Indonesian Society for Science Educators
Journal of Science Learning
journal homepage: ejournal.upi.edu/index.php/jslearning

The Effect of Augmented Reality Applications Integrated with Modeling on Pre-Service Science Teachers' Modeling Skills and Academic Achievements

Nesrin Ürün Arıcı[1]*, Ümit Şimşek[1]

[1]Science Teaching Department, Kazım Karabekir Education Faculty, Atatürk University, Erzurum, Turkey

*Corresponding author: nurunarici@gmail.com

ABSTRACT This study investigates the impacts of augmented reality applications integrated with modeling on pre-service science teachers' modeling skills achievements and determines their opinions toward the implementation process. This study used a simultaneous nested mixed method in which two online and face-to-face groups of fifty-six first-year pre-service science teachers were randomly assigned to the experimental groups. The "Weak Interactions Interparticles Academic Achievement Test", rubric, and diary forms were applied to evaluate pre-service teachers' achievements, modeling skills, and opinions. An independent sample t-test was used to compare face-to-face and online groups. A dependent sample t-test was chosen to compare within groups. Pre-service teachers' academic achievements in the online experimental group are higher than in the face-to-face experimental group. However, pre-service teachers' modeling skills are higher in the face-to-face group than in the online group. In addition, the results revealed that augmented reality application is more effective in pre-service teachers' academic success modeling skills. The qualitative results of this study revealed that face-to-face education had more positive views and welcomed this technology in terms of the learning and teaching process.

Keywords Academic achievement; Augmented reality; Modeling skills, Pre-service teachers, Online, Face-to-face education

1. INTRODUCTION

Weak interparticle interactions are abstract and challenging to learn. Since weak interparticle interactions are a fundamental subject of chemistry, it is essential for understanding more advanced topics. In this study, it was thought that AR would help learn the subject of weak interparticle interactions due to its features such as facilitating understanding of concepts, having three-dimensional images, being very interesting, entertaining, and facilitating learning. After the applications, these groups' success levels and modeling skills were compared.

Chemistry is a fundamental discipline of science, and it is challenging to understand due to many abstract topics that are hardly observed directly in daily life (Hoft, Bernholt, Blankenburg & Winberg, 2019; Yang, Andre, Greenbowe & Tibell, 2003; Yildirim & Canpolat, 2017). Accordingly, one of these topics is weak interparticle interactions. Weak interparticle interactions play a significant role in many advanced chemistry subjects like dissolution, adsorption characteristics, viscosity, boiling, condensation, freezing, surface tension, adhesion, cohesion, and vapor pressure (Atasoy, 2018; Burkholder, Purser & Cole, 2008; Schmidt, Kaufmann & Treagust, 2009). Despite the importance of weak interparticle interactions, most students' explanations are ambiguous (Cooper, Williams & Underwood, 2015; Schmidt, Kaufmann & Treagust, 2009). For instance, students confuse weak interparticle interactions with strong intramolecular bonds, especially covalent bonds.

Information and communication technologies have recently created effective learning environments in chemistry teaching (Opateye & Ewim, 2021). For example, animations, virtual reality, conceptual change texts, argumentation, and computer-assisted teaching are the many methods, techniques, and strategies used effectively in chemistry learning (Doymuş, Şimşek & Karaçöp, 2007; Celik, 2019; Justi & Gilbert, 2002). Among these methods and applications, modeling and Augmented Reality (AR) have attracted attention recently. As shown in the literature, it is helpful to use the AR application modeling method in teaching abstract subjects in chemistry courses (Bilgin & Geban, 2006; Celik, 2019; Justi & Gilbert, 2002).

Received: 25 July 2023
Revised: 24 September 2023
Published: 04 December 2023

1.2 Modeling in Science Education

Modeling is a process that includes activities consisting of many stages and determining which details about the concept or subject can be found in a specific form. The modeling method can be helpful and significant in developing cognitive and affective skills in learning (Justi & Gilbert, 2001). In the literature, there are many studies using modeling in science education. For example, Adbo & Taber (2009) and Van Driel & Verloop (2002) investigated teachers' ideas about modeling. At the end of these studies, it was concluded that teachers have enough theoretical information about modeling, but they have weak practices and demonstrations. In addition, Yayla & Eyceyurt (2011) addressed using models to investigate pre-service science teachers' ideas about basic concepts in chemistry. They reported that modeling is excellent for uncovering students' ideas about the basic concepts in chemistry by analyzing the expressions, drawings, and misconceptions. Another study conducted by Abualia et al. (2016) involved observing students' conceptual understanding level of weak interparticle interactions using modeling. They concluded that students' explanations of interparticle interactions were ambiguous at the beginning of the study. However, they found that modeling improved their conceptual understanding skills.

Similarly, researchers have addressed the case of wrong or incomplete student images, situations such as the students could not visualize the concept in their mind, establish a connection among knowledge elements, or learn the concept (Cooper, Williams & Underwood, 2015; Justi & Gilbert 2001; Schmidt, Kaufmann & Treagust, 2009). In addition, Nichele, Do Canto & Da Silva (2020) stated that modeling methods support the three-dimensional display and learning of the subject. Modeling methods are conceptual systems that explain subjects (Treagust, Chittleborough & Mamiala, 2002). Hence, it can be concluded that modeling simplifies the complex object or process (Mazzuco, Krassmann, Reategui & Gomes, 2022). Furthermore, modeling methods can be used in situations that cannot be observed directly (Justi & Gilbert, 2001).

1.2 AR in Science Education

AR is an application in three-dimensional virtual images and the real world. Cai, Wang & Chiang (2014) and Ferrer-Torregrosa, Torralba, Jimenez, García & Barcia (2015) stated that AR could be used at all grade levels. Moreover, the AR application makes teaching more exciting and enjoyable (Uluyol & Eryilmaz, 2012). Hence, it positively affects attitudes and motivations (Bujak et al., 2013). The AR application allows students to experience visualizing scientific phenomena (Cai, Wang & Chiang, 2014). Through the 3D images of the AR application, students can interact with virtual images, which help them learn the concepts. The literature shows that many studies on using AR in science education exist. For instance, Fuchsova & Korenova (2019) assessed using AR in biology education with pre-service teachers. They reported that AR makes studying more attractive for students and brings greater motivation to understand notions. In another study, Yang, Mei & Yue (2018) aimed to explore pre-service chemistry teachers' perception of mobile augmented reality (MAR) assisted chemical education. They revealed that participants generally had a positive attitude toward the immersive chemistry learning experience.

Additionally, Akcayir, Akcayir, Pektas & Ocak (2016) investigated the effects of using augmented reality (AR) technologies in science laboratories on university students' laboratory skills and attitudes toward laboratories. Their data showed that AR technology improved the students' laboratory skills and helped them build positive attitudes toward physics laboratories. Kerawalla, Luckin, Seljeflot & Woolard (2006) stated that some design requirements must successfully adapt the AR application into classroom practices. These requirements are flexible content that teachers can adapt to the needs of their students. Another requirement is to guide exploration so that learning opportunities maximize learning in a limited time. Finally, it pays attention to the needs of institutional and curricular requirements.

1.3 Modeling Integrated with AR

The AR application is practical and cannot be used during the course alone because it requires much attention. Hence, it can be a distracting thing for students. On the other hand, during the AR application experience, the teacher may distract the students in their discussions on the subject and limit student participatio n in the educational content offered in AR (Radu, 2014). Thus, using the modeling method and AR application together can make students more active in various activities in the course (Figure 1). That is, when virtual images have applications that are added to real-world images, it can help students create three-dimensional models during the modeling method (Carmigniani et al., 2011). The realization of the three-dimensional display could predict a positive effect on the successes and motivations of pre-service teachers by

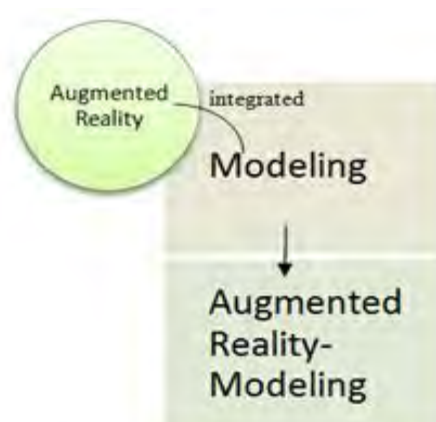


Figure 1 Methods which using in each group

using an AR application integrated with the modeling method that the subject stimulates in their minds.

Within the scope of the study, AR applications were developed to teach the subject of weak interaction interparticles. After pre-service teachers observed the interactions by AR and realized the stages of modeling, it was revealed that the effects of using AR integrated with modeling on the academic achievements and modeling skills of the pre-service teachers in face-to-face and online education and their views. Both groups aimed to increase pre-service teachers' participation in the lesson and teach by doing and experiencing, primarily through modeling after AR applications.

Weak interaction interparticles are abstract and challenging to learn. Since weak interaction interparticles are a fundamental subject of chemistry, it is essential for understanding more advanced topics.

In this study, it was thought that AR would help learn the subject of interaction interparticles because of its features, such as facilitating understanding of concepts, having three-dimensional images, being very interesting and enjoyable, and facilitating learning.

Another critical feature of AR is that students can see and even touch the real world while interacting with AR and simultaneously see a virtual three-dimensional image (Celik, 2019). In this study, it is expected that comprehending weak interaction interparticles by using technology and learning its relationship with other chemistry subjects will contribute to the professional development of pre-service teachers. On the other hand, like AR, modeling can embody abstract content. Primarily, we thought this method would contribute to pre-service teachers observing each interaction through AR, creating three-dimensional models at the modeling stages, and deepening the concepts. In other words, modeling and AR can be used together to describe the microscopic world of each weak interaction interparticle and relate interactions to the macroscopic properties of matter (Taber, 2002). In addition, when the literature was examined, it was revealed that the knowledge of teachers and students about modeling is weak, and they do not have enough knowledge about how to apply model types in the classroom environment (Adbo & Taber, 2009; Van Driel & Verloop, 2002).

Similarly, when students' knowledge of a concept was wrong or incomplete, situations were encountered in the literature, such as they could not visualize in their minds, could not connect information, and could not thoroughly learn the concept (Schmidt, Kaufmann & Treagust, 2009). For these reasons, we thought it would be appropriate to use the modeling method with AR, as it would help students associate the concepts they learned with other subjects and better support them in developing mental models that deepen their knowledge. Moreover, it can be said that this study is crucial as it will allow the pre-service teachers to use their psychomotor skills by making models that they have learned theoretically. In addition, it was thought that taking the pre-service teachers' views about the process would contribute to eliminating their deficiencies and to the in-depth teaching of the subject. Accordingly, this study was conducted with pre-service teachers in face-to-face and online education.

The COVID-19 pandemic is a major challenge for education systems. Schools and higher education have faced challenges (Daniel, 2020). All schools, colleges, and universities were closed. However, because new cases decreased while some courses were conducted remotely in the universities, some were continued in face-to-face education. Thus, this research investigates the effects of modeling integrated with AR applications on pre-service teachers' achievements according to face-to-face and online education. In line with this scope, answers to the following questions were sought in the study.

The research questions (RQs) were as follows: Regarding the online and face-to-face education methods,
RQ1. Is there a significant difference between the pre-test and post-tests of academic achievements of face-to-face groups using AR applications integrated with modeling?
RQ2. Is there a significant difference between the pre-test and post-tests of academic achievements of online groups using AR applications integrated with modeling?
RQ3. Is there a significant difference between the academic achievement of face-to-face and online groups using AR applications integrated with modeling?
RQ4. Is there a significant difference between the modeling skills of face-to-face and online groups using AR applications integrated with modeling?
RQ5. Pre-service teachers: what are their views about AR applications integrated with modeling?

2. METHOD

In this study, the simultaneous nesting technique was used. The simultaneous nesting technique is a mixed-method design in which qualitative and quantitative data are collected and analyzed (Creswell & Clark, 2015). In nested mixed designs, researchers sometimes embed the qualitative part within the quantitative part to support the items of the experimental design. In the nested mixed method used in the research, the quantitative stage was carried out dominantly over the qualitative stage. Then, in this study, quantitative data were interpreted by supporting them with qualitative data. In the qualitative phase of this study, a case study and, in the quantitative phase, a pretest-posttest quasi-experimental were used. This study selected pre-service teachers in a face-to-face experimental group (FEG) and an online experimental group (OEG) from two different classes. In each group, weak interactions with interparticles were taught. Courses were conducted using AR application integrated with modeling in FEG and OEG. To evaluate the achievements of pre-service teachers, (WIIAAT) Weak Interactions Interparticles Academic Achievement Test," which Cronbach Alpha is 0.803, and diary forms were applied to them. The research model is shown in Figure 2.

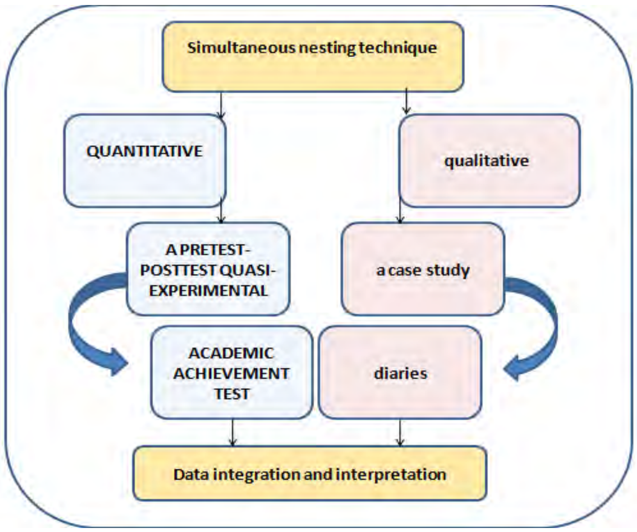


Figure 2 The research model for each group

2.1 Participants

The study was conducted with fifty-six-year pre-service teachers, thirty in the online group and twenty-six in the face-to-face group, who took chemistry lessons at a state university in Turkey. The demographic characteristics of the students are given in Table 1. The groups had never seen or used AR apps and modeling before. The pre-service teachers were randomly selected into experimental groups. That is, experimental groups were assigned according to simple probability sampling. Simple probability sampling is a method in which selected units are sampled by giving each unit an equal probability of being selected (Patton, 2014).

Table 1 Demographic characteristics of the sample.

Groups	Female	Male	Total
Face-to-face Experimental Group (FEG)	24	2	26
Online Experimental Group (OEG)	28	2	30
Total	52	4	56

2.2 Design of AR-Based Learning Materials

Weak interparticle interactions have a three-dimensional nature as a microscopic dimension, which we try to demonstrate with models. In addition, the concepts are abstract and challenging to learn and associate with daily life. For this reason, this subject should be concretized and enriched in three dimensions by AR. AR applications are designed and developed by an expert in computer software. These materials consist of five kinds of interactive activities. The prepared activities have been developed by considering the bond thicknesses from the moment the compounds or ions start to interact, as well as the color, shape, and electronegativity of the elements of the compounds. When two compounds or elemental molecules are brought close to each other, a white line is formed, as in Figure 3. Normally, lines do not form any bonds when the targets are far from each other, and molecular shapes do not change. In addition, when the compounds get closer, as it is thought to attract the negative side to the positive side, the shapes of the molecules change, as shown by the AR app.

The AR applications used in the implementation are given in Figure 3.

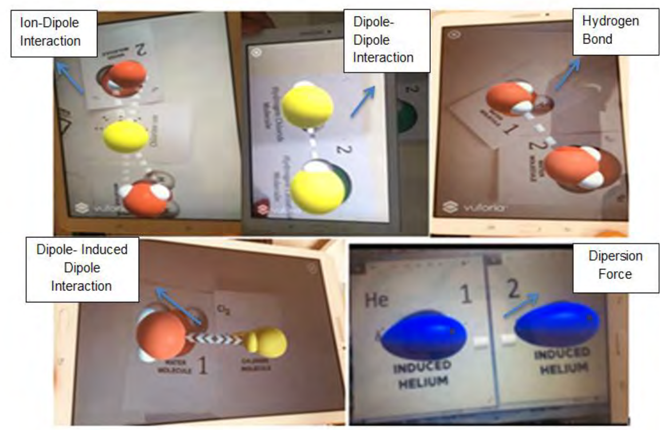


Figure 3 Representation of example of weak interparticle interactions in augmented reality application

2.3 Design of Modeling Activities

Based on the scientific modeling processes of Halloun (2004), Hestenes (2006), Justi & Gilbert (2002), and Ünal-Çoban, (2009), a synthesis modeling process suitable for this study has been put forward as in Figure 4. Modeling stages were created in three-dimensional representation and detailing weak interparticle interactions. Modeling steps are shown in Figure 4.

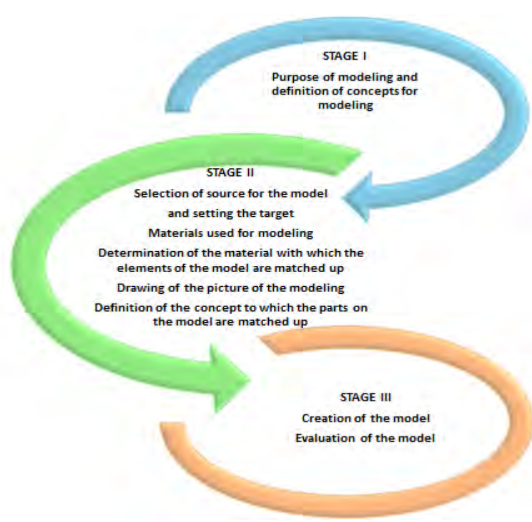


Figure 4 Modeling stages

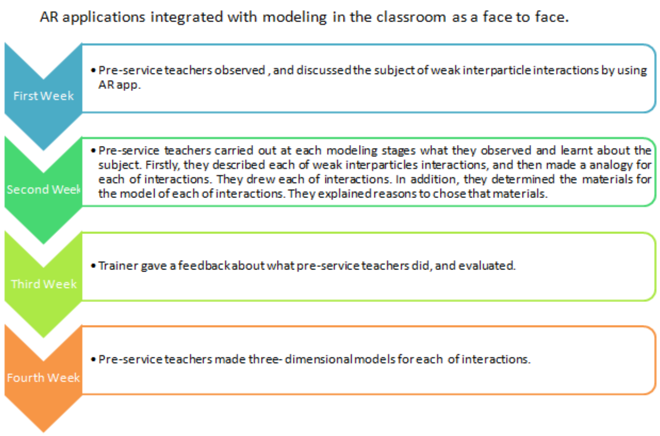


Figure 5 Implementation process in face-to-face experimental group, face-to-face

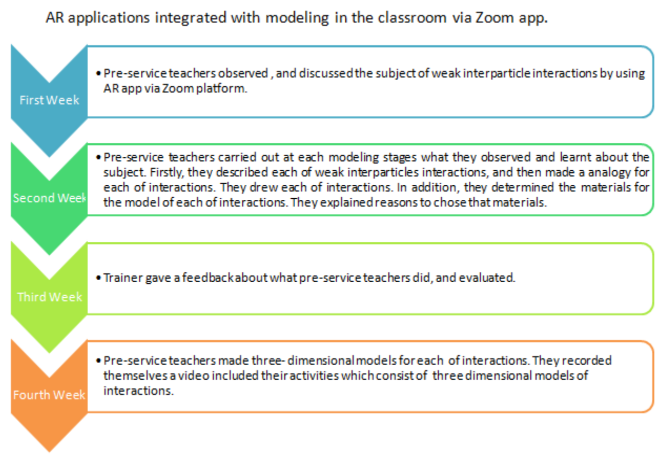


Figure 6 Implementation process in online experimental group, online

2.4 Main Implementation Procedure

The subject was taught to the experimental groups via AR integrated with modeling stages (F igure 4) for four weeks. Before and after the implementation, scales were applied to the OEG and FEG groups. At the end of the lesson, pre-service teachers wrote diaries. The procedure followed during the implementation phase and associated visuals can be found in Fig. 5, Fig. 6, Fig. 7, Fig. 8.

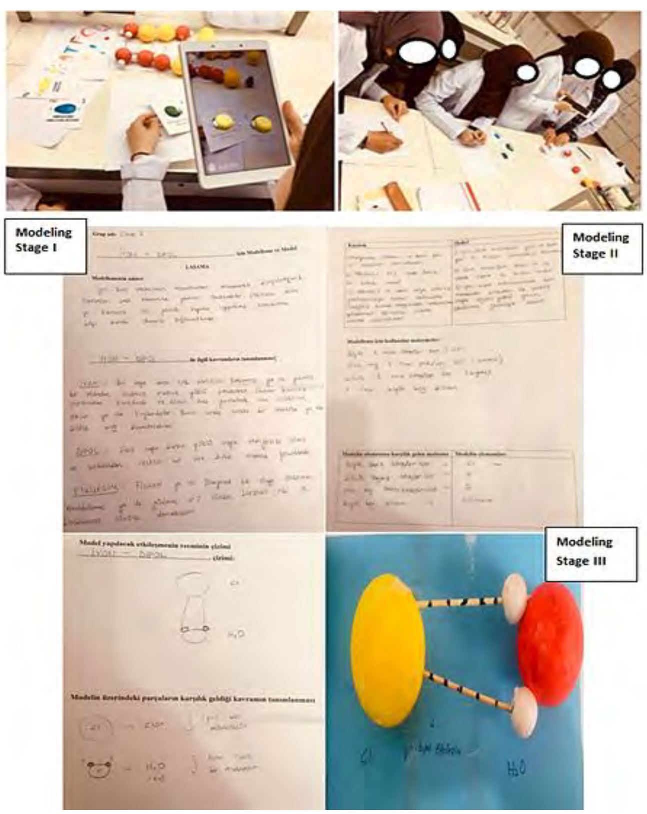


Figure 7 An example of a model made by pre-service teachers in face-to-face group

2.5 Implementation process in the face-to-face experimental group

Before implementation, the researcher conducted academic achievement. Tests The pre-service teacher used the tablet to observe the AR app, which was downloaded and settled by the researcher. All pre-service teachers examined each bond by AR using a tablet. Then, they discussed how molecules make bonds and which molecules can bond together. Pre-service teachers wrote down each

Figure 8 An example of a model made by prospective teachers in online group

bond in the second week of the modeling process. They described bonds, made an analogy, drew each bond, and decided on the material for making a model for each bond.

Also, they discussed which part of the material they will use is similar to molecules and bonds. In the third week, the researcher examined the modeling process, which pre-service teachers did, and gave them feedback about deficiencies in their work. In the fourth week, pre-service teachers made a model for each bond, one of the bonds shown in Figure 7. At the end of the implementation, an academic achievement test was administered to pre-service teachers, and the researcher evaluated the modeling process and models that pre-service teachers used using a rubric.

2.6 Implementation process in the online experimental group

The pre-service teacher used their phone to observe bonds by AR. Before the lesson, the researcher sent the AR app and downloaded and settled by pre-service teachers. All pre-service teachers examined each bond by AR using their phones during Zoom lessons. Then, they discussed how molecules make bonds and which molecules can make bonds together. In the second week, pre-service teachers used Google Forms to explain each bond on the modeling process in the online environment. They described bonds, made an analogy, drew each bond, and decided on the material for making a model for each bond. Also, they discussed which part of the material they will use is similar to molecules and bonds. In the third week, the researcher examined the modeling process, which pre-service teachers did, and gave them feedback about deficiencies in their work. For the fourth week, pre-service teachers made a model for each bond, recorded videos, and shared one of the bonds shown in Figure 8 with the researcher. At the end of the implementation, an academic achievement test was administered to pre-service teachers, and the researcher evaluated the modeling process and models that pre-service teachers used using a rubric.

3. RESULT AND DISCUSSION

This research collected pre-service teachers' modeling skills, achievements, and opinions of the course process. As a result of the academic achievement test applied to the pre-service teachers, their pre-test scores were compared using an independent sample t-test. This analysis included FEG (Mean (M)= 47.69, Std. Deviation (SD) = 10.60), OEG (M=52.66, SD= 8.87) showed that there was no significant difference in mean values for t (-1.886) = .065, p>0.05. Detailed information about the modeling skills and academic achievements of the pre-service teachers in the FEG and OEG groups and their post-scores are given in Tables 2, 3, and 4. When the descriptive statistics of the data obtained from the post-test of WIIAAT are investigated in Table 4, the mean scores of the pre-service teachers in FEG (*M* = 68.07*, SD* = 11.49); OEG (*M* = 89.80*, SD* = 7.71) it can be said that the highest mean is OEG. In addition, pre-service teachers' modeling skills are FEG (*M* = 18.07*, SD* = 1.41); and OEG (*M* = 16.46*, SD*=1.33), which means FEG has the highest mean.

3.1 Is there a significant difference between the academic achievements of face-to-face groups using AR applications integrated with the modeling?

The results are presented in Table 2. As shown in Table 2, there was a significant difference between pre-posttest academic achievement scores of pre-service teachers *(t (10.60-11.49)* = -6.550*, p <.05).*

3.2 Is there a significant difference between the academic achievements of the online group and whether they learned via AR applications?

The results of the data indicated a significant difference in the group. As demonstrated in Table 3, there was a significant difference between the pre-posttest of pre-service teachers' academic achievements (*t (8.87-7.71*) = -16.847, p<0.05).

3.3 Is there a significant difference between the academic achievement of face-to-face and online groups using AR applications integrated with modeling?

To answer this question, an independent sample t-test was used to compare the differences in post-test scores between the groups. As shown in Table 4, the results of the data indicated that the post-test scores of pre-service science teachers in the OEG were significantly higher than in the FEG group *(t (11.49-7.71*) = -8.460, p<.05).

Table 2 Dependent sample pre-post test analysis of the differences between the achievements of the face-to-face experimental groups

Groups	Test	N	M	Sd	t	p
Face-to-face Experimental Group (FEG)	Pre-test	26	47.69	10.60	-6.550	.000*
	Post-test	26	68.07	11.49		

*p< 0.05

Table 3 Dependent sample pre-post test analysis of the differences between the achievements of the online experimental groups

Groups	Test	N	M	Sd	t	p
Online Experimental Group (OEG)	Pre-test	30	52.66	8.87	-16.847	.000
	Post-test	30	89.83	7.71		

*p< 0.05

Table 4 Independent sample post-test analysis of the differences between the achievements and modeling skills of the face-to-face and online experimental groups

	Groups	N	M	Sd	t	p
Academic Achievement Post-Test	Face-to-face Experimental Group (FEG)	26	68.07	11.49	-8.460	.000
	Online Experimental Group (OEG)	30	89.80	7.71		
Modeling Skills	Face-to-face Experimental Group (FEG)	26	18.07	1.41	-2.716	.009
	Online Experimental Group (OEG)	30	16.46	1.33		

*p< 0.05

3.4 Is there a significant difference between the modeling skills of face-to-face and online groups using AR applications integrated with modeling?

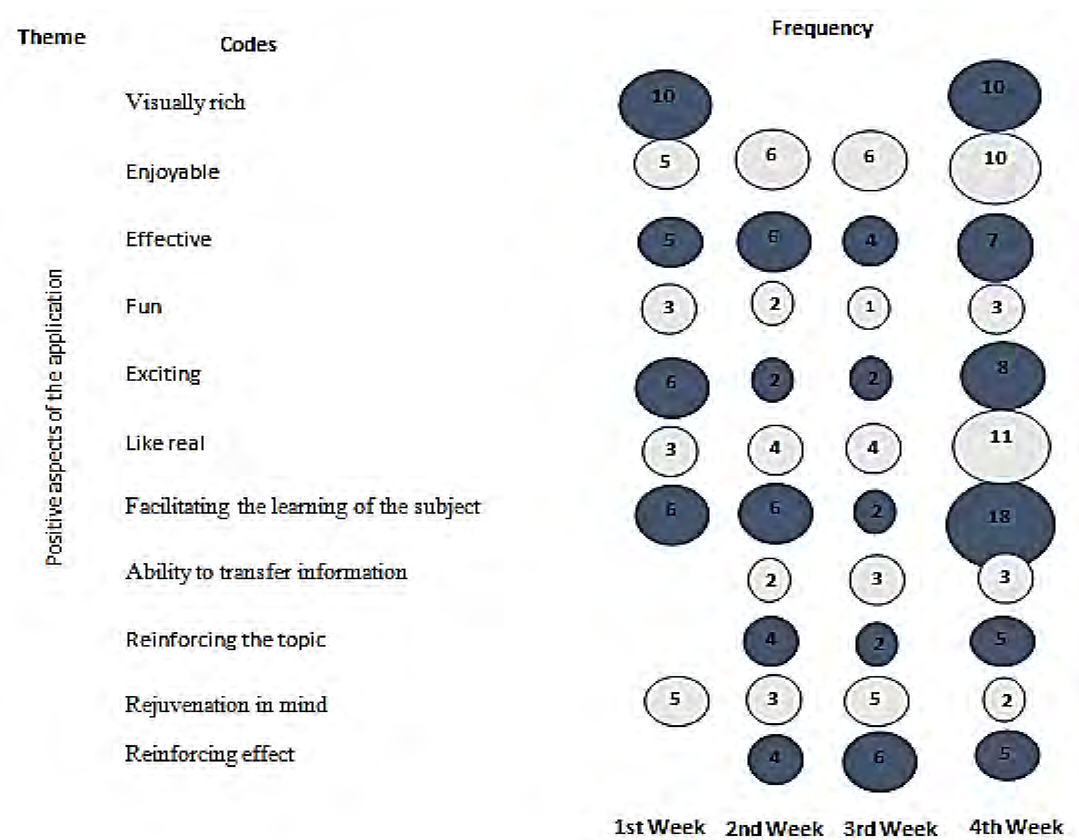
According to Table 4, there was a significant difference in scores between the groups' modeling skills which learning topics in face-to-face and online education *(t (1.41-1.33)* = -2.716*, p <.05)*. Results of data demonstrated that a significant difference was found between FEG and OEG. And FEG's modeling skills were significantly higher than in the OEG group.

3.5 Pre-service teachers: what are their views about AR applications integrated with modeling face-to-face and online?

To answer this question, diaries were conducted with twenty-six pre-service teachers using AR integrated with modeling to determine their opinions about implementation processes.

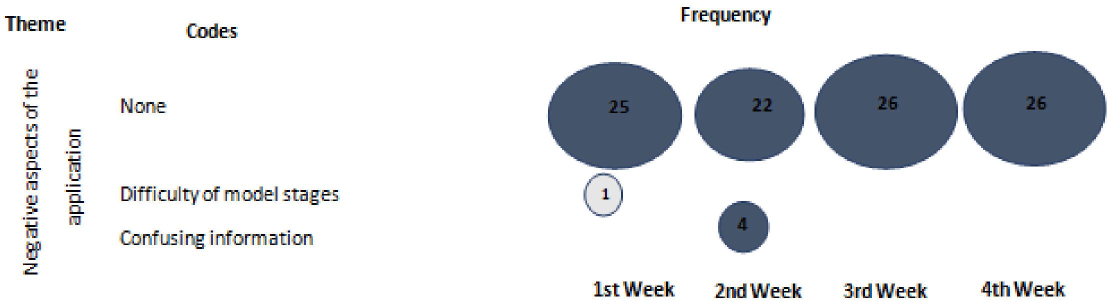
The pre-service teachers reported positive opinions about AR integrated with modeling , and their answers were grouped under three categories (Figure 9). The first category was headed as the "positive opinions about AR with integrated modeling" by including positive cognitive and affective effects on pre-service teachers (the codes: fun, enjoyable, exciting, compelling, visually rich, like real, rejuvenation in mind, reinforcing effect, ability to transfer information, facilitating the learning of the subject). Some examples of the pre-service teachers' opinions related to the positive opinions of AR application are as follows:

"I have learned subject easier, the shapes three-dimensional with the tablet by using AR, and it allowed us to focus more on the subject and understand it better." (PST9)



*One pre-service teacher gave more than one opinion

Figure 9 Daily results of pre-service Teachers about positive aspects of the AR and modeling method in face-to-face



*One pre-service teacher gave more than one opinion
Figure 10 Daily results of pre-service teachers about negative aspects of the AR and modeling method in face-to-face

"In my opinion, the chemistry course should now be strictly used by AR and 3D materials. Hence, this makes it much more fun." (PST11)

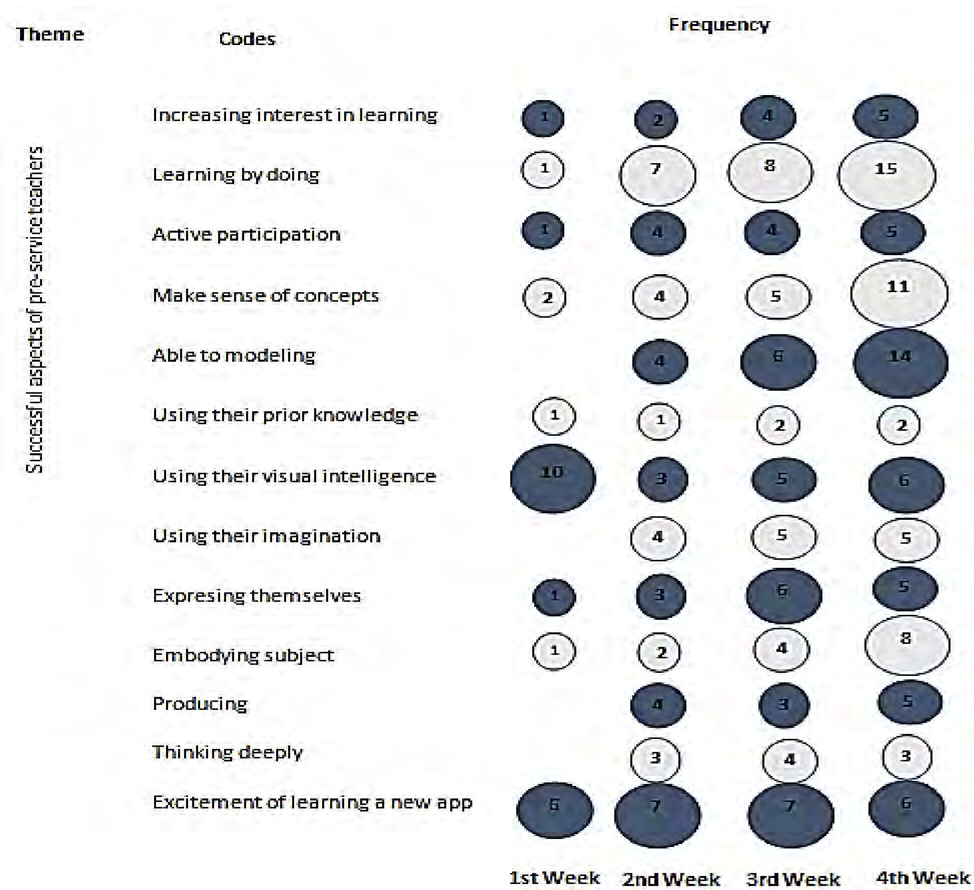
Figure 10 shows daily results of pre-service teachers about negative aspects of the AR and modeling method in face-to-face. The second category had some negative opinions about the experimental process. Accordingly, this category was titled "negative opinions about AR" by including difficulty in modeling stages and confusing previous information with new information. However, pre-service teachers pointed out that the process had no negative aspects over time. The examples of their comments with opposing opinions are as follows:

"I don't think it has any negative aspects." (PST13)

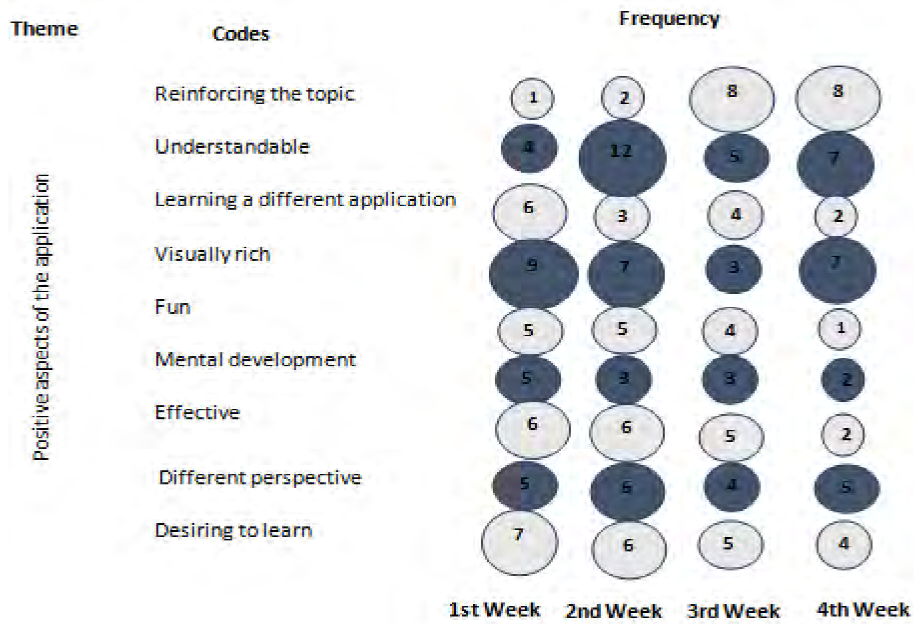
"In my opinion, there is no negative aspect of teaching lessons in this way. On the contrary, it provides permanent learning." (PST5)

Figure 11 shows daily results of pre-service teachers about successful aspects of the AR and modeling method in face-to-face

"It feels powerful because it's visually rich." (PST7)



*One pre-service teacher gave more than one opinion
Figure 11 Daily results of pre-service teachers about successful aspects of the AR and modeling method in face-to-face



*One pre-service teacher gave more than one opinion

Figure 12 Daily results of pre-service teachers about positive aspects of the AR and modeling method in online

"It provides permanent learning and enables teacher candidates to learn by seeing it personally." (PST5)

The final category of the group which used AR is related to their successful aspects. It was titled "The Successful Aspects of Pre-service Teachers". It included the codes: increasing interest in learning, learning by doing, active participation, making sense of concepts, being able to model, using their prior knowledge, using their visual intelligence, using their imagination, expressing themselves, embodying subject, producing, th inking deeply, excitement of learning a new app. Over time, they stated that their successful aspects increased during the experimental process.

Figure 12 depicts daily results of pre-service teachers about positive aspects of the AR and modeling method in online. On the other hand, the pre-service teachers also had a majority of positive opinions about the AR integrated with modeling that uses online education, and their answers were labeled under four categories. The first category was titled "Positive opinions about the AR integrated with modeling" by including positive cognitive and affective effects on pre-service teachers usefully (the codes: reinforcing the topic, understandable, visually rich, fun, mental development, effective, different perspective, desiring to learn, learning different app). Some examples of the pre-service teachers' opinions related to the positive opinions of the AR integrated with modeling are as follows:

"I realized that I understood better observing kinds of interactions by AR and conducting modeling stages. And I think I understand better with the examples given." (PST 13)

"It made the lesson more fun carrying modeling stages with AR out." (PST19)

Figure 13 shows daily results of pre-service teachers about negative aspects of the AR and modeling method in online. Another category was grouped with the opinions of some opposing opinions about the experimental process.

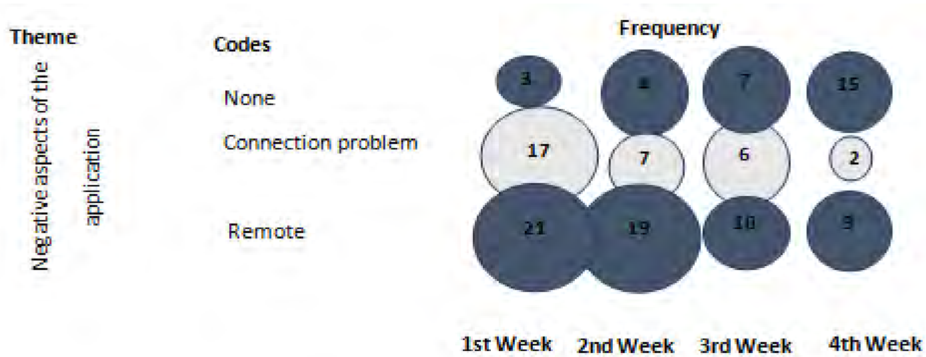


Figure 13 Daily results of pre-service teachers about negative aspects of the AR and modeling method in online

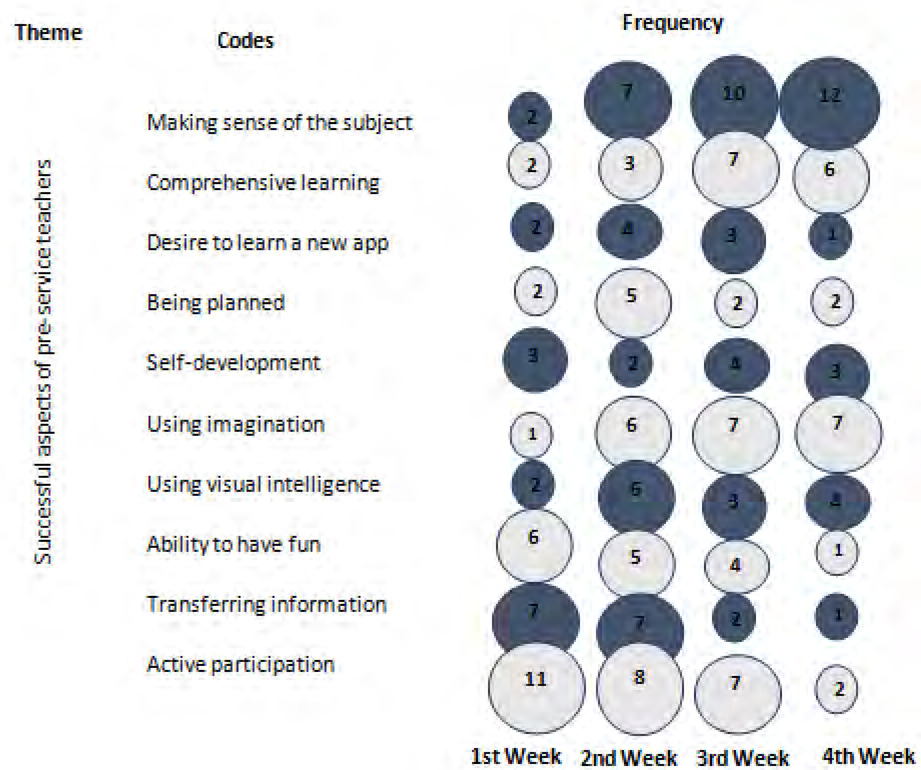


Figure 14 Daily results of pre-service teachers about successful aspects of the AR and modeling method in online
*One pre-service teacher gave more than one opinion

That category had negative opinions of the AR. It included the codes: boring, disagreements in-group, encountering a new method, and having difficulties. The examples of their comments about the negative nature of the experimental process are as follows:

"It is difficult to have courses online like this." (PST3)

"Our work would be better if it was face to face." (PST23)

"I don't think it's a downside, but I think it would be better face-to-face rather than online." (PST16)

Figure 14 shows daily results of pre-service teachers about successful aspects of the AR and modeling method in online. In the last category, pre-service teachers had written about their successful aspects during the experimental process in diaries. In addition, they generally stated that they used many skills by using the AR integrated with modeling. According to their diaries, the fourth category was titled "successful aspects of them, including the codes that have to make sense of the subject, comprehensive learning, being planned, using imagination, visual intelligence, ability to have fun, transferring information, and active participation. The examples of their aspects of pre-service teachers are as follows:

"Through the app, I tried to participate actively in the lesson, so I feel strong." (PST11)

"I realized that I could use my imagination during the modeling phases." (PST17)

AR may have enabled pre-service teachers to learn concepts meaningfully by presenting three-dimensional shapes of models. Moreover, they elaborated interaction descriptions, drew models, and created analogies about interactions during the modeling stages. Thus, AR positively affected the subject, such as affecting the three-dimensional meaning of the weak interaction, active participation, transfer of information, and learning to model. These reasons may also contribute to pre-service teachers' achievements in face-to-face education form. In face-to-face education, it was revealed that AR applications contributed to pre-service teachers' achievements. This finding is similar to the results of some studies in face-to-face education that studied science education assisted with AR application that indicated AR application increased the achievements of students and their learnings (Abdusselam & Karal, 2020; Al Shuaili, Al Musawi & Hussain, 2020; Badilla-Quintana, Sepulveda-Valenzuela & Arias, 2020; Fidan & Tuncel, 2019; Hwang, Wu, Chen & Tu, 2016; Ibanez, Portillo, Cabada & Barron, 2020; Kececi, Yildirim, & Zengin, 2021; Petrov & Atanasova, 2020; Sahin & Yilmaz, 2020; Saidin, Halim & Yahaya, 2019; Wahyu, Suastra, Sadia & Suarni, 2020). Contrary to this, Yousef's (2021) findings demonstrated that AR application does not affect students' success.

The other result was that AR applications in face-to-face education positively affected pre-service teachers' modeling skills more than online education. It can be argued that during observing in AR, the subject developed their modeling skills when pre-service teachers could visualize the invisible subject in their minds, associate it with daily life, and model it through their chosen materials. In addition, the fact that they had strengths that allowed them to use their imagination and prior knowledge, think deeply, produce, express themselves, and, most importantly, learn by doing and living may also have contributed to better modeling skills. It can be said that this situation contributes to the source-target part of the modeling stages to make an analogy. These results of using the modeling method are detected in the relevant literature as developing students' modeling skills (Abualia et al., 2016; Bierema, Schwarz & Stoltzfus, 2017; Cooper, Williams & Underwood, 2015; Dauer, Momsen, Speth, Makohon-Moore & Long, 2013; Schmidt, Kaufmann & Treagust, 2009).

Moreover, there are several reasons why the online experimental group has lower modeling skills scores than the face-to-face group. When the diaries written by pre-service teachers who conducted the process in online education form were examined, taking lessons remotely and the connection problems and inability to communicate face to face may have affected their skills. Other reasons are changes in teaching methods and the anxiety of not being able to complete the online activities. The participants also state that many students do not care much about online courses (Aslan, Turgut & Aslan, 2021). At the same time, during the pandemic, the internal motivation of university students is lower than their external motivation (Tekin, 2020).

In addition, interviewees who used the AR application integrated with modeling in face-to-face education had more positive views and welcomed this technology in the learning and teaching process. This finding is consistent with the results from similar studies by Putiorn, Nobnop, Buathong & Soponronnarit (2018), Seyhan & Kucuk (2021), and Uygur, Yelken & Cenk (2018), in which the opinions of pre-service teachers on AR applications were determined. They pointed out that AR can be remarkable, visually rich, fun, intriguing, exciting, and realistic, showing three-dimensional shapes and helping concretize. Over time, pre-service teachers' views about the negative aspects of the process decreased (Figure 12).

4. CONCLUSION

The current study aimed to identify the effect of AR application integrated with modeling on pre-service science teachers' academic achievements and modeling skills according to face-to-face and online education and determine their views towards the implementation process.

Based on the findings of this study related to academic achievement,

- As the result of the first question, in face-to-face education, it was concluded that the AR integrated with the modeling affected pre-service science teachers' academic achievement ($p=.000$, $p<0.05$).
- Based on the results of the third question, the online education form is more successful than face-to-face education ($p=.000$, $p<0.05$).
- According to the second question, in online education, it was addressed that the AR integrated with the modeling improved pre-service science teachers' academic achievement when post-test scores compared to pre-test scores ($p=.000$, $p<0.05$).
- The result of the fourth question shows that the face-to-face group's modeling skills were higher than the online group's ($p=.009$, $p<0.05$).

When the diaries written by the pre-service teachers who conducted the process in online education form were evaluated (Figure 14), they expressed that AR has enabled reinforcing their knowledge about interactions and made the topic understandable because of having visually rich property. This could contribute to their achievements. Another reason could be the nature of online education forms. It can be said that due to its nature, in online education, there is a greater limit to learning subjects in terms of time and space constraints compared to face-to-face education during class. The online education form can hurt student engagement due to a lack of interaction with instructors and other students, technical problems, and problems with students' time management skills and teaching materials (Kostaki & Karayianni, 2021).

Moreover, online education can also present some difficulties that hinder learning, partly connection problems and slow computer running. Therefore, students provide limited knowledge. In particular, this limited information may be sufficient for some tests. The online environment affects reading comprehension and standardized tests, which require lower attention spans (Gillick & Magoulias, 2020). For this reason, it can be said that the transfer of limited information is sufficient in answering the multiple-choice tests used by pre-service teachers to compare academic achievements online. In other words, multiple-choice tests are not considered valid in assessing many skills needed in the digital age (Bates, 2015). Primarily, it was revealed that the pre-service teachers' academic achievements measured by multiple-choice tests in the online group were higher than those in the face-to-face group. At the same time, their scores were lower from tools that included open-ended tests and in-depth information measurement. Since, in the form of face-to-face education, pre-service teachers can ask more questions. As a result, pre-service teachers can enable them to think more deeply about subjects and enhance their knowledge. Pre-service teachers' detailed thinking about subjects and concepts may lead to poor performance in answering multiple-choice tests (Sitzmann, Ely, Bell & Bauer, 2010). When pre-service teachers think about subjects and concepts in detail, their performance in answering multiple-choice tests may be poor. Thus, pre-service teachers transferred their information about weak interaction when they conducted modeling better.

In conclusion, it showed that AR has the potential to make the learning process more active, effective, and meaningful when pre-service teachers learn interactions using AR applications.

4.1 Limitations and Future Directions

This study has many limitations; first, the learning content was designed for only pre-service science teachers, and the learning contents of the "Weak Interactions Interparticle" unit as a chemistry subject. Hence, the generalizability of the study's findings can be problematic compared to other samples. In the current study, we focused only on pre-service teachers' modeling skills achievements in chemistry. Thus, AR with modeling may be applied to other chemistry or science subjects (atomic models, meiosis mitosis, etc.). It would also be helpful to examine their cognitive and emotional features (e.g., spatial ability, high-order thinking skills, attitude). The second was that the AR application integrated with modeling in a chemistry topic with a low chance of examining directly in daily life needs visualization and facilitation. Through its potential (e.g., embodying abstract objects on the screen), AR allows users to think deeply to observe the objects in more detail. Moreover, it can investigate other learning approaches (e.g., game-based, inquiry-based), which can be integrated with AR like the modeling method. Furthermore, a comparative experimental study can be conducted to determine which approach will be more effective in learning when integrated with AR.

REFERENCES

Abdusselam, M. S.,& Karal, H. (2020). The effect of using augmented reality and sensing technology to teach magnetism in high school physics. *Technology, Pedagogy and Education*, *29*(4), 407-424.

Abualia, M., Schroeder, L., Garcia, M., Daubenmire, P. L., Wink, D. J., & Clark, G. A. (2016). Connecting protein structure to intermolecular interactions: A computer modeling laboratory. *Journal of Chemical Education*, *93*(8), 1353-1363.

Adbo, K.,& Taber, K. S. (2009). Learners' mental models of the particle nature of matter: A study of 16-year-old Swedish science students. *International Journal of Science Education*, *31*(6), 757-786.

Akcayir, M., Akcayir, G., Pektas, H. M., & Ocak, M. A. (2016). Augmented reality in science laboratories: the effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior*, 57 (Supplement C), 334−342.

Al Shuaili, K., Al Musawi, A. S., & Hussain, R. M. (2020). The effectiveness of using augmented reality in teaching geography curriculum on the achievement and attitudes of Omani 10th Grade Students. *Multidisciplinary Journal for Education, Social and Technological Sciences*, *7*(2), 20-29.

Aslan, S. A., Turgut, Y. E., & Aslan, A. (2021). Teachers' views related the middle school curriculum for distance education during the COVID-19 pandemic. *Education and Information Technologies*, *26*(6), 7381-7405.

Atasoy, B. (2018). *General chemistry*. (1st edition). Ankara: Palme Publishing-Akademic Publications.

Badilla-Quintana, M. G., Sepulveda-Valenzuela, E., & Arias, M. S. (2020). Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs. *Sustainability*, *12*(19), 1-20.

Bates, A. W. (2015). *Teaching in a digital age: Guidelines for designing teaching and learning*. BCcampus.

Bierema, A. M., Schwarz, C. V, & Stoltzfus, J. R. (2017). Engaging undergraduate biology students in scientific modeling : analysis of group interactions, sense-making, and justification. *Life Sciences Education*, 16(68) 1–16. https://doi.org/10.1187/cbe.17-01- 0023.

Bilgin, I.,& Geban, O. (2006). The effect of cooperative learning approach based on conceptual change condition on students' understanding of chemical equilibrium concepts. *Journal of Science Education and Technology*, *15*(1), 31-46.

Bujak, K. R., Radu, I., Catrambone, R., Macintyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education*, 68, 536-544.

Burkholder, P. R., Purser, G. H., & Cole, R. S. (2008). Using molecular dynamics simulation to reinforce student understanding of intermolecular forces. *Journal of Chemical Education*, *85*(8), 1071.

Cai, S., Wang, X., & Chiang, F. K. (2014). A case study of augmented reality simulation system application in a chemistry course. *Computers in Human Behavior*, 37, 31-40.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *Multimedia Tools and Applications*, *51*(1), 341-377.

Celik, A. Y. (2019). Pre-service biology and chemistry teachers' experience of augmented reality materials. *Karaelmas Journal of Educational Sciences*, *7*(1), 123-132.

Cooper, M. M., Williams, L. C., & Underwood, S. M. (2015). Student understanding of intermolecular forces: A multimodal study. *Journal of Chemical Education*, *92*(8), 1288-1298.

Creswell, J.,& Clark, V. L. P. (2015). *Mixed methods studies* (Y. Dede, S. B. Demir, trans. ed.). Ankara: Ani.

Daniel, S. J. (2020). Education and the COVID-19 pandemic. *Prospects*, *49*(1), 91-96.

Dauer, J. T., Momsen, J. L., Speth, E. B., Makohon-Moore, S. C., & Long, T. M. (2013). Analyzing change in students' gene-to-evolution models in college-level ıntroductory biology. *Journal of Research In Science Teaching,* 50(6), 639–659. https://doi.org/10.1002/tea.21094.

Doymuş, K., Şimşek, Ü., & Karaçöp, A. (2007). Genel kimya laboratuarı dersinde öğrencilerin akademik başarısına, laboratuar malzemelerini tanıma ve kullanmasına işbirlikli ve geleneksel öğrenme yönteminin etkisi [The effect of cooperative and traditional learning methods on students' academic success, recognition and use of laboratory materials in the general chemistry laboratory course]. *Eurasian Journal of Educational Research (EJER)*, (28).

Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., García, S., & Barcia, J. M. (2015). ARBOOK: Development and assessment of a tool based on augmented reality for anatomy. *Journal of Science Education and Technology*, *24*(1), 119-124.

Fidan, M.,& Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, *142*, 103635.

Fuchsova, M., & Korenova, L. (2019). Visualisation in basic science and engineering education of future primary school teachers in human biology education using augmented reality. *European Journal of Contemporary Education*, *8*(1), 92-102.

Gillick, M.,& Magoulias, C. (2020). Competing Against Outside Distractions in Online Classrooms for Grade-School Students. *Research Gate. DOI*, *10*.

Halloun, I. (2004). Modeling theory for paradigmatic evolution. In *Proceedings of the 12th annual meeting of the Southern African Association for Research in Mathematics, Science and Technology Education*.

Hestenes, D. (2006). Notes for a modeling theory. In *Proceedings of the 2006 GIREP conference: Modeling in physics and physics education* (Vol. 31, p. 27). Amsterdam: University of Amsterdam.

Hoft, L., Bernholt, S., Blankenburg, J. S., & Winberg, M. (2019). Knowing more about things you care less about: Cross-sectional analysis of the opposing trend and interplay between conceptual understanding and interest in secondary school chemistry. *Journal of Research in Science Teaching*, *56*(2), 184-210.

Hwang, G. J., Wu, P. H., Chen, C. C., & Tu, N. T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments*, *24*(8), 1895-1906.

Ibanez, M. B., Portillo, A. U., Cabada, R. Z., & Barron, M. L. (2020). Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course. *Computers & Education*, *145*, 103734.

Justi, R., & Gilbert, J. K. (2001, March). Teachers' views about models and modelling in science education. In *Annual Meeting of the National Association of Research in Science Teaching, St. Louis, MI.*.

Justi, R.,& Gilbert, J. (2002). Models and modelling in chemical education. J. Gilbert O. De Jong, R. Justi, D. Treagust & J. Van Dariel (Eds.) *Chemical education: Towards research-based practice* (pp. 47-68). Springer, Dordrecht).

Kececi, G., Yildirim, P., & Zengin, F. K. (2021). Determining the effect of science teaching using mobile augmented reality application on the secondary school students' attitudes of toward science and technology and academic achievement. *Science Education International*, *32*(2), 137-148.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": exploring the potential of augmented reality for teaching primary school science. *Virtual Reality*, *10*(3-4), 163-174. doi:10.1007/s10055-006-0036-4.

Kostaki, D., & Karayianni, I. (2022). Houston, we have a pandemic: Technical difficulties, distractions and online student engagement. *Student Engagement in Higher Education Journal*, *4*(2), 105-127.

Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education*, *10*(1), e3325.

Nichele, A. G., Do Canto, L. Z., & Da Silva, F. N. (2020). Augmented reality: Apps for teaching and learning chemistry. In *INTED2020 Proceedings* (pp. 7650-7655). IATED. https://library.iated.org/view/GRUNEWALDNICHELE2020CON

Opateye, J.,& Ewim, D. R. E. (2021). Assessment for Learning and Feedback in Chemistry: A Case for Employing Information and Communication Technology Tools. *International Journal on Research in STEM Education*, *3*(2), 18-27.

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage Publications.

Petrov, P. D.,& Atanasova, T. V. (2020). The effect of augmented reality on students' learning performance in stem education. *Information*, *11*(4), 209.

Putiorn, P., Nobnop, R., Buathong, P., & Soponronnarit, K. (2018, November). Understanding teachers' perception toward the use of an augmented reality-based application for astronomy learning in secondary schools in northern Thailand. In *2018 Global Wireless Summit (GWS)* (pp. 77-81). IEEE.

Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing*, *18*(6), 1533-1543.

Sahin, D.,& Yilmaz, R. M. (2020). The effect of augmented reality technology on middle school students' achievements and attitudes towards science education. *Computers & Education*, *144*, 103710.

Saidin, N. F., Halim, N. D. A., & Yahaya, N. (2019). Framework for developing a mobile augmented reality for learning chemical bonds. *International Journal of Interactive Mobile Technologies*, *13*(7).

Schmidt, H. J., Kaufmann, B., & Treagust, D. F. (2009). Students' understanding of boiling points and intermolecular forces. *Chemistry Education Research and Practice*, *10*(4), 265-272.

Seyhan, A.,& Kucuk, S. K. (2021 Social studies teachers' and prospective teachers' experiences on developing educational augmented reality aplications. *Journal of Higher Education and Science, 11*(1), 56-63.

Sitzmann, T., Ely, K., Bell, B. S., & Bauer, K. N. (2010). The effects of technical difficulties on learning and attrition during online training. *Journal of Experimental Psychology: Applied*, 16(3), 281–292. https://doiorg.acg.idm.oclc.org/10.1037/a0019968

Taber, K. S. (2002). Compounding quanta: probing the frontiers of student understanding of molecular orbitals. *Chemistry Education Research and Practice*, *3*(2), 159-173.

Tekin, E. (2020). COVID-19 The effect of COVID-19 anxiety on motivation: an ınvestigation on generation Z. *Electronic Turkish Studies*, *15*(4).

Treagust, D. F. , Chittleborough, G.,& Mamiala, T. L. (2002). Students' understanding of the role scientific models in learning science. *International Journal of Science Education*, 24(4), 357-368.

Uluyol, C.,& Eryilmaz, S. (2014). Examining pre-service teachers' opinions regarding to augmented reality learning. *Journal of Gazi Education Faculty, 34*(3), 403-413.

Ünal-Çoban, G. (2009). (2009). *The effects of model based science education on students? conceptual understanding, science process skills, understanding of scientific knowledge and its domain of existence: The sample of 7th grade unit of light* (Thesis No. 231558) [Doctoral Dissetation, Dokuz Eylul University, Izmir]. National Thesis Center of the Council of Higher Education.

Uygur, M., Yelken, T. Y., & Cenk, A. (2018). Analyzing the views of pre-service teachers on the use of augmented reality applications in education. *European Journal of Educational Research*, *7*(4), 849-860.

Van Driel, J. H.,& Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modelling in science education. *International Journal of Science Education*, *24*(12), 1255-1272.

Wahyu, Y., Suastra, I. W., Sadia, I. W., & Suarni, N. K. (2020). The effectiveness of mobile augmented reality assisted stem-based learning on scientific literacy and students' achievement. *International Journal of Instruction*, *13*(3), 343-356.

Yang, E. M., Andre, T., Greenbowe, T. J., & Tibell, L. (2003). Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education*, *25*(3), 329-349.

Yang, S., Mei, B., & Yue, X. (2018). Mobile augmented reality assisted chemical education: insights from elements 4D. *Journal of Chemical Education,* 95, 1060−1062.

Yayla, R. G., & Eyceyurt, G. (2011). Mental models of pre-service science teachers about basic concepts in chemistry. western *Anatolia Journal Of Educational Sciences, 285-294.*

Yildirim, T.,& Canpolat, N. (2017). Students' views about the effectiveness of peer instruction.*Journal of Bayburt Faculty of Education*, *12*(24), 515-526.

Yousef, A. M. F. (2021). Augmented reality assisted learning achievement, motivation, and creativity for children of low-grade in primary school. *Journal of Computer Assisted Learning, 37(4), 966-977.*

Appendix 1. Modeling skill evaluation rubric

Stages	Categories	Score
Decided in the modeling purpose	Sufficient	3
	Partially sufficient	2
	Insufficient	1
Selection of sources for the model	Sufficient	3
	Partially sufficient	2
	Insufficient	1
Material used for modeling	Sufficient	3
	Partially sufficient	2
	Insufficient	1
The target equivalent of the material used in the model	Sufficient	3
	Partially sufficient	2
	Insufficient	1
Drawing the model	Sufficient	3
	Partially sufficient	2
	Insufficient	1
Indicate which concept the drawings on the model are	Sufficient	3
	Partially sufficient	2
	Insufficient	1
Creating the model	Sufficient	3
	Partially sufficient	2
	Insufficient	1