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The Effects of Mobile AR-based Biology Learning Experience on Students' Motivation, Self-Efficacy, and Attitudes in Online Learning

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Abstract
The purpose of this study is to enhance online biology learning with mobile augmented reality (AR) applications and to assess the impact of mobile AR applications on students' motivation, self-efficacy, and attitudes toward biology learning. Students were interviewed, and the usefulness of mobile AR applications was evaluated using a quasi-experimental pretest–posttest approach. The study group consists of 71 high school students, 26 in the control group and 45 in the experimental group, attending a public high school in the Western Black Sea Region of Turkey during the academic year 2020–2021. The self-efficacy ratings of the experimental group of students who participated in mobile AR-based biology learning were statistically higher than those of the control group after a 12-week trial. However, there were no statistically significant differences between experimental and control group students' motivation and attitudes toward biology learning. In addition, as a result of student interviews, mobile AR applications were deemed innovative, non-distracting, successful in knowledge acquisition, engaging, intriguing, and entertaining, boosting information retention, concretizing the subject, and facilitating learning.

Keywords Augmented reality · Motivation · Self-efficacy · Attitude · Mobile learning · Online learning

Introduction

As the number of mobile users has expanded, mobile devices have begun to be employed in teaching processes. As a natural consequence of this trend, the demand for teaching materials that match the learning needs in mobile and e-learning settings has also increased (Yılmaz et al., 2021). The introduction of mobile devices into education involves the development of instructional materials for mobile devices in order to enhance instruction (Pekyürek et al., 2020). Access to breakthrough technologies, such as augmented reality, has been eased by the quick and broad adoption of wireless communication networks and mobile devices, which has resulted in considerable benefits for technology-based learning (Özdemir, 2017). In this context, AR applications, particularly for mobile devices, appear to be an innovative way to address the dearth of educational materials. Numerous experts have highlighted AR technology as a technology with immense promise for increasing teaching and learning and the quality of education (Billinghurst & Duenser, 2012; Dede, 2009; Dunleavy et al., 2009).

AR, which enables interaction between the virtual world and the real world by adding virtual objects on top of the real-world environment, is a technology that dynamically displays the new object created in the real world (Cheng & Tsai, 2013). One of the technologies whose use has increased in the field of education is AR technology, which has shown significant growth in recent years. Its increasing use in education might be due to aiding in the retention of knowledge by bridging the gap between the real and virtual worlds in the learning environment (Squire & Klopfer, 2007). Moreover, students' motivation and cognitive learning are positively affected by educational materials prepared using AR technology (Sotiriou & Bogner, 2008). Studies show that students can learn subjects more easily and facilitate their cognitive processes thanks to AR applications with significant potential for use in the teaching environment (Leighton & Crompton, 2017). In general terms, students have positive attitudes toward learning subjects if they believe that new technologies like AR will be easy and beneficial to use (Chang et al., 2011; Tsai et al., 2010). For instance, Human Anatomy Atlas AR Application developed by an educational technology company facilitates learning about the human

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body by providing an elaborate three-dimension model of human anatomy, such as organs and tissues (Pochtoviuk et al., 2020).

Mobile AR applications, which appear to be one of the promising technologies, emphasize the importance of being able to interact in an environment where real-world and computer simulations are blended (Huang et al., 2013). AR technology offers interactivity and three-dimensionality, enabling effective presentation of content that can be shown to students. Thanks to these features, mobile-based AR applications, which help to establish meaningful relationships between concepts by making abstract concepts concrete to support learning, provide a learning opportunity where students can interact with the teaching material. When mobile AR applications are utilized in a learning environment, they enhance collaborative learning, permit individual-pace learning, and facilitate learning by constructing a meaningful bridge between the learner and the subject (Wu et al., 2013). In this sense, it is especially emphasized that mobile AR applications can be used in teaching environments (Specht et al., 2011).

The importance of psychological factors such as self-efficacy, motivation, and attitude for the successful completion of a goal cannot be denied (Gregersen & Mercer, 2022). After making a comprehension review of the literature, it is revealed that there is a need that the motivation variable in AR studies should be studied in the field of education (Cheng & Tsai, 2013; Erbas & Demirer, 2019). Nevertheless, studies have shown that using AR technology positively impacts the motivation of students in biology learning (Erbas & Demirer, 2019; Safadel & White, 2018). However, it was determined that all of the studies were carried out in a face-to-face learning environment, and no studies were found on how the use of AR applications in a different environment would affect student motivation. Besides, it was concluded that students' motivation, interest, and success toward a discipline are largely related to their attitudes toward the related discipline (Prokop et al., 2007). Within this scope, although various interventions are used to increase students' attitudes toward a discipline, it is not certain which intervention will yield ideal results (Sheldrake et al., 2017). In this respect, how students' attitudes toward learning will be affected by mobile AR-based biology learning will be an important indicator for the use of AR technology in biology learning. Finally, another issue to be investigated is the effect of AR-based biology learning on students' self-efficacy. This is because, in many studies, the importance of self-efficacy has been stated by expressing its effect on academic achievement (Komarraju & Nadler, 2013; Ustun et al., 2022; Zimmerman, 2000). Considering the aforementioned issues, this study aims to examine the effect of mobile AR-based learning on the motivation, attitude, and self-efficacy of high school students in an online biology course.

Theoretical Background

Advantages and Disadvantages of Augmented Reality Technology

There are potentially many advantages of using AR technology in a learning setting. Chemical reactions that are not possible or dangerous in the teaching environment can be realized thanks to AR technology. Besides, students can perform dangerous or costly experiments with AR applications and improve their practical skills. For example, Akçayır et al. (2016) found that the use of AR technology helped college students develop positive attitudes toward physics laboratory studies and improve their practical skills for physics laboratory applications. In a study by Olsson and Salo (2011) with 90 participants using mobile-based AR technology, it was concluded that the AR application attracted the attention of the participants and aroused curiosity. Similarly, Önal and Önal (2021) revealed that students' interest in the lesson increased by using AR technology. In the study conducted by Jiang et al. (2021), the effect of the instructional materials prepared for the science course with AR technology on high school students was examined. According to the results of the study, students' reasoning skills improved, students actively participated in the lesson, and students' interest increased in the lesson taught with the AR application. As one of the innovative learning technologies, AR provides a fun and authentic learning environment that can potentially increase students' motivation (Ustun et al., 2022). An interactive learning environment that enables authentic and situated learning where students work collaboratively can be created through 3D virtual visualizations of AR technology (Fan et al., 2020). Bower et al. (2014) stated that AR could be utilized in many learning approaches, such as constructivist learning, game-based learning, inquiry-based learning, and situated learning.

The use of AR technology has advantages as well as disadvantages in the field of education. The study conducted by Chang et al. (2011) revealed that students found AR applications complex, had difficulties understanding them, and encountered technical difficulties during use. There are significant barriers, such as technical knowledge and sufficient time, for the successful use of AR in the classroom and to create content (Kerawalla et al., 2006). Along with the need to spend time developing AR-based instructional content, Munoz-Cristobal et al. (2015) emphasized that more time than an average class period is required to effectively use AR technology in the classroom. The study conducted by Kerawalla et al. (2006) found that the participation of the students in the classroom where lessons are taught with AR materials is low and the interaction between the student and the teacher decreases during the use of AR applications.

Also, students should have the necessary equipment, and AR applications need to be suitable for their readiness level in order to provide effective teaching and learning with AR applications (Bujak et al., 2013). In this sense, AR materials prepared for these reasons should be designed in a way that is suitable for their readiness levels and can ensure their active participation. In order to deal with technical problems that might arise during the use of AR and to achieve the desired results, teachers need to be well-trained and well-equipped as intended (Billinghurst & Duenser, 2012). Furthermore, the disadvantage of mobile-based AR applications can be that the small size of mobile devices is not conducive to the realization of long-term teaching activities in particular. Besides, the limited memory size of these devices may cause the quality of the developed instructional material to be low and may negatively affect education (Embong et al., 2012). The aspect ratio of the image of the prepared instructional material on the mobile device is important in terms of readability (Çiloğlu et al., 2021), but when the instructional material is used on different mobile devices, the determined aspect ratio may be distorted due to incompatibilities caused by the mobile device used.

Augmented Reality and Motivation

Studies show that oral explanations remain superficial in traditional teaching methods and have a very limited effect on developing conceptual understanding (Wang et al., 2022). Also, the fact that students have to memorize concepts can be shown as the reason for the low performance of students in biology teaching in traditional teaching approaches. If students merely recall material in biology, their interest in studying will diminish over time, as will their incentive to learn (Kalana et al., 2020). Mobile AR-based biology learning can offer remedial solutions to such problems. AR technology can enhance students' motivation by visualizing learning scenarios (Law & Heintz, 2021). For example, learning scenarios can be visualized to enable students to learn by doing and increase both students' participation in the lesson and their interest in learning (Akçayır & Akçayır, 2017). In this way, students can learn concepts by assimilating them rather than memorizing them, and their motivation to learn increases.

Augmented Reality and Attitude

Attitude determines how individuals perceive a situation, how they feel about it, and how they react to it (Ajzen, 1996; Fazio & Roskos-Ewoldsen, 1994). In this regard, students' attitudes regarding lessons are significant because they influence their feelings and behaviors concerning the lesson. Uitto (2014) stated that a student's attitude toward a field affects his/her course choices. The student's motivation, academic success, and interest in that field are determined by his/her attitude toward that field (Prokop et al., 2007). Before beginning to teach a course, it is crucial to develop an intervention to improve students' attitudes toward it (Ustun & Tracey, 2020). However, there is no ideal conclusion as to which intervention will have the greatest impact on improving students' attitudes (Sheldrake et al., 2017). Because students' attitudes vary widely, especially in the field of science (Osborne et al., 2003), how an intervention will affect students' attitudes toward the biology course will become a vital question that should be answered. Within this scope, since using AR technology in the teaching environment is generally an instructional tool that helps students improve their attitudes, motivation, and academic achievement (Wang et al., 2022), how the integration of mobile AR technology into the biology course will impact students' attitudes toward the biology course emerges as an issue that needs to be investigated.

Augmented Reality and Self-efficacy

Self-efficacy is explained as the individual's belief in self-regulation and the effort to achieve a goal (Bandura, 1977). An individual can construct metacognitive skills such as planning, monitoring, and evaluation process for a situation he/she encounters when he/she has developed self-efficacy (Karaoğlan-Yılmaz et al., 2019). However, research shows the importance of self-efficacy by revealing its impact on academic achievement. For instance, Kitikanan and Sasimonton (2017) revealed that self-efficacy is an effective factor in foreign language learning. As a result of the study conducted by Mornar et al. (2022), the reason behind the success of students with high GPAs is partially explained by their high academic self-efficacy. In light of the studies, it is evident that researchers highlight the significance of self-efficacy. With the importance of self-efficacy, students' achievement of learning goals can be facilitated in AR-based learning environments because AR technology enables students to develop their critical thinking and problem-solving skills by presenting learning scenarios in accordance with their learning preferences and revealing their strengths (Dunleavy et al., 2009). For instance, Cai et al. (2021) revealed that students' self-efficacy for higher-order conceptual knowledge and complex thinking skills increased in physics lessons using AR technology. In this sense, students can develop their self-efficacy to use higher-order cognitive skills to acquire complex knowledge and skills in biology courses taught with mobile AR applications.

Objective of the Study

AR technology provides the opportunity for students to apply their abilities and knowledge by fusing digital data with the real world (Wojciechowski & Cellary, 2013). AR technology can be utilized in many courses as complementary and supportive elements in exercises, field trips, and educational games (Çetinkaya & Akçay, 2013). However, because biology course subjects are difficult for students to comprehend and are not comprehensible, and therefore a need for new technologies and materials that will benefit students (Fuchsova & Korenova, 2019; Yeşilyurt & Gül, 2012), mobile-based AR applications can be used as teaching materials to facilitate biology learning. However, Küçük (2015) stated that research had not been conducted by using AR technology, one of today's technologies, at an adequate level in biology courses.

Considering that AR applications can be utilized as complementary or assessment materials in distance education (Tosun, 2017) such as teaching an online science course with AR applications (Çetin & Türkan, 2022), AR applications can be used in online biology courses. However, there are insufficient studies on AR technology-based biology learning in distance education. Studies have examined the effects of AR applications for biology learning in a face-to-face classroom environment on high school students' motivation (Wang et al., 2022), self-efficacy (Erbas & Demirer, 2019), and attitude (Weng et al., 2020). In this context, instead of examining the effect of AR-based applications on a single variable in biology learning, there is a need for a comprehensive study that thoroughly examines the effect of AR-based biology learning on students' motivation, self-efficacy, and attitude. In order to fill this existing gap in the literature, this study examined the effects of mobile AR applications integrated into the biology course given through distance education on high school students' motivation, self-efficacy, and attitude. Answers to the following questions will be sought within the scope of the research.

Is there a significant effect of mobile AR-based biology learning on high school students' motivation in the online biology course?

Is there a significant effect of mobile AR-based biology learning on high school students' self-efficacy in the online biology course?

Is there a significant effect of mobile AR-based biology learning on high school students' attitudes in the online biology course?

What are the opinions of high school students about the use of mobile AR applications in the online learning environment?

Method

Research Design

This qualitative and quantitative mixed-methods study intends to assess the impact of educational materials created utilizing AR technology on student motivation, attitude, and self-efficacy in a biology course. Mixed methods research benefits from the strengths of qualitative and quantitative approaches and enhances an understanding of the connections between empirical findings and theory (Östlund et al., 2011). Qualitative data of the study were obtained through the interview technique. Quantitative data for that were collected with a motivation scale, attitude scale, and self-efficacy scale. In the experimental group, materials prepared using AR technology were used in activity-based instruction, while traditional instruction was applied in the control group. At the end of 10 weeks of instruction, the scales used in the pre-test were applied as a post-test, and the motivation, attitude, and self-efficacy of the students in both groups were determined. Besides, interviews were conducted after the posttests were applied to the experimental group students. As a result, as can be seen in Fig. 1, this study lasted 12 weeks in total: 1 week for pre-tests, 10 weeks for implementation, and 1 week for post-tests.

In the study, a quasi-experimental design with a pretest–posttest control group was employed. The quasi-experimental method is a method that is realized by forming predetermined classes in cases where it is difficult to randomly form experimental and control groups in experimental research (Robson, 1998). In the quasi-experimental method, except for the random selection of at least one control group and one experimental group, students are determined, both groups are given a pretest and posttest, and the students in the experimental group are exposed to experimental interventions while the control group receives no intervention (Karasar, 1999). However, a posttest is administered to both groups, and the results are reported statistically (Robson, 1998). Besides, quasi-experimental studies are studies in which there are experimental and control groups, and experimental application is performed in cases where the sample cannot be randomly selected (Erkuş, 2013; Yıldırım & Şimşek, 2013).

Participants

This study was conducted in a state high school affiliated with the Ministry of National Education in the Western Black Sea Region of Turkey in the 2020–2021 academic year. The study was conducted with the voluntary participation of a total of 71 high school students studying in the 11th grade, 45 of whom were in the experimental group and 26 in the control group. The control and experimental groups were selected randomly. At the beginning of the study, the Mann–Whitney *U* test was performed to assess whether there was a difference between the control group and the experimental group in terms of biology course motivation, self-efficacy, and attitude. The Mann–Whitney *U* test results of the mean values for the comparison of the motivation, self-efficacy, and attitude score values of the control and experimental groups are shown in Table 1.

Table 1 Mann–Whitney *U* test results regarding the comparison of the pretest scores of the experimental and control groups

Scale	Group	*n*	$\overline{X}$	Mean rank	*U*	*p*
Motivation scale	Experimental group	45	4.15	37.64	511	0.377
	Control group	26	4.06	33.15		
Attitude scale	Experimental group	45	3.72	34.86	533.500	0.539
	Control group	26	3.87	37.98		
Self-efficacy scale	Experimental group	45	3.60	37.71	508	0.358
	Control group	26	3.51	33.04		

As illustrated in Table 1, the mean values of motivation, self-efficacy, and attitude scores of the students in the control and experimental groups are close to each other and do not differ statistically. Moreover, a semi-structured interview was conducted with 37 students from the experimental group to evaluate mobile AR-based learning.

Instruments

As data collection instruments, this study utilized a motivation scale, an attitude scale, a self-efficacy effectiveness scale, and a semi-structured interview form. While the control group was taught in the form of traditional teaching without any intervention, the experimental group was taught with AR materials. Before the study started, the students were given detailed information about the research. Subsequently, motivation, attitude, and self-efficacy scales were administered to the students in both groups before the study started. At the end of the teaching, motivation, attitude, and self-efficacy scales were administered to the students in both groups. Moreover, a semi-structured interview form was applied to reveal the opinions of the students in the experimental group about mobile AR applications.

Motivation Scale

Academic Motivation for Learning Biology scale developed by Aydın et al. (2014) was used. The developed scale was prepared to determine the academic motivation levels of high school students toward learning biology. The scale consists of 19 items in total. The scale is a 6-point Likert scale ranging from strongly agree (6) to strongly disagree (1). Cronbach's alpha internal consistency coefficient of the scale was calculated as 0.911.

Attitude Scale

The attitude scale toward biology learning developed by Tosun (2011) was used. In order to determine student attitudes toward the biology course, the questions in the scale were prepared as a five-point Likert-type scale ranging from strongly disagree to strongly agree. The attitude scale consists of 36 items in total. Cronbach alpha internal consistency coefficient of the scale was found to be 0.968.

Self-Efficacy Scale

The self-efficacy scale developed by Sherer et al. (1982) to assess behavior and behavioral changes and adapted into Turkish by Gözüm and Aksayan (1999) was used. The questions in the scale were prepared to measure the general self-efficacy perception without taking into account any behavioral dominance. The 5-point Likert-type scale consists of 23 items. These are: it does not define me at all, it defines me a little, I am indecisive, it defines me well, and it defines me very well. Cronbach alpha internal consistency coefficient of the scale was found to be 0.853.

Semi-Structured Interview

A semi-structured interview form was prepared and evaluated by 2 field experts and 2 IT teachers. Corrections were made within the framework of the feedback received and finalized. The purpose of conducting a semi-structured interview was to reveal students' experience with the use of mobile AR applications in the online biology course in depth. Were you satisfied with studying materials created with mobile AR technology? In which aspects were you satisfied/dissatisfied? How do you evaluate the presentation of course content with mobile AR applications? were some questions that were asked of the students in the semi-structured interview form. In the study, 37 students were surveyed online to examine the impact of mobile AR applications on students.

Application Process and Data Collection

Due to the COVID-19 pandemic, the implementation and data collection process of the study was conducted through distance education. Mobile AR teaching materials suitable for students' readiness levels were prepared. The prepared mobile AR materials were given to the students in accordance with the semester curriculum. In order to provide AR materials in accordance with the course curriculum, planning was done with the instructor of the biology course at the beginning of the semester before the study started. According to the course curriculum, a total of 18 AR materials were planned and made available to the students between 1 and 3 times a week, in accordance with the subject of the week. Table 2 shows the AR materials prepared in accordance with the instructional plan and their weekly implementation times. In addition, Fig. 2 shows examples of the AR materials specified in the instructional plan.

While some of the AR materials were prepared by the researchers (see Appendix 1 for the material development process), some of them were utilized from existing AR-based teaching resources. Materials were provided to students electronically. Students who wanted to were able to digitally print out readable working pictures for AR technology, and students who wanted to print out digital pictures were able to use the AR materials on their mobile devices under the guidance of the teacher. Figure 3 shows examples of students' use of AR materials.

At the end of 10 weeks of instruction, the scales used in the pretest were applied online as a posttest to determine the motivation, attitude, and self-efficacy of the students in both groups. Besides, interviews were conducted online after the posttests were applied to the experimental group students. As a result, this study lasted 12 weeks in total: 1 week for pretests, 10 weeks for implementation, and 1 week for post-tests.

Table 2 Students' weekly use of mobile AR materials

Material order	Material name	Implementation date
AR-1	Brain	Week 1
AR-2	Nervous system	Week 2
AR-3	Eye	Week 3
AR-4	Ear Kulak	Week 3
AR-5	Skin Deri	Week 4
AR-6	Tongue	Week 4
AR-7	Nose	Week 4
AR-8	Muscles	Week 5
AR-9	Skeleton	Week 5
AR-10	Liver	Week 6
AR-11	Stomach	Week 6
AR-12	Large intestine	Week 7
AR-13	Small intestine	Week 7
AR-14	Heart	Week 8
AR-15	The circulatory system	Week 8
AR-16	Lymph circulation	Week 9
AR-17	Lung (respiratory system)	Week 9
AR-18	Kidney (urinary system)	Week 10

Data Analysis

The kurtosis and skewness values were examined to determine whether the data obtained from the scales were normally distributed. According to Tabachnick and Fidell (2013), a normal distribution is accepted when kurtosis and skewness values are between − 1.5 and + 1.5. In the study, when the kurtosis and skewness values of the data collected from the motivation and self-efficacy scales were examined, it was determined that they were within these limits, and the independent groups' *t*-test, one of the parametric tests, was applied to analyze the data. However, when the values of the data collected with the attitude scale were examined, it was found that they were out of these limits, so the Mann–Whitney *U* test, one of the nonparametric tests, was used to analyze the data. In addition, the content analysis method was used to analyze the qualitative data. In content analysis, meaningful wholes are constructed by combining the concepts and themes that emerge from the examined data, and the meaning of what people intended to say is thus interpreted understandably without losing its meaning (Yıldırım & Şimşek, 2013). The data analyzed by the researchers were coded to be collected under themes and sub-themes. Inter-coder reliability was determined as 93% by calculating the percentage of inter-coder agreement. When the qualitative data were reexamined, it became apparent that the disparity was attributable to the fact that some student responses were included in more than one subtheme.

Results

The descriptive statistics of the scores of the experimental and control groups on the motivation, attitude, and self-efficacy scales are shown in Table 3.

When the averages of the answers of the students in the experimental and control groups to the motivation, attitude, and self-efficacy posttest scales are examined in Table 3, it is understood that the motivation scale of the experimental

Table 3 Descriptive statistics of groups

Group	Scale	n	$\overline{X}$	SD	SE
Experimental group	Motivation	45	4.04	0.894	0.133
	Attitude	45	3.70	0.814	0.121
	Self-efficacy	45	3.77	0.522	0.078
Control group	Motivation	26	4.13	0.761	0.149
	Attitude	26	3.88	0.525	0.103
	Self-efficacy	26	3.49	0.582	0.114

Table 4 Independent groups *t*-test results for comparison of motivation posttest scores of the experimental and control groups

Group	Scale	*n*	$\overline{X}$	SD	*t*	df	*p*
Experimental group	Motivation	45	4.04	0.893	− 0.391	69	0.697
Control group	Motivation	26	4.13	0.760			

group is 4.04, the attitude scale is 3.70, self-efficacy scale is 3.77, while the motivation scale of the control group is 4.13, attitude scale is 3.88, self-efficacy scale is 3.49. When evaluating the 6-point and 5-point Likert-type scale averages, calculations were made as score range = highest value–lowest value/number of category degrees. In the evaluation of the average scores obtained, the score range calculation of the 6-point Likert type was calculated as (6 – 1) / 3 = 1.66, and it was calculated as low level when the average score distributions were in the range of "1–2.66," intermediate level when they were in the range of "2.67–4.32," and advanced level when they were in the range of "4.33–6." The 5-point Likert scale was calculated as (5 – 1) / 3 = 1.33, and the mean score distribution was calculated as low level when it was between "1 and 2.33," intermediate level when it was between "2.34 and 3.67," and advanced level when it was between "3.68 and 5.00." Based on the results of these calculations, it can be concluded that the attitude and self-efficacy levels of the experimental group students were high, while their motivation levels were moderate. It can be concluded that the students in the control group had high levels of attitude but moderate levels of motivation and self-efficacy.

Motivation Toward Biology Course

In order to determine whether there was a statistically significant difference between the posttest motivation scores of the experimental and control groups, an independent samples *t*-test, one of the parametric tests, was conducted. The analysis of the data obtained is presented in Table 4.

Table 4 shows that the mean of the experimental group is 0.09, smaller than the mean of the control group. However, this difference between the mean motivation scores of the experimental group and the control group was not statistically significant ($t = -0.391$; $p = 0.697$). In other sayings, there is no statistically significant difference between the posttest mean scores of the experimental group and the control group ($p = 0.697$; $p > 0.05$).

Attitude Toward Biology Course

In order to determine whether there was a statistically significant difference between the posttest attitude scores of the experimental and control groups, the Mann–Whitney *U* test, one of the nonparametric tests, was conducted. The analysis of the data obtained is presented in Table 5.

When the data in Table 5 were analyzed, it was found that the mean attitude score of the experimental group was lower than the mean attitude score of the control group, but the difference was not statistically significant ($p = 0.374$). In other sayings, there is no statistically significant difference between the attitude mean scores of the experimental group and the control group ($p = 0.374$, $p > 0.05$).

Self-efficacy Toward Biology Course

In order to determine whether there was a statistically significant difference between the posttest self-efficacy scores of the experimental and control groups, an independent samples *t*-test, one of the parametric tests, was conducted. The analysis of the data obtained is presented in Table 6.

Table 6 shows that the mean of the experimental group is 0.28, smaller than the mean of the control group. However, this difference between the mean self-efficacy scores of the experimental group and the control group was statistically significant ($t = -2.092$, $p = 0.040$). In other sayings, the experimental group students' self-efficacy levels were significantly higher than the control group students' ($p = 0.040$, $p < 0.05$).

Student Opinions on the Use of Mobile AR in Biology Course

The opinions of the students about the mobile AR-based learning used in the study were taken and analyzed using by content analysis method. Students' opinions on their satisfaction with mobile AR applications are shown in Table 7.

Table 5 Mann–Whitney *U* test results for comparison of attitude posttest scores of the experimental and control groups

Group	Scale	*n*	$\overline{X}$	Mean rank	*u*	*p*
Experimental group	Attitude	45	3.70	34.34	510.50	0.374
Control group	Attitude	26	3.88	38.87		

Table 6 Independent groups *t*-test results for comparison of self-efficacy posttest scores of the experimental and control groups

Group	Scale	*n*	$\overline{X}$	SD	*t*	df	*p*
Experimental Group	Self-efficacy	45	3.77	0.522	2.092	69	0.040
Control Group	Self-efficacy	26	3.49	0.581			

Examples of student opinions are given below:

Q3: Satisfied. It allows us to see in three dimensions. Things that normally require materials and experiments can be easily accessed with mobile augmented reality, preventing loss of time.
Q20: I was pleased that it presented a 3-dimensional visual and made the subject concrete, but there was a problem in the setting of the application to turn the image while examining the 3 dimensions; it can be more useful if it is improved.
Q30: Yes, I'm satisfied. Presenting the course content thus and so helped us to understand it better and made the course easier.

Students were asked about their opinions on how mobile AR applications affect their learning processes. Table 8 shows the findings of the analysis of student responses.

Examples of student opinions are given below:

Q8: My learning time was shortened because it made the subject more understandable.
Q9: It is more memorable because we can perceive it visually. Useful because instead of just memorizing, we can visually see and associate.
Q15: It affected me positively; I think it is useful because it makes the lesson more interesting.

Table 7 Student satisfaction with the use of mobile AR applications

Size	Frequency	Percentage
The impact of mobile AR applications on student satisfaction		
Satisfied		
Facilitating visual learning	21	56.76
Increased retention of information in the mind	5	13.51
The lesson is fun and good	2	5.41
Helping to concretize information	7	18.92
Not satisfied		
Problems with the mobile device and app	1	2.70
Problems with internet and infrastructure	1	2.70
Total	**37**	**100**

Students were asked about their opinions on the necessity of supporting their future biology courses with mobile AR applications. Table 9 shows the findings of the analysis of student responses.

Examples of student opinions are given below:

Q9: Using mobile AR is always better than just memorizing and reading from a book.
Q17: I think it is necessary. Biology is a field that has a great deal of interest in the human body and demands a great deal of visualization; therefore, mobile AR applications should be utilized.
Q24: I think this app can be good when it is developed, but when it comes to biology and blood, I don't think it can replace real experience.

Students were asked for their opinion on whether they encountered any difficulties in the applications implemented with Mobile AR. Table 10 shows the findings of the analysis of student responses.

Q16: I only experienced it during the learning phase of the app.
Q18: It is a remarkable app. I did not face any difficulties.
Q20: My phone had a bit of a touch problem.

Discussion

Quasi-experimental pretest–posttest research with a control group was conducted to investigate the effectiveness of mobile AR applications for biology courses on 11th-grade high school students' motivation, attitude, and self-efficacy. In addition, interviews were conducted with the students in the experimental group at the end of the study to examine the effectiveness of mobile AR applications in depth. According to the results of the study, the self-efficacy levels of the students in the experimental group toward the biology course were significantly higher than the control group students, but the motivation and attitude levels of the students toward the biology course did not differ between the groups.

At the end of the study, when the self-efficacy of the students in the experimental group toward the biology course was examined, it was revealed that their self-efficacy was high. It was also concluded that there was a statistically significant difference between the mean self-efficacy scores

Table 8 Student opinions on the impact of mobile AR applications on the learning process

Size	Frequency	Percentage
The impact of mobile AR applications on the learning process		
It was effective in my learning		
Facilitated learning and made information concrete	17	45.95
It was an enjoyable, effective, and productive lesson	8	21.62
Increased retention of information	11	29.73
It was not effective in my learning		
Did not affect my learning process	1	2.70
Total	**37**	**100**

of the students in the control group and the mean self-efficacy scores of the students in the experimental group. In other words, the mobile AR-based online biology course had a statistically significant positive effect on students' self-efficacy compared to the traditional online biology course. Similarly, chemistry, biology, and physics topics were taught utilizing AR materials, and the influence on students' self-efficacy was assessed. As an example of these studies, Küçük et al. (2015) found that in the course taught using mobile AR materials, students' willingness to use these materials was high, they had a positive effect on self-efficacy, and they were satisfied with the mobile AR application. In his study, Habig (2020) stated that with the introduction of AR technology into the educational environment, students' self-efficacy did not decrease in the lessons taught using this technology; on the contrary, it increased even more. Similarly, Cai et al. (2021) concluded that students exhibited positive motivation and self-efficacy in using AR applications in the learning environment and therefore emphasized that AR materials are of great importance in education. The results of the studies are parallel with this study. The advantages of employing AR technology include that it allows students to advance at their particular pace, allows students to actively participate in the lesson, helps students to learn by doing, and is an engaging teaching tool that draws students' attention to the topic. In this context, the use of AR technology is expected to positively affect students' self-efficacy, even in online learning. For example, Özçakır and Aydın (2019) found that AR technology is easy to apply, allows students to progress individually by taking into account their readiness, increases active participation by presenting a new technology in the classroom, and attracts learners' attention, and thus, AR technology positively affects students' cognitive processes and self-efficacy. Similarly, Cai et al. (2019) reported that students actively participated in the course taught with AR applications and that AR applications contributed positively to students' self-efficacy.

Students' motivation and attitudes did not differ significantly between the online biology course taught with a mobile AR application and the online biology course taught traditionally. Erbas and Demirer (2019) argue that the literature contains studies with contradictory findings about the effect of AR technology on student motivation in biology courses. For example, Omurtak (2019) examined the effect of the biology course taught with AR technology on student motivation, and as a result of the study, it was found that there was no significant difference in the mean motivation of the experimental group and control group students toward the biology course. On the other hand, Wang et al. (2022) found that AR-based learning in biology courses significantly increased students' motivation to learn. Similarly, according to the results of the studies, it is seen that the effect of the course supported by AR technology on students' attitudes differs. In the study

Table 9 Student opinions on the future use of mobile AR applications

Size	Frequency	Percentage
Willingness to use mobile AR applications in the future		
Should be used		
MAG applications evoke a sense of reality	13	35.13
MAG applications have a positive effect on visual memorability	7	18.92
The positive contribution of MAG applications to the learning process	10	27.03
It is useful in concretizing abstract concepts	5	13.51
Should not be used		
I do not think it is necessary for class	2	5.41
Total	**37**	**100**

Table 10 Student opinions on the difficulty of using the MAG application

Size	Frequency	Percentage
Comparison of any difficulty in MAG implementation		
I had difficulties		
Mobile device disruptions	3	8.11
Disruptions in application installation and use	1	2.70
I did not have difficulties		
I did not face any difficulties	33	89.19
Total	**37**	**100**

conducted by Ustun et al. (2022), it was found that AR-based language learning positively affected students' attitudes, but in a different study, it was found that the attitudes of students who took the course taught with AR technology did not change significantly (Kızılca, 2019). Although there are differences in the results of the studies examining the effect of AR-based learning on students' motivation and attitude in a biology course, all of the studies were conducted in a face-to-face environment, unlike this study. The fact that the study took place during the COVID-19 pandemic process may be the reason why there was no significant effect on student's motivation and attitude in this study. Because the behavioral immune system, which is explained as a result of disease avoidance during the COVID-19 epidemic, is linked to negative emotional responses such as worry, fear, and anxiety, the behavioral immune system is associated with negative emotional responses (Sevi & Shook, 2022). Within this scope, students taking the biology course may have developed more negative feelings owing to the epidemic and spent the instructional period in a condition of reluctance and lack of motivation toward distance education. They may have reflected this in their motivation and attitude toward the lesson. Similarly, in the study conducted by Oducado and Soriano (2021) during the COVID-19 pandemic process. It was revealed that nursing students have negative attitudes toward online learning.

At the end of the study, in the interviews conducted with the experimental group to evaluate the mobile AR applications, it is understood that the students generally stated that the materials prepared with AR technology could provide advantages for them. It was seen that the use of mobile AR applications in biology education is necessary by students as innovative, non-distracting, effective in information acquisition, interactive, interesting, and fun, increasing retention in learning information, concretizing the subject, and facilitating learning. Besides, the students stated that they were satisfied with using the mobile AR application materials and that they wanted to teach their lessons with these materials from now on, that their interest in the lesson increased, and that it helped them to actively participate in the lesson. In parallel with the results of the study, it was reported that mobile AR-based applications increase students' interest and curiosity (Chiang et al., 2014; Khan et al., 2019). In addition, it is believed that student pleasure and interest in classes taught with AR applications rise and that AR applications aid student learning by concretizing the concepts being taught (Akçayır & Akçayır, 2017). Similarly, students can learn in a fun environment, as AR-based activities make the learning environment attractive, inspiring, and exciting (Lee, 2012).

Fig. 1 The experiment process

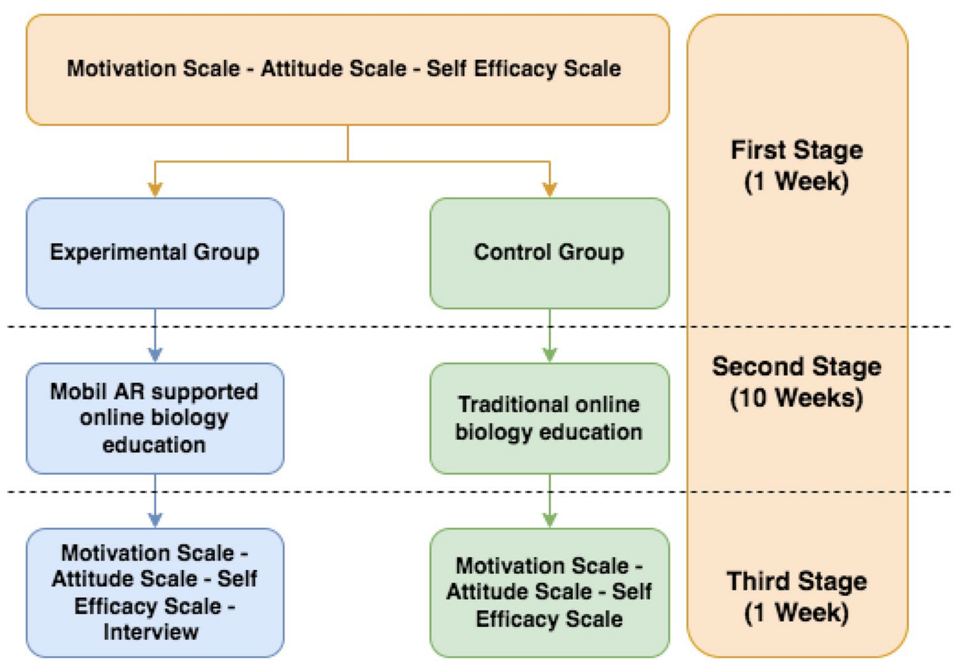


Fig. 2 Sample AR materials

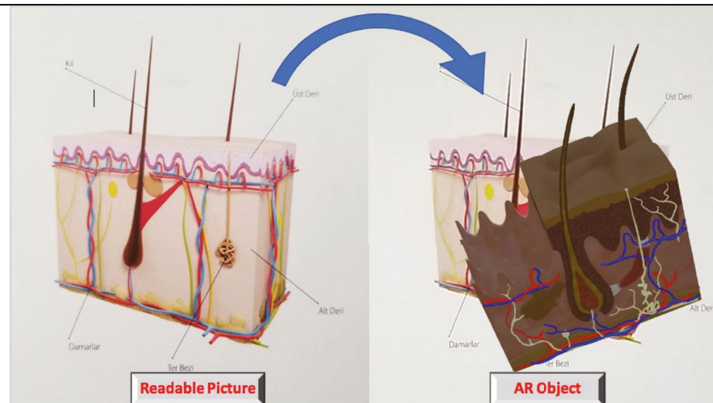
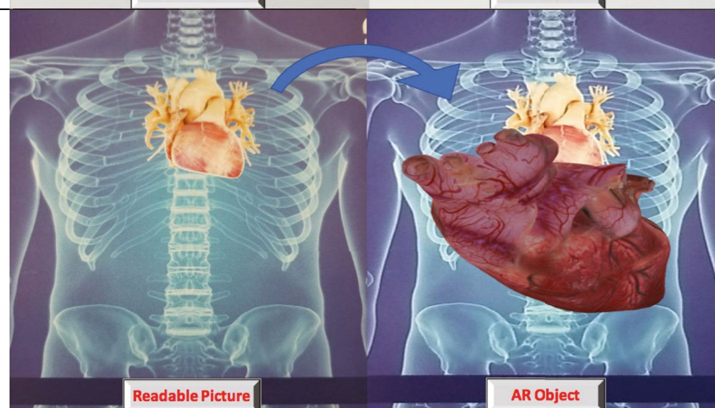
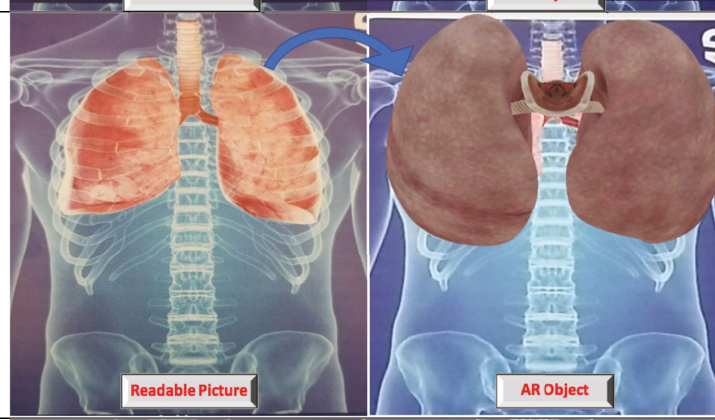
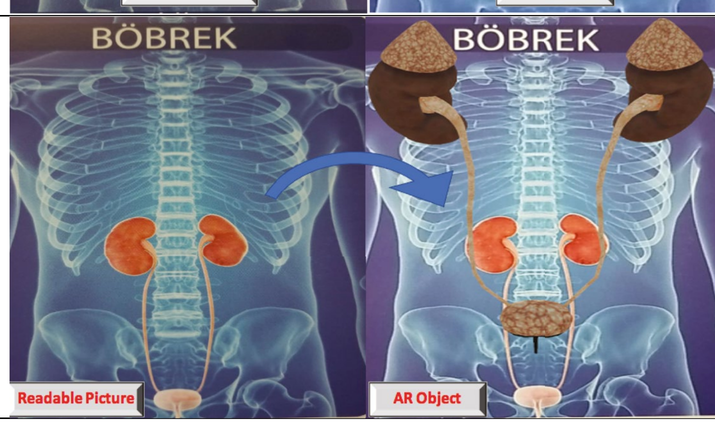
Material Name	Sample of Mobil AR Material
Skin	
Heart	
Lung (Respiratory System)	
Kidney (Urinary System)	

Fig. 3 Examples of AR material usage

DEL
DEL
DEL

Limitations and Suggestions

The research was conducted on mobile devices, and different tools, such as AR glasses, were not used. As a result of the insufficient features of the mobile device, such as camera, memory, RAM, and processor, in the use of mobile AR applications, some students participated in the study from their parents' mobile devices, and students with insufficient internet infrastructure sometimes had difficulties in participating in the study. The generalizability of the results of this study, conducted within the scope of biology courses for different disciplines, is weak. Future studies can be conducted in different disciplinary areas to increase the generalizability of the study. Moreover, since some of the data obtained did not show a normal distribution, nonparametric tests were used in the analyses. If a similar study is repeated and a study in which all of the data are normally distributed is conducted, both the results will be stronger, and the generalizability of the study can be increased. Finally, according to the results of the analysis of quantitative data, it was observed that students' self-efficacy levels increased, and at the end of the analysis of qualitative data, it was concluded that students found AR applications useful in many ways. In this context, learning can be enhanced by incorporating AR learning activities into biology textbooks in accordance with the lesson plan.

Appendix 1

Annex 1 Stages of preparing a sample AR application.

For the AR application to be prepared with the Unity program, the following steps must be fulfilled in order.

- The Unity program is installed on the computer.
- .Net framework library is installed on the system.
- The Java JDK is installed on your system.
- The SDK with Android versions is installed on the system.
- The library of whichever Android version will be used is added to the system.
- Necessary camera settings are downloaded from the Vuforio library, and the license is obtained.
- The skeletal system database is downloaded from the Vuforio library.
- SDK and JDK settings are made in the installed Unity program.
- Vuforio library is added to the application.
- The 3D (.obj extension) skeleton system is included in the system.
- Arrangements are made as necessary. The size and *X* and *Y* coordinates are set.
- It is operated by the system.
- APK application is extracted as an Android.
- The limitations, interface, and proper functioning of our application are tested.

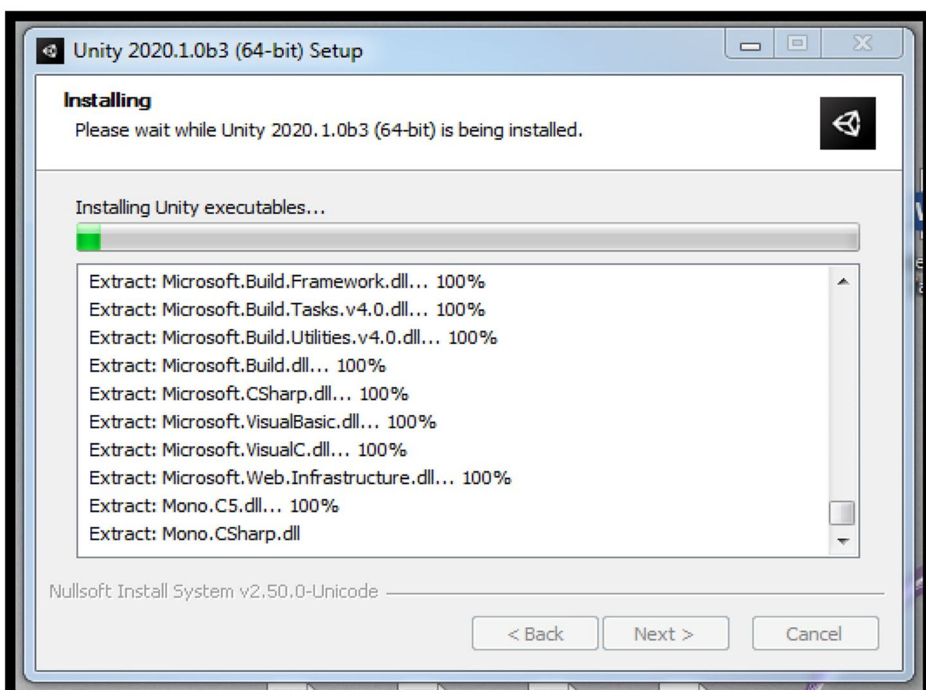


Fig. 4 AR application development steps 1

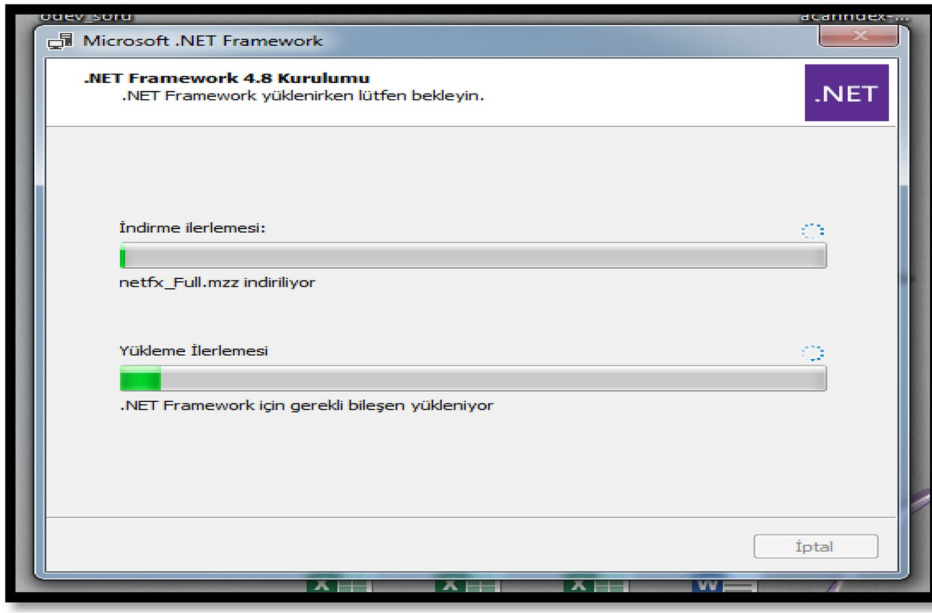


Fig. 5 AR application development steps 2

To develop an AR application, Unity 3D was selected, and the application development process continued accordingly. As shown in Fig. 4, the Unity 3D program should be downloaded to the computer and installed as shown in the figure. Before installing on the computer, the minimum operating systems should be Windows 7 (SP1 +), Windows 10, and Windows 11, IOS 10.13 Sierra, Linux Ubuntu 20.04, Ubuntu 18.04, and CentOS 7, DX10, DX11, and DX12 for Windows, Intel, and AMD with Metal feature for MAC, OpenGL 3.2 +, Vulkan feature as Linux processor feature. As a processor, for Windows, × 86, × 64 architecture with SSE2 instruction set support, ARM, ARM64, for Mac; × 64 architecture with SSE2, for Linux; × 64 architecture with SSE2 instruction set support.

As shown in Fig. 5, the program automatically installs the. NET framework 4.8 itself over the internet during installation. This step does not require any intervention as it continues automatically.

As shown in Fig. 6, the purchase of a license key is mandatory to use the Unity program. License Unity Hub should be downloaded to the computer, and the Unity program should be installed on the computer.

As shown in Fig. 7, the Unity 3D program should be opened after activation. The project should be created in the Unity program that was open. Each project created should have a different name.

As shown in Fig. 8, the Unity 3D application also needs to be installed on the computer. The project made here can be opened. After this, the license and database from the Vuforio library should also be downloaded to the computer.

As shown in Fig. 9, the software development kit of the Vuforia library is readily available for the AR application created. Membership is required to obtain databases and licenses from the Vuforia site. The Vuforia library is important because it is free of charge and works in full compatibility with Unity. A different software development kit can also be used.

As shown in Fig. 10, in order to use the Vuforia library, it is necessary to download auxiliary tools to the computer. Selection is made according to the operating system of the mobile phone (IOS or Android).

As shown in Fig. 11, a license is required to use the Vuforio library. To do this, a license can be obtained for free by selecting “get development key.”

As shown in Fig. 12, making even a single mistake during the licensing process will affect the operation of the generated AR application. The license code needs to be copied with care.

As shown in Fig. 13, it is necessary to create a database for the AR application in the Vuforia library and fill in the required fields by clicking the “add database” tab in the “target manager.”

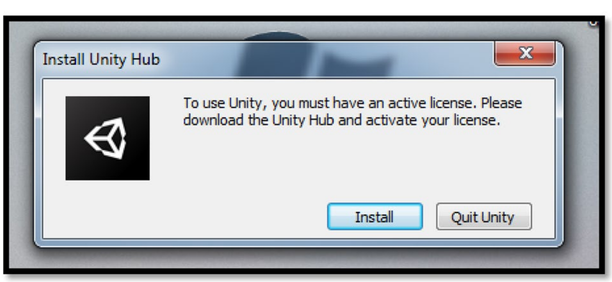


Fig. 6 AR application development steps 3

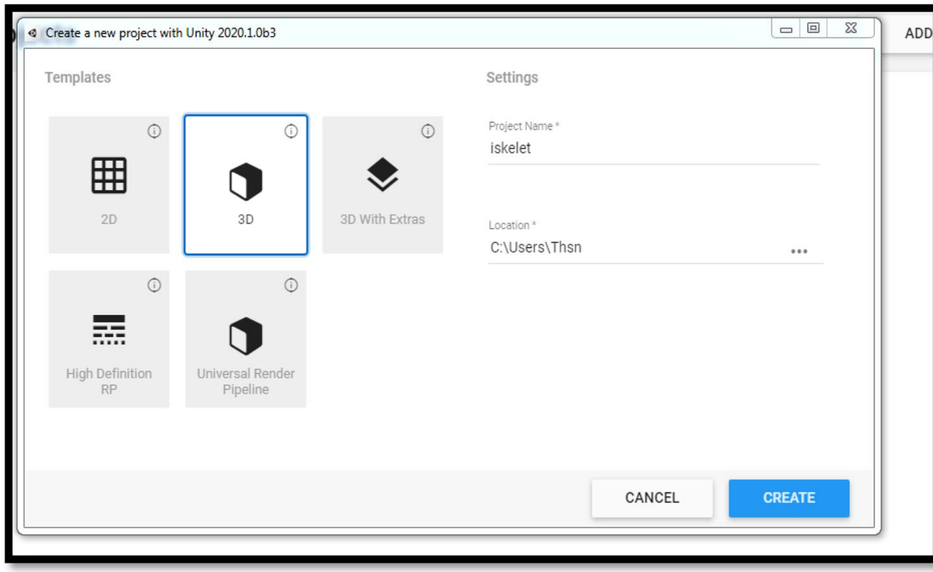


Fig. 7 AR application development steps 4

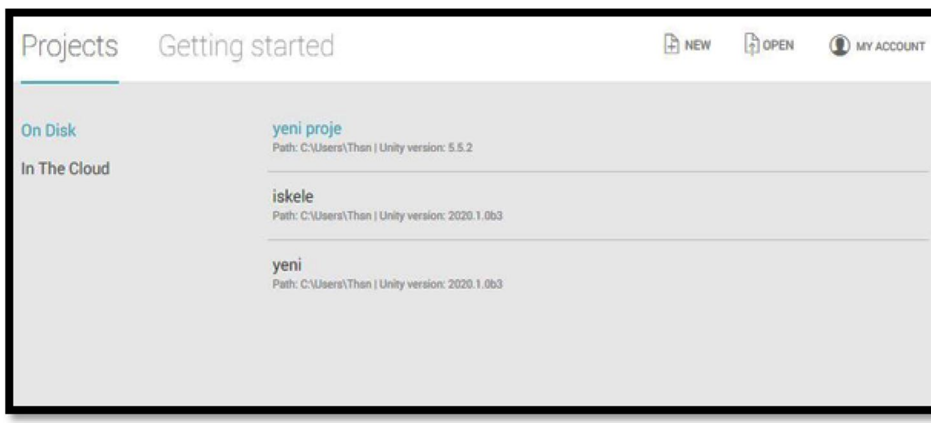


Fig. 8 AR application development steps 5

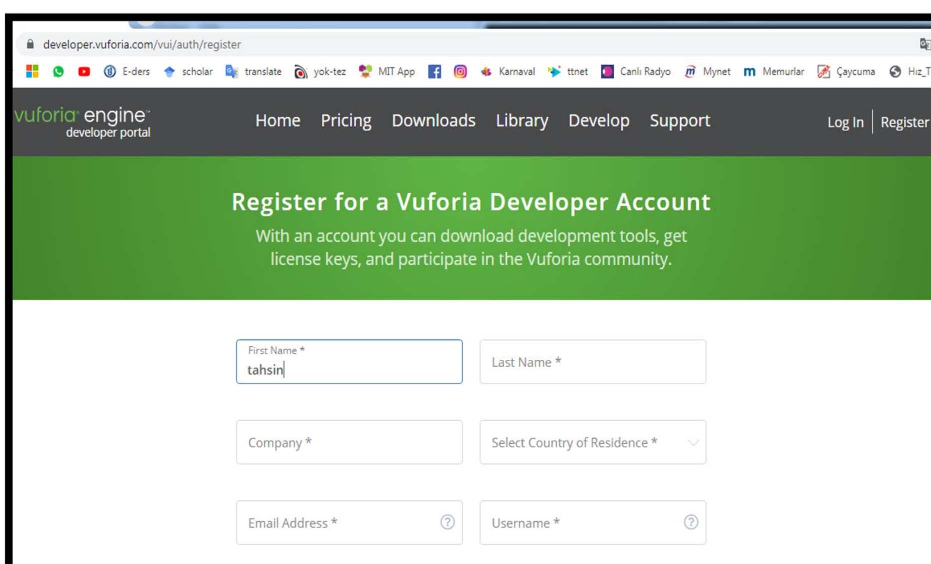


Fig. 9 AR application development steps 6

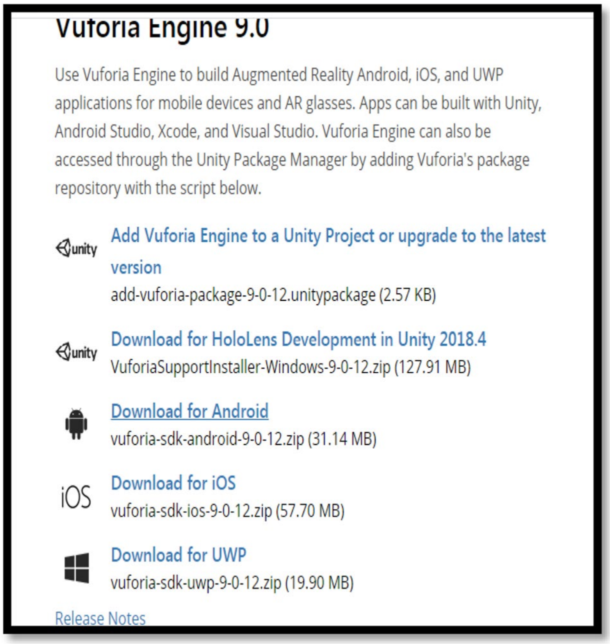


Fig. 10 AR application development steps 7

As shown in Fig. 14, it would be useful not to leave spaces between words when creating the database. For example, a database named Skeleton_data was created in the AG application.

As shown in Fig. 15, two-dimensional images are inserted into the created database. A QR code can be placed here, and this will be displayed in 3D as a result of the two-dimensional image detected by the camera of your mobile device. Good resolution and quality of the selected two-dimensional image are important.

As shown in Fig. 16, whichever of the AR applications of the created database will be used should be selected from this field. Since the prepared AR application will be used in the Unity 3D program, "unity editor" is selected and downloaded to the computer.

As shown in Fig. 17, since it comes ready-made from the Vuforia library, "main camera" should be deleted in the Unity 3D program. The purpose of deleting it is that the Vuforio library is available as an off-the-shelf AR app camera.

As shown in Fig. 18, the ready-made cameras created in the Vuforia library can be added to the Unity 3D program by selecting "import package" and "custom package" from

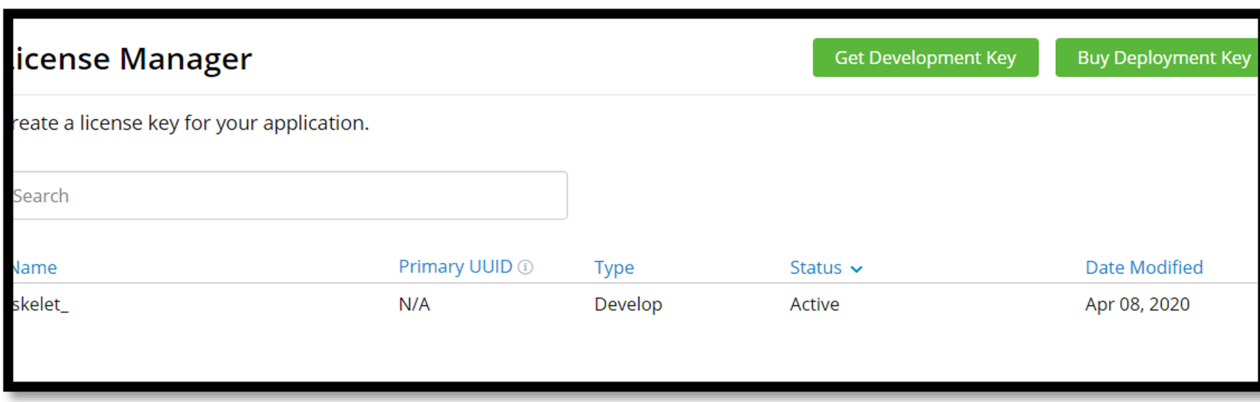
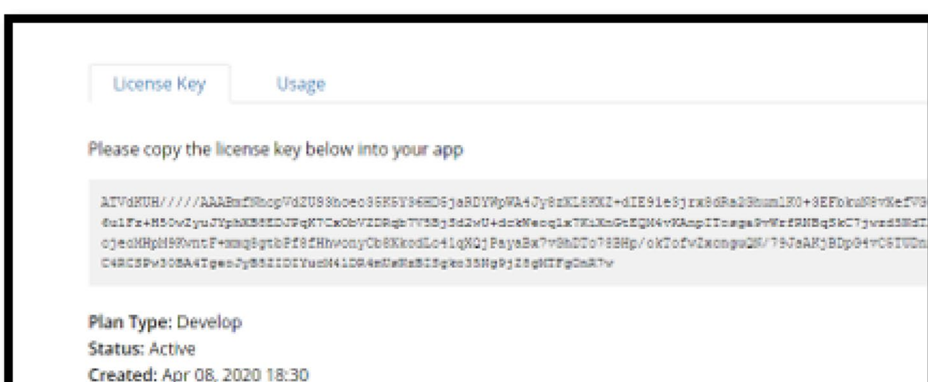


Fig. 11 AG application development steps 8

Fig. 12 AR application development steps 9



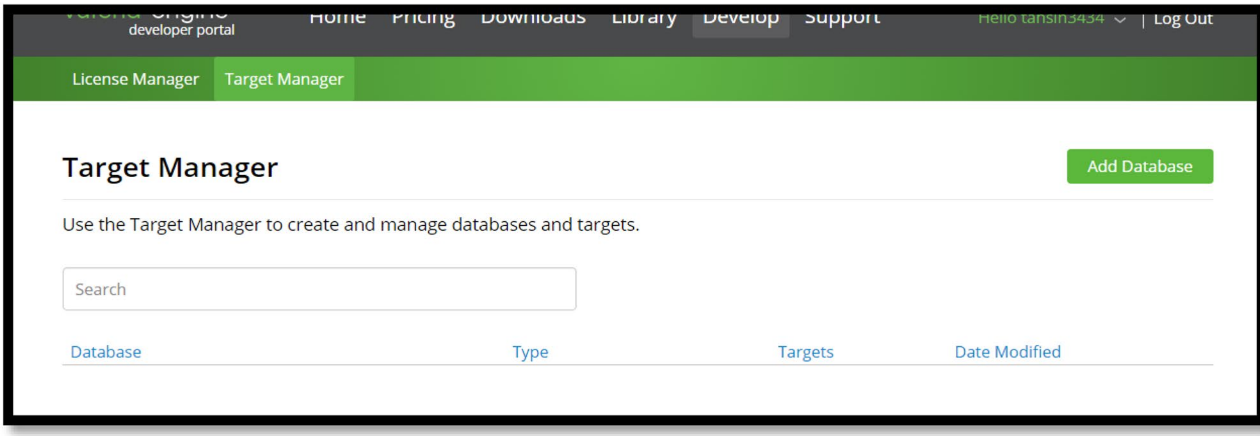


Fig. 13 AR application development steps 10

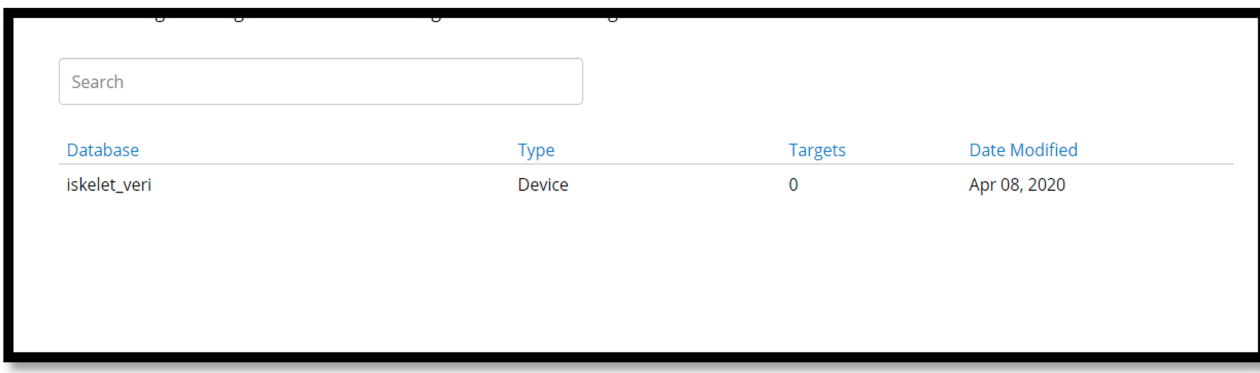


Fig. 14 AR application development steps 11

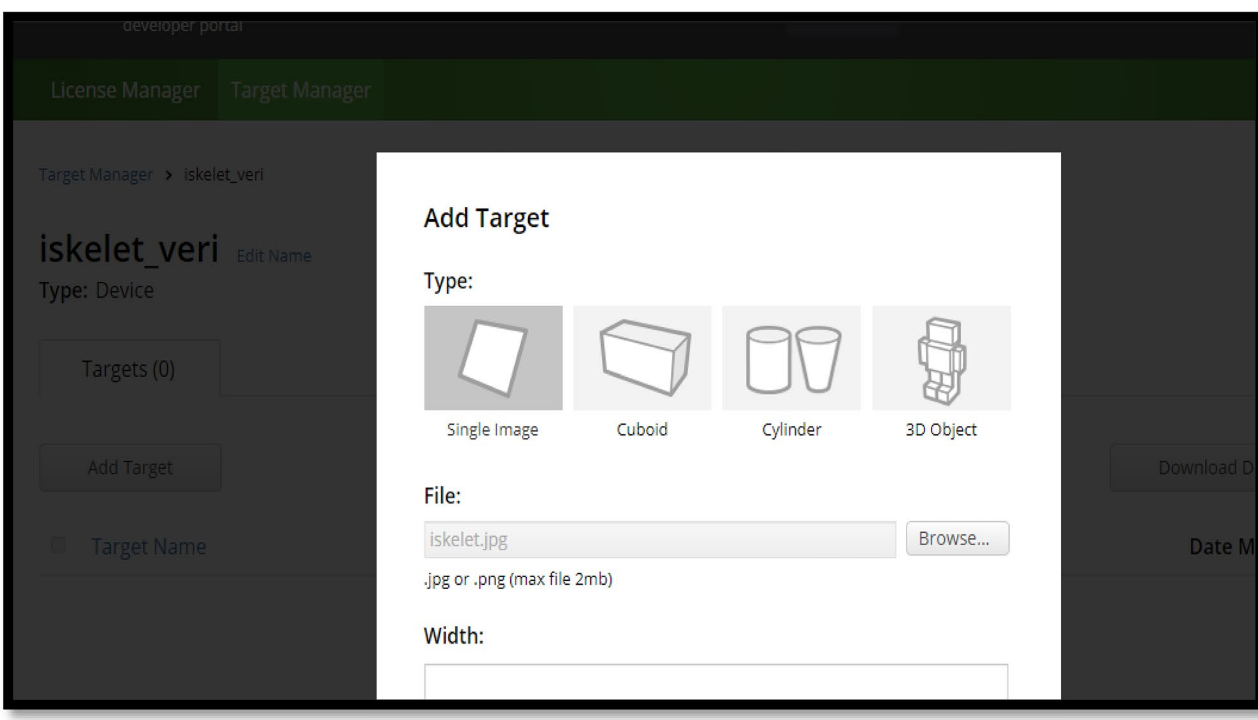


Fig. 15 AR application development steps 12

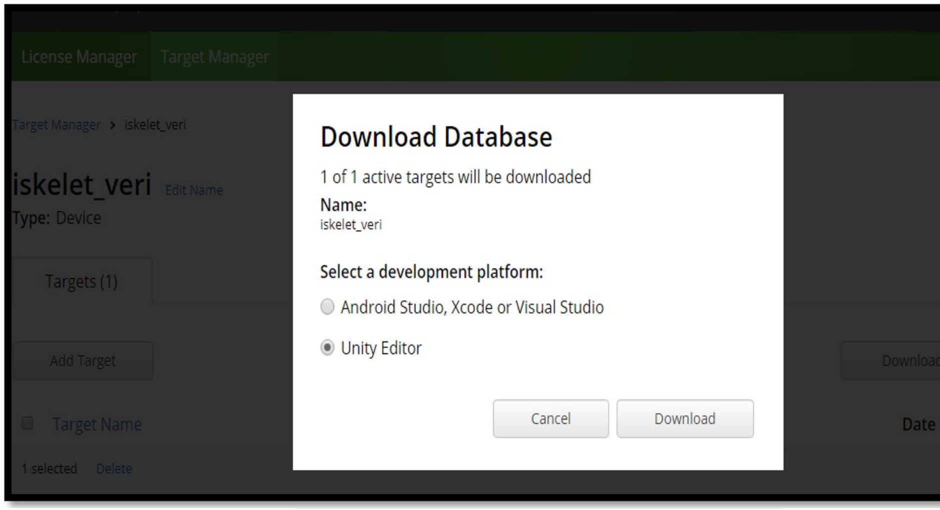


Fig. 16 AR application development steps 13

the "assets" menu, respectively. Unity can import the file downloaded from the Vuforia library from this address.

As shown in Fig. 19, it is necessary to find and select the path of the file downloaded from the Vuforia library and transfer it to the system. This must be done for the Unity program with Vuforia to work stably.

As shown in Fig. 20, when "import" is selected from the pop-up window, the necessary tools are added to the system. Continue with the next step.

As shown in Fig. 21, the prepared database needs to be added to the Unity 3D program. To do this, the file path of

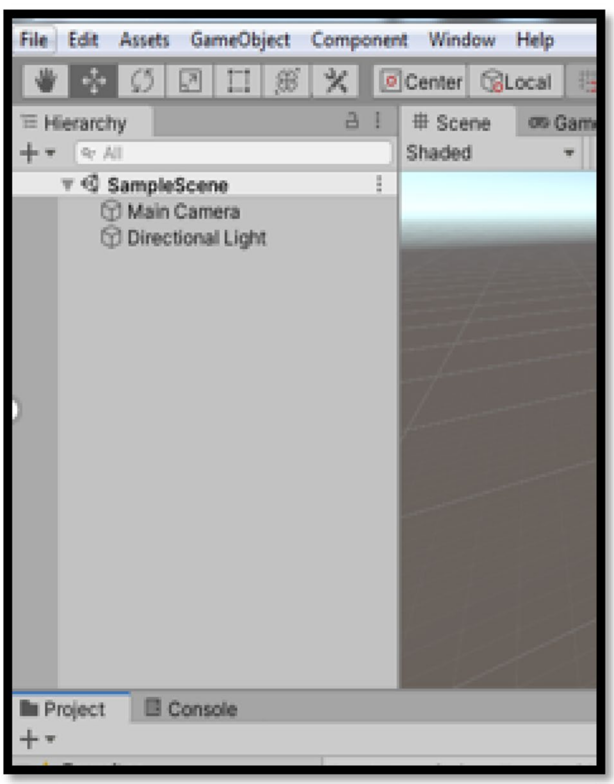


Fig. 17 AR application development steps 14

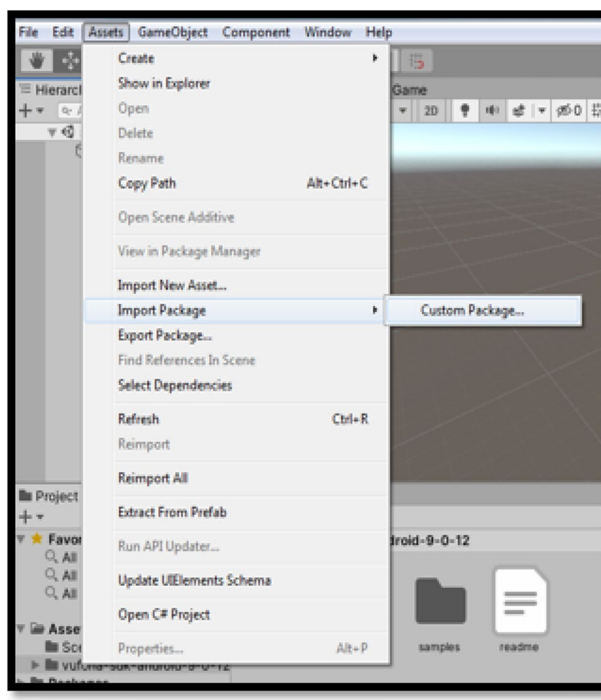


Fig. 18 AR application development steps 15

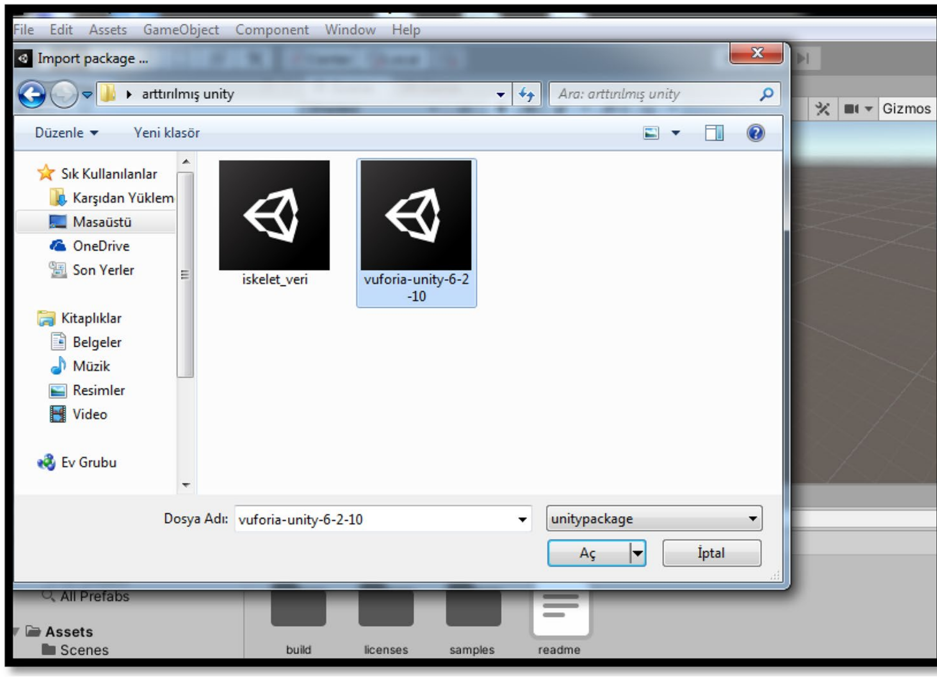


Fig. 19 AR application development steps 16

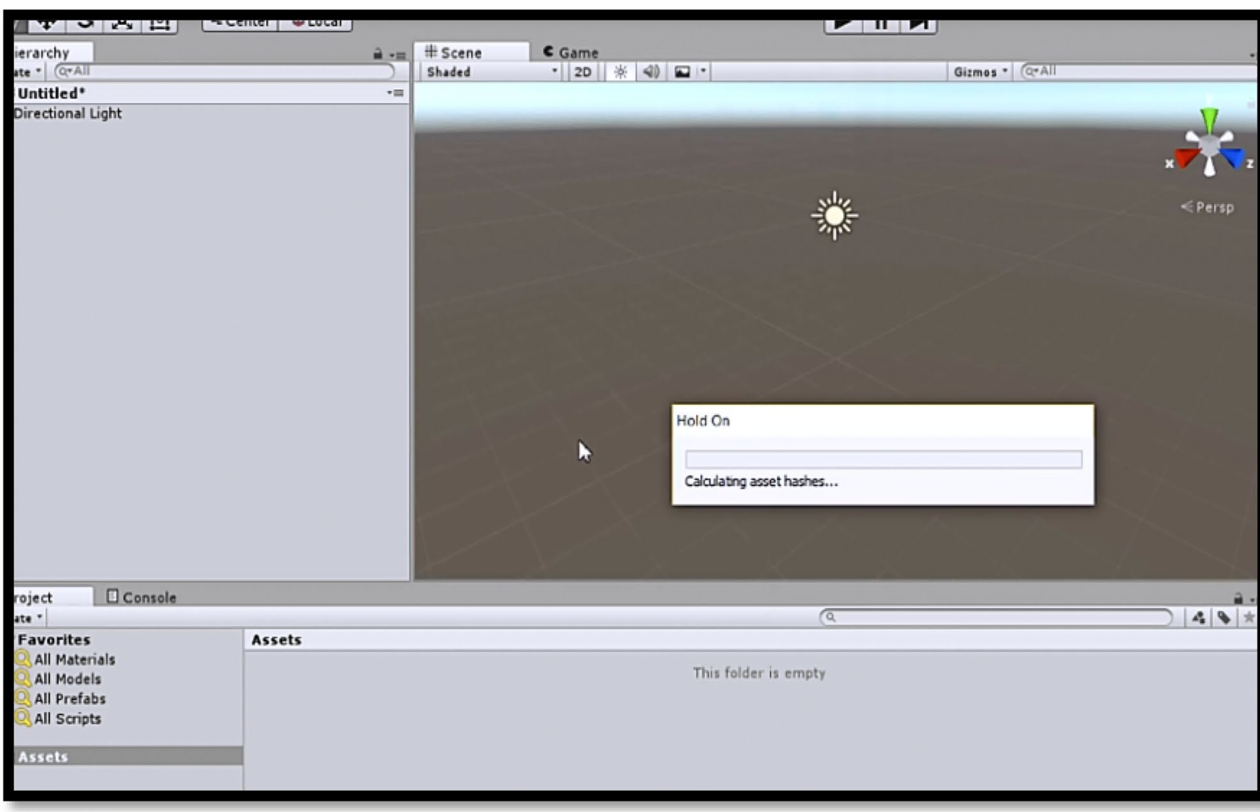


Fig. 20 AR application development steps 17

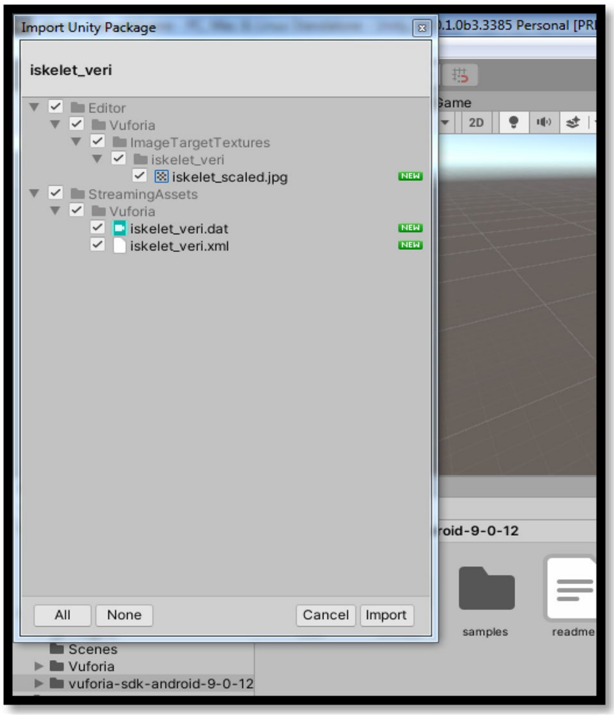


Fig. 21 AR application development steps 18

the data can be found from the "import" menu and added to the Unity program.

As shown in Fig. 22, "Prefabs" is then selected from the Vuforio menu for the selection of cameras and system images from the Unity program. Cameras included in the system from here are made ready for insertion.

As shown in Fig. 23, the created AR camera needs to be selected to be added to the system. "ARCamera" is selected from the "prefabs" menu.

As shown in Fig. 24, after adding the camera to the scene screen, the image is formed as shown in the figure. The camera is activated by entering the license key generated in the following process.

As shown in Fig. 25, after selecting the AR camera, the license key from Vuforia should be added to the "app license key" section under the "ispector" menu. Entering the code incorrectly will prevent the AR application from working.

As shown in Fig. 26, the database called "skeleton_data" added to the Unity 3D program must be activated for it to work. To activate the database, "Load skeleton_data" must be selected at the bottom of the add license code menu, and it must be activated from there.

As shown in Fig. 27, the database can be added in the "dataset" section of the menu to activate the database added to the system in the future.

As shown in Fig. 28, it is necessary to add an "Image Target" under the AR camera from the Unity 3D interface. From the Vuforia library, the title can be changed in the "ImageTarget" option in the submenus of the "Perhabs" menu.

As shown in Fig. 29, the 2D image needs to be added to the workspace screen of the Unity program. After adding the two-dimensional image or QR code to the system, the three-dimensional object should be imported into the Unity program by hovering over the "assets" menu. Once imported,

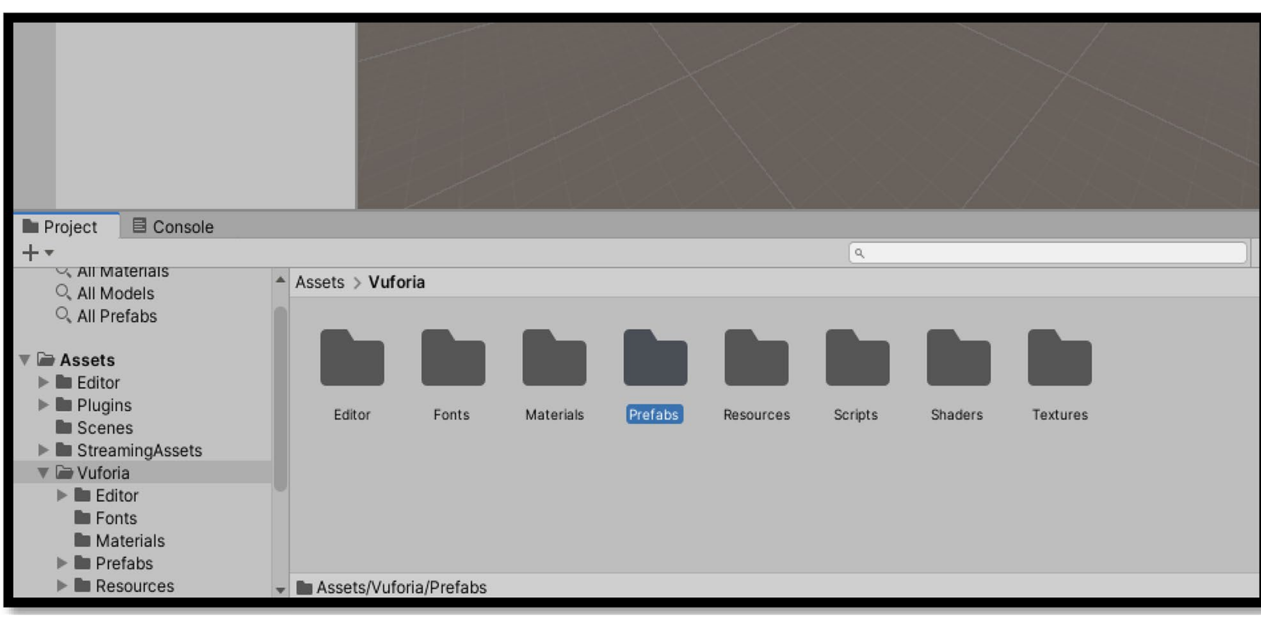


Fig. 22 AR application development steps 19

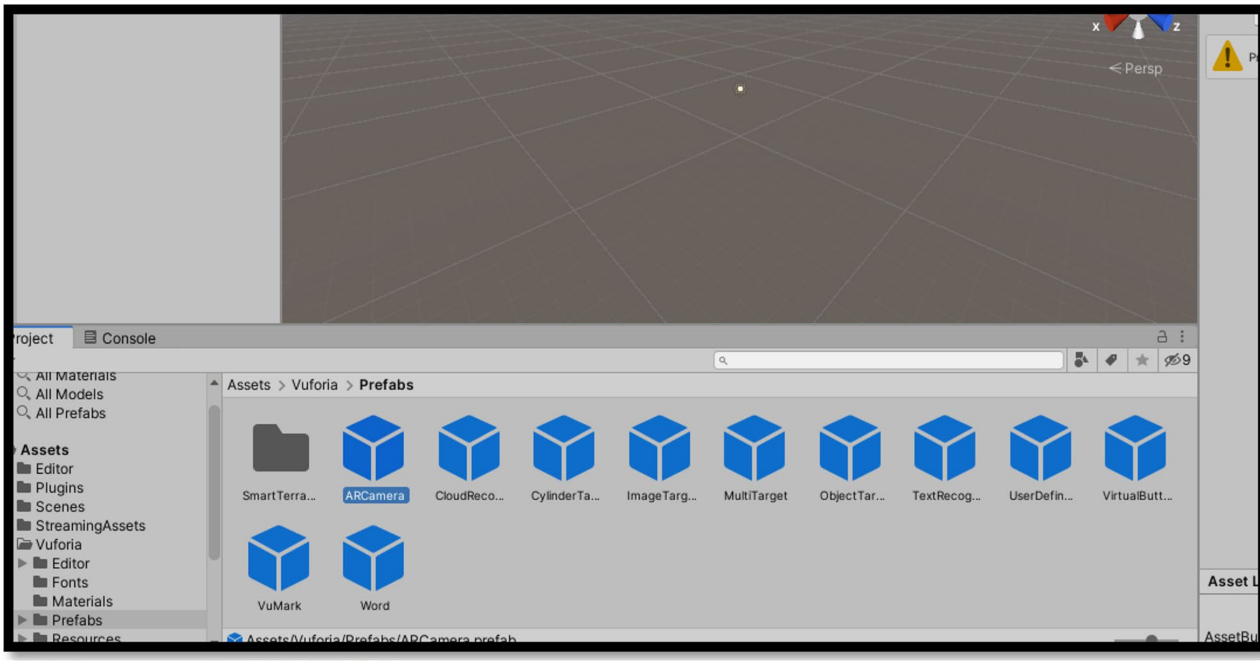


Fig. 23 AR application development steps 20

the 3D skeleton with OBJ extension can be added to the system by pulling and dropping it under the image target.

As shown in Fig. 30, two- and three-dimensional inserted objects in the workspace are set as shown in the figure. From the top-right corner, you can set the required vertical position (*x*) and horizontal position (*y*) directions and the size of the skeleton. Horizontal and vertical positions need to be set correctly, and objects need to be meticulously proportioned. Any slight imbalance here will distort the image on the mobile device.

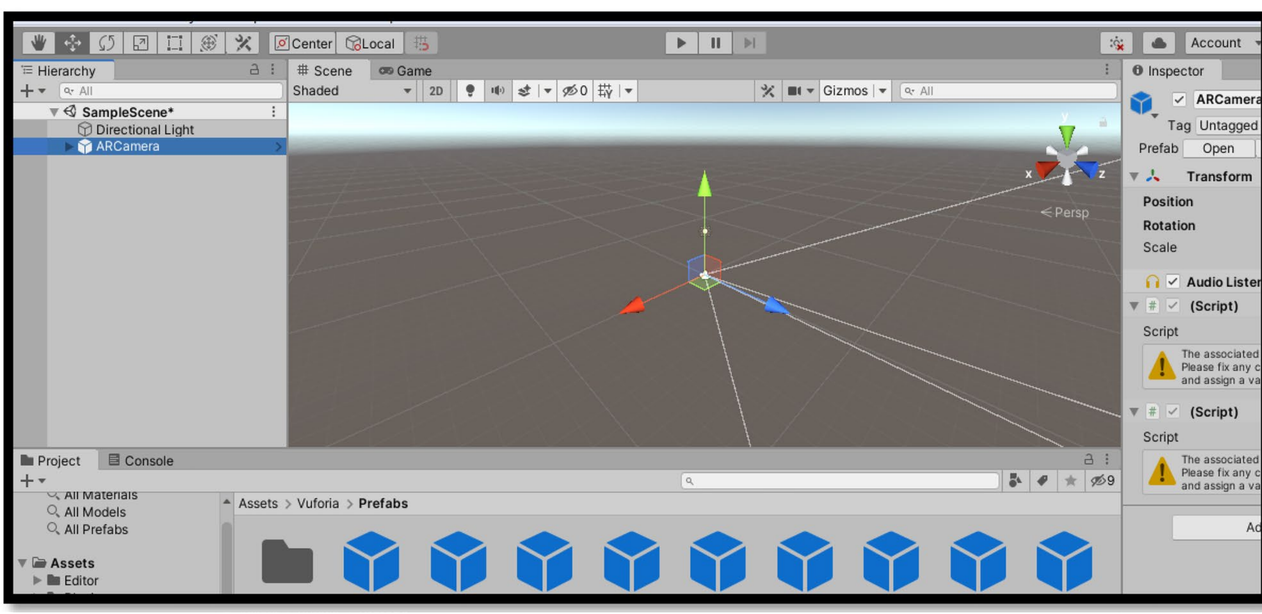


Fig. 24 AR application development steps 21

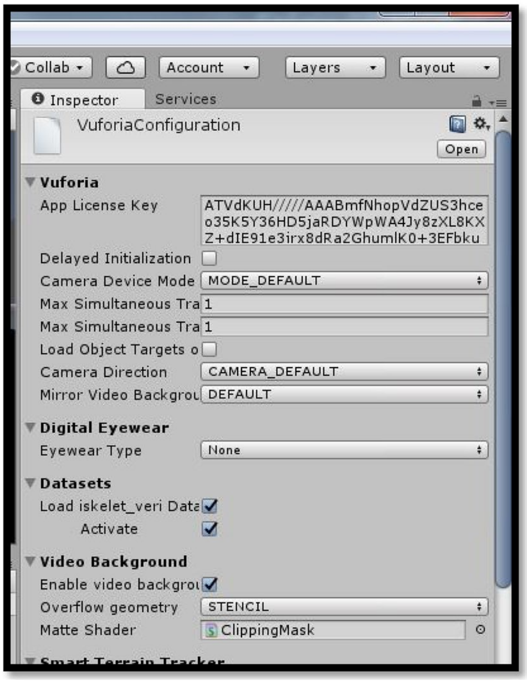


Fig. 25 AR application development steps 22

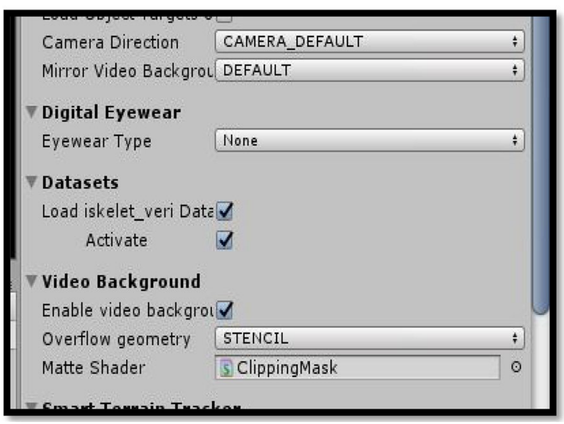


Fig. 26 AR application development steps 23

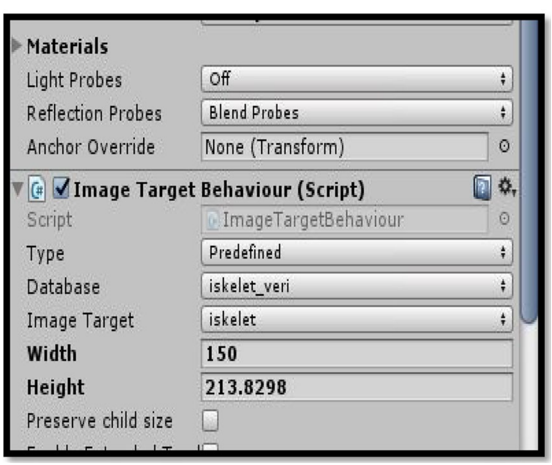


Fig. 27 AR application development steps 24

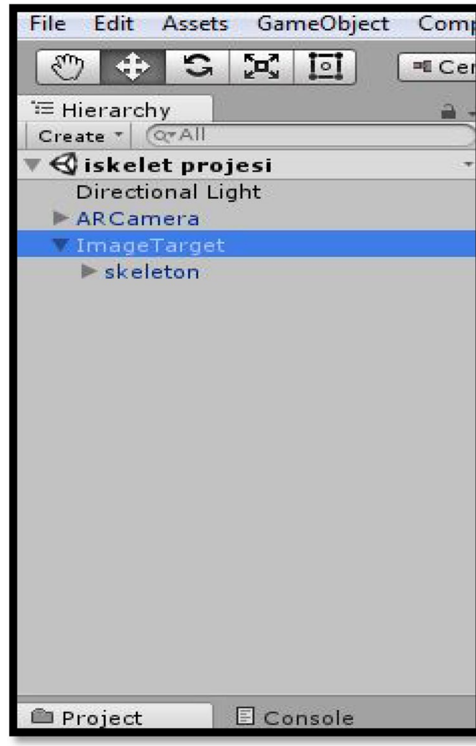
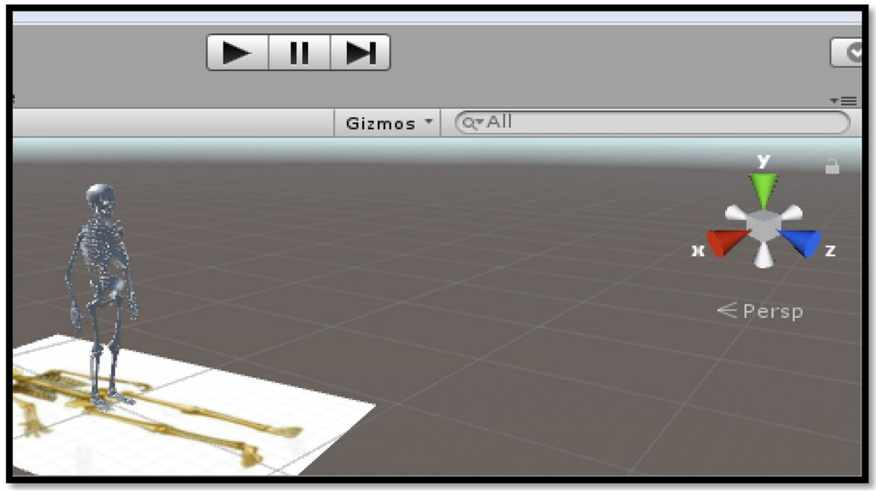


Fig. 28 AR application development steps 25

Fig. 29 AR application development steps 26

Fig. 30 AR application development steps 27



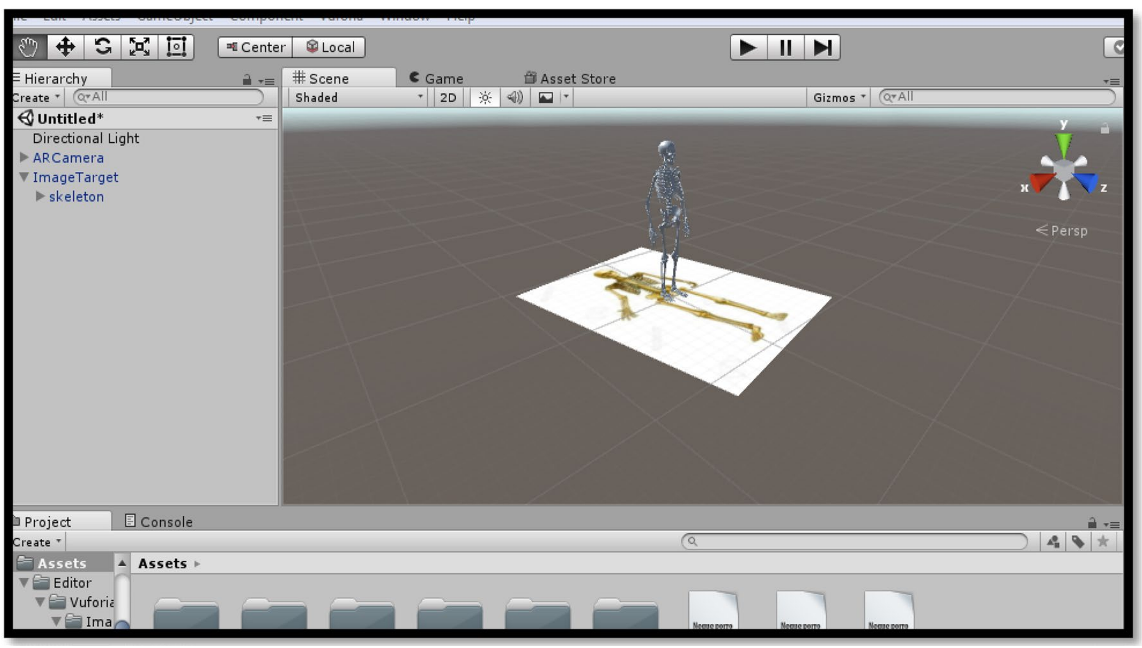
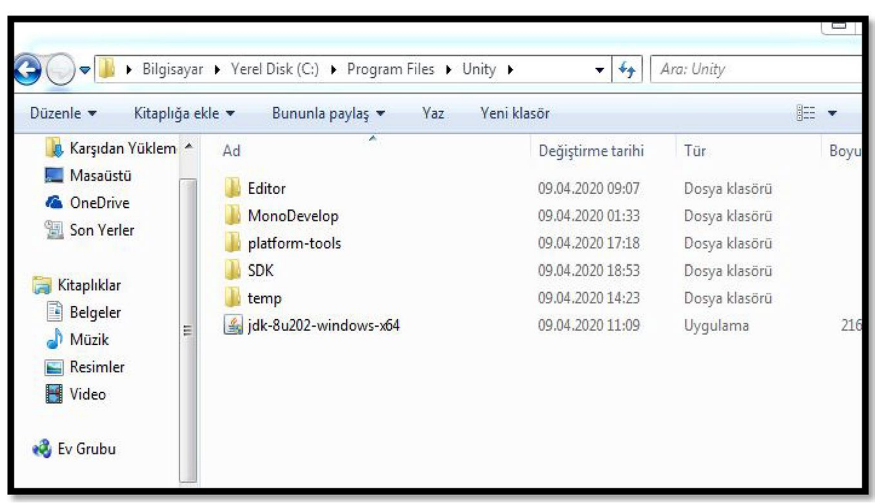


Fig. 31 AR application development steps 28

Fig. 32 AR application development steps 29



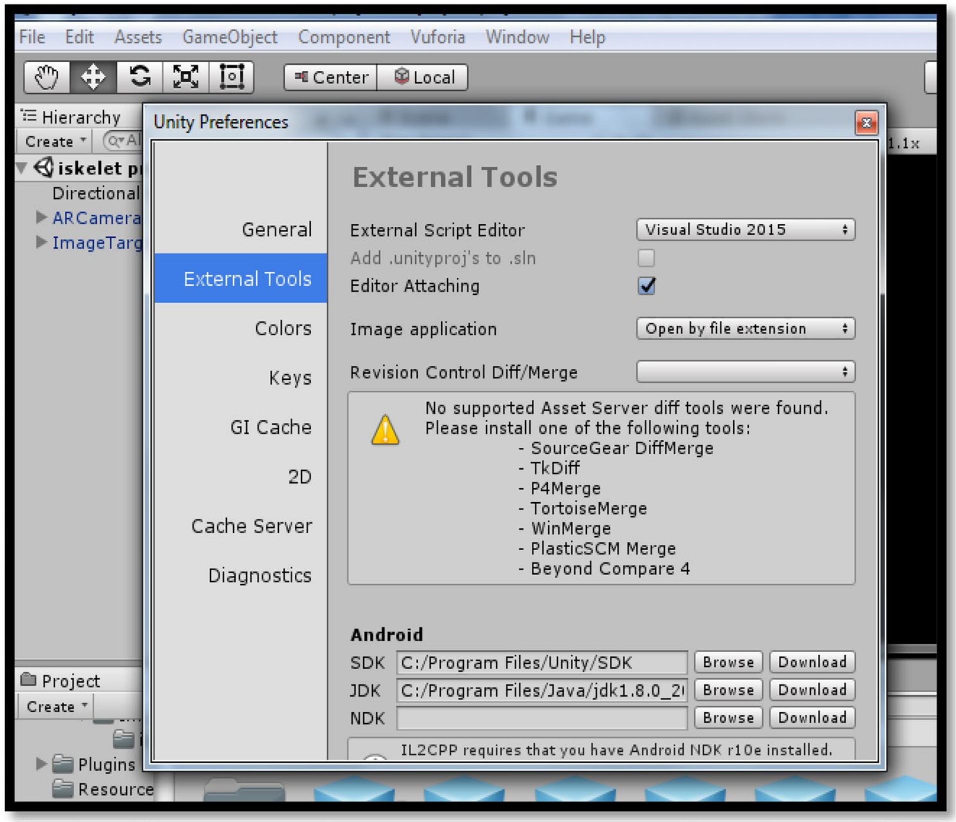


Fig. 33 AR application development steps 30

As shown in Fig. 31, the positions of the objects have been meticulously adjusted. After careful and attentive implementation of the steps, the mobile application can be started to work. Depending on the operating system of the mobile device (Android or IOS), the Java development kit and software development kit must be installed on the computer.

As shown in Fig. 32, the Java software development kit (JDK) and software development kit (SDK) must be installed on the computer.

As shown in Fig. 33, the installed JDK and SDK paths must be entered by clicking “preferences” from the “edit” menu in the Unity program interface. From the “external” menu, the SDK path should be shown as the SDK path in SDK Browse, and the JDK path should be shown as the JDK path in JDK browse.

After completing the steps in full, the application can now be developed, as shown in Fig. 34. To do this, click on “build settings” from the “file” menu and select the necessary steps.

As shown in Fig. 35, the operating system of the mobile device is selected from the drop-down menu. Also, to set the version settings of the mobile device, click on “player settings” when Android is selected.

As shown in Fig. 36, “player settings” settings are made from the drop-down menu. This field should be used to fill in the required fields for the application and to enter personal information. In addition to the information entered, the “other settings” menu opens below.

As shown in Fig. 37, in the bundle identifier section, enter “com.company name”.” product name” with a period between

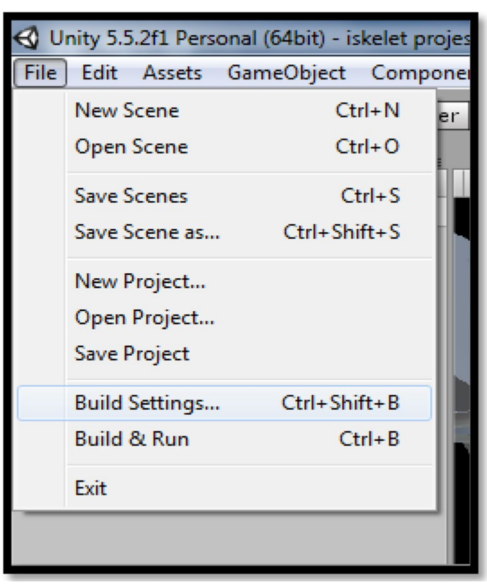


Fig. 34 AR application development steps 31

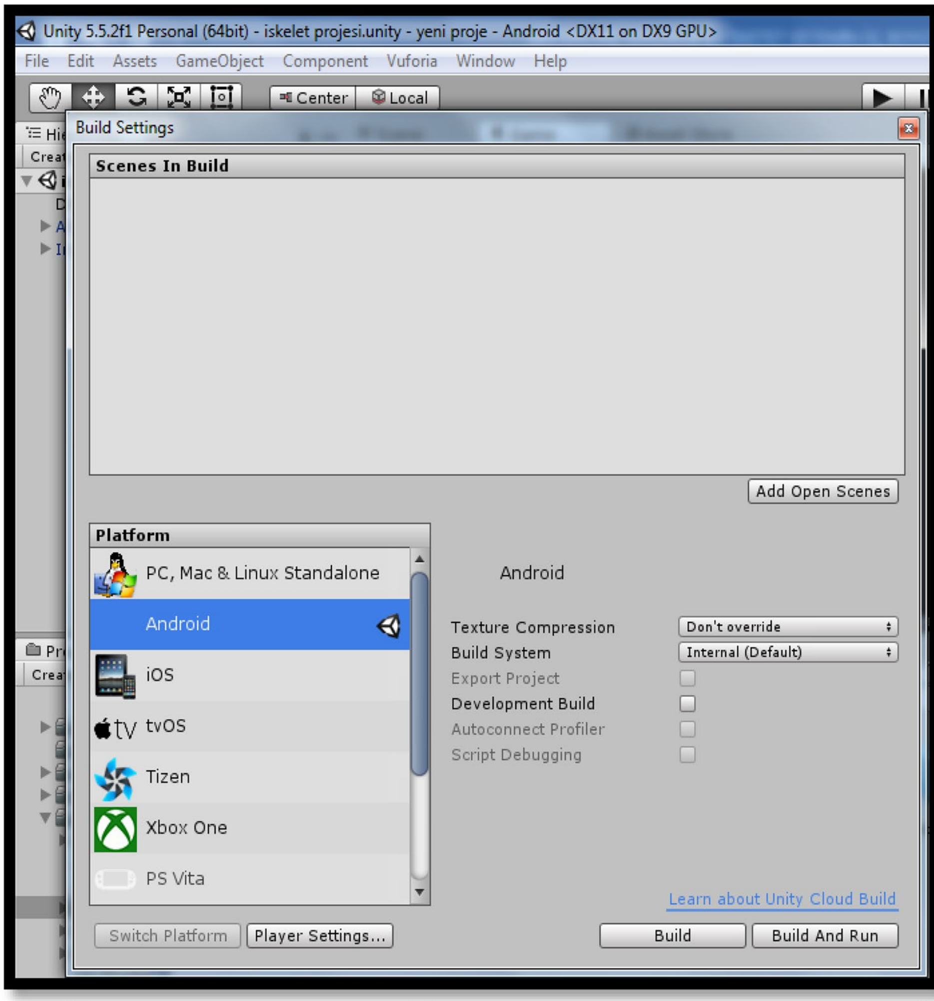


Fig. 35 AR application development steps 32

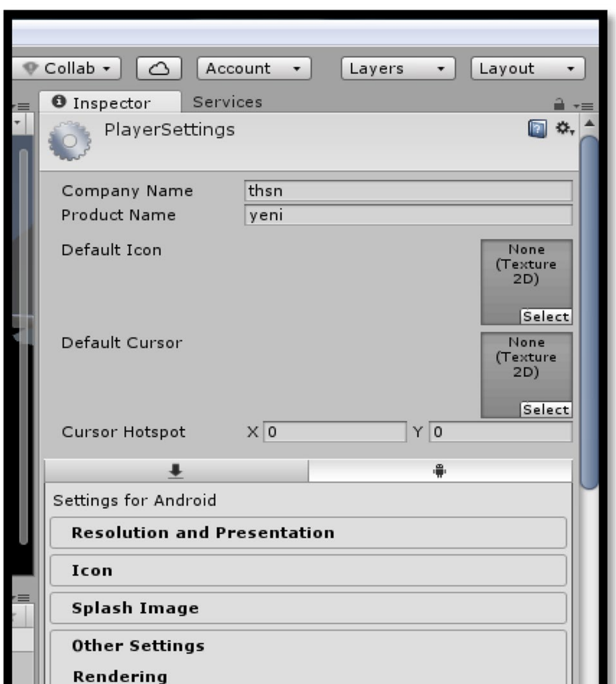


Fig. 36 AR application development steps 33

Fig. 37 AR application development steps 34

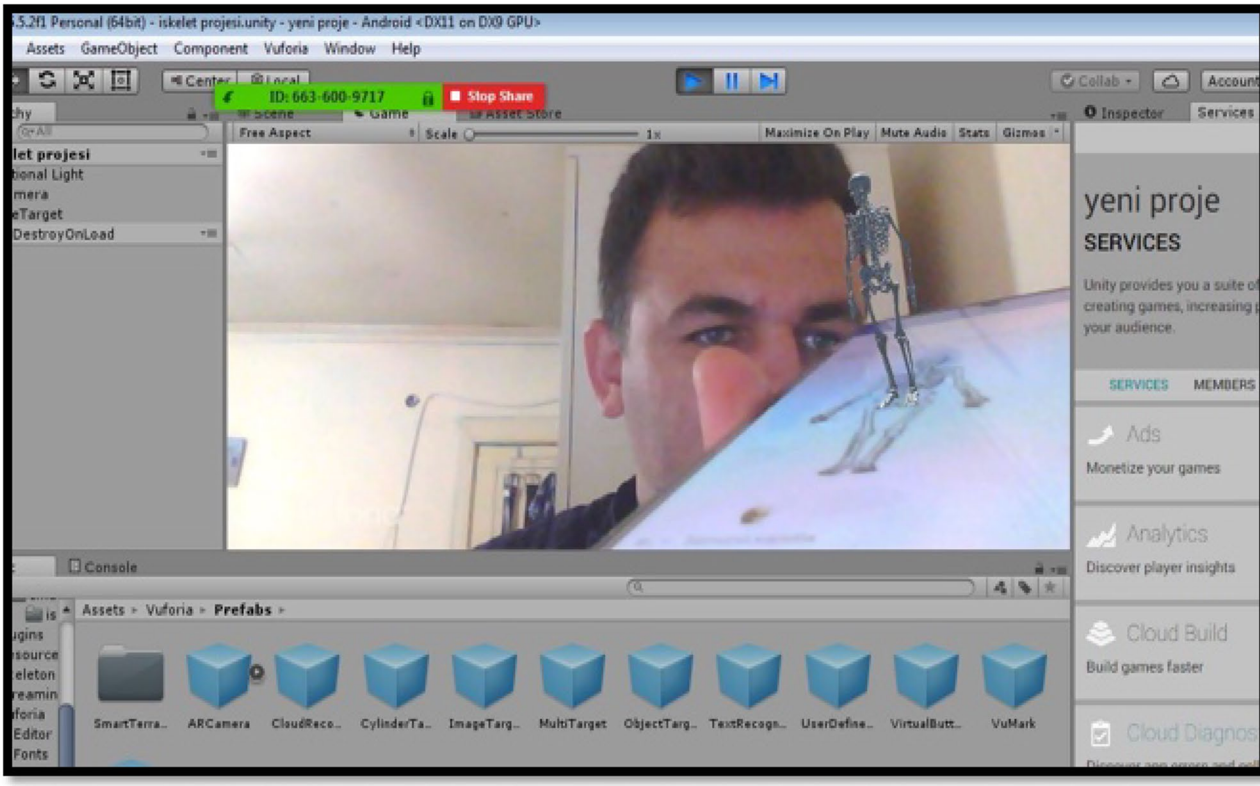


Fig. 38 Computer image of prepared AR application

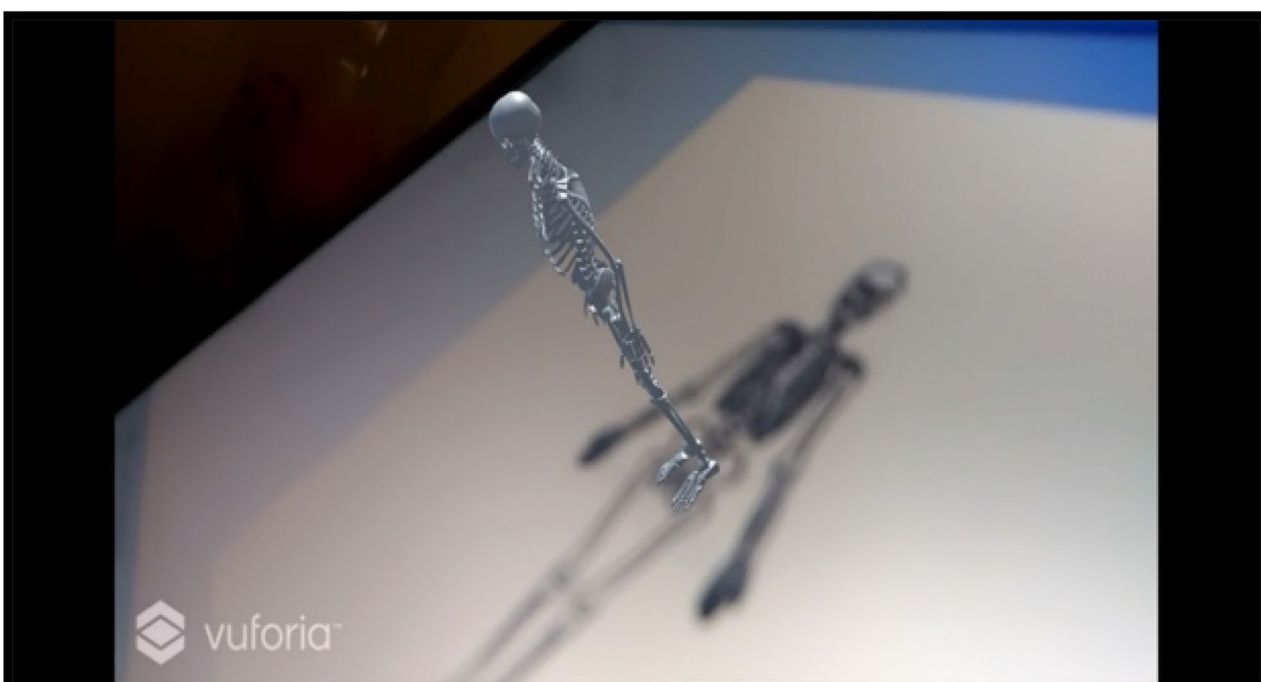


Fig. 39 Mobile device image of prepared AR application

them. At the bottom, in the "minimum API level" section, select which Android SDK is downloaded to the computer and proceed to the next step.

As shown in Figs. 38 and 39, the application can be used from a mobile device or a computer's camera. The AR app also works stably on the mobile device app.

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Data Availability The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Conflict of Interest The authors declare no competing interests.

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