SpaceGeo_AR: augmented reality application for teaching and learning spatial geometry by deaf and non-deaf students

SpaceGeo_AR: aplicativo de realidade aumentada para o ensino e aprendizado de geometria espacial por estudantes surdos e não surdos

SpaceGeo_AR: aplicativo de realidad aumentada para la enseñanza y el aprendizaje de la geometría espacial por parte de alumnos sordos y no sordos

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Abstract
Objective: to present the SpaceGeo_AR application with augmented reality resources for teaching and learning spatial geometry aimed at deaf and non-deaf students. Methodology: the Heroku platform was used to program the application, a cloud system that allows the development of mobile applications through numerous resources of web technologies. Results: the application allows the registration of teachers and students, where the former has permissions to create, delete and edit classes and questionnaires, while the student is allowed access to the contents of Position Geometry (a chapter of Spatial Geometry), as well as how to answer questionnaires associated with this theme. Final considerations: applications to improve teaching and learning in the classroom have become a constant in an increasingly technological world, where augmented reality can help in this process, especially when considering Spatial Geometry, a topic strongly related to the three-dimensional. Another trend is the inclusion of people with disabilities in teaching processes, a feature that was also implemented in the application. With this, it is expected that the application can help deaf and non-deaf teachers and students with the learning of Position Geometry through the interactions that augmented reality allows to perform.
Keywords: Augmented reality; Deafness; Learning; Mobile application; Spatial geometry; Teaching.

Resumo
Objetivo: apresentar o aplicativo SpaceGeo_AR com recursos de realidade aumentada para o ensino e aprendizado de Geometria Espacial direcionado para estudantes surdos e não surdos. Metodologia: para a programação do aplicativo foi utilizada a plataforma Heroku, um sistema em nuvem que permite o desenvolvimento de aplicações móveis através de inúmeros recursos de tecnologias web. Resultados: o aplicativo permite o cadastro de usuários professores e alunos, onde o primeiro tem permissões para criar, excluir e editar turmas e questionários, enquanto ao aluno é permitido o acesso aos conteúdos da Geometria de Posição (um capítulo da Geometria Espacial), assim como responder questionários associados com essa temática. Considerações finais: aplicativos para melhorar o ensino e aprendizagem em sala de aula tem se tornado uma constante em um mundo cada vez mais tecnológico, onde a realidade aumentada pode auxiliar nesse processo, principalmente quando se considera a Geometria Espacial, tema fortemente relacionado com o tridimensional. Outra tendência é a inclusão de portadores de deficiência em processos de ensino, recurso que também foi implementado no aplicativo. Com isso, espera-se que o aplicativo possa auxiliar professores e estudantes surdos e não surdos com o aprendizado de Geometria de Posição através das interações que a realidade aumentada permite realizar.
Palavras-chave: Aplicativo móvel; Aprendizagem; Ensino; Geometria espacial; Realidade aumentada; Surdez.

Resumen

Objetivo: presentar la aplicación móvil SpaceGeo_AR con recursos de realidad aumentada para la enseñanza y aprendizaje de geometría espacial dirigido a alumnos sordos y no sordos. Metodología: para la programación del aplicativo se utilizó la plataforma Heroku, un sistema en nube que permite el desarrollo de aplicaciones móviles a través de numerosos recursos de tecnologías web. Resultados: el aplicativo permite el registro de docentes y alumnos, donde el primero tiene permisos para crear, eliminar y editar clases y cuestionarios, mientras que el alumno tiene acceso a los contenidos de la Geometría de Posición (un capítulo de la Geometría Espacial), así cómo responder cuestionarios asociados con este tema. Consideraciones finales: aplicativos para mejorar la enseñanza y el aprendizaje en el aula se han convertido en una constante en un mundo cada vez más tecnológico, donde la realidad aumentada puede ayudar en este proceso, especialmente al considerar la Geometría Espacial, tema fuertemente relacionado con lo tridimensional. Otra tendencia es la inclusión de personas con discapacidad en los procesos de enseñanza, característica que también se implementó en el aplicativo. Con esto, se espera que el aplicativo pueda ayudar a docentes y estudiantes sordos y no sordos con el aprendizaje de Geometría de Posición a través de las interacciones que permite realizar la realidad aumentada.

Palabras clave: Aplicación movil; Aprendizaje; Enseñanza; Geometría espacial; Realidad aumentada; Sordera.

1. Introduction

This section focuses on teaching and learning of Spatial Geometry, deafness, the advancement of mobile applications for different solutions and augmented reality (AR), a technique that involves virtual reality (VR) and that advances in an accelerated way in applications for mobile devices.

1.1 Mathematics and Spatial Geometry

Learning mathematics represents one of the most difficult stages for students, whether during elementary or high school, and interest in this subject consistently declines over this period (Watt, 2004; Frenzel et al., 2010). In the specific case of Spatial Geometry, an important topic in mathematics and addressed in this work, the student does not always demonstrate a "geometric imagination" sufficient to solve the problems of geometry (Slezáková, 2011).

As for teaching, mathematics teachers show difficulties in presenting the student with an effective thinking mechanism to mentalize and construct spatial images during the process of solving three-dimensional geometry (Garrity, 1998 and Gurny, 2003). Silva et al. (2020) emphasize that there is a gap between students and teachers caused by traditional methods, which are, and sometimes, reduced to content memorization processes, making teaching something demotivating for students, who do not always show interest in learning; and with that they are not able to achieve the appropriation of knowledge.

The latest PISA[1] (Programme for International Student Assessment) census, an instrument that measures student performance in the areas of science, reading and mathematics, placed Brazil in 66th position in the 2018 ranking, which is a cause for concern.

1.2 Deafness

Interfering with the development of language, speech and learning, deafness is considered one of the most serious problems when the individual's social life is questioned, which ends up affecting the student's school performance, as well as his entire life, including in the professional context (Cruz et al., 2009). The Brazilian demographic census of 2010, which registered people with different disabilities for the last time, indicated the country with 9.8 million people with hearing impairment, whose total at the time indicated 5% of the Brazilian population. On the other hand, equal opportunities for all individuals is a trend

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[1] https://download.inep.gov.br/acoes_internacionais/pisa/documentos/2019/relatorio_PISA_2018_preliminar.pdf. Accessed on 04/26/2022.

that is increasingly present at a global level, as can be seen with the Declarations of Jakarta[2] (1997) and Salamanca[3] (1994). Despite all this worldwide effort in terms of inclusive rights, deaf students still face numerous difficulties when questioning school and professional inclusion, or even in social life (Cruz et al., 2009).

Dessbezel et al. (2018) describe that the teaching of mathematics to the deaf person deserves attention as a new element emerges, the mathematical language, with all its theorems, postulates and demonstrations. The authors complete that, when considering official language of the the deaf in Brazil (LIBRAS), there are many mathematical terms that still do not have a gestural translation (signs), which forces interlocutors to negotiate new signs to represent these situations.

Although the Brazilian Federal Constitution of 1988 guarantees access to education without discrimination (Art. 206, paragraph I)[4], most schools are not prepared to receive special students, and when considering education for the deaf, the educator encounters difficulties regarding the communication aspect with students (Silva et al., 2022). And in this context, Mallmann et al. (2014) understand that despite the efforts of educational institutions to include students in these conditions, the communication factor becomes an obstacle for the deaf student to succeed in their learning.

1.3 Mobile Applications

Technological resources, and almost always computational, have made the lives of users much easier, where innovative solutions that are accessible to the population are always sought, and in view of this, smartphones are increasingly present in people's lives, mainly because these devices can be purchased today at a relatively affordable cost. When these technologies are brought to Education, innovative and interactive teaching resources emerge, making the traditional teaching format more dynamic, where the teacher can use technological tools to build more dynamic learning environments (Pereira et al., 2020). Pimenta et al. (2021) describe that the ubiquity of current technologies in people's daily lives ends up imposing potentially mediating resources when these technologies are inserted into teaching processes.

1.4 Augmented Reality

AR can be understood as a kind of advance of VR. Vince (1995) describes VR as a technique that provides interactivity with the user, making its use something interesting because it goes beyond passivity, resources traditionally observed in two-dimensional applications. Burdea (2003) defines VR as an interface that involves simulations and interactions in real time through the different sensory channels of the individual.

Appeared in the 1990s, AR is a technology capable of superimposing virtual objects in the real world through the use of some technological device, allowing the user to increase their vision (Bajura, 1995). For Azuma (1997), AR allows the user to constantly interact with three-dimensional objects that are inserted into the real world through computer applications, and highlights that AR has advantages over VR because it allows manipulation of these objects through different points of view. When comparing both technologies, Feiner (1997), understands that VR only replaces the real world, while AR complements the physical world we live in with additional information.

As described, the pioneering work with AR was developed during the 1990s, and today studies and resources with this technique are observed in different areas of science, with applications in entertainment (Pokémon Go[5]; Costa et al., 2019), in the e-commerce (Welivita et al., 2017), in industry (Costa et al., 2021), in education, as well as in other areas.

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[2] Document signed in 1997 during the Fourth International Conference on Health Promotion and promoted by the World Health Organization. It aims to promote the social responsibility of health.

[3] United Nations resolution for the purpose of dealing with principles, policy and practices in special education.

[4] https://www2.senado.leg.br/bdsf/bitstream/handle/id/518231/CF88_Livro_EC91_2016.pdf. Accessed on 04/29/2022.

[5] https://play.google.com/store/apps/details?id=com.nianticlabs.pokemongo&hl=pt_BR&gl=US. Accessed on 04/27/2022.

AR seems to be increasingly present in teaching processes. Ayer et al. (2016) present a game-based AR system to assist civil engineering students. Lee (2020) carried out a study with technical students in carpentry to find out if the resources offered by the observation of virtual prototypes through AR could facilitate the furniture manufacturing process, saving time and avoiding material waste. Gomes et al. (2019) present an application for learning geometric solids, while Fernández & Delgado (2020) propose a system for modeling polyhedral, both with AR-based visualizations and interactions.

In a literature review study on digital technologies for teaching Spatial Geometry proposed by Oliveira et al. (2021) several digital tools were seen, including AR resources. However, the authors report that most of these works deal only with modeling and interactions with geometric solids, and there are few studies that mention other themes of Spatial Geometry, such as relative positions between lines and planes in space, parallelism and perpendicularity of these elements, in addition to other topics of Position Geometry. Given this scenario, this study aims to present the SpaceGeo_AR application with augmented reality resources for teaching and learning spatial geometry aimed at deaf and non-deaf students.

2. Methodology

Considering the classification criterion by Pereira et al. (2018) for research methodologies, the study has a qualitative approach. The application development considers the requirements gathering, analysis and design, implementation and testing phases, defined by Pressman (2011) as "incremental and interactive life cycle of a system". In this section we will describe the methodology used for the development, and then the test protocols that were performed with the application.

2.1 Application Development

The SpaceGeo_AR application was developed for smartphones and tablets with Android operating systems. For the development of the software, the Heroku platform (https://www.heroku.com) was used, a cloud system that allows the development of computational applications in a scalable environment and free of charge for testing.

The programming language used was Javascript, a high-level, multiplatform language that comes with a large number of libraries, which are blocks of code ready to assist in program development. One of these Javascript libraries is AR.js, dedicated exclusively to AR applications. The AR.js library supports web resources, is free and accepts several formats of virtual objects.

The SpaceGeo_AR application uses obj and mtl file formats for virtual objects. The first stores the geometric data of the virtual object, for example, cubes, spheres, cylinders and others, and its dimensions (length, volume, angle, etc.), while the second stores the data related to the material, such as color, texture, etc. For AR implementations in SpaceGeo_AR, ARCore resources were also used, a system developed by Google to incorporate AR techniques directly into mobile devices.

Another library used in the application development was React.JS. It is a programming resource for web and mobile interfaces in a fast, scalable[6] and simple way. The function of this library is to create all the pages and other resources of the application, involving texts, images, videos, formatting of all elements (textual or not), as well as access to the database (DB).

For the DB service, MongoDB was used. The basic function of a DB is to store data/information that are used in computer applications, whether mobile or not. For this study, MongoDB proved to be a more suitable DB because it is highly flexible[7], cross-platform[8], scalable, presents good computational performance and can handle large volumes of data. The last

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[6] The scalability of a system allows it to be modified simply and quickly, without compromising basic functions. It is extremely advantageous in the computational environment because the possibilities of programming languages and types of hardware and software are very variable in a highly competitive market.

[7] In context, flexible means that the DB accesses data faster because all the data needed for a given query are in unique "documents", unlike other DB formats that have a "relationship" between the data, as is the case of BD SQL (Structured Query Language), which makes it more complex when programming.

[8] Cross-platform: Support for different operating systems.

resource implemented in the application was vLIBRAS, a tool that aims to help the translation of textual content into Brazilian Sign Language (LIBRAS); chapter 3.4 describes this feature in detail.

All the tools described are distributed free of charge to both the programmer and the user, generating no financial expense for the development or use of the proposed applications. Although the more robust versions of the Heroku platform are paid, the free version was sufficient for the intended tests. Figure 1 relates the two types of users and their roles in the system through the use case diagram.

Figure 1. Use case diagram.
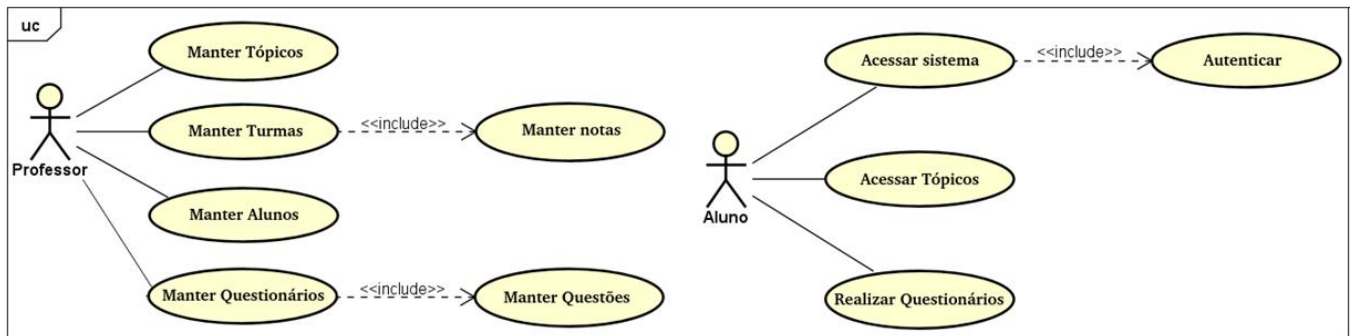
Source: Authors (2022).

The diagram in Figure 1 shows that the teacher maintains two additional functionalities in relation to the student user, which is to maintain Groups (Turmas) and Questionnaires. In fact, while the student accesses Topics and completes Questionnaires, the teacher also manages (creates and edits) groups (turmas) and questionnaires to be carried out by students from different classes.

The activity diagram is shown in Figure 2, defined by Larman (2000) as the sequential and parallel representation of activities in a process, which can be useful for the construction flow of the algorithm to be created.

Figure 2. Activity diagram.
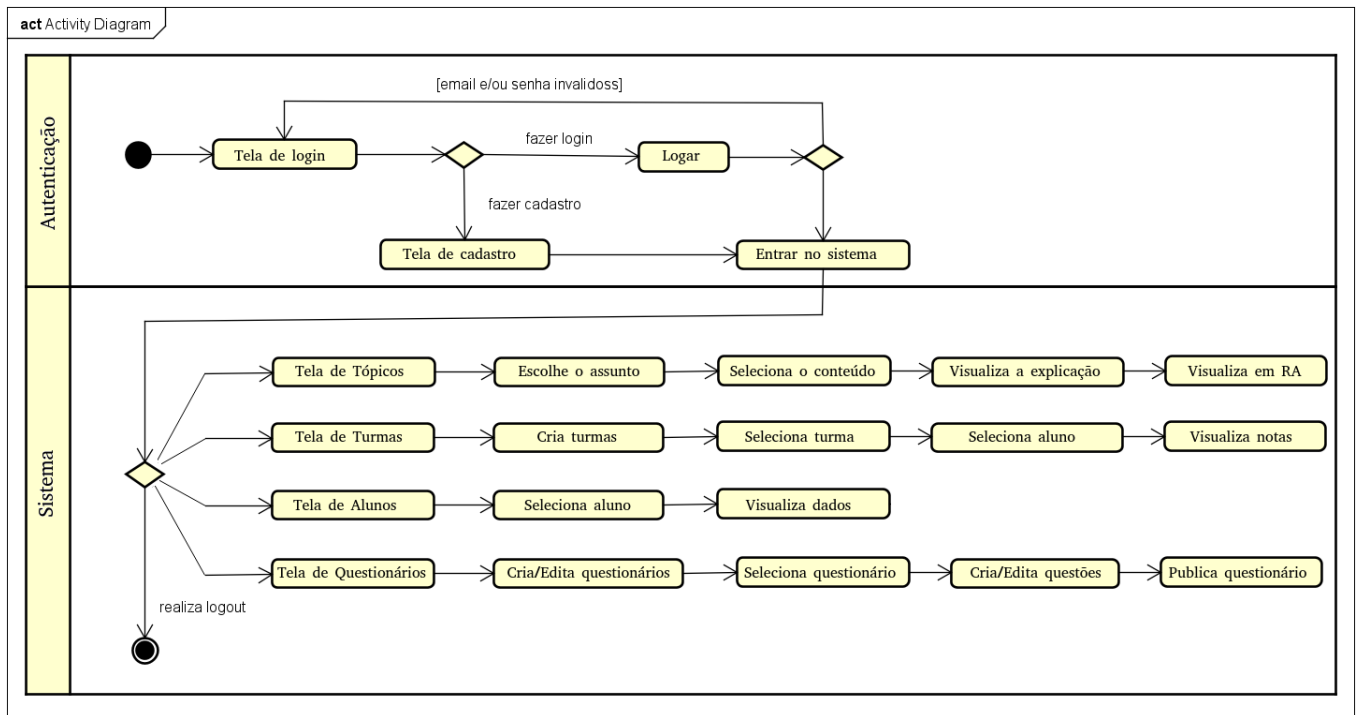
Source: Authors (2022).

The diagram in Figure 2 corresponds only to the activities of the teacher user. For the student user, the authentication diagram is the same, while the other system activities are basically summarized in topic views (Spatial Geometry content) and questionnaires, where the authentication processes and access to the application's various functionalities can be observed.

2.2 Testing Protocols with the Application

The SpaceGeo_AR application was used on five smartphones, according to the configurations described in Table 1. On all devices, the system worked without difficulties, crashes and other inconveniences that could hamper or prevent the use of the application, especially with the AR resources, functions that demand minimal memory and camera resources for good application performance.

Table 1. Smartphones used with the SpaceGeo_AR tests.

| Modelo (ano)	Processador (GHZ)	RAM (GHZ)	Armazenamento (GB)	Câmera (megapixel)	Sistema Operacional
Samsung Xcover3 (2015)	Quad-Core 1.2	1,5	8	5	Android 7.0
Samsung S5 (2015)	Quad-Core 2.5	2	16	8	Android 7.0
Samsung S8 (2017)	Octa-Core 2.3	4	16	8	Android 8.0
Samsung S9 (2019)	Octa-Core 2.3	6	64	12	Android 10.0
Xiaomi Poco F3	Octa-Core 3.2	8	256	48	Android 11.0

Source: Authors (2022).

With the first two devices (Samsung Xcover3 and Samsung S5) it was necessary to update the Android system to version 7.0 (previous: versions 5 and 6, respectively). This update was necessary because the AR implemented in the app is

dependent on ARCore (currently Google Play Services for AR), a system offered for free by Google, is 22 MB and can be easily installed on devices with Android 7.0 operating system or higher.

3. Results and Discussion

The first version of the application is accessible via https://spacegeo.herokuapp.com. To register in the system, the user must click on the corresponding button or log in directly through Google (Figure 3a).

Figure 3. Screens: login (a), register (b) and start (c).
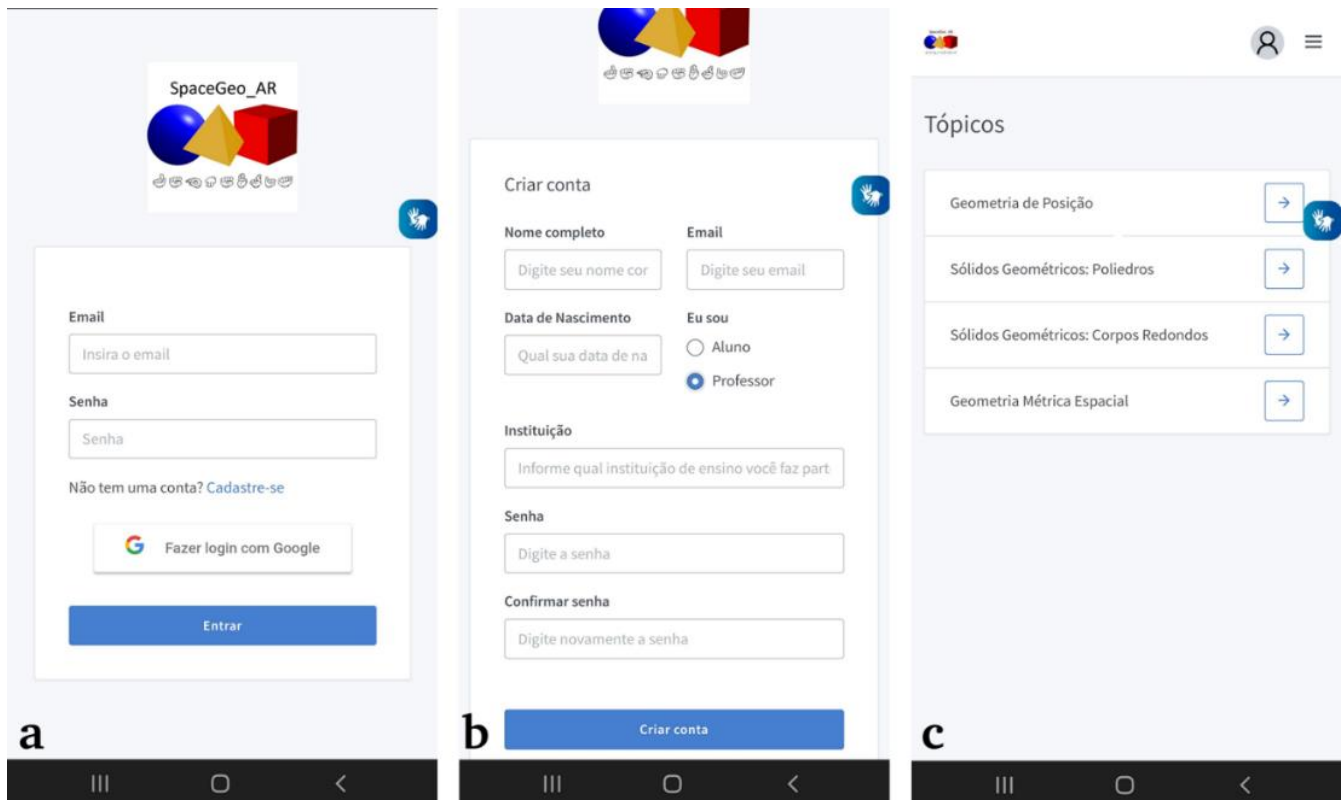
Source: Authors (2022).

In both cases, to complete the registration, it is necessary to inform the type of user (Figure 3b), whether student or teacher. For future logins, it is important to memorize the e-mail (and password), because only through this data will it be possible to access the system.

3.1 Teacher User

After logging in, the teacher user will have access to the first screen of the application (Figure 3c). Figure 4a shows the screens for accessing theoretical content (Topics functionality). For the first version of SpaceGeo_AR, only the topic Position Geometry was implemented, a theme that covers four classes in the application (Figure 4b).

**Figure 4.** Access to theoretical content (Topics functionality).
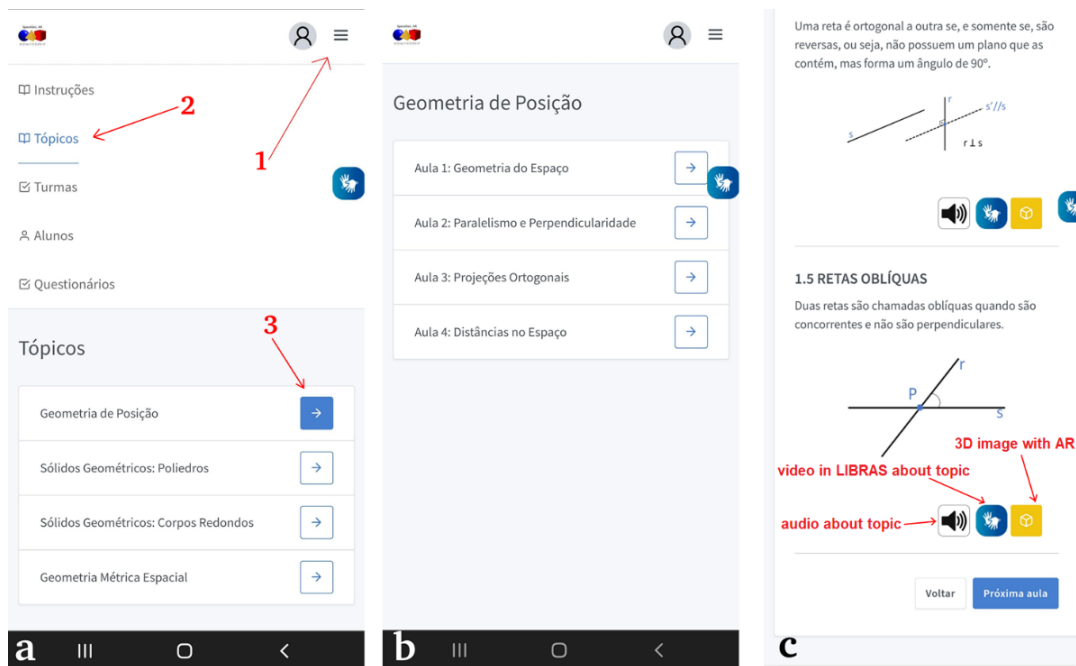
Source: Authors (2022).

All Position Geometry themes implemented in the application have the same access resources, and as an example, we are considering the theme '1.5 Oblique Lines' (Figure 4c). For each concept, the application provides its 2D image, an audio and a video in LIBRAS on the subject, as well as an access button to the AR resource, where it is possible to observe and manipulate a 3D scenario.

The Classes functionality (Figure 5a) allows you to create, delete and manage teacher-administered student classes.

Figure 5. Classes functionality.
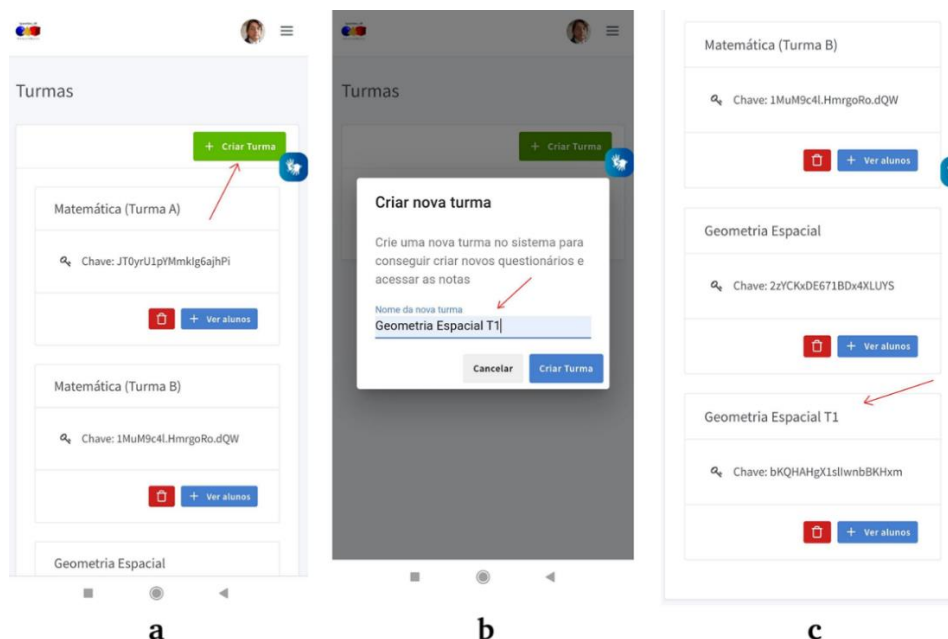
Source: Authors (2022).

Every time a class is created, the system generates a key, which can be sent to the students who will be part of that group (Figure 5c). The delete class function is irreversible, where all student information is lost, such as completed questionnaires, personal data, among others.

The SpaceGeo_AR Students functionality displays the list of all students enrolled in the teacher's different classes (Figure 6a). This space allows five options for the user, according to the icons shown in the images in Figure 6.

Figure 6. Students functionality.
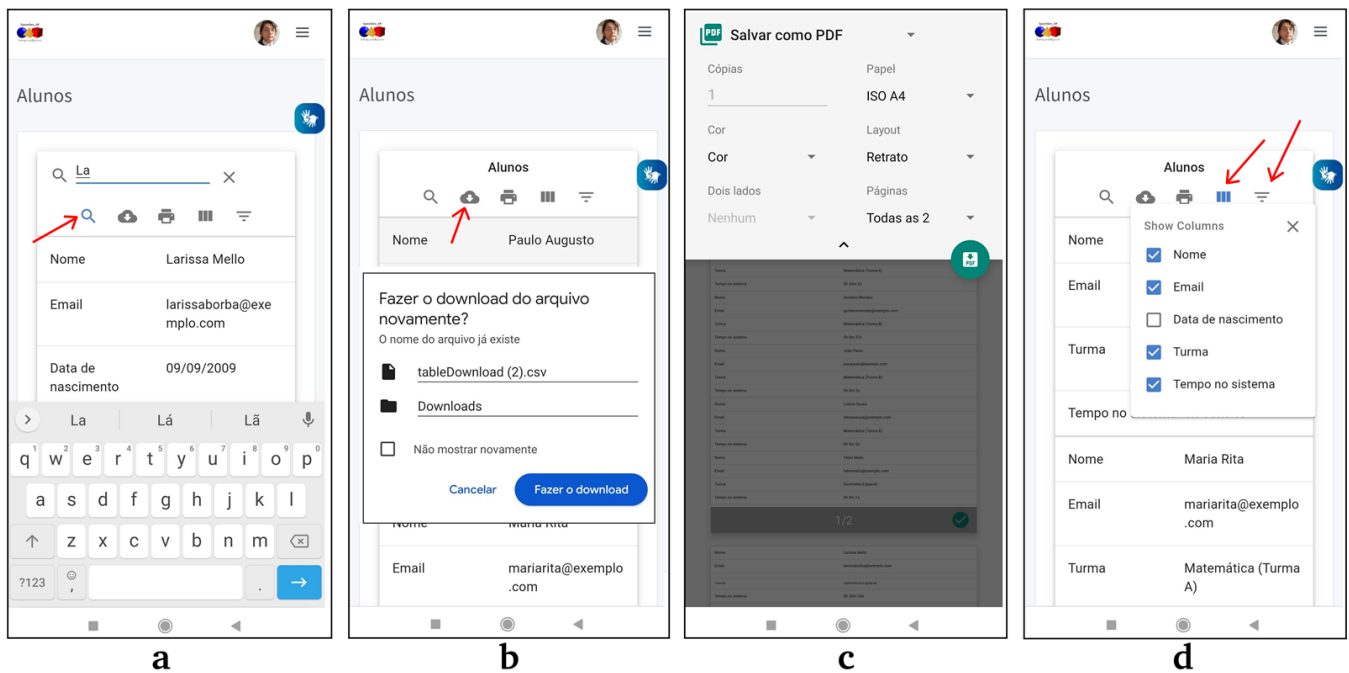
Source: Authors (2022).

The first function (a) allows you to search for a student from the list. With the second (b) it is possible to download a CSV file with the data of all students; this document format can be imported by spreadsheets and text editors. The printer button (c) has two functions. With the first it is possible to print the list of students and their data, while the second saves the same document directly in PDF format. The last two icons (d) allow the teacher to select the student data they want to display in the app.

In Questionnaires, two options are presented. The Standard Questionnaire represents a previously created document with ten Spatial Geometry questions. For the teacher, this questionnaire can only be viewed, while the student can answer it as an evaluative activity. The second, and main functionality, corresponds to My Questionnaires, where it is possible to create, delete, edit and apply questionnaires to different classes of the teacher, even simultaneously. In our example, the 'Assessment 4 (29/03/2022)' questionnaire was first created with a value of 11.50 (grade) and associated with two classes (Figure 7a).

Figure 7. Questionnaires functionality.
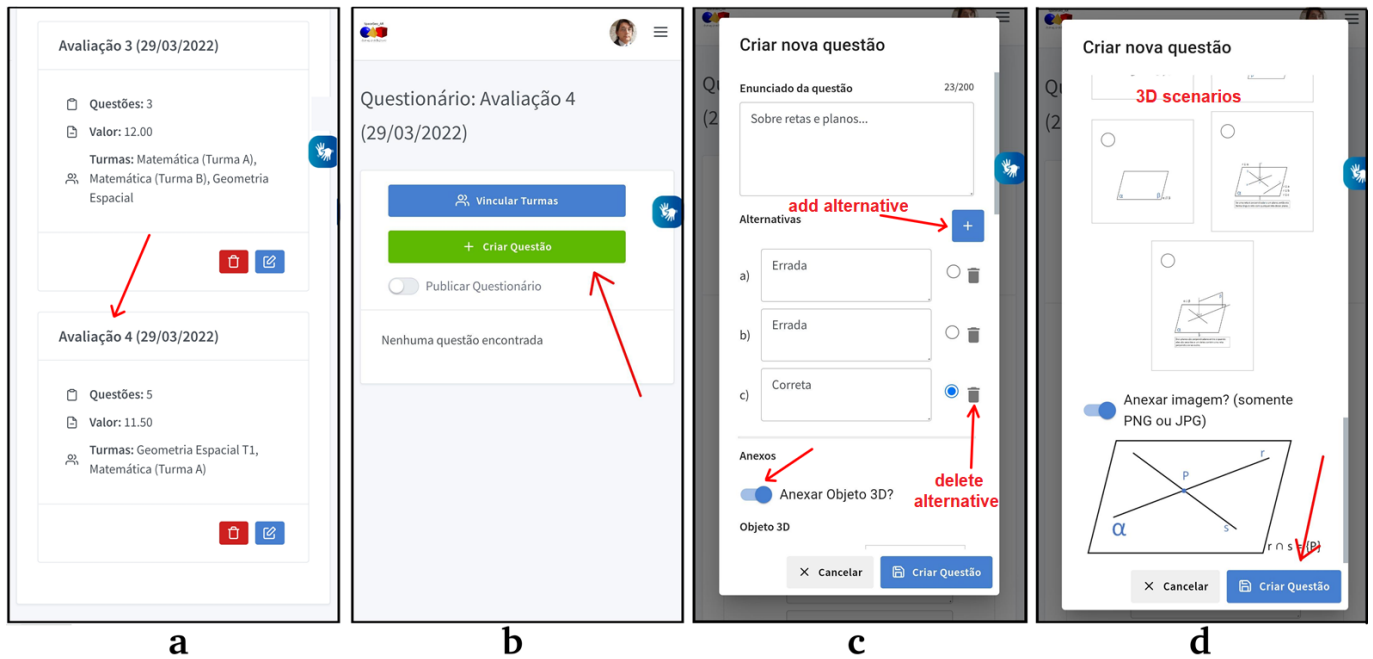
Source: Authors (2022).

After its creation, the questionnaire enables the functions to create, delete and edit the questions that will be part of the new document. When a question is created within a questionnaire (Figure 7b), the user can attach a 3D scenario registered in the system (Figure 7c), in addition to a two-dimensional image (Figure 7d), which can be advantageous to improve the wording of the question.

3.2 Student User

As a student, the user does not have the features of Classes, Students and, in My Questionnaires, cannot create questionnaires, since these assignments apply only to the teacher. Otherwise, the permissions and functionality are basically the same.

3.3 Use of AR in SpaceGeo_AR

The AR scenarios were implemented in all classes of the Position Geometry topic for both users (student and teacher), totaling 33 virtual environments. Some of these scenarios are illustrated in Figure 8, where the user interacts with the virtual contents of some classes available in the system, for example, distance between parallel lines and planes (Class 4.4), orthogonal projection between figure and plane (Class 3.2), relative positions between two straight lines in space (Class 1.2), in addition to other contents observed in Figure 8.

Figure 8. Some 3D scenarios observed in the theoretical part of the application.
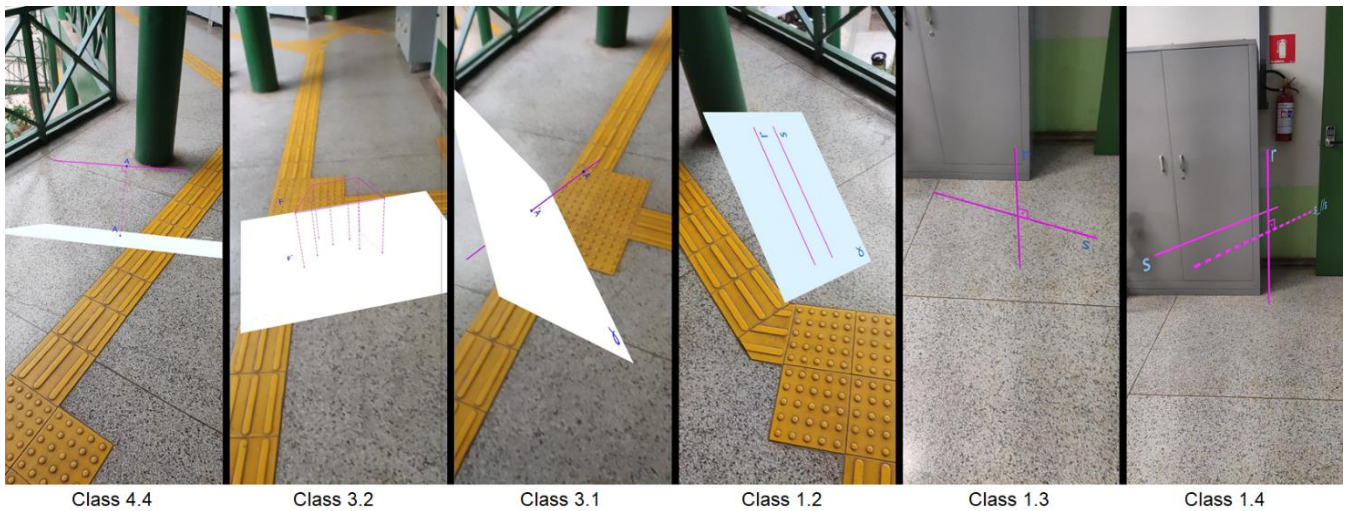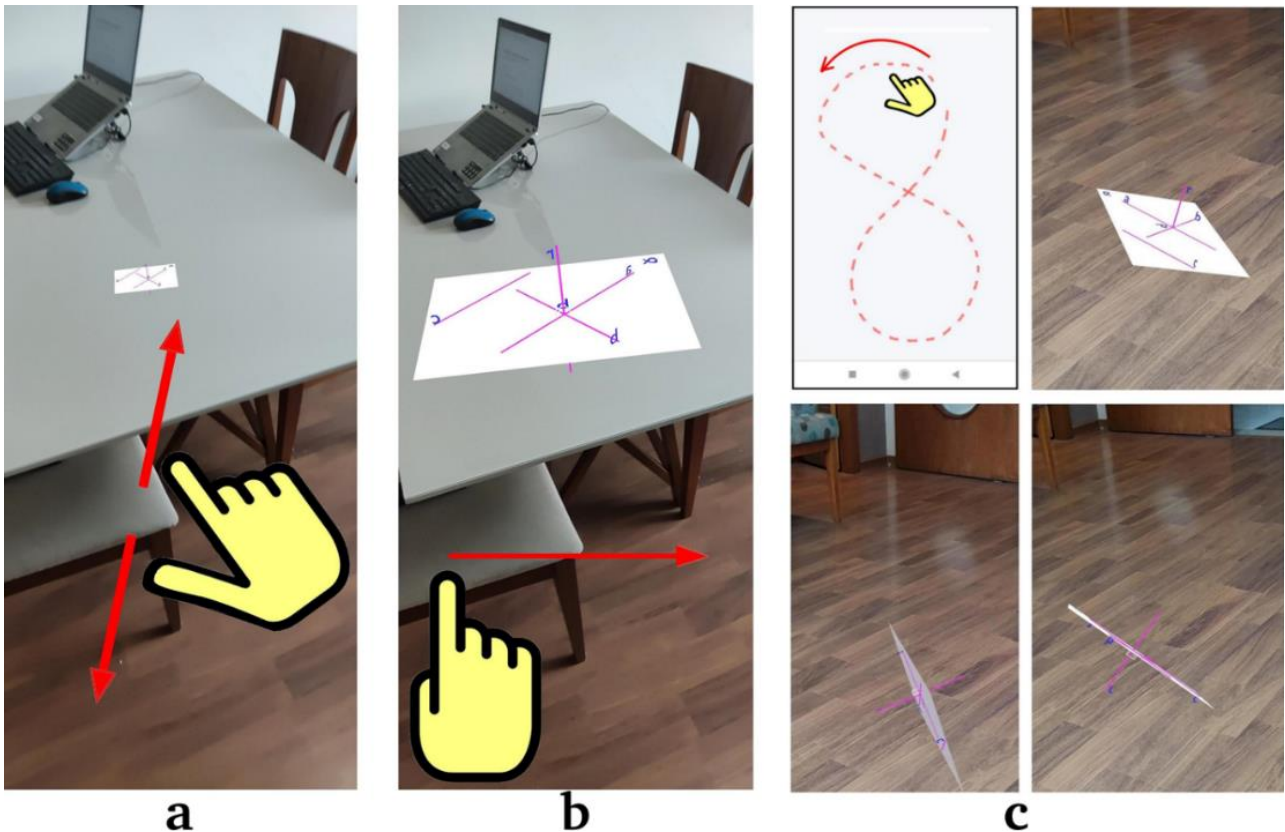

Source: Authors (2022).

As a teacher, the user can attach a 3D scenario to a question in a quiz (Figure 7c), which will be viewed by students in related classes. To enable the phone for 3D views, you need to install the 'Google Play Services for AR' tool, although most devices already come with this feature pre-installed from factory.

When the 3D scenario is rendered on mobile, that is, when it is shown on the device's screen, the application allows some interactions with the virtual object, as seen in Figure 9.

Figure 9. Interactions with the 3D scenario of Lesson 2.3: scale (a), rotation (b) and random movements (c).
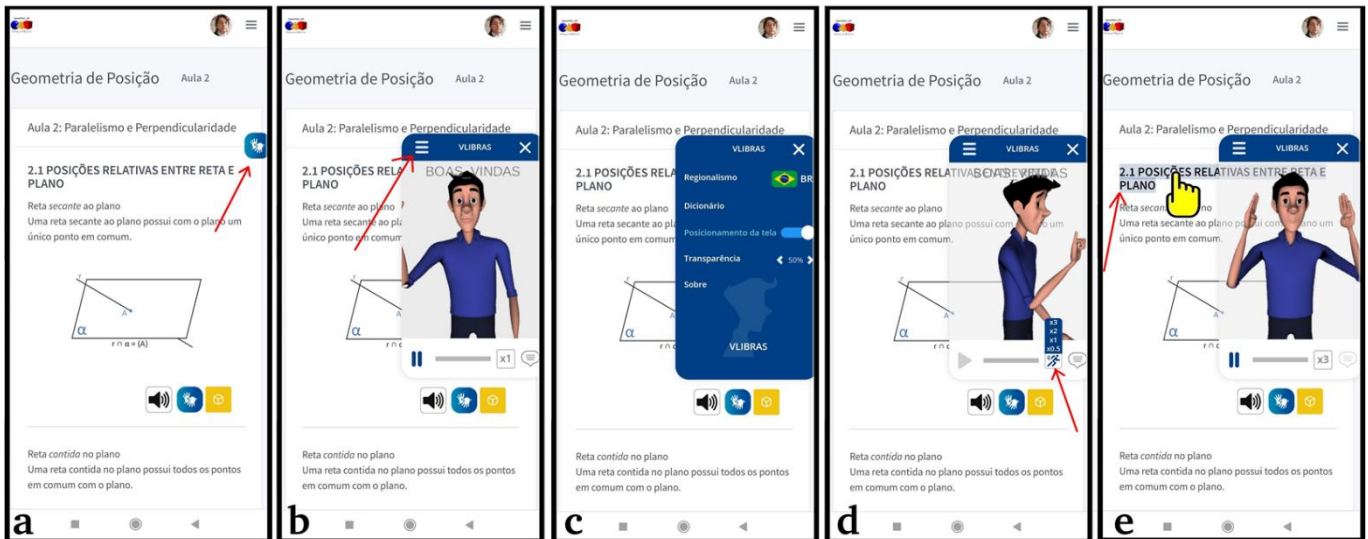

Source: Authors (2022).

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In (a) there is an interaction with the scale (size) of the scenario, where you can enlarge or reduce the 3D object. In (b) a rotational movement is observed, while in (c) random movements of the object are performed. Translation (change of position) is not possible because the 3D object is always rendered in a single position relative to the real world.

3.4 LIBRAS and vLIBRAS in SpaceGeo_AR

LIBRAS (Brazilian Sign Language) is the official language of Brazil for gestural communication between people who master it. vLIBRAS[9] is a software developed by the Federal University of Paraíba. The system is based on translations of digital content (texts, audio and videos) into LIBRAS, facilitating communication for people with hearing impairment who use this language. Open source, the software can be used free of charge and modified according to the needs of the applications. The vLIBRAS tool was implemented in all SpaceGeo_AR functionalities, in such a way that it is possible to translate the entire textual part of the application, including that which is not related to the theoretical part. Figure 10 shows some screens of the application.

Figure 10. Translations of textual content with vLIBRAS.
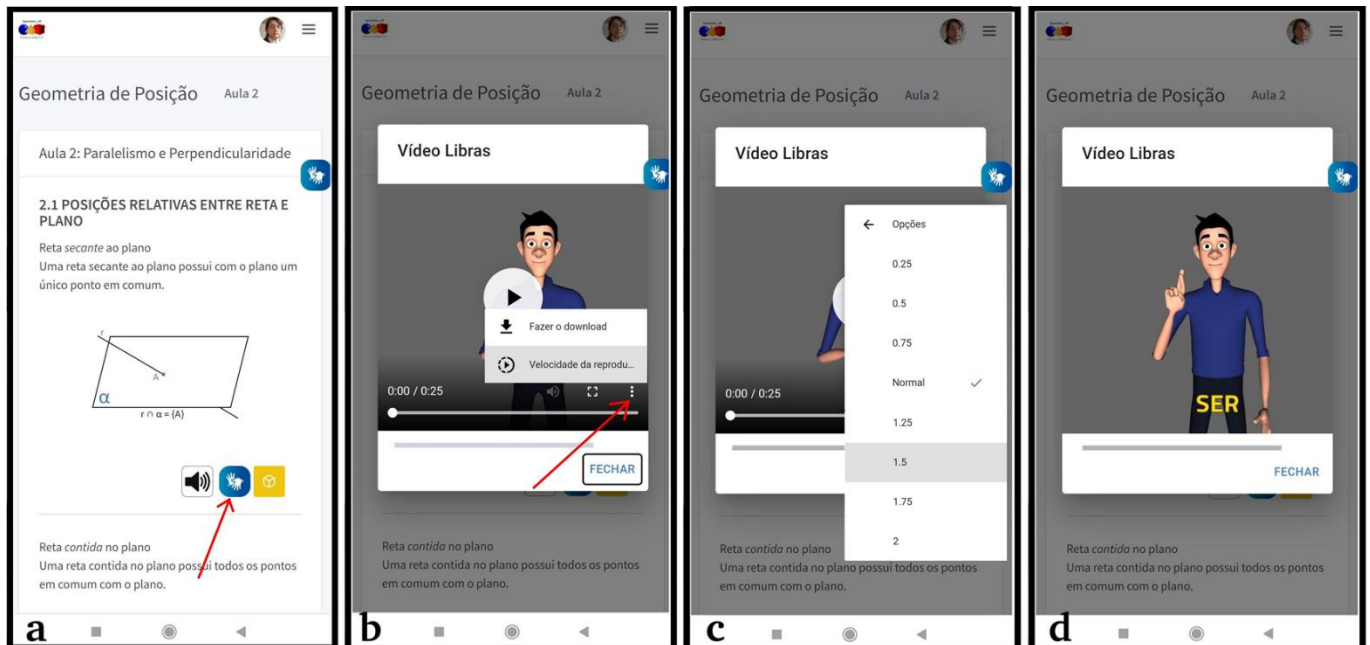

Source: Authors (2022).

In (a) access to the translation service. In (b), (c) and (d) some configuration options of the tool, such as video playback speed, window transparency, which could be useful to show only the avatar, causing less occlusion of part of the text, in addition to other settings. In (e) you can see the translation of the title of one of the classes.

In addition to the resources offered by vLIBRAS already described, additional and pre-recorded translations of all thematic contents were implemented in SpaceGeo_AR, in this case, only the concepts of each of the Position Geometry topics covered in the application. All contents available in the application have a second vLIBRAS button (Figure 11a). As with the translations of the previous model, here it is also possible to change some settings, as shown in (b) and (c) of Figure 11.

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[9] https://www.gov.br/governodigital/pt-br/vlibras. Accessed on 03/27/2022.

Figure 11. LIBRAS translations pre-recorded in the application.

Source: Authors (2022).

In (d) the avatar can be seen translating content from Class 2. The second option described for using vLIBRAS in the application can be useful in two situations. The first is that it allows the user to download content directly to their local system. Another is the possibility of accessing the content of a class directly, without the need to search and select the text to be translated. However, the first vLIBRAS addressed gives access to the entire written part of the application, regardless of whether it is Spatial Geometry content or not.

4. Final Considerations

In the introductory part, it was seen that mathematics represents a disciplinary curriculum with a complex approach in the classroom, especially when considering some topics, such as Spatial Geometry. The 2010 Brazilian demographic census recorded that 5% of the population has a hearing impairment, and on the understanding of Cruz et al. (2009), deafness interferes with the development of language, speech and learning, constituting one of the most serious problems when questioning the student's social life, affecting their school performance, as well as throughout their lives, even in the profession.

Technological solutions arise all the time with the purpose of making people's lives easier, where smartphones are shown as increasingly active devices, including in Education. And in this approach, new didactic and interactive resources emerge, providing teachers with tools to build more dynamic learning environments (Pereira et al., 2020). It is noteworthy that all the tools (systems) used in the application were distributed free of charge, both for the programmer and for the user, generating no financial cost for the development, nor for the use of the applications that were implemented.

AR tools are a strong trend nowadays, where applications are observed in practically all areas of knowledge. In the context of Education, and as described by Oliveira et al. (2021), there are several computational tools for learning Spatial Geometry, however, most deal only with visualizations and manipulations of geometric solids, with no relation to other themes of Spatial Geometry, such as relative positions between points, lines and planes in space, parallelism and perpendicularity between lines and planes, orthogonal projections and distances in space between these elements, in addition to the study of angles and their relationship between lines and planes.

Some of these solutions were implemented in the SpaceGeo_AR application, although other functionalities may improve the application in the future, such as the implementation of other Spatial Geometry themes (Geometric Solids and Spatial Metric Geometry), the possibility for the teacher to insert his own textual content in the Topics functionality, a resource for the teacher to attach other 3D scenarios, in addition to those already implemented in the system, and possibly other functionalities.

The Heroku system supports several features of web technologies and allows responsiveness in its implementations, that is, applications developed on the system are able to dynamically adjust their elements (texts, images, etc.) on the display devices, without depending on the operating system or even the computing equipment used by the user, which can be a computer, tablet or smartphone, although the AR resource implemented in SpaceGeo_AR cannot be used on computers (notebooks and desktops), since the system is dependent on user interaction with a camera for real-time AR use.

The next steps of the project involve two interventions. The first (in progress) is testing the application with sixteen experts in the areas of mathematics, computing, augmented reality and LIBRAS. After this step, we intend to test the application with teachers and high school students, and with that verify if the system can be useful for the teaching and learning of Spatial Geometry by deaf and non-deaf students.

At the end of the mentioned interventions and if the application proves useful, it is intended to develop the software also for local use, and not just through a web address, as it is currently. Other functionalities could also be incorporated into the software, such as allowing the teacher to include their own disciplinary content (topics), completing topics not yet implemented (geometric solids and spatial metric geometry), allowing the teacher to insert their own 3D scenarios, and possibly other features. Finally, it is also in the authors' interest to translate the entire content of the software into the English language, so that the application is more universal.

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