GEOMY: A Mobile Augmented Reality Application For An Efficient and Heuristic Geometry Education

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The high school mathematics course within the scope of the standardized curriculum offered by the Turkish Ministry of National Education, is a course in which students perform very poorly in the university exam, according to the data published by OSYM. Yet, students' performance in mathematics is of high importance for the development of their problem solving and analysis skills. To enhance students' performance, augmented reality (AR) technology can provide a great basis for heuristic learning in the first stages of problem solving, such as understanding and analyzing problems. The role that AR can play in the teaching and learning of geometry is comprehended, and it is aimed to utilize this role in the most efficient way by developing an augmented reality mobile application for geometry, focusing on 3D objects in its initial state. The main tools used for the development of the application are Unity, the world's largest game engine, and Vuforia, a highly advanced augmented reality development kit. The use of these tools is completely costless, as well as enabling the application to be used on different platforms, making the project accessible to all students/teachers. In this way, it is hoped that geometry, especially the subject of 3D objects, can be better understood by high school students between the ages of 14-18. It is also hoped that such steps in digital transformation will increase the overall level of education in our society over the long run.

Keywords: 3D Objects, Augmented Reality, Dynamic Geometry, Geometry Education, Heuristic Learning

I. INTRODUCTION

The primary purpose of this project is to develop a mobile application for teaching and learning geometry, focusing on 3D objects, using augmented reality technologies that stand out with their suitability for embodying 3D objects. The ultimate goal to be achieved as a result of the development process is to provide a cost-free solution that students can easily access, making up for the shortage of opportunities for students to reach quality mathematics education on mobile platforms.

Mathematics education has a great effect on developing a formation that is prone to providing a basis for creative and technological developments by improving students' problem-solving skills. Students, who synthesize information by using various skills together during the problem-solving process, have the chance to partake in the production of new information beyond merely memorizing or transferring it. Problem-solving skills that these students use lay the foundations for the development of original ideas in society. In fact, according to Bindak (2005), the acquisition of mathematical skills are the most important elements to be learned for the order and organization of the world (Korkmaz, Tutak, 2017). The features of mathematics, described as a system of ideas (structures) and relations derived from various sequential abstractions and generalizations, are listed by Korkmaz and Tutak (2017) as follows:

- People benefit from counting, calculating, measuring and drawing with mathematics.
- Mathematics is a language that uses some symbols.
- Through the logic of mathematics, people think logically.
- With mathematics, people can easily understand the world and improve the environment they live in.

The connection of mathematics with both scientific and casual problem solving & data association increases the importance of successful comprehension by students (Altun, 2018). For this reason, the low level of mathematical success acquired by the students in Turkey represents a desperate situation, as it shows the lack of essential problem solving skills. There is a lot of data showing the success level of Turkish students in the field of mathematics, including the results of exams such as TIMSS, PISA, and TEOG (Transition from Basic Education to Secondary Education), ÖBBS (Student Success Determination Exam). The data published by ÖSYM shows that the basic mathematics average is 5.12 correct answers out of 40 questions in the Basic Proficiency Test (TYT). Besides, in the Field Proficiency Test (AYT), the mathematics average is 6.19 in 40 questions (ÖSYM, 2021). As another example, according to the PISA (2016) national report, while the general average of all participating countries is 461, the average score of Turkey in mathematics is 420. Turkey ranks 50th among 72 participating countries (Savaşçı, 2018). This situation shows us concretely that mathematics education in Turkey is below the average, and pushes us to question the barrier to the development of mathematical problem-solving skills.

There are various opinions about the reason for students' low mathematical achievement. One of these opinions is that abstract expressions and doctrines remain in theory, leading to a prejudiced approach to mathematics and revealing the problem of not being able to relate mathematics to real life (Korkmaz, Tutak, 2017). Since the opinion presents a fairly generalized picture of the problem, other views can be examined in the light of this view. For example, as stated by Savaşçı (2018), students prefer shortcuts such as formulas while solving a problem to reach the solution in a short time rather than processes such as drawing or analyzing the problem; and this shows that what is learned remains in theory, as stated by Korkmaz and Tutak (2017). Therefore, students are not even aware of what they are doing while solving questions (Savaşçı, 2018). Acting with a mechanical problem-solving principle rather than actively synthesizing knowledge, experiences, skills and intuitions about the problem and the overall subject causes many students to remain at a limited level in understanding problems. This is a situation that can be interpreted by looking at the stages of problem solving. Wilson et al. schematized the problem-solving process as follows:

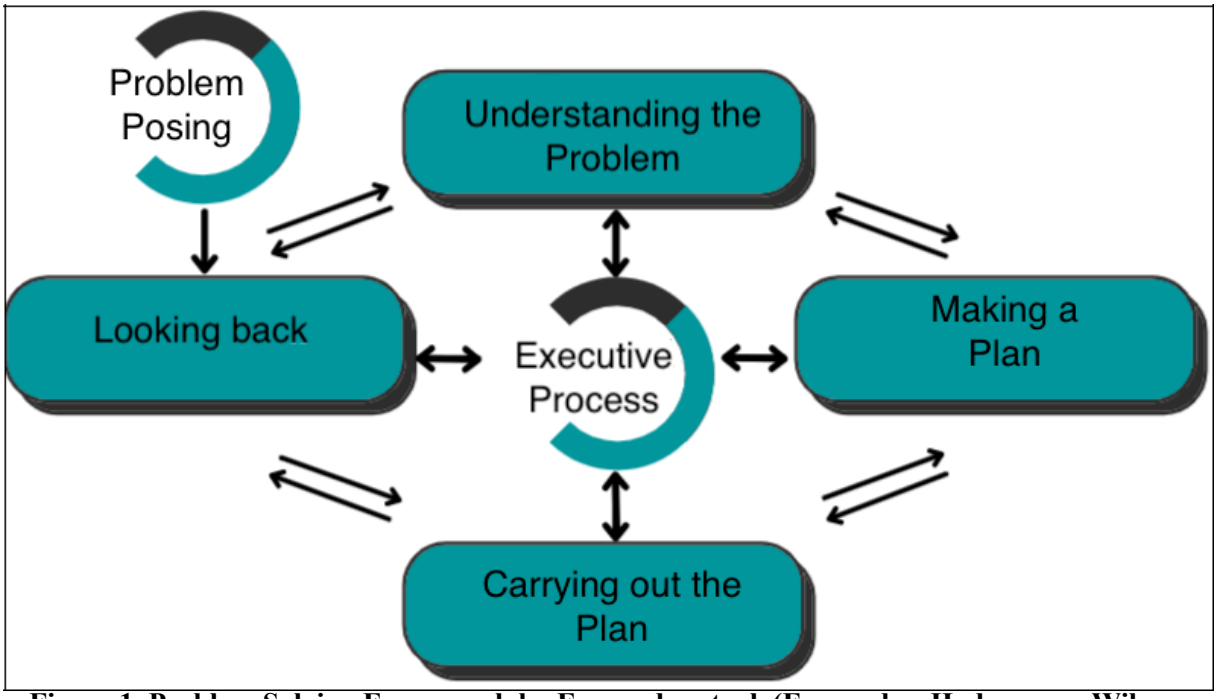


Figure 1. Problem Solving Framework by Fernandez et. al. (Fernandez, Hadaway ve Wilson, 1994)

As mentioned, the absence of processes such as synthesizing knowledge, skills, observations, experience and intuition, is also an indication that some of the steps in the problem solving scheme in Figure 1 are not fully met by the students. The numerical data shows that students cannot take the necessary steps in problem solving: According to the PISA (2016) report, the rate of students at the lower level is 35.8% in all countries and 51.3% in Turkey. While the rate of students at the top level is 8.2% in all countries, it is 2.01% in Turkey. That is, the vast majority of students can only answer simple, clearly defined questions at the lowest level in problem solving. Only very few students are able to solve high-level questions that require complex reasoning and developing an appropriate problem-solving strategy (Savaşçı, 2018). The fact that only well-defined, familiar questions can be solved by most students signifies problems even in understanding the problems. As it was done in this project, providing visualization of questions with augmented reality applications is one of the solutions that can be used to increase the success in understanding the problems, as it will facilitate 3D perception and thinking abilities. Many different solutions have been tried on this matter and are still being developed.

Since the high school mathematics class is a broad course covering many subject areas, one focus area in mathematics was chosen with the aim of keeping this project in the context of a clear research question. Therefore, in this project, the field of geometry was chosen with a focus on 3D objects. Geometry is one of the most important and fundamental subject areas and conceptual building blocks of mathematics, as determined by the American National Association of Mathematics Teachers (NCTM). Geometry, examining the properties of shapes and the relations between properties, enables students to develop their thinking skills and to express what they think in a mathematical language.

It has been stated that to the extent that students understand the concepts in geometry lessons, they gain the ability to understand and explain the entities around them in terms of shape and size (Altun, 2018). In order for these benefits to occur, a more effective geometry education should be provided.

Current studies focusing on enabling an effective geometry education are mostly based on integrating technology with traditional education, utilizing the power of technology to visualize shapes. Due to the developed software, it is aimed that the students intuitively realize a stronger level of comprehension. The characteristics of intuitive learners are given in Table 1.

INTUITIVE LEARNERS
Dominant Features
❖ They prefer to produce internal data by using their foreknowledge, intuition, predictions, imagination and thinking about possibilities. ❖ They prefer soft information (concept, rule, principle, theory, mathematical expression, etc.). ❖ In the learning process, they like to explore possibilities and relationships using their imagination. ❖ They may be better at grasping new concepts and more comfortable understanding abstract materials and mathematical formulas. ❖ Concepts, principles, theories, interpretations, equations are more interesting. ❖ They like variety in their work, they like confusion and surprises. ❖ They do not like memorization and repetition. ❖ They are impatient to study and find the details. ❖ They tend to work faster, they are more progressive ❖ but they can be careless.
Weak Traits
❖ They do not like classes that involve constant memorization and routine calculations. They get bored in situations where activities such as establishing relationships, interpreting, and exploring possible applications of new knowledge are not provided. ❖ They are more comfortable perceiving and understanding symbols, but may fail on time-based tests because of impatience: They don't read the questions fully and they respond immediately, causing them to make mistakes.

Table 1. Features of intuitive learners (Özgür, Veznedaroğlu, 2005).

Considering the features described in Table 1, it can be said that heuristic learning, made possible by the intuitive features of the application, develops skills such as the ability to think abstractly and to establish relationships between information, which can enhance success in mathematics. This is why the software developed on behalf of mathematics education have come to the forefront with their tendency to use visual contexts in which heuristic learning can be practiced more actively. The method with the highest efficiency among the developed software is the method called Dynamic Geometry Software (DGS). Examples of DGSs, which are reflections of the rapid progress in computer technology to classrooms, are specialized software such as Cabri Geometry, Geometer's Sketchpad, and Cinderella (Guven, Karatas, 2003).

In addition to the ease of creating geometric shapes, these software provide an opportunity to “explore” thanks to many features such as zooming in, zooming out, moving and seeing from different angles.

As a result of the student reaction research conducted by Güven and Karataş -with a DGS created in 2003- very positive feedback was received. After this study with Cabri Geometry, students expressed drastically different ideas about geometry, which they previously saw as 'memorization', 'abstract', 'meaningless formula sequence'. In the interviews, students interpreted learning geometry in an environment like Cabri software as 'enjoyable', 'fun', 'colorful', 'like a puzzle'.

The reason for this was that students played an active role as an explorer in the learning process and make an inductive sense of the shapes they see (Guven, Karataş, 2003). In a study conducted in 2010 using the same DGS, it was observed that the use of DGS had a positive effect on the success of 12th grade students in the field of space geometry. In fact, while the success rate of students was 63% before the use of Cabri, it increased to 79% after the study (Eryiğit, 2010).

The given circumstances clearly present the benefit of heuristic learning and the advantage of software-based supporting mechanisms in the heuristic learning process. Therefore, it is of great importance to increase and disseminate accessible technologies in this field. Augmented, virtual and mixed reality technologies are some of the significant technologies that have become accessible with their rapid development in recent years. Augmented reality is greatly suitable for creating a system where students can see the textbook questions as 3D models, just above the question. Augmented reality brings together the real and virtual world; It encompasses the reinforcement of reality by providing people with information that is not normally detectable by people's senses and cognitive processes. This technology makes it possible to improve the perception of the user by placing virtual objects or information clues in the real world (Somyürek, 2014).

Therefore, the use of augmented reality technology in DGSs is a very useful method. The reason for this is the necessity of transforming spatial geometry subjects such as 3D objects, which require three-dimensional thinking, from abstract representations to concrete models. Thus, the augmented reality mobile application “Geomy” was developed, aiming to provide an accessible, effective and heuristic geometry education by adding a third dimension to two-dimensional geometry books.

II. METHODS

a. Selection of the AR Method

Among the options available for creating augmented reality applications, Vuforia was chosen because of its user-friendly interface and its power in processing target images. At the same time, it has been a big plus that Vuforia can be used without any cost up to a certain number of requests. The number of requests is the number of times a target image has been accessed from the cloud. Considering how the limit for requests is calculated per user, the fact that 1000 (thousand) requests can be submitted per month indicates that the limit will be a

hypothetical detail for most users. It is very unlikely that a user who uses Geomy to concretize geometry questions will reach 1000 questions every month. An image of how target images are processed and shared in the "Rating" column in Vuforia is given in Figure 2.

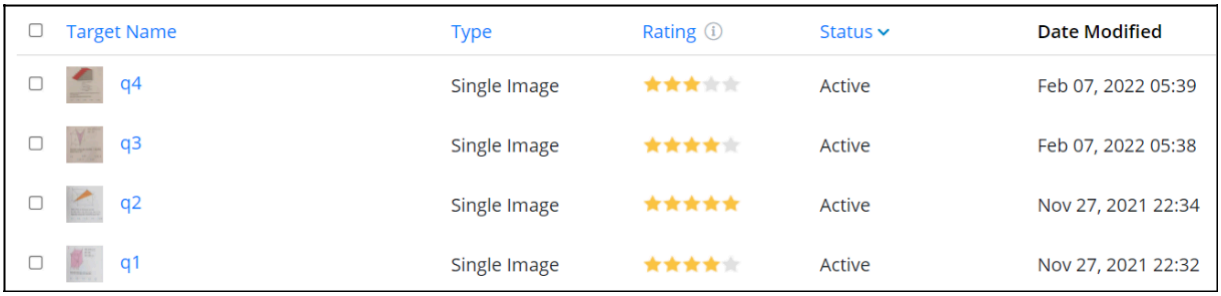


Figure 2. The addition of target images to the database.

b. Tools and Equipments

The tools and equipments that were used in the development of this project were a computer, Unity game engine, ProBuilder tool from Unity, Vuforia augmented reality development kit, and a smartphone to test the application.

c. Augmented Reality Pipeline

While developing this project, a database named "geomy_database" was created in Vuforia. Target images (some different style of geometry questions) were loaded into this database as can be seen in Figure 2.

Then, the license information obtained from Vuforia was entered into Unity, and the application in Unity was integrated with Vuforia. Thus, when an image out of the target images is given to the application as an input, the Vuforia development kit detects it and displays it on the console. As Vuforia detects target images as a result of continuous checking, the shapes in the folder of target images called "ImageTarget" in Unity get activated and begin to appear. In Figure 3, its file hierarchy in the project is shown.

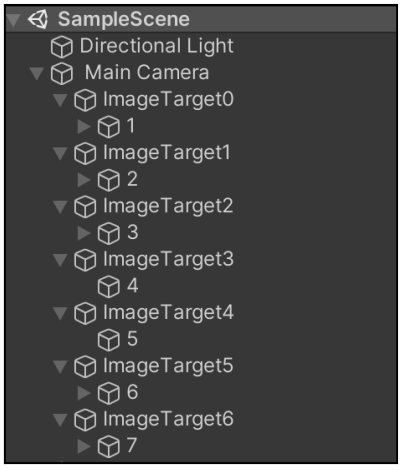


Figure 3. The hierarchy between target images and the 3D models belonging to them. 3D models are named as numbers for ease in the coding processes.

d. 3D Object Modeling

The modeling of three-dimensional solid objects that will be displayed using AR on the smartphone screen was carried out with the ProBuilder 3D modeling tool in the Unity game engine. Unity game engine stands out as the world's largest game engine (“Game Engines on Steam: The Definitive Breakdown”, 02.09.2021). ProBuilder was the most frequently used feature of Unity in this project. In this way, 3D models could be sampled. ProBuilder features, which can be seen in Figure 4, were evaluated and used according to their requirements and benefits.

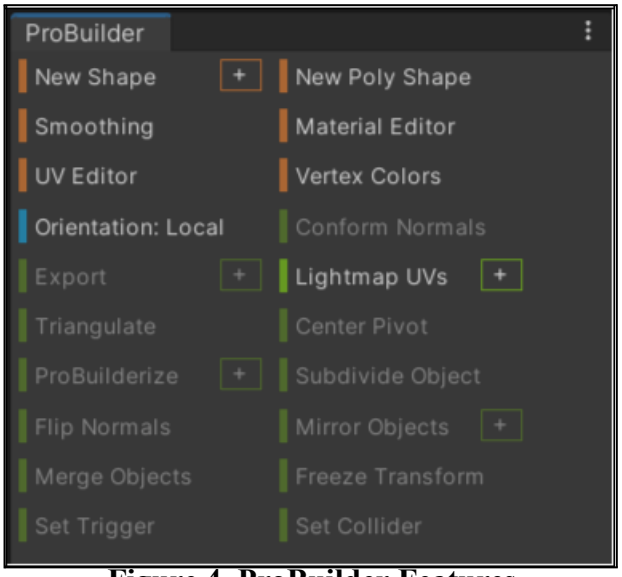


Figure 4. ProBuilder Features

One of the ProBuilder functions, “New Shape” has been the most used function. Thanks to the “New Shape”, new three-dimensional solids could be created and customized. Figure 4 illustrates the interface used during the creation of a ladder-shaped object for one of the sample questions used in this project.

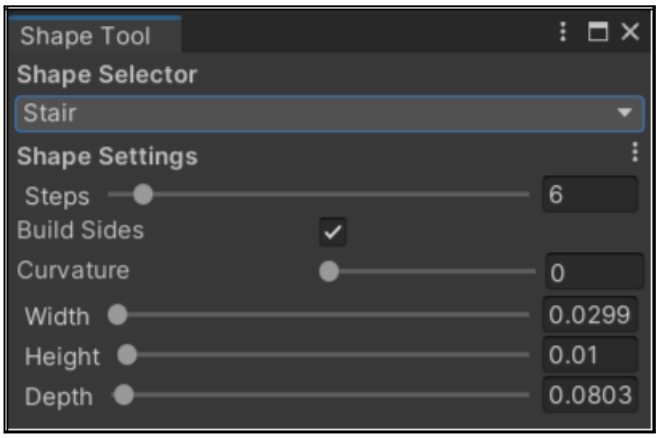
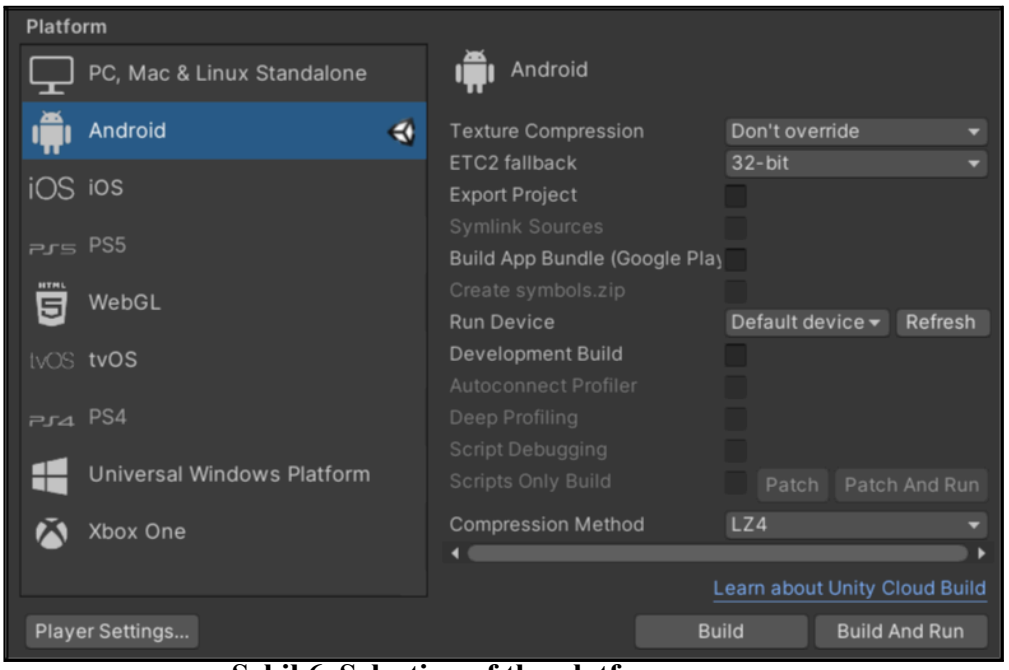


Figure 5. "New Shape" Shape Tool

As a result, all the shapes developed in the project were created with this method.

e. Scope of the Project on Mobile Platforms

One of the features of the Unity engine is that the developed applications can be built cross-platform. Although this project was carried out by targeting the Android operating system, it is possible to install the application on the IOS or Linux operating system thanks to the convenience provided by Unity in cross-platform transition. The cross-platform transition was made in this project as can be seen in Figure 5.



Şekil 6. Selection of the platform.

In this way, it can be downloaded by phones with Android, IOS and Linux operating systems. However, this is not the only feature that makes the application accessible to everyone; The tools and equipment selected during the development phase of the project ensure that the cost of the application is absolutely non-existent, enabling everyone to download it without any cost.

III. RESULTS

The sample models that are used for creating the augmented reality when the textbook questions are scanned are shown in Figures 7, 8, 9, 10.

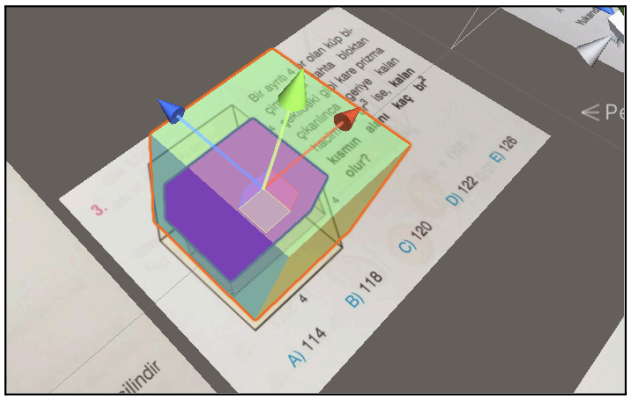


Figure 7. Sample Model 1 (Top)

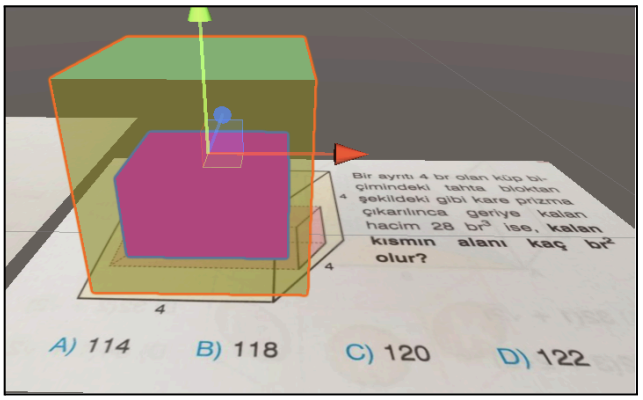


Figure 8. Sample Model 1 (Front)

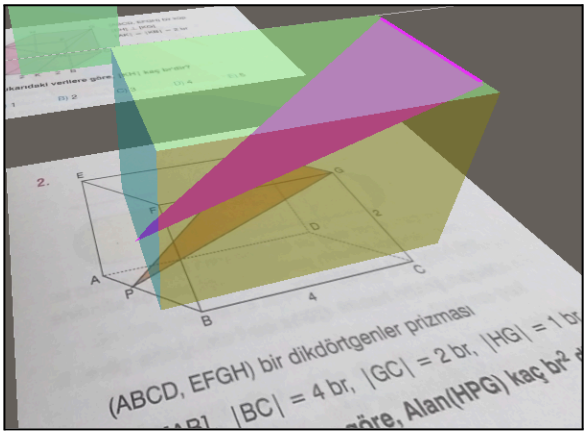
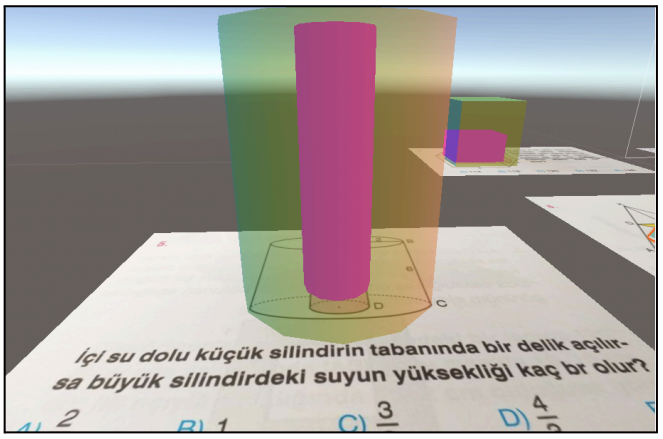


Figure 9. Sample Model 2



Şekil 10. Sample Model 3

After the sample figures were displayed on the Unity platform, the application was installed on a phone. As shown in Figure 11, the pre-built models were successfully seen on the phone.

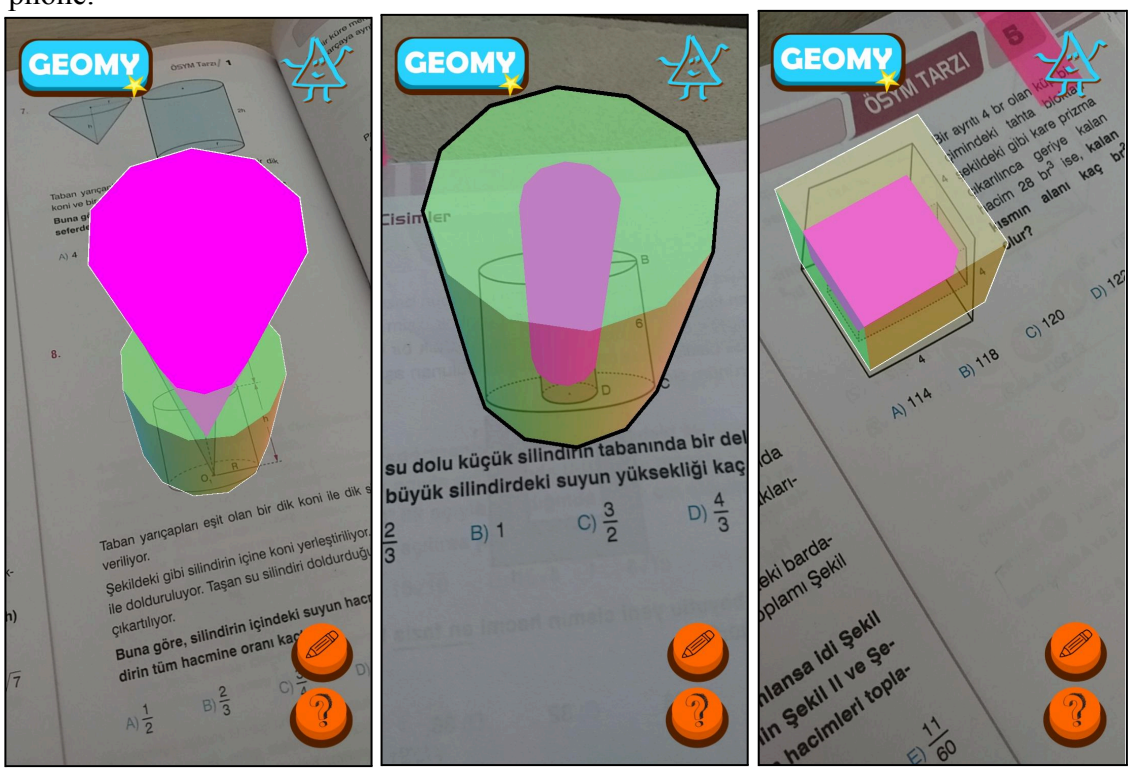


Figure 11. Demonstration on a Smartphone

The development/design environment in which the application was developed throughout this entire process, is shown in Figure 12.

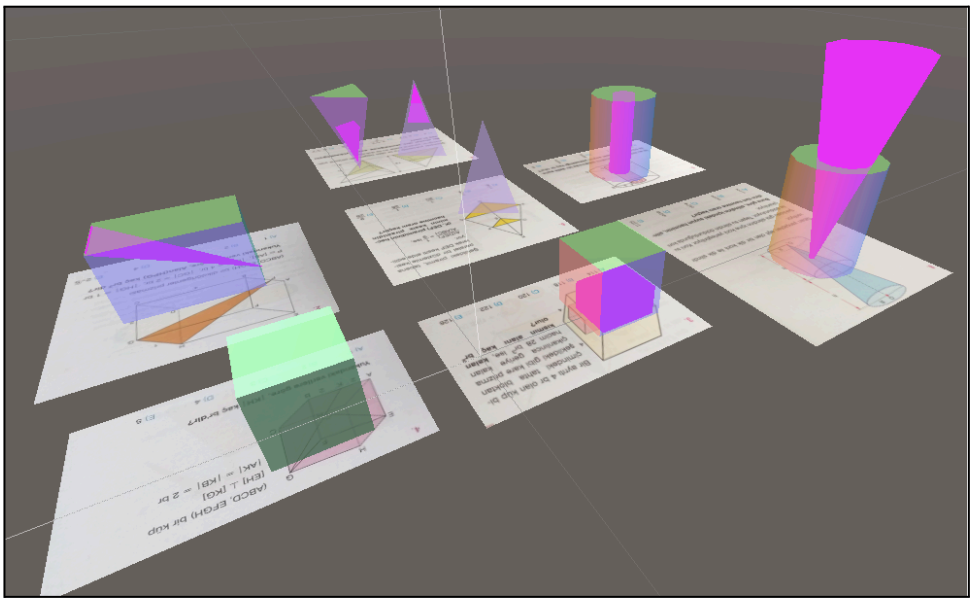


Figure 12. The development environment (Unity)

IV. CONCLUSION

The mobile application Geomy was developed in a way that it can be easily accessed from mobile phones to provide effective & intuitive learning with augmented reality. It has indeed succeeded in adding a third dimension to the two-dimensional spatial geometry questions in the test books. As can be seen in the Findings section, Geomy was able to show the shapes assigned to the detected questions ("ImageTarget") on a phone where it was downloaded in .apk format. It was also able to keep his communication with Vuforia at all times. This consistency was made possible by the sharp image quality of the target images, since it was a determining factor for constant accuracy.

The fact that the application is downloadable on Android, IOS and Linux platforms makes the application accessible. Moreover, there is another factor that makes it much more convenient for users who cannot meet high system requirements: All target detection processes are done in the cloud in Vuforia. Thanks to the lack of high system requirements, it was ensured that the students did not encounter obstacles in downloading the application. Since the development and installation of the application is completely costless, the obstacles to the further development and dissemination of the project was also prevented.

a. Suggestions for short-term development

In order for this project to be more effective, a potential further development is to integrate solid object expansions, which students have difficulty in visualizing in their minds, to actualise intuitive learning more comprehensively. For example, by pressing a button on the screen, the solid object in the question can be expanded, when the button is pressed again, the figure can return to its old (closed) state. In this way, it can be ensured that the student can make mental transitions between two dimensions and three dimensions more easily and internalize this process.

Increasing the level of interactivity of the application is another useful development point so that students can better visualize solid objects in their minds. In order to be more interactive, a system can be established in the application where students can draw on or inside the figures shown in three-dimensional form. Seeing the results of their drawings in three-dimensional space will improve their spatial thinking abilities and will be a useful step in the intuitive learning of solid objects.

b. Foresight for long-term development

As the experimental data on the subject already suggest, the use of innovative technologies in the classroom environment is beneficial for understanding the concepts while the students are in the learning phase. The features proposed to be integrated into the application developed in this project in the short term will also lay the groundwork for the Geomy application to contribute to classroom learning. For example, students will be able to visualize sample questions solved by a teacher on their own devices, see them from different angles, and draw on them. In order to facilitate this situation, it would be useful to contact the publishing houses producing textbooks for the classroom environment. When registered in Geomy, these textbooks can be integrated to the database in cooperation with the publishers.

In a very special case, it is possible to use Geomy for textbooks without needing any database. The technology that unlocks this possibility converts two-dimensional drawings into three-dimensional models. Many people are working on building this technology, including Google engineers and Middle East Technical University researchers (Dvorožňák, et al, 2020; Yetiş, 2019). This technology considerably shortens the time that would have to be spent for three-dimensional drawing thanks to CNN (Convolutional Neural Network) deep learning models using convolutional neural networks (Yetiş, 2019). When this technology reaches a level that is advanced enough to adapt to the differences of varying phone cameras, it may be feasible for the application to turn geometry questions into three dimensional models without the need for any database. In future research, it is recommended to further examine the potential of convolutional neural networks in this area, predictably one of the keys to digital transformation in education.

V. REFERENCES

Dvorožňák, M., Sýkora, D., Curtis, C., Curless, B., Sorkine-Hornung, O., & Salesin, D. (2020). Monster mash: a single-view approach to casual 3D modeling and animation. *ACM Transactions on Graphics (TOG)*, *39*(6), 1-12.

ERYİĞİT, P. (2010). *Üç boyutlu dinamik geometri yazılımı kullanımının 12. sınıf öğrencilerinin akademik başarıları ve geometri dersine yönelik tutumlarına etkileri* (Doctoral dissertation, DEÜ Eğitim Bilimleri Enstitüsü).

Fernandez, M. L., Hadaway, N. & Wilson, J. W. (1994). Problem Solving: Managing It All. The Mathematics Teacher, 87(3), 195 – 199.

Accessed from https://www.jstor.org/stable/2796879

Game Engines on Steam: The Definitive Breakdown (02.09.2021)
Accessed from,
https://www.gamedeveloper.com/business/game-engines-on-steam-the-definitive-breakdown
on February 8th 2022.

GÜVEN, B., & KARATAS, I. (2003). Dinamik geometri yazilimi cabri ile geometri ögrenme: ögrenci görüsleri. *TOJET: The Turkish Online Journal of Educational Technology*, *2*(2).

KORKMAZ, E., & TUTAK, T. (2017). Dönüşüm Geometrisi Konusunun Öğretiminde Öğrencilerin Gerçekçi Matematik Eğitimi Yaklaşımına ve Yapılandırmacı Yaklaşıma İlişkin Görüşleri. *Itobiad: Journal of the Human & Social Science Researches*, *6*(5).

ÖSYM (2021). YKS Değerlendirme Raporu 2021. *Değerlendirme Raporları Serisi No: 27. Accessed from,*
https://dokuman.osym.gov.tr/pdfdokuman/2021/GENEL/yksdegrapor_24122021.pdf

Savaşçı, H. S. (2018). Öğrencilerin matematiksel problem çözme becerileri ile algısal öğrenme stilleri arasındaki ilişki.

Somyürek, S. (2014). Öğretim sürecinde z kuşağının dikkatini çekme: artırılmış gerçeklik. *Eğitim Teknolojisi Kuram ve Uygulama*, *4*(1), 63-80.

Veznedaroğlu, R. L., & Özgür, A. O. (2005). Öğrenme stilleri: tanımlamalar, modeller ve işlevleri. *İlköğretim Online*, *4*(2), 1-16.

Yetiş, G. (2019). *Auto-conversion from2D drawing to 3D model with deep learning* (Master's thesis, Middle East Technical University).