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RESEARCH ARTICLE

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AR Book, augmented and mixed reality applications in the education of mineral processing machines

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Abstract

This study investigated the effects of three different augmented reality (AR) applications on the education of mineral comminution and classification machines. In the first application, an augmented reality booklet (AR-Book) was prepared, which included the basic machines used in mineral processing and classification. The application was designed for mobile devices and has an image target type structure. In the second application in the image target type, the mixed reality (MR) device MS Hololens 2 was used, which provides visualization in the environment and hand interactions on the models. The third application has a spatial-ground plane structure that provides hand interaction experience with MS Hololens 2. The contributions of these approaches, which aim to support traditional training, were examined through student feedback. As a result, student assessments, it was concluded that

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they improve learning, increase focus, make education more fun, and positively affect both the retention of knowledge and the overall quality of education.

Keywords: Mineral Processing; Augmented Reality; Mixed Reality; AR Book; Unity; Hololens 2

1. Introduction

Unlike virtual reality, augmented reality (AR) is a relatively new technology in which virtual designs can be intertwined with the environment without being isolated [1, 2, 3]. Although it dates to 1968, the major advancement in today's usage occurred with the ARToolKit software in 2000. The brief history of AR journey is explained with milestones in the Assemblr [4]. AR content includes visual, auditory, and haptic aspects [5]. Mobile devices and smart glasses are used as basic hardware. It is also possible to interact with these holographic images generated in living spaces, which are known as mixed reality (MR). In other words, MR is a composition of the physical environment and digital worlds through multiple sensors, advanced optics, and holographic processing [6].

It can be used in many areas, such as engineering, science and health sciences, education, work safety, geographic sciences, communication, etc. [7]. If it is considered specifically for education, the contribution of both virtual reality and augmented reality to classical education has been demonstrated by many scientific studies [8, 9, 10, 11].

There exist various virtual and augmented reality applications in mining engineering education [12, 13, 14]. Most of them use virtual reality, and some of them use partly augmented reality. The dominating scope of these studies is related to mining operations of open pits and underground galleries, tunnels and settlements [60-69]. On the other hand, there are a very limited number of studies [25-28] in which VR and AR are used in the training of mineral processing machines, and there are none for *augmented reality books, image and ground plane applications of mixed reality on mineral processing machine training.*

AR Books, as one of the branches of AR applications, represent a creative blend of traditional literature and digital media. They strive to offer an engaging reading experience by incorporating interactive features like 3D models, animations, audio, and videos, enabling readers to connect with the narrative in fresh and exciting ways [15].

The most up-to-date and advanced hardware in the AR field is smart glass. The most senior of these devices, products of high electro-optic technology, are Microsoft Hololens [16], and the newest is Apple Vision Pro [17].

Based on this strong infrastructure from the past to the present, an application was made in the field of mineral processing by using Unity's real-time development engine [18]. An AR Book was designed for the most basic machines, and first, a deployment was made for mobile devices that everyone can access. A second application was made using the Image Targets approach for the same AR Book, using MS Hololens 2 smart glass. With the application, hand interaction is also possible with the virtual machine models that appear on the AR Book. Drag, rotate, and scale operations can be performed with hand interaction, which is a realization of the concept of MR. The third application, a study called ground plane, was made for MS Hololens 2. Virtual models of machines appeared in space without the need for any Image Target. It is possible to intervene in these models with hand interaction and investigate them by handling or walking around them. This is also an MR application.

In augmented reality, packages and engines such as AR-Foundation, AR-Kit, and Vuforia. Vuforia [19] was preferred in this study due to its practical compatibility with Hololens 2 for mineral processing applications. Target shapes were loaded into the created database. Then, a *unitypackage* file was created and downloaded.

To measure the contribution of the study to education, which is the purpose of the study, students were asked for their opinions. In this way, the study is a novelty for mineral processing education in Turkiye.

Because augmented and mixed reality is a totally different approach in comparison to virtual reality, it has its own characteristics and study area. The scope of this study focused on *augmented reality and mixed reality* applications by using mobile devices and Hololens 2 for *mineral processing machinery and its training*.

2. Material and Method

In this study, Unity real-time development engine and Vuforia AR engine were used for the three applications to be aimed to develop. Two of the three applications in the study are called image targets, which are the camera reading the specially formatted and displaying three-dimensional models, animations and videos on them. The difference between them is in the deployment process to mobile devices or Hololens 2 devices and the subsequent hand interaction capability.

The third application, called the ground plane, displays models, animations, and videos on the ground or the surface scanned in space. Hand interactions are also offered in this application.

In the Unity project created, depending on the first scenario, JPG or PNG-type images of mineral processing machines were prepared to be used as image targets, and three-dimensional models with FBX, OBJ, or DAE extensions were prepared. 3D models were obtained from sharing sites such as GrabCAD [20], Warehouse Sketchup [21], Rigmodels [22], and Sketchfab [23]. A database with fifteen machines was created in Vuforia (Fig.1), and the package created here (unity package) was downloaded and imported to the Unity scene. As seen in the figure, a quality rating is expressed in stars for each figure added to the database. A quality of five or four stars is required to avoid mismatch and failure during viewing.

Hololens targeted applications also require the installation of Visual Studio (VS) C# editor because of the deployment procedures. The executable program is prepared in VS, and it is transferred to the device by cable or internet IP.

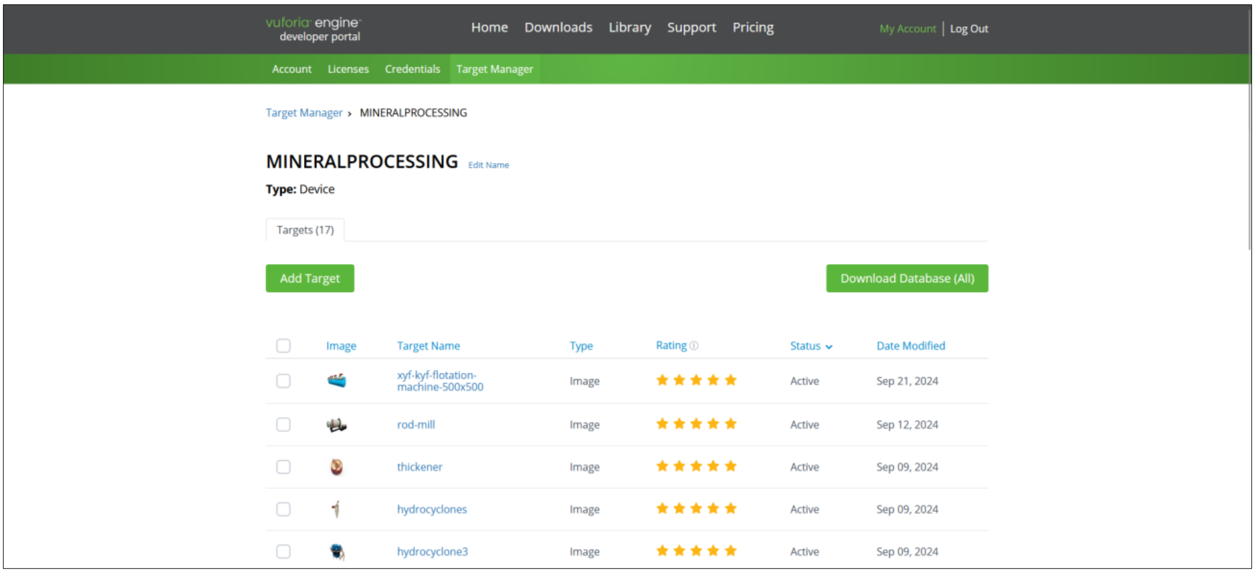

Fig.1. Vuforia Engine database for mineral processing machines.

Thus, the target images of the mobile device to be used as the AR camera have been defined (Fig.2a and 2b). The figures are shown here as they are to represent the editor where the applications are developed with their real outlook.

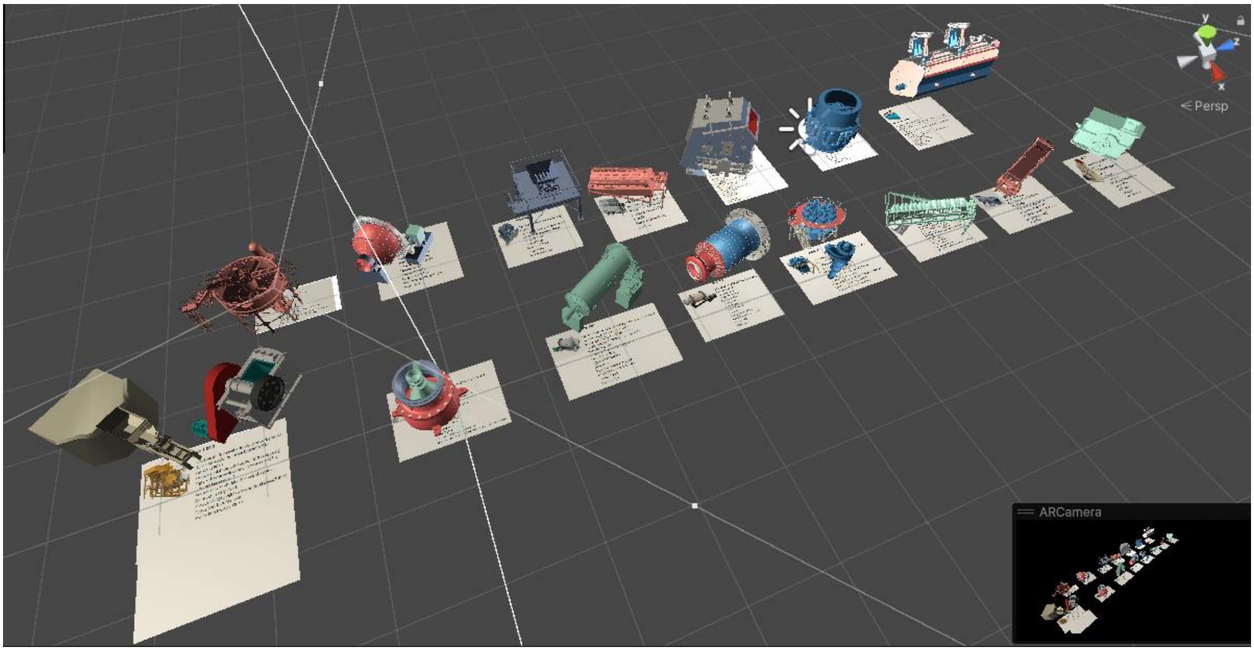

Fig. 2a. Unity scene designed for applications.

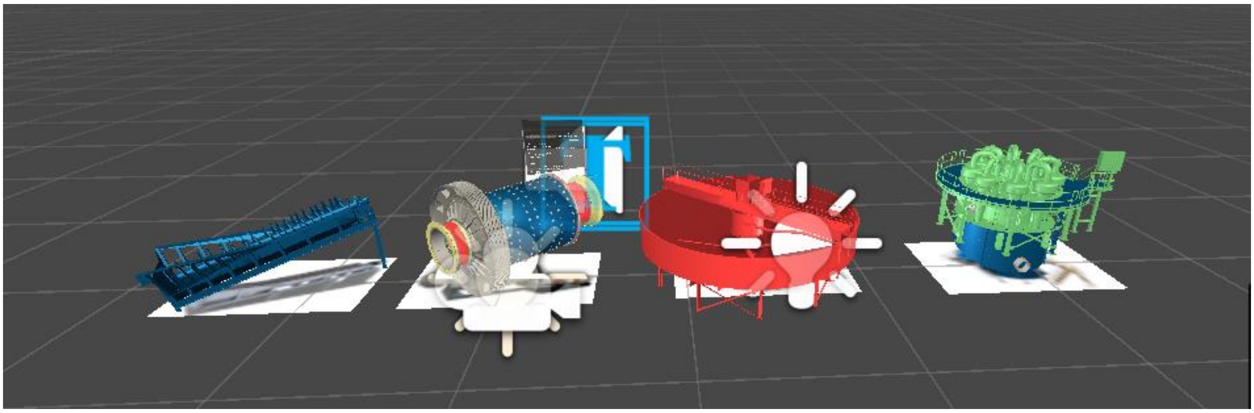

Fig. 2b. Various machines in the scene from another perspective.

The Image Target scene created with the MR Toolkit [24] in the Unity project was used for the second application. The difference between the first two applications, which are basically similar, is that the device on which the deployment will be made is the Hololens 2. Due to the nature of the application, the deployment process is a two-stage process. After the project is built in Unity, it is transferred to this device via the Visual Studio C# editor (Fig.3).

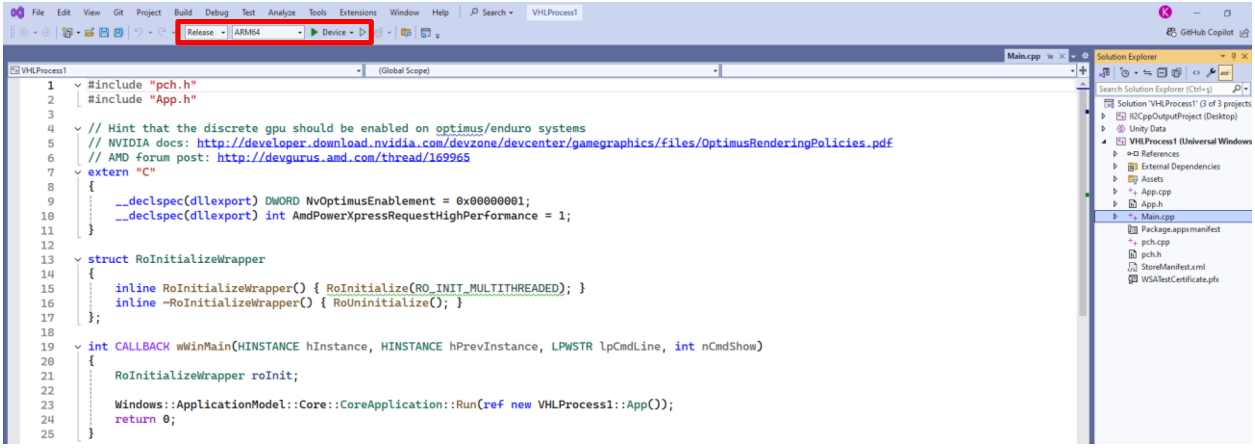

Fig.3. Deployment to Hololens 2 from Visual Studio after building in Unity.

With the hand interaction components assigned to 3D models, in addition to the models appearing on image cards, operations such as drag, rotate, and scale can also be performed on them.

The third application was also developed for the Hololens 2 smart glass. For this ground plane type application, MR Feature Tool and MR Toolkit [6, 25] templates were used (Fig.4).

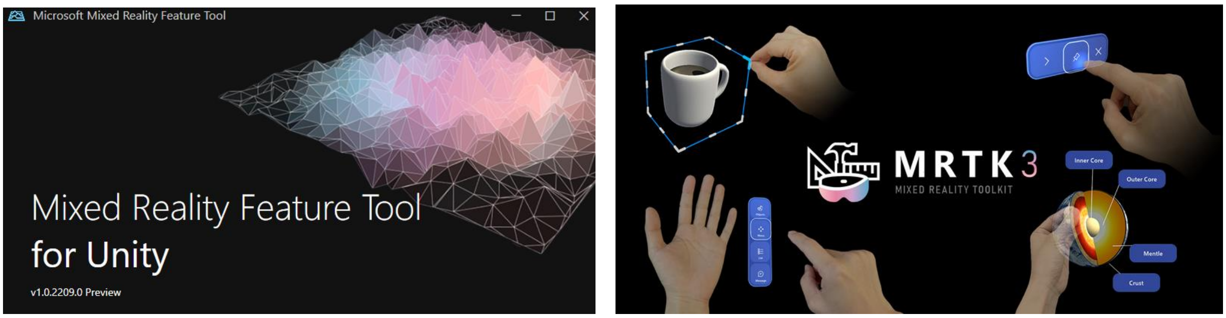

Fig.4. (a) MR Feature Tool for Unity; (b) Hololens 2 MRTK 3 templates.

Each machine in the Unity scene was assigned to the components below that would provide hand interaction controls:

- *Object Manipulator*
- *Bounds Control*
- *MinMax Scale Constraint*
- *MRTKUGUI Input Field or UGUI Input Adapter Draggable*
- *Box Collider*
- *Constraint Manager (if not included with Object Manipulator)*
- *NearInteractionGrabble.*

3. Mineral Processing AR Book and MR Applications

In the study, the fourteen most basic machines (Table 1) used in the size reduction and classification processes of mineral processing were used [43-56].

Table 1. Comminution and Classification Machines used in the project.

Comminution Machines		**Classification Machines**	
Crushers	**Mills**	**Classifiers**	**Screens**
Jaw Crusher Gyratory Crusher Cone Crusher Impact Crusher Hammer Crusher Roll Crusher	Ball Mill Rod Mill SAG Mill	Hydro-cyclone Spiral Classifier	Rotary Screen Vibrating Screen

The AR Book database created in Vuforia was placed on the scene as Image Target cards in Unity. Figures 5 and 6 represent sample previews from the communication and classification pages in the AR Book, respectively. The 3D models matched with the Image Target cards were found in GrabCAD, Warehouse Sketchup, Rigmodels, and Sketchfab and were matched to shapes in the database.

JAW CRUSHER

It is a primary crusher. It consists of one movable and one fixed jaw.

They can break ores of any hardness.

Capacity: <1500 t/h

Maximum ore size to be fed: 0.8 - 0.9 x Mouth opening.

The proportion of larger ore that can pass through the throat opening: 15-20%

Size reduction ratio: 3/1 – 6/1

Breaker safety is provided by breaking the weak retaining arm.

Worn linings can be replaced.

Nominal size: Mouth width x mouth length (1800 mm x 2500 mm)

Vertical height = 2x Mouth opening

Max. feeding size: 1500mm

Max. outlet opening: 300 mm

Max. output grain size: 450 mm

Crushing type: Impact and compression

Settings: Throat opening, speed and amplitude adjustment

Power: 536 HP

Fig.5. An example page from the comminution machines part of the AR book [57-59].

HYDROCYCLONE

It consists of a cylindrical upper and a conical lower part with no moving parts.

a few mm to 2.5 meters in length,

Structurally CYLINDRICAL-CONICAL,

tangential feeding for its operation ,

Supply pressure: 30-35 kPa to 345-700 kPa, (5-50 psi)

Solid ratio in open circuit: 20-30%, in closed circuit: 60%

Feed size: 1-1.5mm to 45 microns (300 - 5 microns)

Capacity, large size: 25 – 30 m ^{3} /min.

Taper angle: 12 degrees (below 250 microns) – 20 degrees (above 250 microns).

Feed: 3.7 – 15 m/sec (at feed inlet)

Size: Diameter: 4 – 80 cm, height: 0.61 – 3.06 m

Fig.6. Preview of a classifier machine page in the AR Book [57-59].

3.1. Augmented Reality (AR) Book Mobile Device Application

The first application of the study is the image target method for mobile devices. This application, developed for smartphones or tablets, has a quality that can be preferred in terms of accessibility for everyone. The scenario created by using Vuforia Engine was implemented. Some of the mobile device records are represented in Figures 7a and 7b.

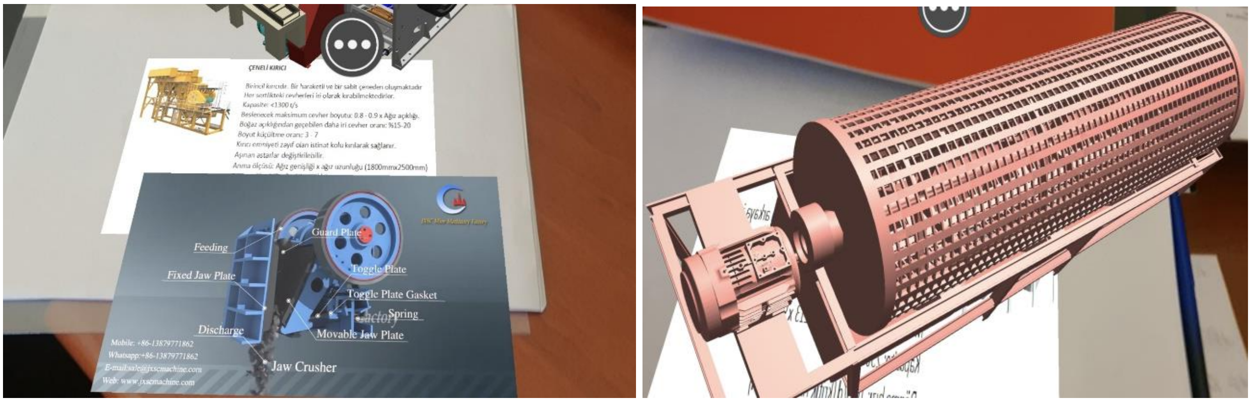

Fig. 7. (a) AR video player plane for Jaw crusher and 3D model of a spiral classifier.

AR assets matched with the images are of three types in general such as 3D models, video players and animation. Three dots surrounded by a circle existing on the screen is called Device Options which include necessary setting controls for the user.

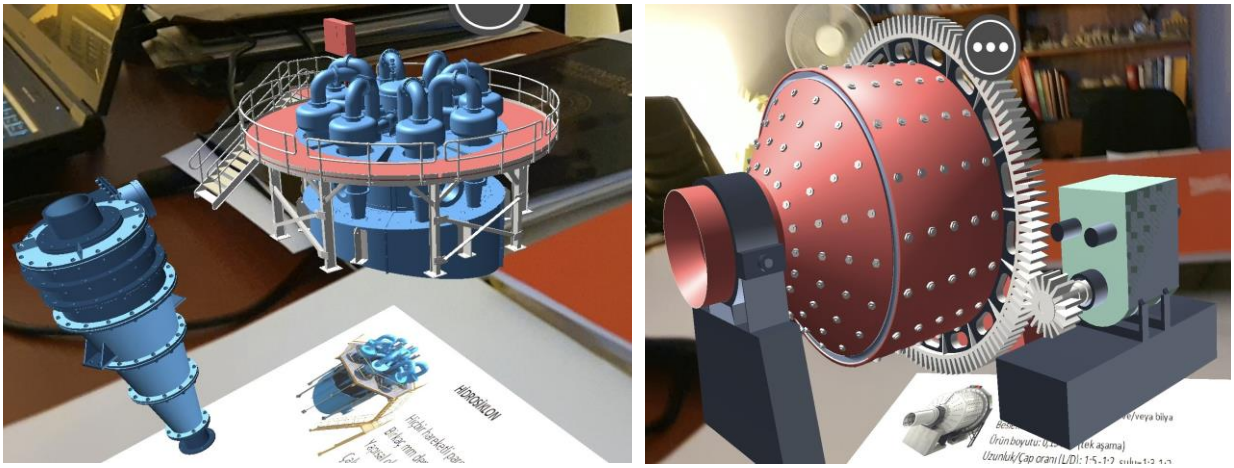

Fig.7. (b) Examples from AR Book Image Target application for mobile devices [28-42].

3.2. Image Target MR Smart Glass Hololens 2 application

In this application, the image target method was again preferred. Image cards were taken from the database previously created in Vuforia Engine. After the deployment process to Hololens 2 smart glass, models were displayed on the cards. In addition, all models are controlled with hand interactions such as drag, rotation, and scale. In this application, virtual designs were combined in a real environment, and the MR feature was experienced with hand control. The visuals of the study are in Figure 8.

Fig.8. Hololens 2 application with Image Targets scene use.

3.3. Ground Plane MR Smart Glass Hololens 2 Application

In this application developed for Hololens 2, models created in Vuforia Engine are displayed on the ground without being dependent on images, and all hand interaction operations can be performed. Some images of the work performed in the MR Toolkit (MRTK) [24] template are shown in Figure 9.

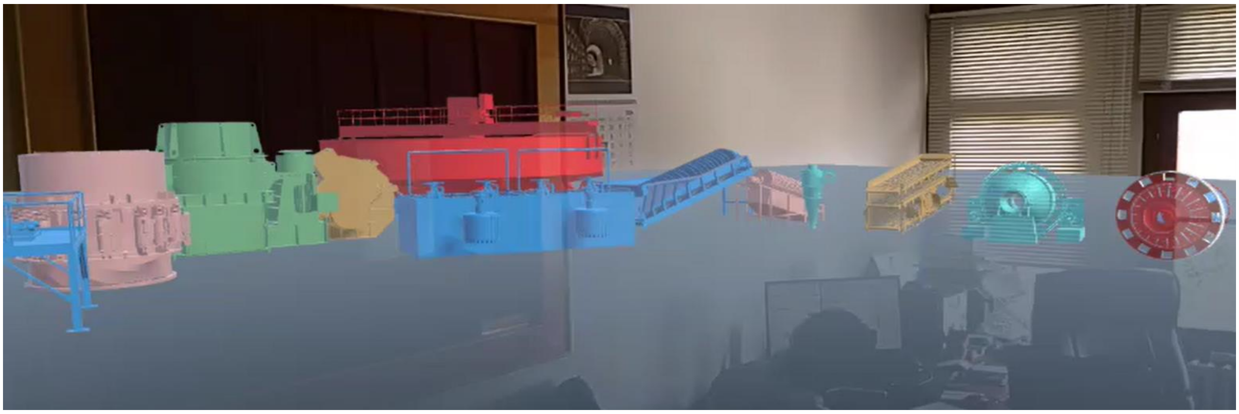

Fig.9. (a) AR view of the mineral processing machine group.

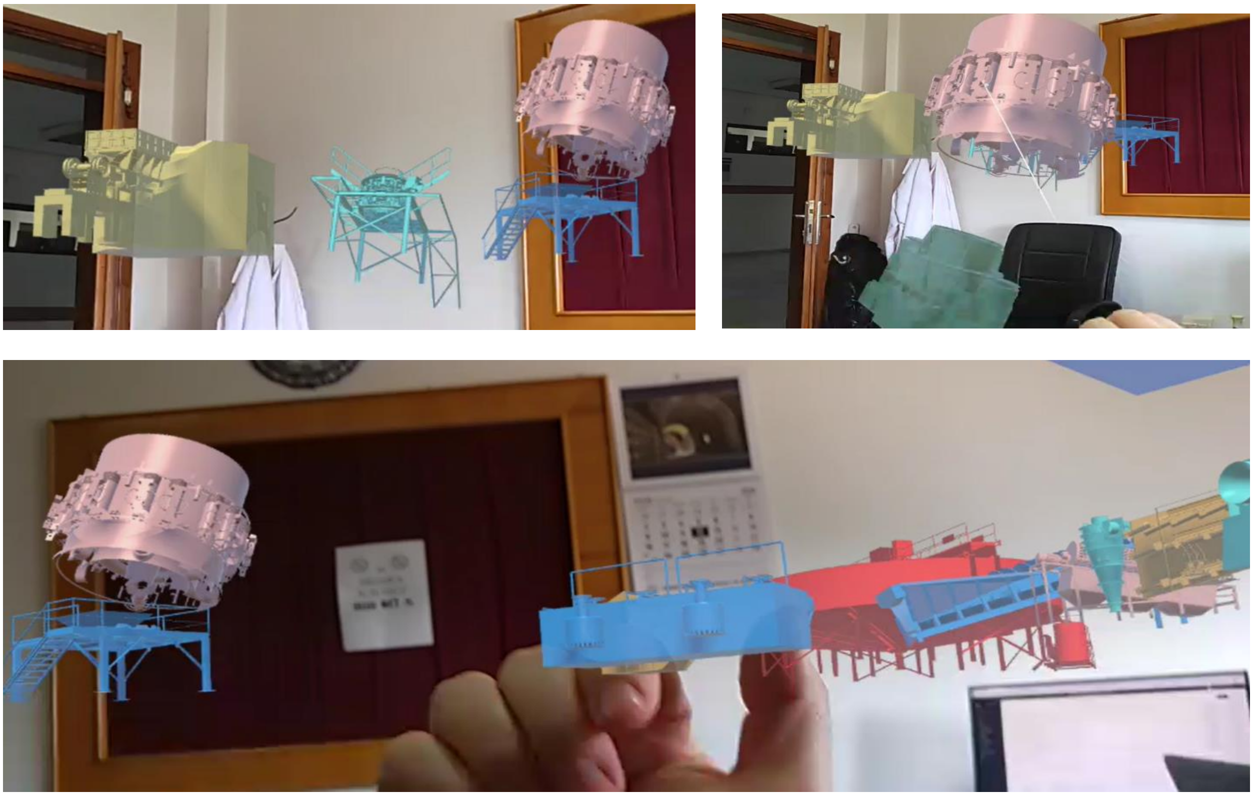

Fig.9. (b) Hololens 2 ground plane MR toolkit application.

The three applications that comprise the study were completed and tested this way. After the deployment process to Mobile and Hololens 2 hardware, it was opened for students to experience and evaluate.

4. Student Survey

The scope and aim of the questions are currently confined to measuring the instant perception of the students rather than a detailed statistical analysis. The course students are asked to assess the contribution of augmented reality applications to their training. The assessment was for three application frames:

1- Augmented Reality (AR) book (AR-Book) mobile device application
2- Image Target holographic head (Hololens-2) application
3- Ground Plane holographic head (Hololens-2) application

They are requested to write a score between 1 and 10 on the questions (Table 2).

Table 2. Template of the first group questions directed to the students for each application.

	QUESTION	**POINTS (1-10)**
1	I think knowledge is more retainable	
2	It contributes positively to learning	
3	Education becomes more enjoyable	
4	It contributes to the quality of education	

5	It increases the interest in the course	
6	It would be beneficial if this application became more widespread	

Finally, a comparison table was given to the students for a holistic evaluation of the three applications to be graded from 1 to 10 (Table 3).

Table 3. Template of the second question related to holistic grades of the approaches and their comparison.

1. AR Book mobile	2. Hololens-2 (Image-Target)	3. Hololens-2 (Ground Plane)

Before the students experienced these applications, a general explanation was made about the content, purpose and what was expected of them. They were asked if they had experienced this kind of experience in the lessons before. They stated that they had never experienced such a setup in any lesson. Then, they were given training on the devices and the use of the application.

Twenty students from various nations were selected from different classes who have taken the relevant courses. Three of the students were female, and seventeen were male.

4.1. First Group Questions for Assessment of Particular Applications

The first question group was directed at the students for the assessment of the AR Book Mobile case. The average values of the answers are shown in Figure 10.

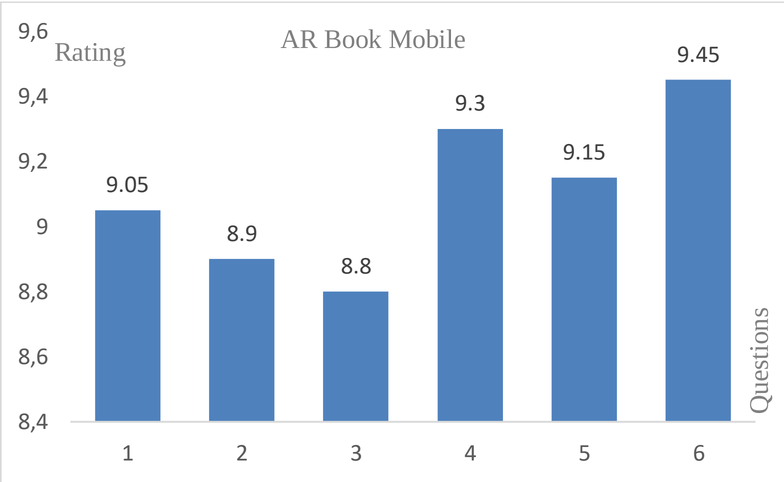

Fig.10. Assessments of the students for AR Book – mobile application.

The results show a positive perception of the application regarding grades ranging between 8.8 to 9.45. ANOVA Table of the student-question matrix is presented in Table 5.

Table 5. ANOVA Table for AR Book Mobile assessments.

Source of Variation	**Sum of Squares (SS)**	**Degrees of Freedom (df)**	**Mean Square (MS)**	**F-Statistic (F)**	**P-Value**
Between Groups	7.93	5	1.586	3.2868	0.0093

Within Groups	54.98	114	0.4823		
Total	62.91	119			

Here, the F-value, 3.2868, suggests that the variation between the groups (differences in scores for different questions) is moderately greater than the variation within the groups. This indicates that there are notable differences in scores across the questions. The P-value 0.0093 is quite below the typical significance level of 0.05, which means that the probability of the observed differences occurring by chance is quite small. Therefore, we can conclude that the differences between the questions are statistically significant.

The second question group was for the assessment of the AR Book Hololens 2 (image target) case. The average grades regarding the answers are shown in Figure 11.

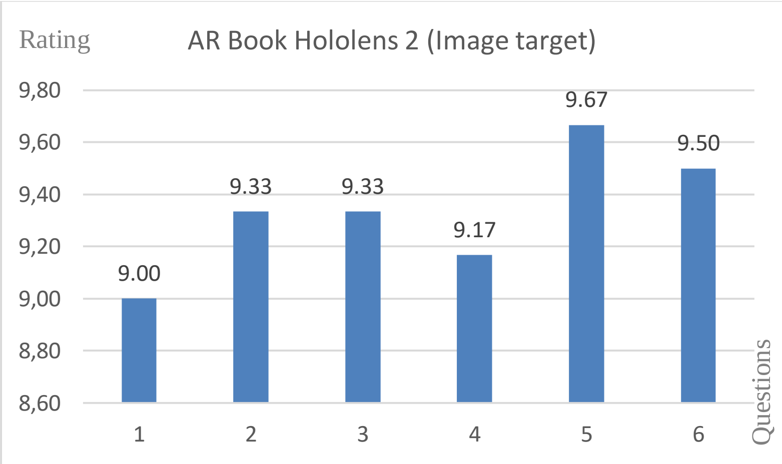

Fig.11. Assessments of the students for AR Book – Hololens 2 case.

Here, there is an obvious increment in the grades relative to the mobile case. The grades range between 9.0 to 9.67 which shows a better contribution of Hololens 2 application on AR Book images. ANOVA Table (Table 6) supports this graph.

Table 6. ANOVA Table for AR Book Hololens 2 (Image target) assessments.

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic (F)	P-Value
Between Groups	3.87	5	0.774	3.0338	0.0126
Within Groups	29.1	114	0.2553		
Total	32.97	119			

The F-value 3.0338 expresses that the variation between the groups (differences in scores for different questions) is moderately greater than the variation within the groups, which indicates the notable differences in scores across the questions. The low value of P 0.0126 differences between the groups are statistically significant.

The third case was the Hololens 2 Ground Plane application. Here, all the machines exist at the same time on the ground and cause some decline in the speed of interactions. So, the grades are slightly less than in the previous case. This is due to control difficulties, sometimes interruptions and breaks. However, this is a relative decrease in comparison to others and particularly, in total, the grades are still satisfactory. The positive thinking of the students exists in the ranges from 7.83 to 9.0 (Fig.12).

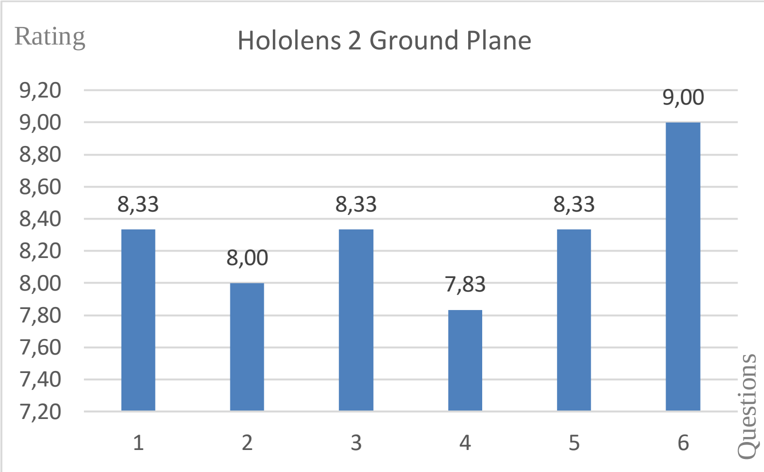

Fig.10. Assessments of the students for (a) AR Book – mobile, (b) AR Book Hololens 2, and (c) Ground Plane Hololens 2

Besides, the ANOVA Table (Table 7) points out that the variation between the groups (differences in scores for different questions) is much greater than the variation within the groups and significant differences in scores across the questions with an F-value of 9.09. Also, 0.000001 P-value is so low P-value and indicates that the probability of the observed differences occurring by chance is very small.

Table 7. ANOVA table for Ground Plane Hololens 2 assessments.

Source of Variation	**Sum of Squares (SS)**	**Degrees of Freedom (df)**	**Mean Square (MS)**	**F-Statistic (F)**	**P-Value**
Between Groups	61.2	5	12.24	9.09	0.000001
Within Groups	125.7	114	1.103		
Total	186.9	119			

Considering the 100% scale, maximum average grades and their application types can be listed according to the student's assessments:

i. knowledge will be more retainable (90.5%, AR Book Mobile),
ii. it contributes positively to learning (93.3%, AR Book Hololens 2),
iii. education becomes more enjoyable (93.3%, AR Book Hololens 2),
iv. it contributes to the quality of education (91.7%, AR Book Mobile),
v. it increases interest in the course (96.7%, AR Book Hololens 2),
vi. it would be beneficial if this application became more widespread (95%, AR Book Hololens 2).

4.2. Holistic Comparison of the Three Applications

In the second feedback table, they were asked to evaluate the AR applications they experienced from a holistic perspective and rate them between 1 and 10 (Fig.11). Here, the purpose is to get an immediate idea about which application provides better influence and contribute to the training experience. All the questions were directed after the practice in the class to understand the immediate reaction of the students. So, both the first group questions and the second holistic question aim to measure this application.

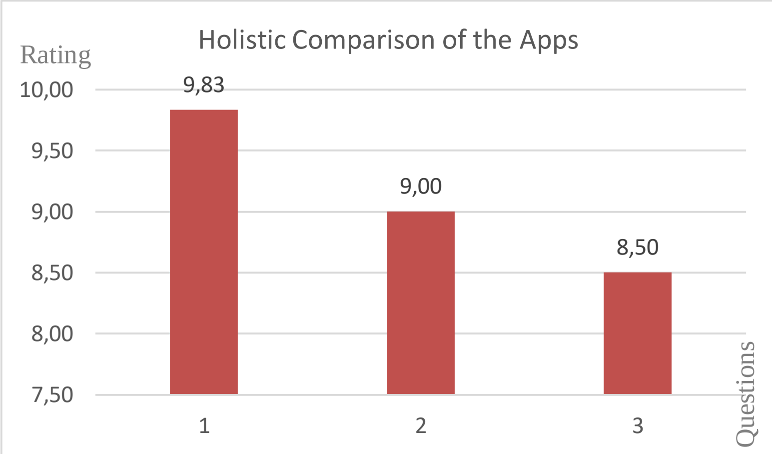

Fig.11. A holistic assessment of the students for the applications.

Students stated that they mostly found Hololens 2 visually superior and impressive and made the evaluations in the first tables from this perspective, as seen in Figures 8 to 10. However, they verbally stated that they prioritized accessibility and applicability in daily education when evaluating the applications holistically. In this respect, they concluded that the mobile application was preferable with 98.3%. ANOVA Table related to this assessment is given in Table 8.

Table 8. ANOVA table for Holistic assessments.

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic (F)	P-Value
Between Groups	14.63	2	7.315	7.5587	0.0012
Within Groups	53.75	57	0.942		
Total	68.38	59			

Accordingly, the F-value of 7.5587 indicates that the ratio of the variance between the groups to the variance within the groups is relatively high, which points out that the differences between the applications are more substantial than the variations within the applications. The P-value of 0.0012 is much lower than the typical significance level of 0.05. This strongly suggests that the differences between the means of the three applications are statistically significant.

5. Conclusion and Recommendations

In this research, a study was conducted in which AR Book and mixed reality applications were developed with smartphones and Hololens 2 in the training of mineral processing machines, which has not been done before, and the effects on education were evaluated by the students after the traditional education. In other words, the study investigated the contribution of augmented reality (AR) and mixed reality (MR) applications to the traditional training of mineral processing machines, including some of the comminution and classification ones. For this purpose, two image targets and a ground plane application were developed by using Unity and Vuforia engines. Image target applications in AR Book format were designed for smartphones and MS Hololens 2, a mixed-reality device. The ground plane application was implemented for Hololens 2.

For the image target-based part of the study, a visual database for communication and classification machines was created in the Vuforia AR engine and converted into a Unity package. An asset folder was created with 3D models for all machines and videos simulating the working systems for some machines. Image cards, 3D models and videos were matched in the Unity editor. Smartphone and Hololens 2 were determined as the AR cameras required for the application. The created application files were deployed to Android phones and the Hololens 2 disk.

The booklet designed for communication and classification machines was transformed into an AR Book with the use of smartphones and Hololens 2. In other words, the applications were triggered with the images in the booklet, 3D models and videos were created virtually in the book and the machines were visualized in 3D and hand interaction in a real environment. It was also possible to obtain hand interaction on smartphones with the Lean-Touch component. Since the Hololens 2 device already has standard AR and MR features, both AR and MR applications were performed. The first of these applications was an AR Book, and the other was a ground plane application that did not need to trigger a book.

Regarding all feedback, it can be concluded that the training supported by AR and MR applications provides more retainable and memorable knowledge. It contributes to learning positively; education becomes more enjoyable. AR and MR contribute to the quality of teaching and increase interest in the course, and it would be beneficial if their application became more widespread.

This study is a basic study used to ensure that some machines used in the field of Mining Engineering-Ore preparation are taught to students better and more effectively with AR technologies. In this context, AR application for mineral processing machines can be considered as a complementary study.

Additionally, AR technologies can also be used in education and training in the following cases:

- Use of these machines in process stages in facilities.
- Disassembly and assembly of these machines.
- Occupational health and safety for these machines or in facilities
- Operation and maintenance of these machines.
- Use of AR and MR technologies in all relevant disciplines of engineering, natural science, architecture, historical places and education-related activities.

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There is no conflict of interest

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