academic performance achieved by students in the use of learning objects in augmented reality.
- **H17.** The attitude towards use can positively and significantly affect the intention to use learning objects in augmented reality.
- **H18.** The intention to use augmented reality objects can positively and significantly affect the academic performance achieved by students in the use of augmented reality learning objects.

In the case of the designs, that were used regarding motivation. Note that the designs were replicated with the different augmented reality objects produced that corresponded to different areas of knowledge, in different faculties and universities.

For the production of learning objects in augmented reality, the students learned different programs: Augment, Aurasma, Quiver and Chromville. The students were presented with three program topics of the subject, so that, on one of them, and organized by groups, they had to elaborate on them the learning object in augmented reality. The contents offered were Web 2.0, emerging technologies and the role of teachers and students in new technological environments. The objects made by the students were designed using 2D images as markers and included digital content in video format and mainly web links; that is to say, the productions they made could be classified in what is called «notes enriched with augmented reality objects». The degree of acceptance that the experience of producing objects in augmented reality aroused in the students, motivation and academic performance were analyzed (figure 2).

Figure 2. **Production of augmented reality objects by students**



Source: own elaboration.

4. Conclusions

The different investigations that we have carried out through the Rafodiun Project allow us to point out some ideas for the use and incorporation of augmented reality in teaching-learning situations:

- Students have shown high levels of satisfaction when participating in interaction experiences with augmented reality objects, as well as a high degree of acceptance of the technologies involved in the study. In this sense, our results go in the direction of the findings found by other authors (Cheng *et al.*, 2013; Ho *et al.*, 2013; Kim *et al.*, 2016; Marín-Díaz and Sampedro-Requena, 2020; Park *et al.*, 2012; Tarhini *et al.*, 2014; Villalustre Martínez, 2020; Wojciechowski and Cellary, 2013; Yong *et al.*, 2010). At the same time, it should be noted that the technology acceptance model formulated by Davis (1989) has been shown to be effective in knowing the degree of acceptance of augmented reality technologies by students, and as an element to determine future intention of use by them.
- The use of augmented reality is possible in different scientific disciplines, the results found have been identical in the different areas of knowledge where the studies have been carried out. Specifically, these were carried out in the areas of education sciences, medicine, fine arts, architecture, music, and engineering.
- The studies carried out reveal three aspects:
  - Participation in augmented reality experiences increases the motivation of students measured through the IMMS and the different dimensions that make it up (confidence, attention, satisfaction, and relevance).
  - Have found a significant relationship between the degree of motivation and increased performance, the higher the motivation (confidence, attention, satisfaction and relevance), the higher the performance or recall of the information obtained. Similarly, a significant and positive relationship was obtained between motivation and the evaluation made of the objects.
  - The motivation shown is higher when they become producers.
- Students can become resource producers.
- After participating in experiences, students tend to show a high level of intention to use.
- The expert judgment allowed to identify the ten most common programs for the production of objects in augmented reality: Arlab, Armedia, Arpa, ARToolKit, Aurasma, Blippar, Designers ARToolKit, Layar, Vuforia and Wikitude. Of these, the three programs that were rated as requiring more technical knowledge for potential users were: Designers ARToolKit, Vuforia and ARToolKit; the three with more navigation complication: Arlab, Designers ARToolkit and Vuforia; the three that allow incorporating a greater number of resources: Vuforia, Vuforia and Layar; and those that are easier for users to use: Aurasma, Blippar and Arlab.

- The students valued the objects produced, different principles for the design of materials can be obtained from them. The requirements that objects in augmented reality must meet to be used from an educational point of view must be:
  - Brief and direct content modules: according to the characteristics of tablets and smartphones to access educational resources and their main advantage of operating on demand (at any time and place), it is recommended the design of modules of short duration that do not exceed 5 minutes.
  - Flexibility and simplicity: the differences in student abilities in ICT-related topics must be taken into consideration to adapt the contents for a successful teaching process
  - Accessibility and error tolerance: the activities generated must have an intuitive interface that allows quick correction of errors related to navigation and use of the device.
  - Multimedia: augmented reality is one more resource that must be related to other integrated elements such as audio, video, images, considering the aspects of flexibility and synthesis mentioned above.
- Action-oriented: tablets and smartphones are not the goal of the educational process; therefore, the methodology must be practical and interactive.
- Communication and visibility: the portability and connectivity of these devices should lead to the creation of collaborative activities and allow the possibility of sharing the contributions generated in the learning process.
- In constant renewal and updating: the contents used in m-learning and that are directly related to the use of augmented reality must refer to the methodology used, since mobile devices and their software systems are in rapid evolution, incorporating improvements that can be transferred to the proposed educational process.
- The results agree with those achieved in other studies carried out in our context (Garay Ruiz, Tejada Garitano and Castaño Garrido, 2017; Garay Ruiz, Tejada Garitano and Maiz Olazabalaga, 2017).
- Adapted to the characteristics of the devices: not all devices are the same and differ in processing power, size, sensors, memory, etc. (Cabero-Almenara *et al.*, 2022). Each activity devised must be adapted to the different types of hardware and software for the educational process to be successful).
- Improve performance.
- The modality of books and notes enriched with augmented reality objects offers many possibilities to be incorporated into university education. The results found have shown that its use improves learning and awakens a true degree of acceptance of technology by students and the objects produced are valued positively by students. Our work also allows us to point out that augmented reality-enriched notes are perceived by students as easy and flexible to use, showing at the same time a true intention to use them in their training.

Finally, indicate that our study indicates that from an operational point of view it is necessary to provide instructions for handling the object, for students, as the guide/tutorial that was developed in our case.

Regardless of these findings for the educational use of augmented reality, we found others that were more related to the reliability and usefulness of the instruments used and the designs used.

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Contribución de autores. J. B.-O. y A. P.-R. han participado a partes iguales en la elaboración de todos los apartados que constituyen este proyecto y aportación académica.