An Overview of 3D Holographic Visualization Technologies and Their Applications in Education

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***Abstract* - Three-dimensional (3D) visualization is the process of creating graphical content using software technologies, where the object is displayed using a computer or mobile device with appropriate software, and the visualized 3D object can be viewed from different angles and sides. 3D objects can be visualized using a display on a computer screen with 3D graphics or using technologies such as augmented reality or holograms. This technology has significant potential and is used in education. Interaction with software solutions is recognized as one of the most important learning experiences. This paper provides an overview of holographic visualization technologies, their interaction capabilities, and technology integration. It also presents and describes an example of a holographic application for learning geometry that can be used in a 3D holographic pyramid projection system.**

Keywords – visualization technologies; holograms; interactions;

I. INTRODUCTION

The use of visualization tools in the learning process is not a novel concept; it has been practiced for a long time. The visualization provides an opportunity for learners to understand and accept complex concepts more easily and conveniently [1]. Nowadays, educators have access to a wide range of visualizations, including different technologies such as augmented reality, virtual reality, holograms, etc. Analysis of the use of visualization technology in education [2] revealed that it had a favorable impact on students' cognitive growth. Holographic projections draw students' attention because they enable them to examine a topic from various perspectives, which improves their comprehension of the subject. Usage of this technology also benefits the student with learning disabilities which usually presents unique challenges. Children with developmental disabilities often have limited attention spans, making it difficult for them to stay engaged with a task for long periods of time. New technologies for visualizing learning content, such as augmented reality, can capture their interest and direct their attention enough to ensure effective learning [3].

One of the most important aspects of educational applications is accessibility. Digital accessibility is the extent to which a computer program, website, or device is acceptable and suitable for use by people with disabilities and the elderly. This results in a greater degree of inclusion of people with disabilities in modern society. Digital inclusion stands for all efforts to increase the level of social inclusion of people with disabilities and older people by adapting existing or developing new services based on information and communication technology that enable more efficient communication, access to information, and assistance with education [4]. The need to develop accessible applications for educational purposes is reinforced by the increased inclusion of children with disabilities in the standard education system.

Given that visualization technologies are proven to help in the education of all children, especially children with disabilities, we were motivated to develop an application that will help them learn geometry. As a part of INNOSID consortium, we have developed application called HoloGeometry which prototype will be described in this paper. INNOSID, whose full name is "Innovative solutions based on new technologies to improve the social inclusion of people with disabilities"[1], was an Erasmus+ project led by the Faculty of Electrical Engineering and Computing at the University of Zagreb. The aim of the project was to improve the social inclusion of people with disabilities, particularly people with Down syndrome, by developing innovative IT solutions based on new technologies. The project involved six higher education institutions, two from Croatia and one each from Hungary, France, Spain and Portugal, as well as a non-governmental organisation, the Croatian Down Syndrome Association.

The rest of the paper is organized as follows: Section II describes visualization technologies and gives an overview of their application in education, Section III describes HoloGeometry application and, finally, Section IV concludes the paper.

II. VISUALIZATION TECHNOLOGIES

Three-dimensional (3D) visualization is the process of creating graphical content using software technologies, where the object is reproduced with the help of a computer or a mobile device with appropriate software and it is possible to view the visualized 3D object from different angles and from different sides [5]. 3D objects can be visualized using visualization technologies such as displaying them on a computer screen with 3D graphics or using technologies such as augmented reality or holograms [6]. All types of interactions that a user can perform in a 3D virtual world are called three-dimensional (3D) interactions [7].

[1] INNOSID, http://sociallab.tel.fer.hr/innosid/

3D visualization has significant potential and finds application in various fields such as science, art, health, etc. Among them, education stands out. Visualization and interactive manipulation of 3D objects can greatly enhance the learning experience [8]. 3D visualization and the possibility of interaction are associated with the concept of virtual learning environment. A virtual learning environment is a software platform available via the Internet that provides students digital solutions that enrich learning. Students can access required materials or data regardless of time and location and share knowledge through online communication applications [9]. There are at least three conditions that should be met for a virtual learning form to be successful: (1) the availability of the Internet, (2) the availability of support to maintain the system, and (3) the availability of a teacher who can help students in situations where they have learning difficulties [10]. In addition to the virtual learning environment, there is also a traditional learning environment with a teacher who teaches the material, i.e., explains the concept of knowledge while the students listen and take notes [9]. In this form of teaching, the teacher is the focus, and the information is delivered in only one way (through a traditional lecture), while in the virtual form of learning, the students are the focus, and the desired information can be delivered in different ways through lectures and various practical and visual representations [9]. In addition to traditional and virtual learning environments, the so-called combined form of learning can also be found in literature. The combined or hybrid form of learning is not just a simple mixture of both mentioned forms of learning, which complements the traditional form of learning with a virtual one and vice versa, but refers to their integration, whereby what is considered the best in both forms is combined, such as, for example, the integration of technology such as of augmented reality in classes that take place physically in classrooms [11].

A. Holographic technologies

Holographic projection is a technological novelty that will bring great changes in many fields: Education, science, art, and health are just a few. To understand how a holographic projector works, it is necessary to define a hologram. Holography is a method of recording patterns of light. These patterns are reproduced as a three-dimensional image called a hologram. There are three types of holograms: Reflection, Transmission, and Hybrid. Each type of hologram has its own characteristics, and its use depends on the type of object to be represented [12].

Authors in paper [13] describes the advantages of using visualization technologies with emphasis on holographic technology in education. The use of these technologies involves performing various activities in a risk-free environment, facilitates mutual collaboration and communication between students and teachers, and helps visualize abstract ideas and concepts. In addition, teachers are positive about the potential use of technologies to visualize classroom content. A study of 400 teachers in the United Kingdom examined the effectiveness of holographic technology as a teaching tool. The research results show that the majority of respondents believe that holographic technology will improve learning and will be an effective supplement to traditional teaching in the future [14]. While holographic technology offers positive learning experiences, more studies are needed in order to find ways to fully exploit their educational potential [15] .

Analysis of the application of holograms in education [2] showed that holograms have a positive effect on the cognitive development of students. Holographic projections attract the attention of students because they allow them to study a subject from different angles, which indirectly results in an increase in the understanding of the material. The research [16] mentions the lack of infrastructure, high costs of implementation and lack of experts as the main disadvantages of the application of this technology. For this reason, the authors in [17] present an example of a pyramidal hologram that would be used for educational purposes, and whose surface is made of glass with a base containing a mirror. The hologram is placed on the screen of the smartphone, which displays a three-dimensional object whose reflection will be reflected from the mirror of the pyramid and the object will be displayed as a hologram. In addition to holograms, they also propose the use of hologram control with the help of hand movements (Hand Gesture Control). Holograms often come in combination with augmented reality [18]. People who have learning or reading difficulties, using wearable devices such as HoloLens virtual reality glasses, can visualize and represent the described object or location in the passages of the books they are reading with the help of holograms.

B. Virtual and Augmented Reality

Virtual Reality (VR) is an environment that focuses on visual and immersive experiences. Through the use of interactive simulations, users are given the opportunity to immerse themselves in an environment where objects and events from the real world can appear, giving the user a subjective sense of presence [19]. Virtual reality has reached a broad user base that includes people with disabilities. In contrast to VR, augmented reality (AR) is based on augmenting the real objects around us using technology. Augmented reality can be interpreted as a subcategory of the virtual environment, where the image of the virtual world is blended with the image of the real world [20].

The use of VR and AR is most widely recognized in medicine, where it is most often used to learn anatomy [21]–[24] and to train skills such as resuscitation and, for example, as an aid in preparing for surgery [25]. The use of these technologies has also been recognized in music education , as an aid in learning material in the faculty of civil engineering [26] and graphics [27], and as a solution for learning computer security [28].

According to authors in [29], the goal of augmented reality is to use 3D virtual objects as a tool to enhance user perception and interaction with the real world by seamlessly inserting 3D virtual objects into the 3D environment of the real world. AR Technologies can be designed to interact across many sensory channels (e.g., auditory, visual, auditory, and haptic), so definitions that focus only on visual data are insufficient for future augmented reality development. Paper [30] offer an organizational chart that divides the applications of AR

into three main categories: Presentation and Visualization, Industry, and "Edutainment". The term edutainment was created by combining the words education and entertainment and includes anything that is both educational and entertaining [30].

Game-based learning with augmented reality has become a new trend in education because it has the potential to increase children's motivation to learn subjects such as mathematics. However, to be maximally effective for children's learning, the applications of AR must be appropriately designed, especially considering their new interaction and representation paradigms [31].

Teachers often use games to help students understand instructional concepts. Using technologies such as VR and AR, games set in the real world and enriched with digital data can provide powerful new ways for teachers to show relationships and connections between things. Games that use marker technology often consist of a flat game board or map that transforms into a 3D environment when viewed from a mobile device or webcam. A game like this could easily be used in a variety of subjects, including archaeology, history, anthropology, geography, and many others [30].

Related to the topic of accessibility and use of technologies for people with disabilities, in [32] the authors describe the development of a user interface for the system LIRKIS CAVE, which is used in the education of people with limited intellectual functions. CAVE stands for a room-sized space in which an image of the virtual world is projected on the walls and ceiling, where users can move freely. In such environments, users can often interact with the system through non-touch hand gestures or touch screens. This type of interaction can greatly facilitate use by people with limited intellectual abilities, as they are often unable to use a mouse and keyboard properly. The use of technologies for VR and AR has shown promising results in the education of children with autism spectrum disorders [33], where it has been demonstrated that these technologies help in independent learning and maintaining concentration.

III. HOLOGEOMETRY

HoloGeometry is application designed to help students learn geometric objects. In geometry, it is important to consider the phenomenon of ostensive, which is an obstacle for students. This phenomenon results from the representation of figures and geometric solids in textbooks from a single perspective, which means that students are not able to apply the knowledge they have learned when they move to a different spatial orientation, i.e., they are not able to extrapolate. This application provides them with a visualization of geometric solids in space with the possibility of interaction. It meets the needs of learners who process information primarily visually and enhances learning for all students. This product enables students to clearly see and understand geometric objects and improves tactile hand-eye-mind connections that enhance the ability to memorize facts and retain what they learn.

Target group are all people who like mathematics and want to learn geometry. The product is intended to help learning, which also leads to better social inclusion of people with Down syndrome. Mathematics education usually focuses on arithmetic because people with learning disabilities, including people with Down syndrome and autism. These mathematical concepts are undoubtedly important for understanding the world quantitatively, and they also enhance communication skills and the ability to think, reason, and learn. The abstract ideas that geometry conveys from direct experience make the world more understandable to them, so it is worth developing a method to teach them geometry. Mathematics, especially geometry, was developed by humans specifically to embody abstract ideas from experience. Therefore, choosing this subject as a way to better understand the world could particularly enhance children's cognitive strengths [34].

The application was developed for computers and mobile devices and uses holographic technology for easier visualization of geometric solids. Accessibility was considered during its development, e.g., every geometric solid has both a written and an audio description. It is also possible to change the font to one suitable for people with dyslexia. The Unity development environment[2] was used to develop the application. The Unity asset "Hologram pyramid"[3] was used to implement the hologram in the application. The application includes three levels: (1) “Learn geometrical shapes”, (2) “Recognize geometrical shapes” and (3) “Test your knowledge”. (Figure 1).

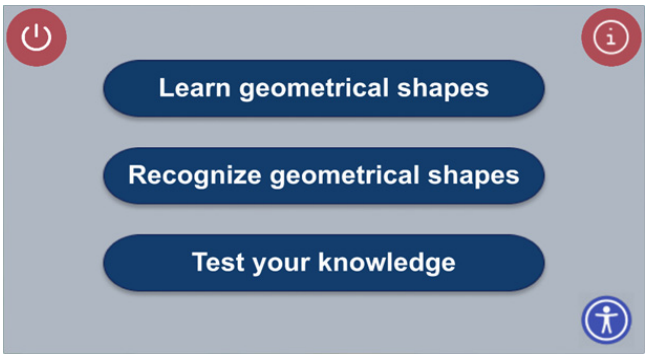

Figure 1 Initial screen of HoloGeometry application

The first level is about learning geometric solids. Users can familiarize themselves with 4 different geometric solids: a sphere, a pyramid, a cylinder, and a cube (see Figure 2)

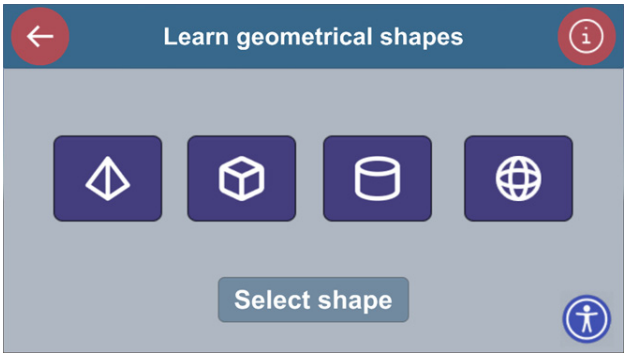

Figure 2 First level “Learn geometrical shapes”

[2] Unity, https://unity.com/download
[3] Unity Asset “Hologram Pyramid“, https://assetstore.unity.com/packages/tools/hologram-pyramid-61735

For each geometric body there is a written and audio description. The hologram can be zoomed in and out and rotated. It is also possible to change the color of the hologram. All these customization options serve to give the user a better idea of the 3D shape. Example of the design of description of one geometrical solid, in this case cube, is shown in Figure 3.

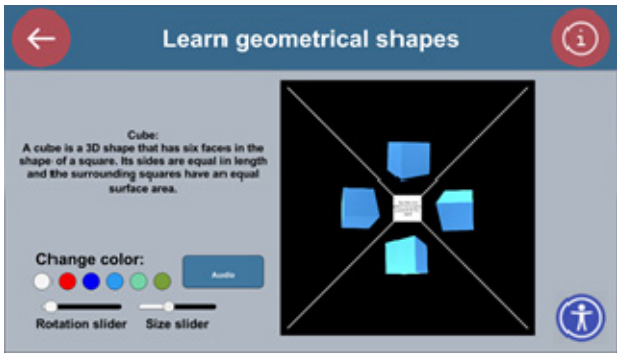

Figure 3 Example of description and interaction possibilities of Cube

The second level is similar to the first, but it is used to determine the knowledge acquired in the first level. The screen is designed to display the hologram in the center. On the left side of the hologram are buttons to interact with the hologram, and on the right side are the answers offered. The screen of this game is shown in Figure 4, and the appearance of the hologram can be seen in Figure 5.

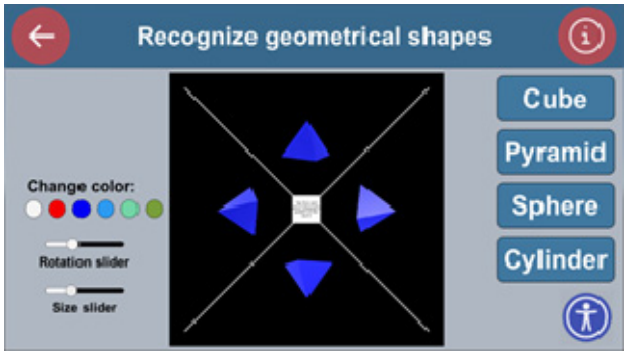

Figure 4 Second level “Recognize geometrical shapes”

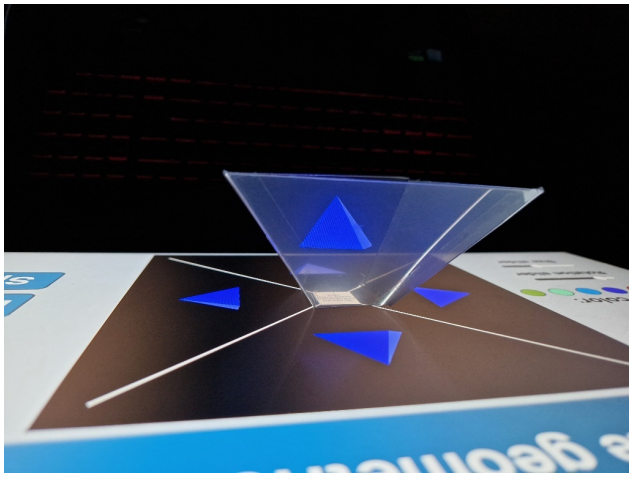

Figure 5 Holographic display of pyramid

Selecting the third level, "Test your knowledge", starts a quiz with ten random questions about geometry and geometric solids. The user is given one question and four suggested answers, only one of which is correct. If the user selects an incorrect answer, the selected answer turns red. If the user selects the correct answer, the selected answer turns green. At the end of the quiz, statistics are displayed with the number and percentage of correctly answered questions. The screen of this level of the game is shown in Figure 6. Figure 7 shows how the statistics look at the end of the third level.

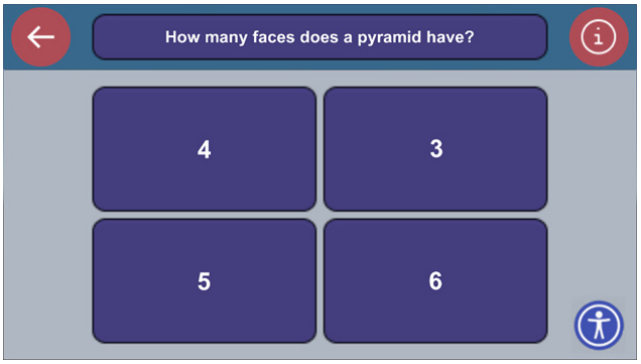

Figure 6 Third level “Test your knowledge”

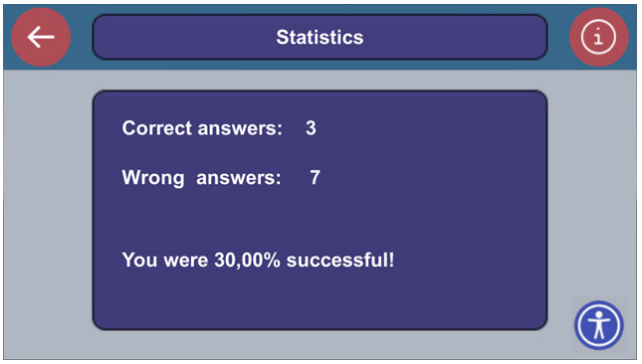

Figure 7 Example of statistics

Since the application was designed from the beginning to be accessible to as many people as possible, some accessibility options were introduced. It is possible to change the color of the hologram. The possible colors are white, red, dark blue, light blue, light green and dark green. It is also possible to rotate the hologram to get a better perception of the three-dimensional shape. The hologram can be zoomed in and out so that the application can be used smoothly on both small and large screens. It is also possible to listen to an audio recording with a description of a geometric body. In addition to these options, there is an accessibility options button in the lower right corner of all screens. When clicked, all text in the application is displayed in a font for people with dyslexia (see Figure 9).

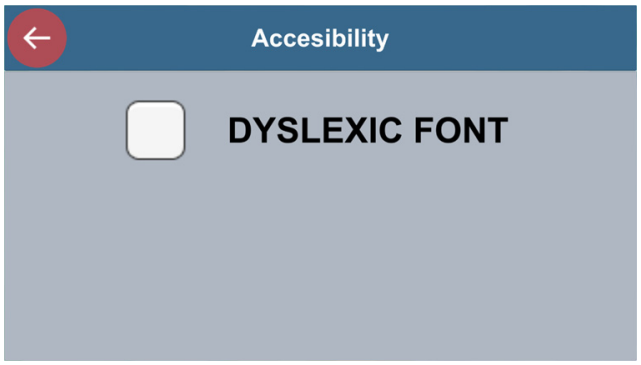

Figure 8 Accessibility option menu

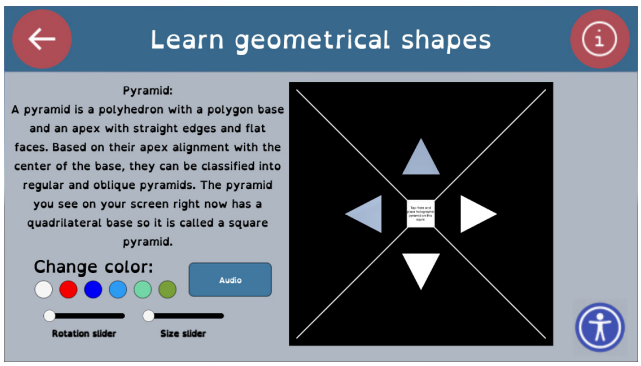

Figure 9 Screen design with dyslexic font enabled

IV. CONLCUSION

Visualization technologies have been around for many years, but only recently they have become prevalent in marketing, telecommunications, education, etc., with an emphasis on holographic technology. The application of this technology stands out in education, where it has been shown to enable students to understand concepts faster and better. Visualization technology in the classroom has a stimulating effect and attracts the attention of students. Similarly, these technologies have been found to positively impact the educational experiences of students with disabilities, increasing confidence, engagement, and interest, providing opportunities for independent learning, and increasing student satisfaction and motivation. Thanks to the development of these technologies, we now have the opportunity to learn and research in the virtual world without the possibility of our actions and decisions affecting the real world. Numerous industries use the virtual world to perfect their products or even experiment to the last detail before the process is carried out in reality. In this way, costs and various risks that could arise are significantly reduced. The development of holographic projection has also expanded its scope. Holograms are certainly an interesting group of visualization technologies that have proven to be an attractive and useful solution, especially in the educational field. An example of a holographic application that helps in learning geometric solids is HoloGeometry.

Given that HoloGeometry is currently in its prototype stage, in forthcoming iterations of the application's development, certain metrics that assess user performance will be incorporated, and the application will be evaluated with end users accordingly.

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