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RESEARCH ARTICLE

# Merge Cube as a New Teaching Tool for Augmented Reality

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**ABSTRACT** Due to the massive popularity of smartphones among people of all ages, Augmented Reality is becoming a commonly available technology for which we do not need to have special equipment, just an ordinary cheap smartphone with a camera. In this paper, we will deal with the use of Augmented Reality in education through the popular Merge cube, which has been enjoying increasing popularity in the educational process since 2017. In our article, we focus on the comparison of existing applications with the support of the Merge cube and the possibilities of it's use in education. We pay the main attention to the creation of our own educational application, which consists of five independent parts (three educational parts, like the solar system, world monuments, and marine animals, and two entertainment parts with the possibility of setting the difficulty, respectively-game type, like Pexeso and the 3D Labyrinth). Application development was carried out in the Unity 3D environment for mobile operating system Android. The application is mainly intended for hospitalized children, but it was tested due to pandemic restrictions among 134 children in regular primary and secondary schools. The main advantage of our application compared to other applications is that it is free, contains several educational areas and also that we can modify the content - it is open source.

**INDEX TERMS** Augmented reality, merge cube, mobile learning.

## I. INTRODUCTION

Smartphones are generally the most common type of mobile device among people of all ages. It is not uncommon for children from three years old to use mobile devices such as smartphones and tablets. Pupils at schools use them for education, communication, and playing games, and working people use them for work, entertainment, photography, navigation, etc. Some pensioners use them for web browsing, Internet banking, and communication with family members. As far as this is concerned, seniors are the worst, several countries are working to improve the digital skills of these people. In Slovakia, in June 2022, the Ministry of Investment, Regional Development and Informatization of the Slovak Republic began project of training seniors over 65 years of age to improve their digital skills and distribute the tablets to who want to learn to work with computers or increase their computer literacy.

Teaching through mobile devices is called m-learning or mobile learning. Crompton [1] defines mobile learning as learning in multiple contexts, through social and content interactions, using personal electronic devices. Mobile learning can be practiced in almost all subjects at schools. Recently, successful utilization of mobile learning in mathematics teaching can be found, for example, in [2], [3], [4], and [5]. An exploration study related to investigating the possible use of mobile learning to learn the chemistry course in elementary school can be found, for example, in [6] and [7]. Purbohadi [8] use mobile learning as a learning aid for medical students, Dolzhich [9] in teaching foreign languages and many others researchers use mobile learning in almost all fields. The advantage of mobile devices is that almost all smartphones contain a camera that can be used, e.g. with augmented reality (AR), which in turn can be used, e.g. for education not only in computer science. An AR system

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supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world [10].

In 2013, Volkswagen's car company introduced the Marta (Mobile Augmented Reality Technical Assistance) application. The application contained service manuals for car repairs and, through augmented reality, instructed the user on how to perform individual service tasks [11]

In 2014, the Snapchat application made it possible to insert geofilters with the current user position into the scanned image. A year later, the lenses function appeared on this social network. It allowed face scanning with the ability to insert various graphic elements. This trend was quickly taken over by several social networks to retain their users [11], [12]

In 2016, the mobile game Pokemon Go was introduced, which represented a revolution in gaming - millions of players moved into the real world with mobile phones in their hands and tried to find Pokémons. Pokemon Go - mobile application that used augmented reality did these technology popular among all age groups. A number of scientists and teachers have begun to explore the various possibilities of using augmented reality in various fields. Mamone et al. [13] proposed in their research an alternative to head-mounted displays for surgeon's, based on projected augmented reality. Their results suggest that projected augmented reality can be a valuable alternative to standard see-through head-mounted displays to support in-situ visualization of medical imaging data as surgical guidance. Cutolo et al. [14] did an experimental study was designed to assess the efficacy of the platform in guiding a simulated task of surgical incision. In the experiments, the user was asked to perform a digital incision task, with and without the aid of the augmented reality headset. The results confirm that the proposed framework coupled with the new-concept headset may boost the integration of augmented reality headsets into routine clinical practice. Hořejší et al. [15] have developed a brand-new smart solution for designing and presenting work instructions throug augmented reality. The solution can be easily adapted to use in other fields like healthcare or smart-homes. Lai and Cheong [16] did survey various interactive multimedia associated with XR before examining the implications of XR as an educational tool for existing mathematics pedagogy.

In 2017, an interesting cube called Merge appeared on the market, which in conjunction with a mobile device (through it's camera) and software can turn the cube into a hologram. By synchronizing the cube with the application and then rotating the physical cube, we see a virtual representation of 3D objects through the screen of the device. It is a completely new way of interacting and experiencing AR. Suddenly we can hold in our hands mathematical 3D objects, historical artifacts, human organs, etc. The Figure 1 shows the original Merge cube on the right picture and the printed version of the Merge cube on the left picture. There are several studies on the use of the merge cube in education. Taufig in his research [17] aims to determine the feasibility of learning media for solar systems based on merge cube augmented reality to embedding problem solving skills. Lin [18] applied Merge Cube applied to a multifunctional app and emphasized more on the story elements in Glycoscience dissemination (Glycoscience is the study of the complex carbohydrates on the surface of proteins and lipids). Ameen [19] aimed to investigate the effectiveness of dramatized content through augmented reality applications (Merge cube) in improving the English language proficiency of high school students. Ntuli [20] reports on a qualitative study conducted with K-3 teachers after a STEM workshop that focused on integrating augmented reality using Merge Cubes.

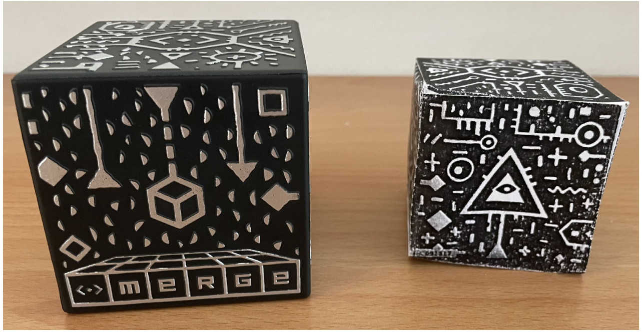

**FIGURE 1. Original merge cube on the right picture and on the left picture printed version of merge cube.**

## II. AUGMENTED REALITY

The term AR first appeared in the early 20th century in the novel The Wizard of Oz, where the author, L. Frank Baum described glasses that can now be compared to Google Glass [11].

AR was defined by Tom Coudell in 1990, an employee of Boeing Computer Services Research. Boeing employees had projected through their glasses the process of assembling cable bundles using AR. It was an universal workflow that they could apply to all aircraft models [21]

AR is a technology that allows us to enrich the real environment with interactive digital elements such as images, 3D models, sounds, and text in real time. The basic idea of augmented reality is to overlay images, graphics, and audio and other intelligence enhancements over a real environment in real time [22]. The term of AR is often mistaken for the term virtual reality (VR). The difference between the two technologies is that VR requires special headsets that evoke in the user the impression that he is in a different digital world, while AR allows interaction with the digital objects of the real world. AR is more accessible as most of used applications require only a smartphone, which most of us already own. Just activate the camera, and the application will take care of inserting digital content into the image we capture. Chatzopoulos [23] in his research did survey of using AR. Whitley-Walters and Muhammad [24] did in their study focus on positive aspect of augmented reality in the educational process. Jang et al. [26] did study explores teachers' willingness to integrate AR and VR technologies for teaching and learning practices. Rossano et al. [27] presented in their paper an AR application, called Geo+, for supporting primary school students in the acquisition of knowledge on the solid geometry. Al-Gindy et al. did research [28] demonstrates using the knowledge of integrated disciplines with AR through Merge cube.

An AR study [30] shows that these tools help all students including students who have an intellectual Examination of the Integration of Augmented Reality in Technology in Science Curriculum 19 disability (ID) and autism. De Souza et al. [29] developed an AR app using a three-dimensional marker inspired by the Rubik's Cube for architectural design.

### A. PRINCIPLES OF AUGMENTED REALITY

AR works on several principles. Image scanning is the most commonly used. It can be a single target image or a group of images located around the perimeter of a body. Another principle is used by games that detect a plane, for example on the ground, where applications then display the required objects. We also know the different principles of scanning the body, whether it is the hands, face, or the whole body:

- 2D Image tracking - tracking and detection of image elements obtained from the camera image, which are compared with the target images stored in the device database.
- 3D Object tracking - detection and tracking of 3D objects, which are created by scanning a physical object from all sides.
- Face tracking - identifying the facial area and creating a 3D network (drawing elements that correspond to the contours of a human face).
- Body tracking - tracking and recognition of the human body, its position (we obtain an outline that we can overlap with graphic elements or insert into the image of avatars).
- Plane detection - detection of the plane (table, floor, etc.) on which we place 3D models.
- Point clouds - a map consisting of millions of points containing unique data that defines their location in 3D space.
- Cloud recognition - an online image recognition service that can recognize and track as many as millions of image (more info is describe [30] ).

The Figure 2 shows augmented reality using a handheld device [29]. Current state of how augmented reality works is described at the research of Shea [32].

## III. MERGE CUBE EDUCATION

In 2017, the Merge cube made of foam material was introduced, which contains unique shapes on the sides of the cube, due to which it is possible to subsequently convert the cube into a hologram.

Due to its unique properties, the Merge cube can be an ideal educational aid. It will allow students to literally grasp various models of real-world objects in the palm of their hand.


**FIGURE 2.** Augmented reality using a handheld device [31].

Due to the unique patterns on the sides of the cube, these models can rotate and view in detail. This way of learning - discovering new things is more valuable than looking at this information in the picture. In addition, these models can contain various animations and sound effects, which will support the participation and development of multiple senses of students. Today, available applications cover a wide range of technologies.

Merge cube can be used in various educational areas such as mathematics, geology, biology, geography, etc. The Figure 3 is an example of a human body application for a Merge cube [33].

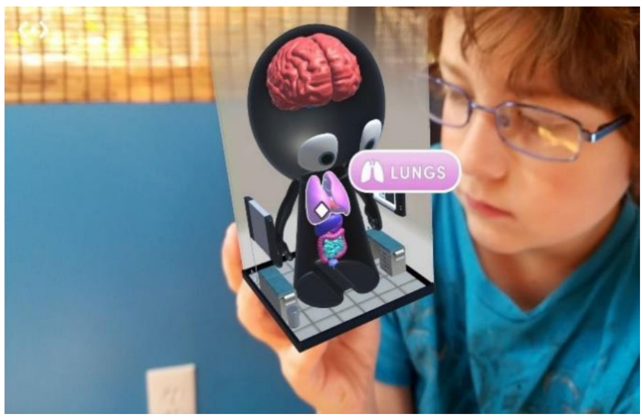


**FIGURE 3.** Human body application for a merge cube.

### A. EDUCATIONAL APPS FOR THE MERGE CUBE

There are currently several applications that can harness the potential of the Merge cube. The disadvantage of these applications is that they provide only part of their functionality for free and then you have to pay for a license.

#### 1) EXPLORER

Explorer is the official Mergeedu application that offers the largest database of comprehensive educational materials in the form of animated scenes. The application is divided into several areas. In addition to animated scenes, the application is complemented by various knowledge quizzes. The application is available on common hardware such as smartphones and tablets with the Android operating system[1] and iOS.[2] The Figure 4 shows a sample of educational materials from the Explorer application - the development of the solar system.

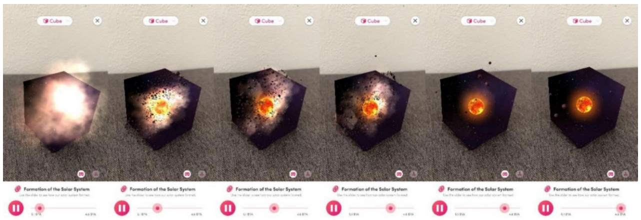

**FIGURE 4. Example of a merge cube application explorer.**

### 2) OBJECT VIEWER

Object Viewer is application that focuses on separate objects. The database consists of hundreds of objects that can be viewed in detail, arbitrarily enlarged, and reduced. The application covers a wide range of fields suitable for education (for example dinosaurs, ancient artefacts - history, animals, anatomy of human parts - biology, computer parts - computer science, etc.). The application also has support for smartphones and tablets with the Android[3] and iOS operating systems.[4] The Figure 5 shows a preview from the Object Viewer.

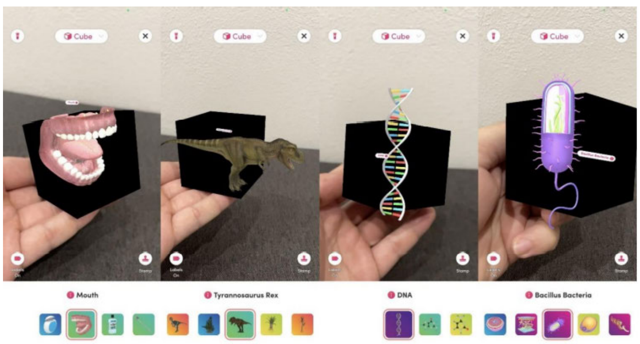


**FIGURE 5. Example of a merge cube application object viewer.**

### 3) HOLOGLOBE

Hologlobe is an application that allows you to examine satellite images of the planet Earth in detail. It allows you to view various views containing scientific data, such as information on precipitation, clouds, ocean and land temperatures, the occurrence of glaciers, fires, etc. Individual animations are supplemented by text descriptions, which can contain a voice commentary in English. The application supports the Merge cube, and it is available for devices with the Android[5] and iOS operating systems.[6] The Figure 6 shows a collection of images from the HoloGlobe application.

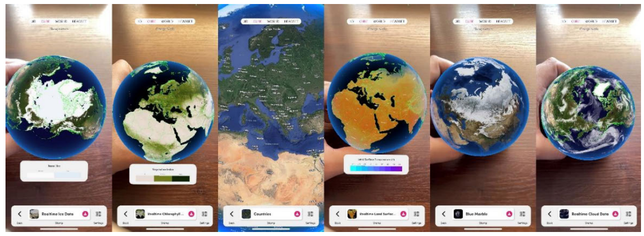

**FIGURE 6. Example of a merge cube application hologlobe.**

### 4) COSPACES

CoSpaces is a web-based application[7] that allows users to build virtual worlds or to create object which can be located in augmented reality. The application has also Merge cube support, but the implemented object gallery is limited. The Figure 7 shows a preview of some models from the application gallery. The pictures show models from CoSpaces.

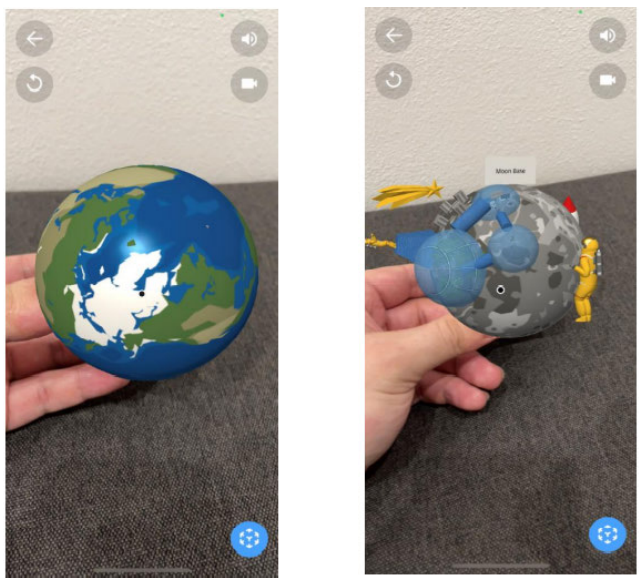

**FIGURE 7. Example of a merge cube application CoSpaces.**

## B. CREATING OWN APP FOR THE MERGE CUBE

Creating our own application for Merge cube can be an interesting alternative, whether for teachers or students who know how to prepare interesting examples of objects and animations that are directly related to the curriculum. It is a good way for young students to develop their creativity

[1]https://play.google.com/store/apps/details?id=com.MergeCube.EDUExplorer

[2]https://apps.apple.com/us/app/merge-explorer/id1453098606

[3]https://play.google.com/store/apps/details?id=com.MergeCube.ObjectViewer

[4]https://apps.apple.com/us/app/merge-object-viewer/id1367544362

[5]https://play.google.com/store/apps/details?id=com.MergeEDU.HoloGlobe

[6]https://apps.apple.com/us/app/merge-hologlobe/id1586658852

[7]https://cospaces.io/edu/

and imagination, work in a team, and at the same time increase their digital skills, which will be beneficial for their future. We can use several tools or web pages to create own applications for the Merge cube, for example:

- Merge Edu - A simple online tool [30] to create AR. Allows you to insert your own 3D models, textures, which can then be displayed using the Object Viewer application (we must be logged in with the same account in the mobile application and on the online tool page).
- CoSpaces - a more advanced online editor in which the Merge cube is directly integrated. The editor has an implemented programming environment for TypeScript, Python and block programming.
- Unity - a game engine to create 2D and 3D games. Unity allows the most comprehensive ability to create a variety of applications. In our case, using the Vuforia extension, we can create extended reality applications for the Merge cube. Vuforia SDK is an AR software development kit for mobile devices, it utilizes computer vision technology to recognize and capture planar images or 3D objects in real time and permits developers placing virtual objects through the viewfinder of the camera and adjusting the position of objects on the background of the camera [31].
- Unreal Engine - a game engine to create 2D and 3D games. Very similar software as Unity.

## IV. APPLICATION MERGE CUBE ADVENTURE

For the creation of the Merge cube application, it is advisable to use the Unity game engine together with the import of the Vuforia Engine library, which allows you to create an APK (Android Package Kit) application that, we can then use to install Android. To create our application, we used Unity in version 20.3.22f1, to create logic, we used the C# programming language. We downloaded the models used in our application from the model database from [36].

Use of the application will be conditioned by the physical Merge cube in its original form or by printing and folding a paper template. It will be recommended to use the application for its convenient operation with the device stand, which is part of the Merge cube package or another suitable alternative. Device support will be limited by the screen resolution for the correct display of controls; the recommended value is at least $1920 \times 1080$ pixels. The recommended screen size is 7 inches or more. The application requires a camera of sufficient quality to continuously capture the Merge cube. The availability of the application will be for devices with the Android operating system in version 6.0 and later, which is due to the limitations of the software used.

As part of the analysis of existing applications, we decided to create educational materials for the solar system, world monuments, and marine animals. The content of educational parts of the application is adapted to the age group of primary school children due to its information requirements. The selection of models and animations is also designed with the assumption of arousing interest among these students. Another part of our application is focused on entertainment with the possibility of setting the difficulty, respectively - game type. For this purpose, we chose the 3D entertainment part of the application Pexeso and the 3D Labyrinth. They include color combinations and images supported by sound and visual effects to enhance the better experience of this application.

### A. CREATING AN APPLICATION

We create a new project in the Unity game engine, while selecting a project with a 3D template. In the next step, we add the Vuforia Engine library. The application requires a Merge cube for its functionality. Therefore, it is necessary to define this cube and create an appropriate database for it, which consist of patterns of all six sides of the cube. We open the page [33], where we create the necessary database on the Target Manager tab, choose Cuboid from the menu, and define its dimensions. Then we need snapshots of the Merge cube, which we can create on our own by taking a photo of the physical cube or by downloading a pre-prepared template in PDF. We download the created data base and import it into the Unity environment in the same way. The Figure 8 shows preparing of a Merge cube in Vuforia Engine library.

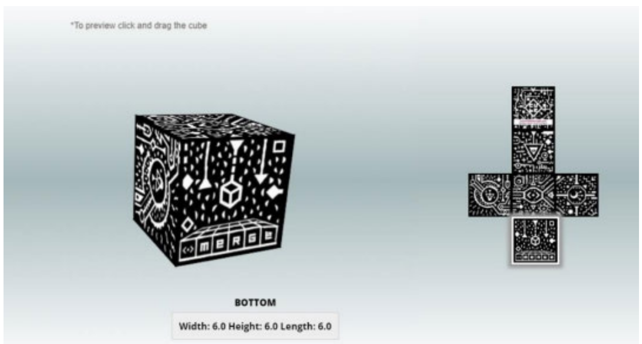


**FIGURE 8.** Vuforia engine - preparing merge cube images.

The Figure 9 shows the loading of a database with a Merge cube in Unity software (pictured right) and the import of Vuforia into Unity (pictured left).

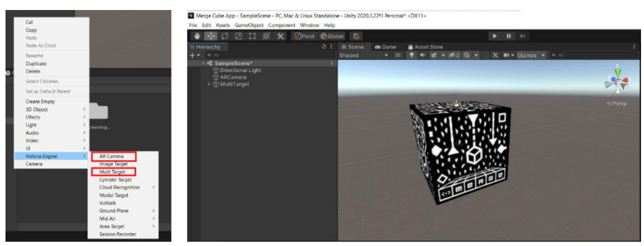

**FIGURE 9.** Unity engine - loading a database with a merge cube in unity software and importing Vuforia into unity.

In the Hierarchy window, right-click to add AR Camera and Multi Target from Vuforia Engine. That is practically everything we need from this engine. Following this sequence automatically load the database with the Merge cube. We still have to insert the license key for Vuforia Engine. To do this, click on AR Camera, click on Open Vuforia Engine configuration in the Inspector window, and enter our license in the License key field. In general, we add an empty object to the Multi target object. We set its dimensions and position, or rotation. Every other object whose parent be this empty objectl inherit its properties, which help us to adjust the size, position, show, or hide all objects. The Figure 10 shows importing Merge cube object into Unity Engine.

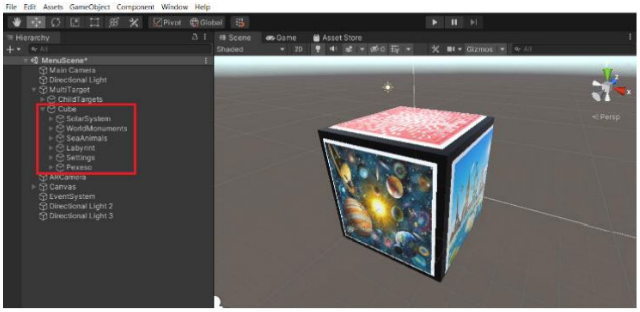

**FIGURE 10.** **Unity engine importing merge cube object.**

Unity 3D used for basic setting of object positions, relationships between objects, setting of textures and materials, animations, etc. However, the entire logic of the application is located in the main script. We associate it with the main objects of our applications. In the Inspection window, we add a script component. In the script, we define the necessary variables of various types, whether we need them public or private. We create methods in the same way. Subsequently, we can assign all the necessary objects that we have created, respectively imported from external sources into the script and manipulated them. As for methods, we can call all public methods from the Canvas object. Canvas is a 2D panel that contains application controls and various information windows. This help us to call different methods to control the application.

### *B. ADDING OBJECTS*

As we wrote sooner, we downloaded the models required for our application from [32]. The database offers a wide range of models that cover selected areas of education. We create a folder structure according to the name of the application. We move the downloaded models to the individual folders. Unity supports several model formats such as.obj,.fbx, etc. Most of these models consist of a separate model and a package of textures that we can use for it. In the Figure 11 we see models of marine animals, for which we have identified the object Animals as a parent.

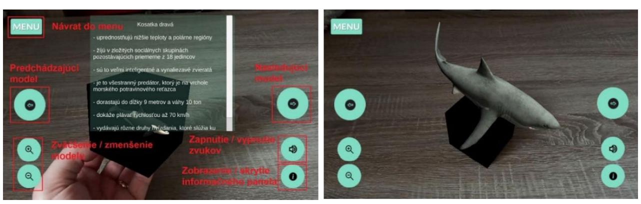

**FIGURE 11.** **Merge cube adventure - marine animals part.**

In the Figure 12 we can see the solar system in our application Merge Cube Adventure.

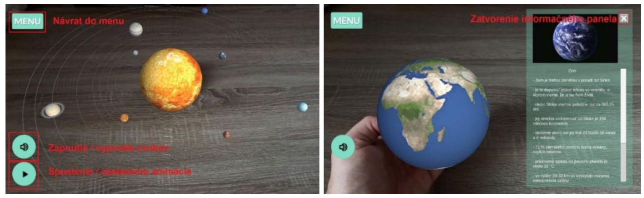


**FIGURE 12.** **Merge cube adventure - solar system part.**

Parts of the application, Menu and Pexeso, use only the basic menu of objects in Unity 3D. Their controls are plane objects. Depending on the need, we can change their visuals by modifying the material component. The Figure 13 shows a preview of the Pexeso application, where each cube control is rendered with anonymous material. After clicking on the given card, the material with the shape from the game set of cards is rendered on the plane object. The Figure 14 is an example of a portion of the code where, after detecting the first click on the dice game cards, the game pattern material is rendered. Subsequently, a check is performed against the auxiliary field, which records the status of the detected positions of the cube. The application is waiting for the second position to be entered so that it can evaluate a pair of cards based on the name attribute.

**FIGURE 13.** **Merge cube adventure - pexeso.**

The last part of the application - Labyrinth combines imported models and a range of objects in the Unity environment. The playing field is composed of cube objects in the Figure 14, whose visual is modified by a combination of created colored materials. The player's ball and target point are models imported from external sources.

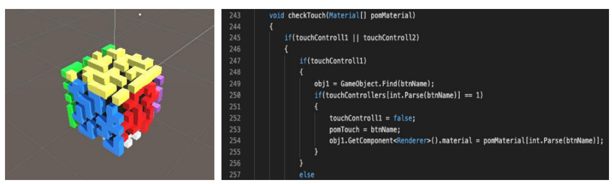


**FIGURE 14.** **Merge cube adventure - labyrint.**

### *C. MERGE CUBE DETECTION*

After launching the application, we are waiting for the detection of the Merge cube. To do this, we create a simple panel that informs the user to place the cube in the camera image. The Figure 15 shows what appear on the mobile device screen after the application is launched.

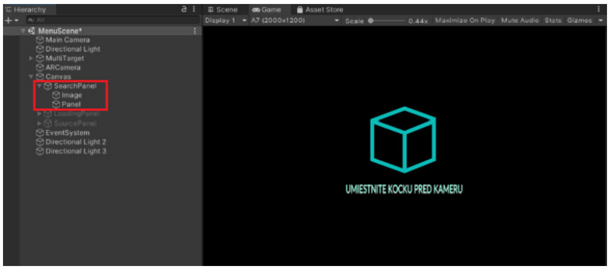


**FIGURE 15.** **Merge cube adventure - loading merge cube through camera.**

In the main script, we create two methods that called from the Multi Target object based on the detection, resp. loss of cube detection. The Multi Target itself contains two events to which you can call your own method. Event On Target Found () performs an action if the camera detects a Merge cube. In this case, we display the main object, our models, and hide the cube location search bar. Event On Target Lost () has the opposite function, then we hide the main object and display the search bar.

### D. TESTING THE APPLICATION

The application was tested in several ways. We first tested the application at the primary school Ďumbierska 17. and then at the High School Andrej Sladkovic, both in Banská Bystrica, Slovakia by regular students. Further testing was carried out in the form of a workshop by teachers from Elementary school at the Banská Bystrica health facility, where teachers work with hospitalized children. During the workshop, the teachers tested the individual parts of app and received a user manual, based on which they will be able to instruct the children in its use. Next testing took place was at the Faculty of Natural Sciences Matej Bel University by teachers and high school students, who also had the opportunity to test all our applications, which we prepared for the same reason. In 2023 was our application tested on High School Železiarne Podbrezová during workshops for high school students focus on virtual and augmented reality.

We used an anonymous questionnaire to determine the results. The questionnaire consisted of eight questions. With the help of a questionnaire, we wanted to find out if they liked our created application, which parts they liked the most. If they didn't like something, they could express themselves in the questionnaire so that we could improve it in the future. A total of 134 respondents participated in the evaluation of the application. Unfortunately, only 104 filled out the questionnaire of which 49 were girls and 54 were boys aged 9-18 years. Our created application contains various areas that are suitable for both primary and secondary school (for repeating the curriculum). Of this number, only 14 respondents had previous experience with augmented reality. The Figure 16 shows answers from the questionnaire "Did you have personal experience with any of the realities (AR/VR/MR) before trying the application?" Answers to this question were very interesting for us - because after they filled the questionnaire we asked them if they played Pokemon Go and they said that they played, but they didn't know that this is an augmented reality.

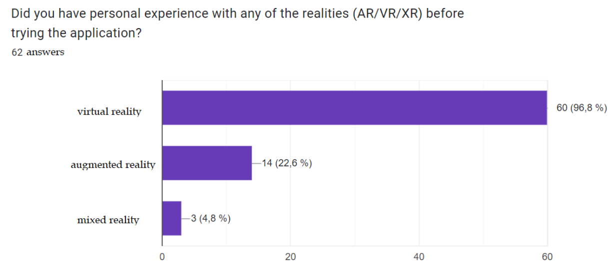


**FIGURE 16.** **Questionnaire - "Did you have personal experience with any of the realities (AR/VR/XR) before trying the application?".**

Another question was aimed to user feeling from the application. We wanted to know if the application was fun for them. The Figure 17 shows question "Were the Merge cube apps fun enough for you?" From the answers follows that for 65% it was fun and 21,4% rather fun. Based on the answers and also the observation, we can conclude that our application was interesting for the students.

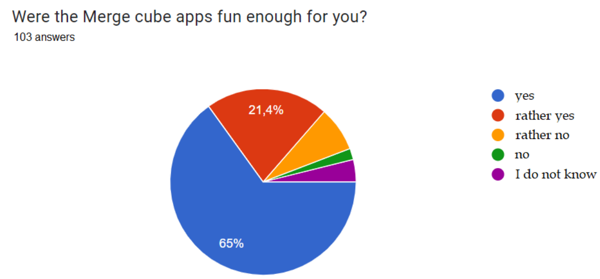


**FIGURE 17.** **Questionnaire - "Were the merge cube apps fun enough for you?".**

We asked the pupils which part of our application they liked the most. The Figure 18 shows the respondents' answers. They liked the part solar system, labyrinth and pexeso the most. The answers did not surprise us, because these three parts are more interactive than the remaining two parts, where students can look at a static object.

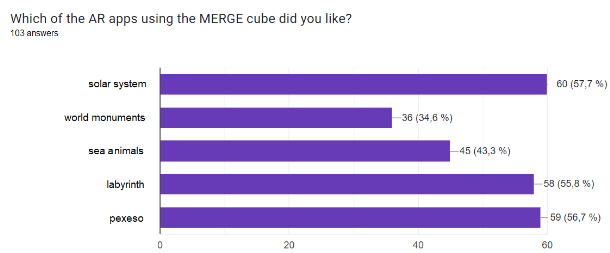


**FIGURE 18.** **Questionnaire - "Which of the AR apps using the MERGE cube did you like?".**

Because the application is aimed to education, we wanted to know if they learn something new. The Figure 19 shows answers from question "Did you learn something new using one of the apps?". Based on the question almost all of them learned something new. A week after our workshops, we communicated with the teachers and wanted to find out from them if the students remembered anything from the lesson. The teachers wrote to us that the students knew how to answer the questions from the application, what they tried and what they saw in the workshops. They were also able to answer questions about augmented reality.

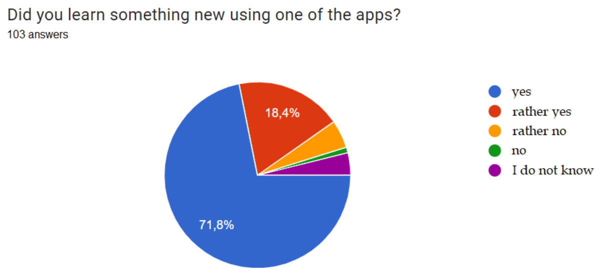


**FIGURE 19.** **Questionnaire - "Did you learn something new using one of the apps?".**

As contributions to education, we can specify the contact of students with new technologies, increasing their digital skills, supporting spatial orientation, creativity, or imagination. We selected the content part of our application based on the analysis of available solutions. We tried to choose models with the assumption of arousing interest in hospitalized children. We added interesting information to the selected models that supplemented the educational page of the application.

Students were excited from the Merge cube and our application. Sometimes we identified problem with showing some elements in the application, the problem was during switching horizontal-vertical mobile device. This problem we fixed in code after the workshops. Students liked the application, but some of them have problem at the begining what they should do (we didn't have much time for the introduction).

## V. DISCUSSION

In Section III-A, we describe existing applications that can be used for training with the Merge Cube. The biggest problem with existing apps is that they are not free. Therefore, in Section III-B, we describe the pages and tools that can be used to create your own educational application for the Merge Cube. Merge Edu and CoSpaces are suitable for creating an augmented reality for the Merge Cube even in elementary school (block-based programming). Unity and Unreal Engine are more suitable for high schools with a focus on computer science.

The aim of our application is to provide children with a visual experience and support their spatial perception and train their memory with a set of fun applications. We tested our application on pupils from primary and secondary schools; we found out whether they liked the application, what they would like to change, and whether they had previous experience with augmented reality. Compared to other research described in Chapter 1, we can confirm based on observation, interviews with teachers, and the results of the questionnaire that the use of the Merge Cube can be an interesting supplement for students in the teaching process in various subjects. The responses to the questionnaires showed that the application had minor errors, which we removed based on the responses.

The main advantage of our app is that it is free compared to other apps described above. Another advantage of our app is that contains several educational areas and also that we can modify the content - it is open source.

## VI. CONCLUSION

In this paper, we focused on the technology of AR, which is increasingly popular not only in the education process. We described some of the applications for augmented reality that used hologram cube Merge. The biggest reason why we devote ourselves to such creation is in the popularization of various AR, VR and MR technologies in education. During the school year, many children who suffer from various diseases and have various problems take turns in the hospital school. For these children, distraction from the disease is very important. The applications presented by us fulfill this task, and children look forward to any meaningful variety of life in the hospital. However, our applications can serve similar purposes to other children in many Slovak elementary schools, as they are not demanding on hardware and software. We described the process of creating our own application created in the Unity engine. The application is free of charge and available for Android devices on the Google Play Store.The application was tested in two schools and based on the results from the questionnaire and observation, it is suitable for the education process - students learned something new, they had the fun. From the questionnaire followed that they don't know what AR is, but after the questionnaire they told us that they played Pokemon Go - so they have experience with AR, but don't know about it. Based on our small research followed that it is important to continue with propagation of augmented reality for students and to continue with developing more Merge cube applications. For educational software developers, we recommend using the Unity environment to create a Merge Cube application because it is free and contains many assets.

Students were excited from the Merge Cube and our application. Sometimes we identified problem with showing some elements in the application, the problem was during switching horizontal-vertical mobile device. This problem we fixed in code after the workshops. Students liked the application, but some of them have problem at the begining what they should do (we didn't have much time for the introduction).

We are currently working on another educational app for Merge Cube with new educational functionality focusing on other areas such as physics, mathematics and other natural sciences.

## REFERENCES

[1] H. Crompton, "A historical overview of mobile learning: Toward learner-centered education," in *Handbook of Mobile Learning*. New York, NY, USA: Routledge, 2013, pp. 3–14.

[2] J. Fialová, "On a mobile application for learning positive and negative Integers1," in *Proc. 17th Int. Conf. Emerg. eLearning Technol. Appl. (ICETA)*, Nov. 2019, pp. 179–184.

[3] J. Fialová and M. Pokorný, "E-learning can reduce the negative impact of COVID-19 in teaching mathematics," in *Proc. 18th Int. Conf. Emerg. eLearning Technol. Appl. (ICETA)*, Nov. 2020, pp. 102–107.

[4] M. Pokorný, "Online learning in teaching initial math education," in *Proc. Int. Conf. Recent Innov. Comput.* (Lecture Notes in Electrical Engineering), vol. 1001, 2023, pp. 657–667.

[5] M. Pokorný, "Experience with online learning of mathematics in primary education," *Int. J. Emerg. Technol. Learn. (iJET)*, vol. 18, no. 2, pp. 203–213, Jan. 2023.

[6] A. Ewais, R. Hodrob, M. Maree, and S. Jaradat, "Mobile learning application for helping pupils in learning chemistry," *Int. J. Interact. Mobile Technol. (iJIM)*, vol. 15, no. 1, pp. 105–118, 2021.

[7] M. Nazar, K. Puspita, and H. Yaqin, "Android-based mobile learning resource for chemistry students in comprehending the concept of redox reactions," *Int. J. Interact. Mobile Technol. (iJIM)*, vol. 16, no. 3, pp. 123–135, Feb. 2022.

[8] D. Purbohadi, S. Afriani, N. Rachmanio, and A. Dewi, "Developing medical virtual teaching assistant based on speech recognition technology," *Int. J. Online Biomed. Eng. (iJOE)*, vol. 17, no. 4, pp. 107–120, 2021.

[9] E. Dolzhich, S. Dmitrichenkova, and M. K. Ibrahim, "Using m-learning technology in teaching foreign languages: A panacea during COVID-19 pandemic era," *Int. J. Interact. Mobile Technol. (iJIM)*, vol. 15, pp. 20–34, Dec. 2021.

[10] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," *IEEE Comput. Graph. Appl.*, vol. 21, no. 6, pp. 34–47, Nov. 2001.

[11] B. Poetker. (Aug. 2019). *A Brief History of Augmented Reality*. [Online]. Available: https://www.g2.com/articles/history-of-augmented-reality

[12] Numerized. (2020). *A Brief History of Augmented Reality*. [Online]. Available: https://numerized.com/augmented-reality/history-augmented-reality/

[13] V. Mamone, V. Ferrari, S. Condino, and F. Cutolo, "Projected augmented reality to drive osteotomy surgery: Implementation and comparison with video see-through technology," *IEEE Access*, vol. 8, pp. 169024–169035, 2020, doi: 10.1109/ACCESS.2020.3021940.

[14] F. Cutolo, B. Fida, N. Cattari, and V. Ferrari, "Software framework for customized augmented reality headsets in medicine," *IEEE Access*, vol. 8, pp. 706–720, 2020, doi: 10.1109/ACCESS.2019.2962122.

[15] P. Horejsí, K. Novikov, and M. Simon, "A smart factory in a smart city: Virtual and augmented reality in a smart assembly line," *IEEE Access*, vol. 8, pp. 94330–94340, 2020, doi: 10.1109/ACCESS.2020.2994650.

[16] J. W. Lai and K. H. Cheong, "Adoption of virtual and augmented reality for mathematics education: A scoping review," *IEEE Access*, vol. 10, pp. 13693–13703, 2022, doi: 10.1109/ACCESS.2022.3145991.

[17] M. Taufiq, M. Nuswowati, and A. Widiyatmoko, "Feasibility study of a solar system learning media based on merge cube augmented reality to embedding problem solving skills," *J. Phys., Conf.*, vol. 1918, no. 5, Jun. 2021, Art. no. 052064.

[18] G. L. Lin, "The application of augmented reality using merge cube in glycoscience dissemination," *Int. J. Digit. Media Des.*, vol. 13, no. 1, pp. 1–13, 2021.

[19] L. G. Ameen, "The effectiveness of using a dramatized content through augmented reality to improve English language fluency of high school students," Ph.D. dissertation, Fac. Educ. Stud., Nat. Egyptian e-Learn. Univ., 2021.

[20] E. Ntuli, "Augmented reality in early learning: Experiences of K-3 teachers with merge cubes," in *Proc. World Conf. E-Learn. Corporate, Government, Healthcare, Higher Educ.*, 2019, pp. 557–560.

[21] B. Vaughan. (Jul. 30, 2019). *Augmented Reality: From Research to Ubiquity in 30 years*. Medium. [Online]. Available: https://medium.com/scape-technologies/augmented-reality-from-research-to-ubiquity-in-30-years-1570a8653d63

[22] V. Agrawal and P. Jignesh, "A review: Augmented reality and its working," *Int. J. Eng. Technol.*, vol. 4, no. 5. pp. 602–604, 2017.

[23] D. Chatzopoulos, C. Bermejo, Z. Huang, and P. Hui, "Mobile augmented reality survey: From where we are to where we go," *IEEE Access*, vol. 5, pp. 6917–6950, 2017.

[24] D. Whitley-Walters and J. Muhammad, "The analysis of implementing augmented reality within remote learning," in *Proc. Symp. Comput. Minority Institutions*, 2021, pp. 1–7.

[25] A. Al-Gindy, C. Felix, A. Ahmed, A. Matoug, and M. Alkhidir, "Virtual reality: Development of an integrated learning environment for education," *Int. J. Inf. Educ. Technol.*, vol. 10, no. 3, pp. 171–175, 2020.

[26] J. Jang, Y. Ko, W. S. Shin, and I. Han, "Augmented reality and virtual reality for learning: An examination using an extended technology acceptance model," *IEEE Access*, vol. 9, pp. 6798–6809, 2021.

[27] V. Rossano, R. Lanzilotti, A. Cazzolla, and T. Roselli, "Augmented reality to support geometry learning," *IEEE Access*, vol. 8, pp. 107772–107780, 2020.

[28] A. C. Bierman, "An examination of the integration of augmented reality in science curriculum," M.S. thesis, Dept. Teach. Learn. Found., Eastern Illinois Univ., Charleston, IL, USA, 2021.

[29] L. N. de Souza, A. R. M. Cuperschmid, and D. C. Moreira, "Augmented reality using cuboid tracking as a support for early stages of architectural design," in *Proc. Conf.*, vol. 19, 2022, p. 20.

[30] *Working With Cloud Recognition*. Accessed: Jul. 2023. [Online]. Available: https://library.vuforia.com/cloud-recognition/working-cloud-recognition

[31] L. Fade. *Augmented Reality in Business: How AR May Change the Way We Work*. Accessed: Jul. 2023. [Online]. Available: https://www.forbes.com/sites/theyec/2019/02/06/augmented-reality-in-business-how-ar-may-change-the-way-we-work/?sh=7e197efc51e5

[32] R. Shea, D. Fu, A. Sun, C. Cai, X. Ma, X. Fan, W. Gong, and J. Liu, "Location-based augmented reality with pervasive smartphone sensors: Inside and beyond Pokemon go!" *IEEE Access*, vol. 5, pp. 9619–9631, 2017.

[33] CoSpaces. *Build Your Own Creations for the MERGE Cube*. CoSpaces. Accessed: Jul. 2023. [Online]. Available: https://www.cospaces.io/edu/merge-cube.html

[34] *Learn Science, Master STEM, Be Future Ready*. Accessed: Jul. 2023. [Online]. Available: https://mergeedu.com/l

[35] X. Liu, S. Y.-H. Sohn, and P. Dong-Won, "Application development with augmented reality technique using Unity 3D and Vuforia," *Int. J. Appl. Eng. Res.*, vol. 13, pp. 15068–15071, 2018.

[36] *The Leading Platform for 3D and AR on the Web*. Accessed: Jul. 2023. [Online]. Available: https://sketchfab.com

[37] *Vuforia Engine*. Accessed: Jul. 2023. [Online]. Available: https://developer.vuforia.com

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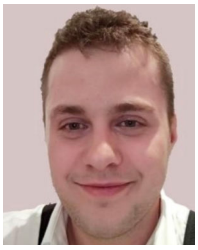

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