

<https://doi.org/10.23913/ride.v14i27.1721>

Artículos científicos

Geometría aumentada: desarrollo de un objeto de aprendizaje con realidad mixta usando la metodología Dicrevoa 2.0

***Augmented geometry: Developing a learning object with mixed reality using
Dicrevoa 2.0 methodology***

***Geometria aumentada: desenvolvimento de um objeto de aprendizagem com
realidade mista utilizando a metodologia Dicrevoa 2.0***

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Resumen

Este artículo presenta el desarrollo de un objeto de aprendizaje para apoyar la enseñanza del tema de geometría del espacio en educación básica. Se utilizaron las metodologías Dicrevoa 2.0 y Cascada para el desarrollo de *software* debido a que ambas contienen cinco etapas similares entre sí que pueden abordarse de manera simultánea. Los resultados presentan una aplicación web con distintos cuerpos geométricos y sus características principales, capaces de ser proyectadas en realidad aumentada en dispositivos móviles directamente desde el explorador sin la necesidad de instalar *software* adicional. Se concluye que es posible crear recursos educativos que incorporen realidad virtual o aumentada en páginas web usando la propuesta del World Wide Web Consortium para el uso de realidad mixta WebXR Device API.

Palabras clave: aplicación web, educación, matemáticas, realidad aumentada, recurso educativo abierto.

Abstract

This article presents the development of a learning object to support teaching space geometry in basic education. The DICREVOA 2.0 and waterfall methodologies were used for software development because both contain five similar stages that can be addressed simultaneously. The results present a web application with different geometric bodies and their main characteristics, capable of being projected in augmented reality on mobile devices directly from the browser without installing additional software. It is concluded that creating educational resources that incorporate virtual or augmented reality in web pages is possible using the World Wide Web Consortium proposal for using mixed reality, WebXR Device API.

Keywords: Web Application, Education, Mathematics, Augmented reality, Open Educational Resources.

Resumo

Este artigo apresenta o desenvolvimento de um objeto de aprendizagem para apoio ao ensino do tema geometria espacial na educação básica. As metodologias Dicrevoa 2.0 e Cascade foram utilizadas para o desenvolvimento de software porque ambas contêm cinco etapas semelhantes que podem ser abordadas simultaneamente. Os resultados apresentam uma aplicação web com diferentes corpos geométricos e suas principais características, capaz de ser projetada em realidade aumentada em dispositivos móveis diretamente do navegador sem a necessidade de instalação de software adicional. Conclui-se que é possível criar recursos educacionais que incorporem realidade virtual ou aumentada em páginas web utilizando a proposta do World Wide Web Consortium para utilização da API WebXR Device de realidade mista.

Palavras-chave: aplicação web, educação, matemática, realidade aumentada, recurso educacional aberto.

Fecha Recepción: Abril 2023

Fecha Aceptación: Noviembre 2023



Introduction

Computers have the ability to display complex elements in a graphical interface in a way that is understandable to humans, such as forces on charged particles or in non-uniform fields, as well as the effects of non-projective geometric transformations and high-inertia, low-friction motion (Sutherland, 1965). In recent years, different tools have been created to generate these graphics, known as *virtual reality* (VR) or *augmented reality* (AR), among which are the frameworks for developing mobile applications on IOS and Android operating systems, ARKit (Apple Inc., February 9, 2023) and ARCore (Google LLC, February 9, 2023), respectively. These facilitate the task of implementation on smartphones and unified development platforms, such is the case of Unity, which offers a set of products for the creation of objects in 2D, 3D and VR (Unity Technologies, 2023).

These tools have been used to create video games and simulations, but also to face social problems, such as HuVi, a virtual reality mobile application developed by the National University of La Plata in Argentina (Chirinos, 2020) that aims to show the heritage manifestations of that country to children in vulnerable situations.

The educational field has also benefited from these technologies with the creation of digital teaching material, as is the case of the application for mobile devices developed by Bezares *et al.* (2020) for learning the English language in children in Mexico or the constructivist learning object EnseñAPP implemented in Spain with Unity and Vuforia. This mobile application is aimed at students in the first cycle of primary education and includes topics of linguistic communication, mathematics, basic skills in science and technology, and learning to learn (Castellano and Santacruz, 2018).

Virtual and augmented reality in education is not limited to basic training, since at the higher level there are different applications that help understand different concepts. In the case of fluid mechanics, Álvarez-Marín *et al.* (2017) developed a virtual learning object (VLO) with AR on tablets and smartphones for industrial engineering students at the University of La Serena in Chile.

The above applications belong to non-immersive augmented and virtual reality. This means that they are found on mobile devices and have limited interaction with the user, although there are also those that transport the user to a completely artificial world, hence they are called *immersive*. To do this, they use glasses and hardware specially designed for this purpose. In this section are clinical simulations with VR such as those carried out by the Center for Simulation in Stomatology in Peru (Quenta, 2019), which provide a safe environment for carrying out medical practices.

Recently, the development of applications that implement AR and VR on web pages has begun, using the WebXR Device API, which was presented in 2018 by the World Wide Web Consortium (W3C), an organization in charge of proposing recommendations and standards that ensure the long-term web growth (W3C, 2021). This new API (application programming interface) is based on the device's camera to generate augmented reality, as well as on accelerometers to provide movement images, which may have up to 6 degrees of freedom (6DoF).

Within these applications is the web platform implemented by Ro'fatulhaq *et al.* (2020), who built a database to store images in three dimensions, later retrieve them and present them in mixed reality through WebXR with the aim of helping higher education teachers in teaching engineering concepts.

For their part, Luigini *et al.* (2020) created a game for basic education students that shows different environments in 360 degrees with different states of aggregation of water, some of the landscapes presented are rain, rivers, seas, glaciers, and snow. It is an immersive application based on web technology, which uses the WebXR Device API. The authors dedicate a section to immersive web virtual reality in which they highlight the cross-platform capacity of the standard.

The applications made with the WebXR Device API have shown usefulness in the areas of knowledge where it has been used, so it could be useful in mathematics, specifically in the area of space geometry, where each body is a virtual element projected into the real world. Our proposal (augmented geometry) is a learning object (LO) in web format that presents an interactive way to learn about the different three-dimensional figures that are studied in basic education; In addition, it incorporates augmented reality and has tools for measuring knowledge and evaluating the LO.

Method

The methodology for the design, creation and evaluation of learning objects (version 2) (Dicrevoa 2.0) developed by Maldonado *et al* (2017) was used because its stages are similar to those of the waterfall model of software development (Sommerville, 2011), which is used for the application implementation process.

Figure **1** contains the five phases of each methodology where it is observed that the first three are the same, while the testing stage of the waterfall model has been called evaluation in Dicrevoa 2.0. However, both consist of determining that the program meets the objectives set in the analysis stage. The implementation stage in software development is similar to the publication stage, and both consist of deploying the LO.

Figure 1. Stages of the Dicrevoa 2.0 and waterfall methodology



Source: Self-made

Analysis

The first stage has the purpose of identifying the needs of the learning object and the target audience, for which Table Table 1 proposed by Maldonado *et al* (2017) has been used. The information on the topic, level, profile and context was obtained from the Ministry of Public Education (June 7, 2022).

Table 1. Dicrevoa 2.0 needs matrix

Issue	Geometric bodies
Description	The LO is a web application that presents a set of three-dimensional geometric figures with three degrees of freedom implemented in augmented reality. Each of these highlights the edges and vertices, as well as a short description.
Level	Last grade of primary education and second grade of secondary school.
Student profile	This learning object is designed for students with basic knowledge of geometric bodies. The LO is intended to reinforce the understanding of related concepts.
Estimated time to cover	The estimated time to explore all geometric bodies and interact with the application is 1 hour.
Educational context	Students in the last grade of primary education continue the study of geometric bodies, which they had already begun in the previous grade by analyzing the characteristics of right triangular and rectangular pyramids. Activities are proposed for the student to develop their spatial imagination.
Type of license	Creative Commons Attribution-ShareAlike License 3.0
Non-functional requirements	WebXR-compatible web browser

Source: Own elaboration based on Maldonado *et al.* (2017)

Design

This phase of the Dicrevoa 2.0 methodology is divided into two sections: on the one hand, there is the instructional design that addresses the educational aspect and, on the other, the multimedia design, which contemplates the technological aspect.

Instructional design of the learning object

This section addresses the educational topic, that is, the objectives, contents and activities that the educational resource will contain. For this section, the tables proposed by Maldonado *et al* (2017) have been used for this purpose, following the Dicrevoa 2.0 methodology.

The objective of this LO has been to analyze the different bodies and the concepts involved in three-dimensional figures that are studied in basic education. In this sense, it has been considered that the taxonomy of the word *analyze* is to discriminate, distinguish, select, integrate, structure and delineate (Bloom *et al.*, 1956). In this way, after using the LO, the student will be able to remember the name of the different figures, discriminate between edges and vertices and incorporate new terms into their knowledge. To create the structure of the learning object, the template proposed by Maldonado *et al.* (2017) was used, which is shown in Table 2.

Table 2. Internal structure of the learning object

Structure	Issue	Description
Start	Description	Presentation of the LO.
	Aim	Purpose of the use of the learning object.
	Manual	Brief steps to follow for the use of augmented reality.
Contents	Compatibility	Browsers that can implement WebXR.
	Faces, vertices and edges	Geometric body in augmented reality highlighting a face, a vertex and an edge.
	Cube	Cube in augmented reality. Information displayed: name, number of faces, edges and vertices.
	Sphere	Sphere in augmented reality. Information displayed: name.
	Prism	Rectangular prism in augmented reality. Information displayed: name, number of faces, edges and vertices.
	Cylinder	Cylinder in virtual reality. Information displayed: name, number of faces, edges and vertices.
	Pyramid	Pyramid with square base in augmented reality. Information displayed: name, number of faces, edges and vertices.
	Cone	Cone in augmented reality. Information displayed: name, number of faces, edges and vertices.
	Icosahedron	Icosahedron in augmented reality. Information displayed: name, number of faces, edges and vertices.
	Dodecahedron	Dodecahedron in augmented reality. Information displayed: name, number of faces, edges and vertices.
Activities	Projection	Incorporation of predetermined virtual objects into the real world.

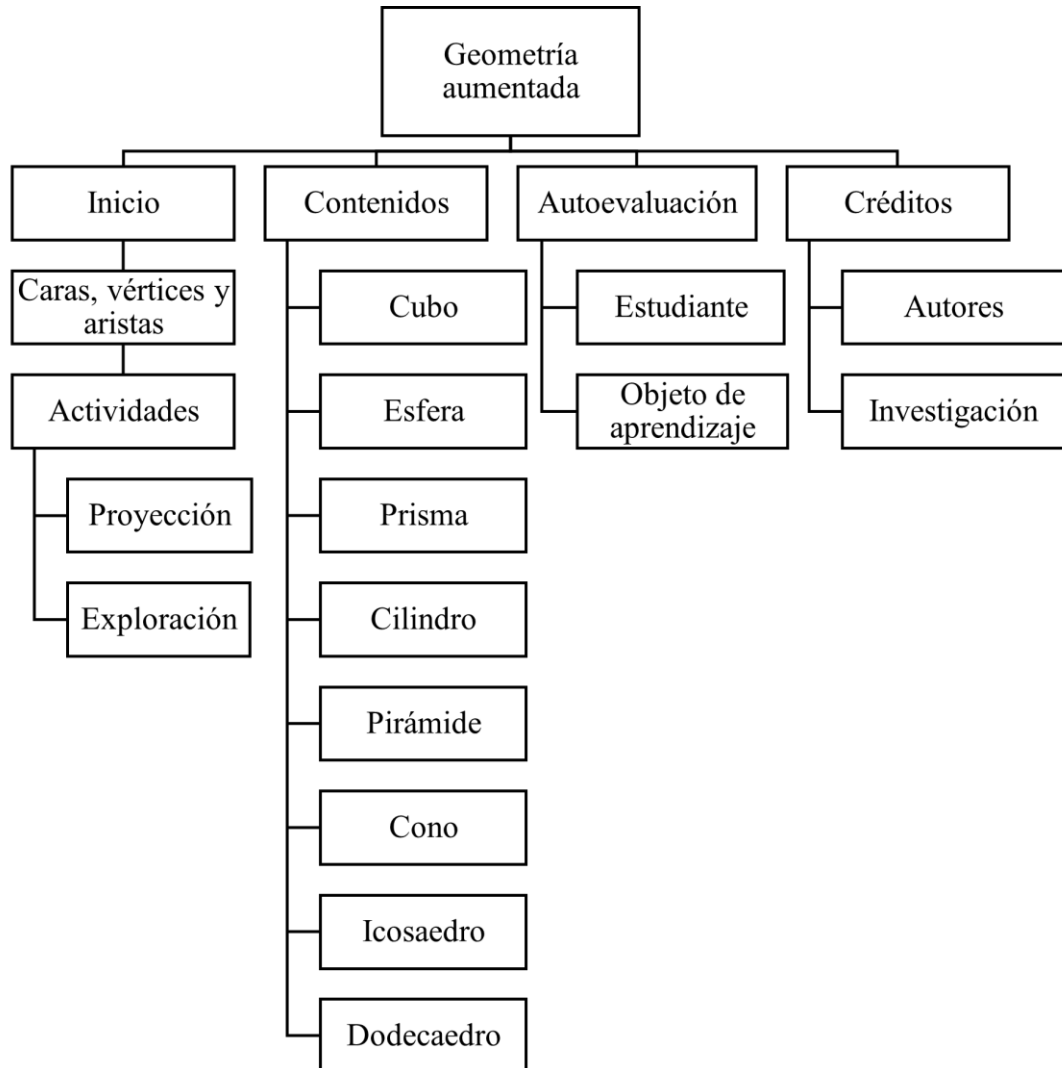
	Figure exploration	Observation of objects in three dimensions with augmented reality from different angles.
Self-assessment	Student assessment	Eight questions with images about the name and components of the different figures presented. The result is shown to the student upon completion.
	LO evaluation	Evaluation of the learning object by scoring from 1 to 5 the different characteristics that it must meet.
Credits	About	Acknowledgment of authors and sources.

Source: Own elaboration based on Maldonado *et al.* (2017)

The objective of the learning object is to analyze the concepts that involve geometric bodies, so its contents must be conceptual. In this sense, it is recommended that they have a hierarchical structure (Figure 2), which presents the hierarchical structure of the contents of the learning object. In this you can see the projection and exploration activities.

- Projection. Students must execute the creation of the virtual object and establish it in a real place with the help of the device's camera. The application provides a button to start viewing the figure in augmented reality that students have to press and accept the necessary permissions.
- Exploration. They must physically move around the virtual object to observe it from different angles, since the figure remains fixed in the real place in which it was created.

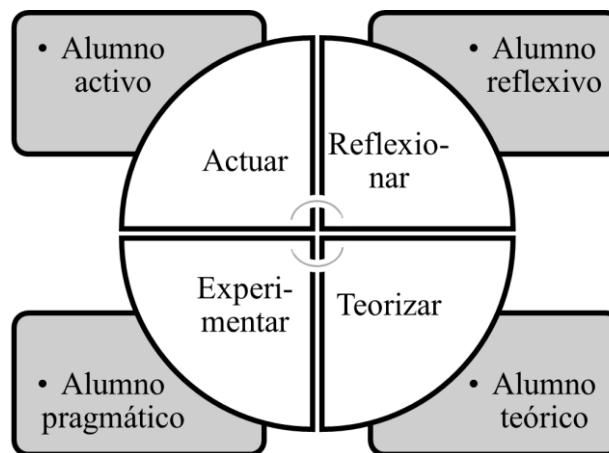
Figure 2. Contents of the learning object



Source: Own elaboration based on Maldonado *et al.* (2017)

For developing the teaching strategy the cycle of Kolb and Kolb (2023) has been considered, who ensure that optimal learning is achieved through the implementation of the four phases summarized by Maldonado *et al.* (2017) (figure 3).

Figure 3. Kolb's cycle



Source: Maldonado *et al.* (2017)

According to Kolb and Kolb (2023), a complete learning experience must allow the student to reflect, theorize, and experiment. Furthermore, Maldonado *et al.* (2017) point out that when using this strategy, the four types of students are considered, that is, active, reflective, theoretical, and pragmatic established by Alonso *et al.* (2007). Considering the above, the following activities have been defined according to each stage:

- **Act.** The LO begins by showing a geometric body different from those the student knows (torus knot) with a button that invites him to project it in augmented reality. The active type of student seeks new experiences, which is why they need to execute AR before understanding the structure of a three-dimensional geometric figure, which awakens their attention.
- **Reflect.** Reflective students tend to be observers and analyze situations from different perspectives to draw their own conclusions. For this, the educational resource has been provided with different geometric bodies that change their color each time the AR is executed. In addition, they are in constant movement, which allows each element to be viewed from multiple angles, which offers the student information to build their own knowledge.
- **Theorize.** Once the student has obtained his conclusions in the reflective stage, he can continue with the theoretical aspect. This type of student seeks to base their knowledge on logic and coherence. To do this, the educational resource provides specific data for each element, such as name, description and mathematical formula to calculate area and volume.
- **Experiment.** The learning object has been developed under the premise that experimentation is the best way to learn. For the pragmatic student, practice is the

fundamental element to build knowledge; for this reason, interaction with the figures is included through the device's sensors and camera.

From the above, the teaching strategy has been established based on the pedagogical theories of different authors applied to the development of learning objects. At the end of this phase, two multiple-choice digital questionnaires have been implemented for the self-assessment stage. The first evaluates the student's performance, that is, if the learning object reinforces the students' knowledge about geometric bodies and the parts that compose them. The second is designed to check whether the LO is functional and practical. Both are presented in the evaluation phase.

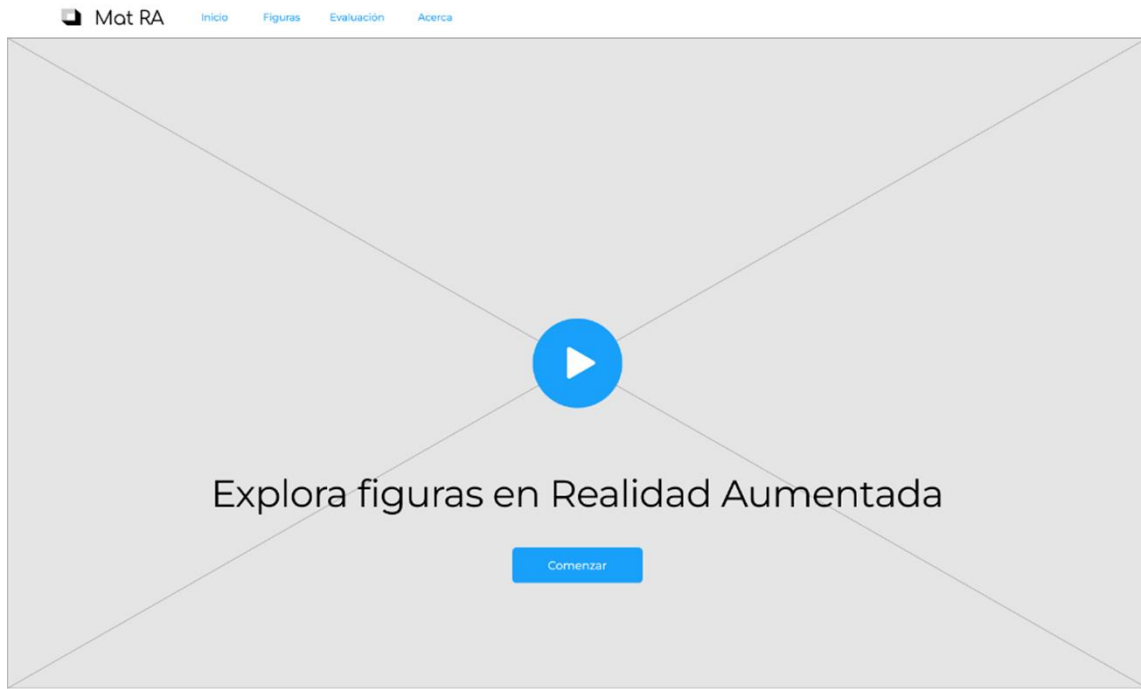
Multimedia design of the learning object

The design of the interface prototypes was carried out with the help of Figma (December 27, 2022), a vector graphics editor that contains templates for different purposes, one of which is used in the development shown in Figure 4 . A simple and sober theme has been chosen in order to give the user the message that mathematics is easy, but formal.

The application includes spaces to reorder the elements on mobile devices, with small screens without losing the general structure of the learning object; Font size and images are also adapted to each device. This responsive design allows the page to increase its audience by being able to be viewed on a desktop, tablet or smartphone.

The theme typography and colors have been taken from the original Figma design (December 27, 2022); However, some features have been modified to achieve adaptability to different devices, incorporating the recommendations of the Bootstrap cascading style sheet (CSS) framework (Bootstrap team, June 13, 2022).

Figure 4. General interface design



Bienvenid@

Descripción

Nemo enim ipsam voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est.

[Saber más](#)

Objetivo

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[Saber más](#)

Manual

Consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit amet, consectetur, adipisci velit, sed quia non numquam.

[Saber más](#)

Compatibilidad

Eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit amet, consectetur, adipisci velit, sed quia non numquam eius modi tempora.

[Saber más](#)

Source: Own elaboration based on the Figma template (December 27, 2022)

Implementation

The third stage of the Dicrevoa 2.0 and waterfall methodology is the implementation of the software. In this, Maldonado *et al.* (2017) recommend using authoring tools such as eXeLearning, which allow the generation of learning objects quickly and easily; However, they are limited to predetermined designs that, although good, are insufficient for this case study. For this reason, we have chosen to develop our own using code editors for web applications creation.

The LO has been programmed in HTML, CSS and JavaScript using the Bootstrap CSS framework for responsive design and Three.js from JavaScript for the creation of

three-dimensional objects. Three.js in version r148 implements WebXRManager, a class that represents an abstraction of the WebXR Device API and internally uses WebGLRendered for image rendering (Three.js, December 27, 2022).

Metadata

Learning objects consider metadata an essential part of their composition because they allow them to be classified and found efficiently. Currently, there are standards for this purpose, such as the Dublin Core Metadata Initiative (DCMI), Learning Object Metadata (LOM) and Metadata Learning Resource (MLR) (Maldonado *et al.* , 2017).

Given that the main function of metadata is the location and description of the educational resource, it has been decided to add them in the implementation phase (waterfall) or publication (Dicrevoa 2.0) because the learning object repositories implement different fields according to with their policies. Furthermore, Table 3 shows the Dublin Core metadata tab that will be used in the last stage of development.

Table 3. Metadata

Metadata	Value
Title	Augmented geometry
Creator	Leonel Hernández-González
Issue	Solid geometry
Description	Web application that presents a set of geometric bodies capable of being projected in augmented reality. Each figure highlights the edges and vertices, and also presents a short description.
Editor	Leonel Hernandez Gonzalez
Collaborators	Anabelem Soberanes Martín Magally Martínez Reyes
Date	2023-01-01
Type	Image collection
Format	Website
Identifier	https://www.geometriaaumentada.com
Source	ISBN: 9978-310-34-7
Language	Spanish
Relation	Requires WebXR

Coverage	Latin America
Rights	Creative Commons

Source: Own elaboration with information from Merlot (December 1, 2022)

Tests/evaluation

The next stage of the development of the learning object is probably the most divergent between the selected methodologies, since waterfall considers this phase for the review of the implementation process and the correction of possible errors. On the other hand, Dcrevoa 2.0 consists of the development of instruments for measuring the knowledge acquired by the student and the efficiency of the LO. Since the testing phase is essential in any software implementation and its result is the version of the application that is presented in the results section, this section only addresses the evaluation.

Student assessment

It consists of a questionnaire of eight multiple choice questions. In each item, a three-dimensional image is shown without augmented reality, but it can be rotated with the help of the pointer or fingers. Subsequently, there is the question and three answer options of which only one is correct. Table Table 4 presents the distribution of the questionnaire.

Table 4. Student assessment

Image	Question	Answers	Correct
Cube with highlighted points at the vertices.	What element does the image highlight?	a) Edges b) Vertices c) Faces	b) Vertices
Cube with faces of different colors.	What element does the image show?	a) Edges b) Vertices c) Faces	c) Faces
Sphere	What is the name of the figure?	a) Cube b) Sphere c) Pyramid	b) Sphere
Pyramid	What is the name of the figure?	a) Cylinder b) Sphere c) Pyramid	c) Pyramid
Cylinder	What is the name of the figure?	a) Cylinder b) Cone c) Icosahedron	a) Cylinder
Cone	What is the name of the figure?	a) Pyramid b) Cone c) Icosahedron	b) Cone
Icosahedron	What is the name of the figure?	a) Pyramid b) Dodecahedron c) Icosahedron	c) Icosahedron
Dodecahedron	What is the name of the figure?	a) Cone b) Dodecahedron c) Icosahedron	b) Dodecahedron

Source: Own elaboration based on Maldonado *et al.* (2017)

Evaluation of the learning object

The evaluation is made up of ten questions that can be answered on a scale from 1 to 5, where one is not complying with what is established and five is equivalent to satisfying what is required. The different items represent the characteristics that a learning object must cover according to different authors. Table 5 shows the evaluated concept and a brief description.

Table 5. Evaluation of the learning object

Characteristic	Description
Reuse	This learning object can be used for different subjects or academic degrees.
Accessibility	Searching and locating it on the Internet is easy.
Interoperability	It can be used on different devices and platforms, which allows it to be part of other learning objects.
Adaptability	The learning object does not require modifications to be used in different schools, groups or grades.
Granularity	The entire site forms a single learning object and each page (cube, cone, pyramid, evaluation, etc.) can be used independently for different purposes.
Durability	It is not perishable. It cannot be spoiled by common use by the end user.
Independence	It does not require other learning objects or the intervention of technical personnel for its operation.
Scalability	It can serve several students at the same time and increase its capacity; In addition, there is the option to request the addition of more content.
Educability	Its purpose is to support the teaching-learning process of a specific topic.
Reachable	It is designed so that students at the recommended level understand the content and obtain or reinforce their knowledge, which can be measured and verified.

Source: Own elaboration based on Maldonado *et al.* (2017)

Publication/implementation

This last stage consists, in both cases, of the deployment of the educational resource with the intention of presenting it to the general public. For this purpose, the Merlot repository has been chosen, a system that provides access to online learning and support materials (Merlot, December 1, 2022). This repository of educational resources contains its own fields that make up the metadata of each LO, within which are:

- Title. Name of the learning object.
- Discipline. Branch of science to which it belongs.



- Description. Brief explanation of the functionality of the educational resource.
- Keywords. Short phrases to optimize the location of the LO.
- Type of material. The way in which the information is presented.
- Audience. Target audiences.
- Language. Language in which the content is presented.
- Authors. Developers' name.
- Cost. Access price.
- License. Creative Commons level.

With this, the learning object development process ends. Up to this point, a web application has been created for the study of geometric bodies in three dimensions with the ability to be projected in augmented reality.

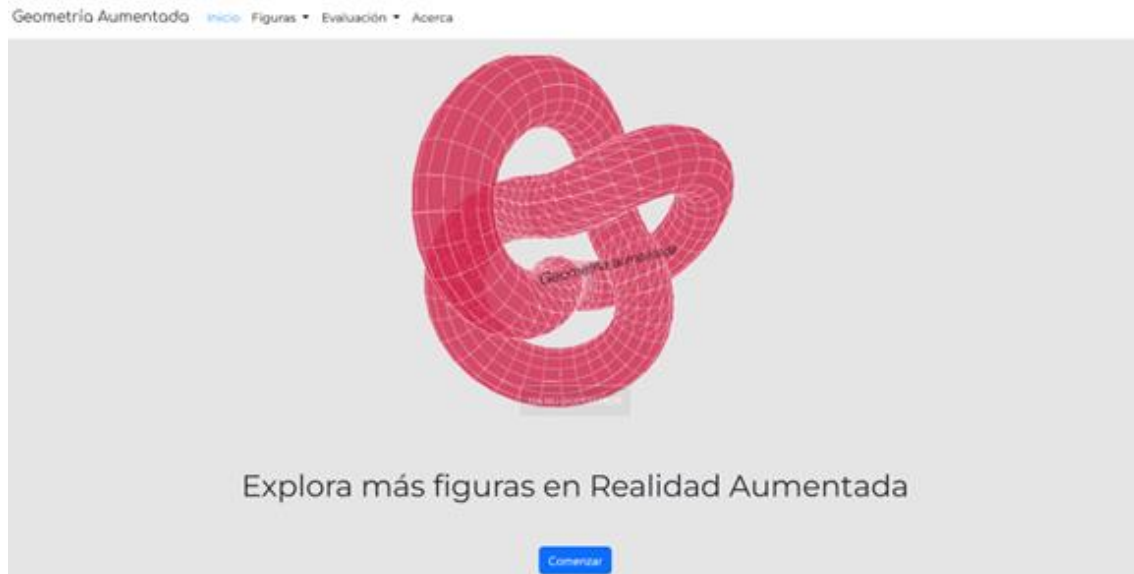
Results

Using the Dicrevoa 2.0 methodology for learning objects and waterfall for software development, an educational resource has been created using the WebXR API with the purpose of implementing augmented reality in a web application. The result is available at <https://www.geometriaaumentada.com/>, and is described in three sections: main page, figures and evaluation.

Homepage

Figure 5 shows the LO home page based on the design presented in the method section. At the top left is the name of the learning object (augmented geometry). This name has been selected to refer to the use of augmented reality in teaching geometry. Next is the menu containing four elements: the start (main page), the catalog of available figures, the evaluation instruments described in the previous section and the description of the educational resource.

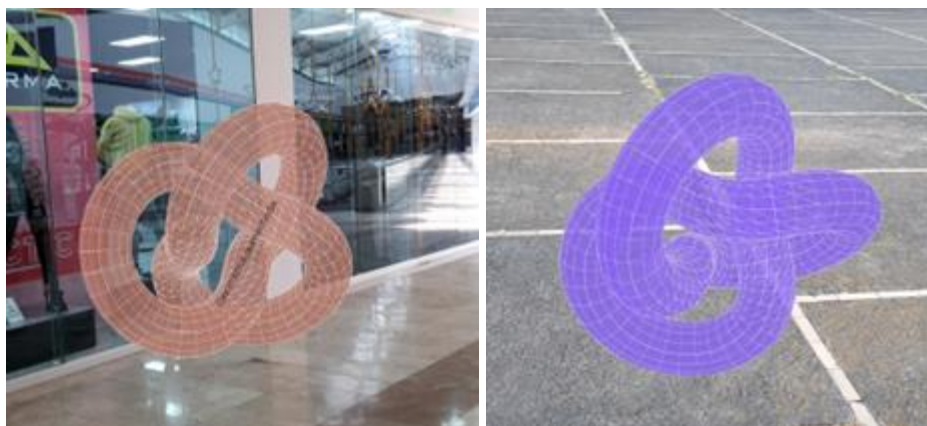
Figure 5. LO home page



Source: Self-made

The main element is a toroid knot that, although it does not belong to the geometric bodies studied in basic education, has the objective of attracting and generating interest in the student. To do this, there is an action button that motivates the student to explore the catalog of figures; In addition, it contains a button labeled *Start AR*, which executes the projection of the figure in augmented reality (figure 6).

Figure 6. Figure in augmented reality

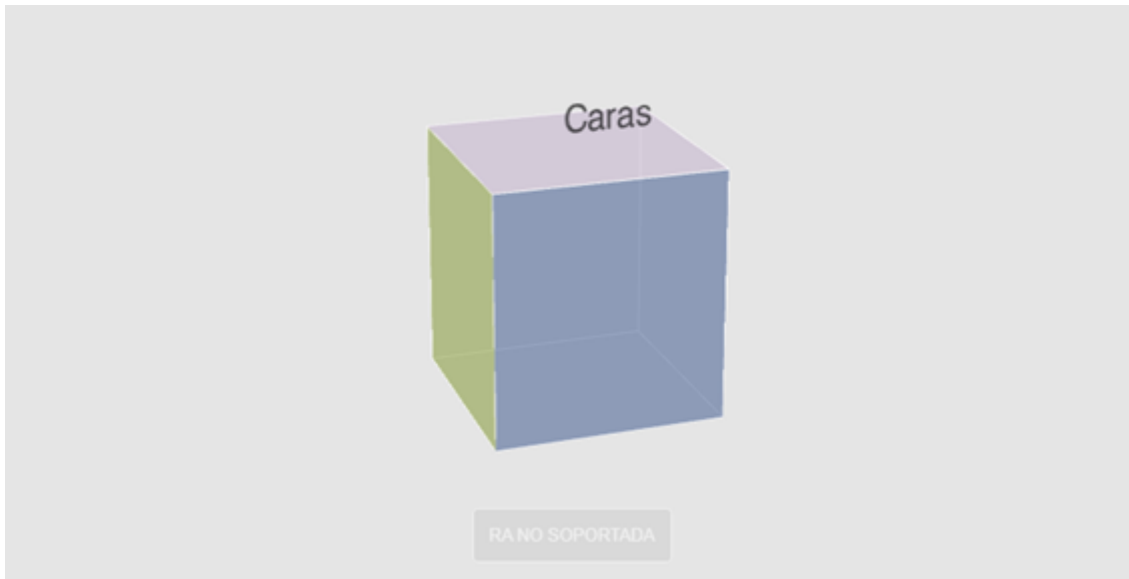


Source: Self-made

Subsequently, there is the section of elements of geometric bodies represented by three cubes: the first highlights the vertices, the next the edges and the last the faces. Figure 7 shows the cube designed to highlight the faces, which have different colors that

also change each time the page is refreshed. This applies to all figures in the learning object.

Figure 7. Faces of a geometric body

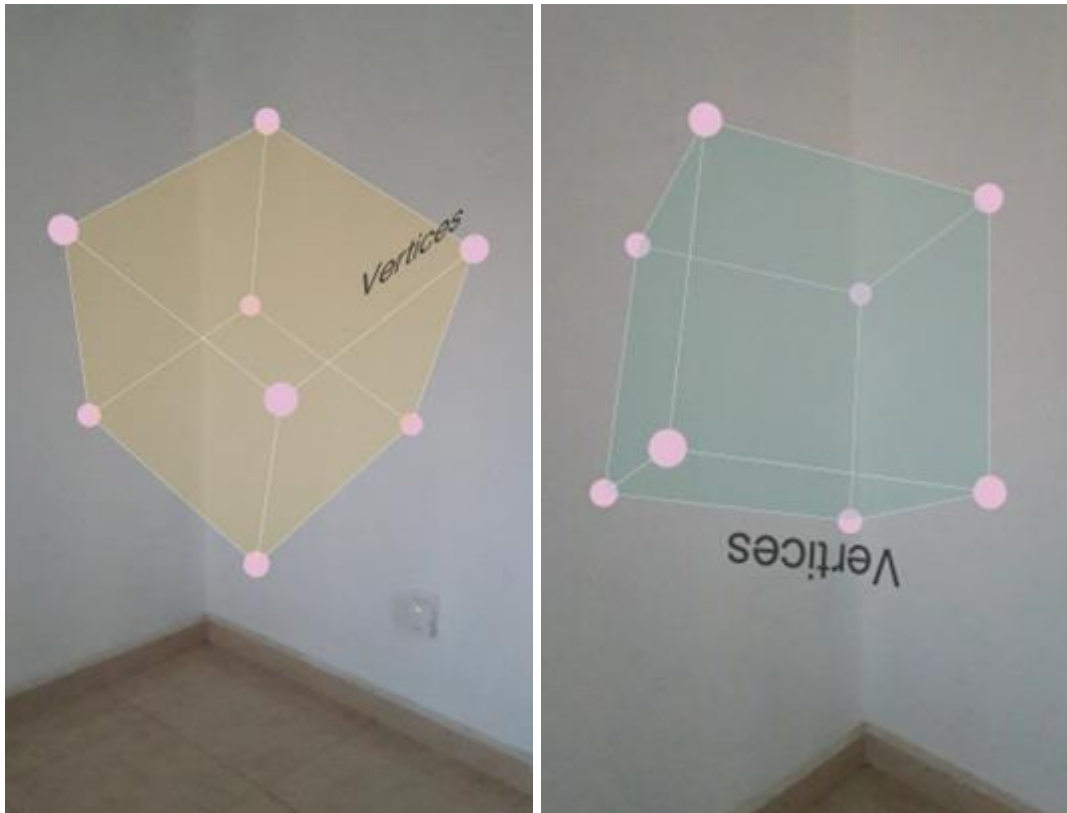


Source: Self-made

When the device does not have the features to use augmented reality, a disabled button is displayed with the legend *AR not supported*. This component is displayed on devices that are capable of rendering the element, but not projecting it, such is the case of desktop computers, which mostly do not implement the necessary hardware (such as sensors and camera).

Figure 8 shows the projection of the cube in augmented reality, highlighting its eight vertices represented by small spheres. This shows the rotation of the geometric body in execution: the image on the left was taken at the beginning of the projection, while the one on the right a few seconds later. For this, a function was created that performs rotation in the X and Y axis, which is executed each processor cycle, so the speed may vary in devices with different characteristics.

Figure 8. Vertices in augmented reality



Source: Self-made

Later, there is a list of the available geometric bodies; In addition, a contact button that directs the user to a page with a form and the technical support email has been added. In this section you can make suggestions or report errors. Finally, the footer contains links related to the learning object and the Creative Commons license type.


Figures

The learning object contains eight geometric bodies available for projection that are studied in basic education: cube, sphere, rectangular prism, cylinder, pyramid, cone, icosahedron and dodecahedron. Each element has a special page with its definition — taken from the Institute of Mathematical Sciences of the Escuela Superior Politécnica del Litoral de Ecuador (2006) —, its characteristics (such as the number of faces, vertices, and edges), as well as the formulas for the calculation of area and volume.

Figure 9 shows the page for the dodecahedron on a non-compatible desktop computer, where the content described above can be seen, while Figure 10 (on the left) presents the image of a smartphone capable of running augmented reality, and at right the projection of the geometric body.

Figure 9. Dodecahedron page on desktop

Geometría Aumentada Inicio Figuras * Evaluación * Acerca



Dodecaedro

Dodecaedro

Descripción

Un dodecaedro es un poliedro regular, limitado por 12 caras que son pentágonos, tiene 20 vértices y 30 aristas.

Características

Caras: 12
Aristas: 30
Vértices: 20

Área

$$A = 12 \frac{\sqrt{25 + 10\sqrt{5}}}{4} a^2$$

$$A = 3 \frac{\sqrt{25 + 10\sqrt{5}}}{4} a^2$$

$$A \approx 20.65a^2$$

Donde a es la longitud de una arista.

Volumen

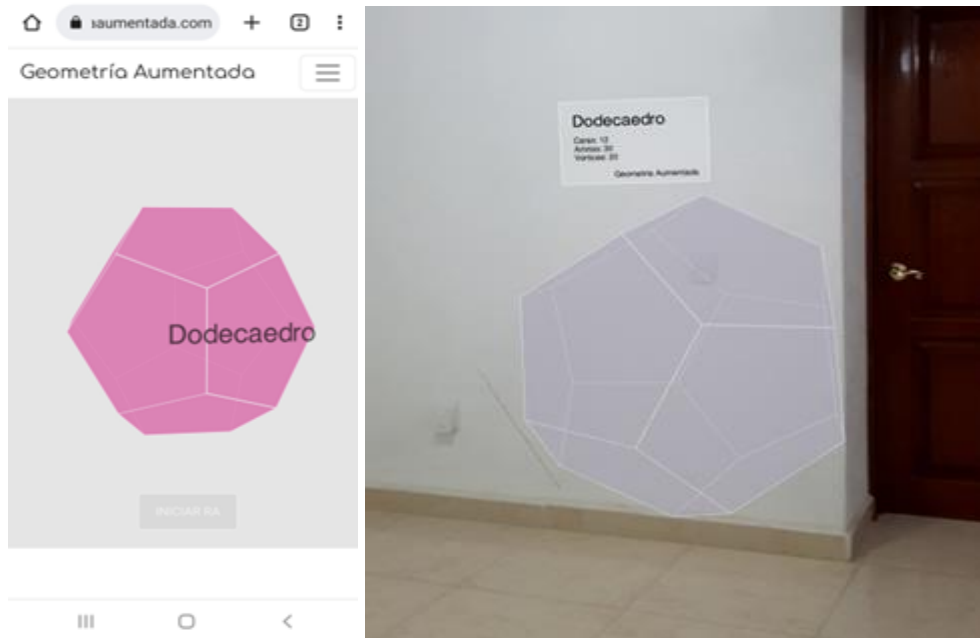
$$V = \frac{1}{4} (15 + 7\sqrt{5}) a^3$$

$$A \approx 7.66a^3$$

Donde a es la longitud de una arista.

Fountain: Own elaboration

Figure 10. Dodecahedron page on supported device



Source: Self-made

The projected image in augmented reality implements a white plane on top (as shown on the right of Figure 10). This contains the name of the element and its characteristics and is intended to remind the student of the information while exploring the geometric body. This way, he learns while having fun.

Assessment

As an indispensable element of a learning object, two evaluation instruments have been added: the first has been designed to measure the student's progress. It contains eight items with a three-dimensional image capable of being manipulated with the pointer or fingers on mobile devices. Although it is not possible to project them in augmented reality, the user can rotate and increase the size to view all angles and thus select the correct answer from the three options provided.

Figure 11 shows the first element of the student assessment with a cube on the left and the item number, question, and three options on the right. All questions are required fields, so if any is not answered, the student will be notified with a message at the bottom of the form. In addition, the score obtained in this evaluation will be indicated to the user.

Figure 11. Student assessment



Source: Self-made

On the other hand, the evaluation of the learning object is incorporated, which consists of the ten most relevant characteristics of the LOs. These can be rated from one to five stars, depending on the user's perception. Each element contains a short description to help understand the concept. Figure 12 presents the first three elements of this instrument. The results of this evaluation are stored in a relational database for the purposes of analysis and improvement of the application.

Figure 12. Evaluation of the learning object



Source: Self-made

With the elements presented in this section of the research, the development of a learning object for the topic of space geometry that incorporates augmented reality through the WebXR Device API proposed by the W3C as the new standard for this

purpose has been shown. Furthermore, the final result is a responsive web application that contains activities for the student and evaluation instruments for the student and for the created resource.

Discussion

The results obtained in the implementation process of the described LO confirm that the Dicrevoa 2.0 methodology proposed by Maldonado *et al.* (2017) is useful for the creation of learning objects, since it provides a set of well-defined and documented steps capable of being reproduced and applied to modern systems. Furthermore, it adapts to traditional software development methodologies that have similar stages, as is the case of waterfall, which allows them to be addressed jointly and reduce development time, as proposed by Fierro and Bosquez (2016) and Bermeo *et al.* (2018).

In addition, the standard proposed by the W3C WebXR Device API (2021) has been shown to be suitable for the implementation of augmented reality on the web. This confirms what was stated by Fanini and Cinque (2020), Luigini *et al.* (2020), Ro'fatulhaq *et al.* (2020), Fanini *et al.* (2021), Rodríguez *et al.* (2021) and Rodríguez *et al.* (2022) regarding the use of WebXR in the development of web applications containing mixed reality.

Therefore, WebXR Device API can be used to create learning objects that require AR or VR in a web environment. The most common 3D rendering frameworks on the web implement this technology to abstract functionality and provide the programmer with a fast and efficient way to incorporate extended reality into their applications, such is the case of Three.js (2022) in recent versions.

Conclusions

Using the Dicrevoa 2.0 and waterfall methodology, it is possible to develop modern learning objects, such as those that use augmented or virtual reality due to the similarity that exists between the stages of each one; However, it is necessary to consider that software development is often cyclical, that is, it requires the iteration of each of the stages to reach a finished product (at least in the implementation stage). On the other hand, the stages of Dicrevoa 2.0 are similar to other educational software development methodologies, which could be adapted to the waterfall model; However, it has detailed and robust documentation, with enough examples to address the pedagogical and technological aspects.

From the tests carried out on the LO presented in this research, it is observed that the virtual elements generated with WebXR have a similar performance to that of mixed

reality applications created specifically for mobile devices; However, web technologies do not require the installation of additional programs, which represents an advantage on devices with little storage capacity.

This concludes that the new standard for the use of virtual and augmented reality on the web is efficient in the implementation of educational software, since it reduces the development time of learning objects by being able to create them in a single technology and implement them in different platforms.

Future lines of research

Some future work to demonstrate effectiveness in the teaching-learning process can be done through a pretest and posttest using the student assessment instrument provided in the application. In this way, it can be confirmed that the use of virtual or augmented reality in education promotes the acquisition of knowledge efficiently, as proposed by Yarin and Gamarra (2022).

In addition, the use of WebXR is recommended in the implementation of educational technology not only in learning objects, but also other open educational resources, such as serious video games, videos where the use or development of web applications with this API is disclosed, elements reusable as a plugin or complements for web pages, all based on the results of this research and the works cited above.

Finally, the use of the new standard is recommended in updating educational applications that are currently found on native operating system platforms - such as Windows, MacOS and Android, among others - in order to provide cross-platform functionality and thus achieve greater reach.

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