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Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education

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ABSTRACT

This study investigates the effects of Problem Based Learning (PBL) assisted with Augmented Reality (AR) on learning achievement and attitude towards physics subjects as a part of science education. The sample of the study included 91 seventh graders from a province in the north of Turkey. A quasi-experimental design with two experimental groups and a control group was utilized. Based upon marker-based AR technologies, FenAR software was developed to support with PBL activities in the classroom. The experimental results indicated that integrating AR into PBL activities both increased students' learning achievement and promoted their positive attitudes towards physics subjects. This technology contributed to students' long-term retention of the concepts in the field of physics. In semi-structured interviews, the students emphasized that AR applications were more useful, realistic, and interesting for their learning; helped them to understand and analyse the problem scenarios. Apart from educational advantages, AR applications may lead to physical disorders among some of the students. It has been suggested that AR technology can be a potential and effective tool for activating students' positive emotions in PBL process. Moreover, implications on use of AR for physics education and recommendations for further studies are also discussed in the study.

1. Introduction

PBL is a student-centred learning model based on constructivist approach in education (Hendry, Frommer, & Walker, 1999; Savery, 2015). In PBL, students can work both individually and cooperatively within an inquiry process to solve the complex and ill-structured problems from real-life contexts (Barrows & Tamblyn, 1980). During the PBL process, instructors have a guiding role in facilitating the information configuration of students rather than transferring the information to them. Over the last half-century, educators have shown that PBL can be useful and effective to enhance cognitive and affective skills in learning (Dolmans, Loyens, Marcq, & Gijbels, 2016; Hmelo-Silver, 2012; Lu, Bridges, & Hmelo-Silver, 2014; Savery, 2006). With the rapid advancement of educational technologies, the researchers nowadays have become interested in integrating the emerging technologies into PBL to support learning (Beaumont, Savin-Baden, Conradi, & Poulton, 2014; Lajoie et al., 2014; Phungsuk, Viriyavejakul, & Ratanaolarn, 2017; Virtanen & Rasi, 2017).

As a matter of fact, integrating the PBL method with various technologies can support and faciliate learning in order to meaningfully construct the learners' real world problems (Donnelly, 2010; Jin & Bridges, 2014; Sadlo, 2014; Walker et al., 2011). Some researchers suggest that the technology-based PBL has a more significant effect on cognitive and affective skills in comparison with

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traditional or face to face PBL (Jin & Bridges, 2014; Ong-art & Jintavee, 2016; Phungsuk et al., 2017; Tomaz, Mamede, Filho, Roriz Filho, & van der Molen, 2015; Tosun & Taşkesenligil, 2011). As other educational disciplines, if science education is also deprived of the developments in instructional technologies or these technologies are not effectively included in learning environments, this can affect on the productivity of learning negatively. Doğru and Kıyıcı (2005, p. 7) noted that the use of technology in science education contributes to the presentation of hard-to-reach materials, the concretization of learning, the performance of an experiment more easily, and the organization of the learning environment according to the individual differences among students. The researchers have addressed to some challenges in relation to the instruction of sub-disciplines of science such as physics; abstract and complex subjects, expensive experimental materials, lack of equipments, unreachable objects, misconceptions (Argaw, Haile, Ayalew, & Kuma, 2017; Cai, Chiang, Yuchen-Sun, Lin, & Lee, 2017; Yoon, Anderson, Lin, & Elinich, 2017). The findings of study conducted on a large sample size in Turkey by Tuncel and Fidan (2018) have demonstrated that the early age students studying in middle and junior high schools have more difficulty in physics subjects such as force, movement, and pressure in science course.

AR is one of the immersive technologies which can be promising for reducing these challenges in physics education thanks to its potential (Cai et al., 2017; Cheng & Tsai, 2013). It is a technique that improves user's sensory perception of the real world by superimposing virtual elements dynamically onto physical environments (Klopfer & Squire, 2008). As highlighted in Horizon Report, the common point is the fact that AR is expected to find a widespread use in higher education in the medium term (Johnson et al., 2016). Similarly, the report published by Educause has predicted that the use of AR will be popular in K-12 and higher education (Pomerantz, 2018). AR has been widely used in education, as well as in various fields such as medicine, advertising, defense, military, and entertainment by evolving year by year. It has brought a new dimension to education and offers possibilities for learning experiences and teaching process by creating an interactive and immersive environment (Bujak et al., 2013; Dunleavy, Dede, & Mitchell, 2009). Thus, AR provides flexibility in learning by offering an interactive environment adaptable to the real-world environment (Barsom, Graafland, & Schijven, 2016). Unlike other instructional technologies, it offers students with an enjoyful, exciting, enthusiastic, and immersive learning environment. Some studies have synthesized the findings of previous studies and pointed out that AR applications have a positive effect on educational outcomes such as learning achievement, attitude, motivation, attention, and retention in learning process (Akçayır & Akçayır, 2017; Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014; Cheng & Tsai, 2013; Dunleavy et al., 2009; Ibanez & Kloos, 2018; Radu, 2014; Saltan & Arslan, 2017; Wu, Lee, Chang, & Liang, 2013). While AR has numerous potentials for learners and educators in educational settings, some researchers have reported that there are some challenges such as an excessive cognitive load in multiple and mixed tasks (Cheng & Tsai, 2013; Wu et al., 2013), discomfort and poor perception (Wolf, Grodzinsky, & Miller, 2016), difficult design and lack of usability (Akçayır & Akçayır, 2017), low sensibility in recognition of marker (Cheng & Tsai, 2013; Rabbi & Ullah, 2013), and GPS/Wi-fi errors (Akçayır & Akçayır, 2017; Wu et al., 2013). However, if well-designed, AR can strengthen real-world context awareness and faciliate learning (Dunleavy et al., 2009; Wu, Hwang, Yang, & Chen, 2017).

In recent years, the researchers have investigated the use of AR technology to support the various learning approaches in education such as collaborative (Ke & Hsu, 2015; Vassigh et al., 2014), game-based (Hwang, Wu, Chen, & Tu, 2016; Tobar-Munoz, Baldiris, & Fabregat, 2017), and inquiry-based learning (Chiang, Yang, & Hwang, 2014; Kyza & Georgiou, 2019). Despite the fact that there are studies that integrated the emerging technologies with PBL, such studies might still be needed to evaluate the effects of AR on learning with tangible evidence (Jacobson, 2015). Nevertheless, few studies have been published about AR to support PBL based on real-life problem contexts (Villaran, Ibanez, & Kloos, 2015) and therefore, there is no emprical study providing enough evidence at middle or junior high school in related literature, especially in the field of physics. Thus, physics which is one of the key disciplines for technological developments or engineering, has a substantial function in understanding the natural events in real life and expressing them mathematically with theoretical models and laws (MNE, 2018).

As mentioned above, physics as a learning field in science education includes abstract or complicated concepts and students encounter several challenges while learning physics subjects and solving physics problems. AR has drawn the attention of researchers with its use as an effective learning and teaching tool in this field (Akçayır, Akçayır, Pektaş, & Ocak, 2016; Cai et al., 2017; Cai, Wang, & Chiang, 2014; Ibanez, Di Serio, Villaran, & Kloos, 2014). It also provides an interactive and integrated learning environment to perform the physics experiments (Cai, Chiang, & Wang, 2013). Considering physics subjects, AR has been integrated into various learning-teaching approaches such as game-based learning (Cai, Chiang, Sun, Lin, & Lee, 2017; Enyedy, Danish, Delacruz, & Kumar, 2012) and simulation (Ibanez, De Castro, & Kloos, 2017; Wang, Duh, Li, Lin, & Tsai, 2014) in previous studies. Pellas, Fotaris, Kazanidis, and Wells (2018) reviewed the previous studies on the integration of AR with game-based learning. According to the results of their study, physics was one of the popular fields as a topic of research in primary and secondary education. These integrations can provide an opportunity to interpret of the impact of method and technology on learning with strong evidence related to physics education.

Based upon the extant literature overview, the present study can differ from these studies because of its addressing to the combination of AR with the PBL model in the learning of physics subjects. Cai et al. (2013) pointed out the necessity of an interactive and realistic learning environment which reflects the daily or natural events for physics education. Thanks to their advantages, the combination of AR with PBL has unlocked various opportunities for students in the classroom. Since AR technology has a realistic structure and PBL is also based on real life contexts, this integration seems to be compatible with the nature of physics by bringing to light the complicated, abstract or invisible concepts. More importantly, a strong learning model may emerge for physics by reducing the challenges of PBL through AR. Specifically, the integration of AR into PBL can enable learners to visualize or understand the problem states better, gather the information related to the problems and analyse the underlying factors of them. Therefore, the current study could be a guide for educators and educational technologists trying to combine immersive technologies with PBL and realistic AR designs in order to facilitate understanding the complicated or abstract concepts in physics subjects. Hence, the current study focuses on the effects of PBL assisted with AR on learning achievement and attitude towards physics subjects as a part of science education.

2. Literature review

2.1. PBL and its support with technology

PBL is a learning method which drives the learner under investigation to solve the real-life problem cases (Savery, 2015; Torp & Sage, 2002). As being both problem and learner-centred, PBL is seen as a dynamic process in which students who are responsible for their own learning are actively engaged in problem solving.

Theoretically, some of the scholars have noted that the structure of PBL is appropriate for the constructivist approach in the relevant literature (Hmelo-Silver, 2004; Liaw et al., 2010; Savery, 2006; Yew & Schmidt, 2012). Dolmans, De Grave, Wolfhagen, and Van Der Vleuten (2005) emphasized that PBL is based on theoretically four modern learning insights; (i) constructivist, (ii) collaborative, (iii) self-directed, (iv) contextual learning. Though PBL is implemented in different ways, it has three main characteristics (Dolmans et al., 2005); (i) problem situation as a stimulus for learning, (ii) the role of teacher as a facilitator or guide, (iii) teamwork for interaction. Some of other core characteristics of PBL are real-life contexts, interdisciplinarity, authenticity, motivating, student-centeredness, being self-directed and self regulated, reflective learning (Hmelo-Silver, 2004; Hung, 2006; Savery, 2006). Based upon authentic real-life cases, PBL starts meaningful problems which are complex, ill-structured, and open ended. Hence, the structure of problem in PBL has a critical role for effectiveness of learning. If PBL is well-structured and implemented effectively, the learner can be motivated to learn, develop a deep understanding of subjects and invest in the solution of problem (Hung, 2006).

During PBL process, students first encounter a problem. Next, they determine clearly the problem situation. Then, they generate the hypotheses about possible or good solutions to this problem situation. They learn collaboratively with other students by seeking solutions to real-world problems. After that they collect the missing information about the problem by searching from various sources such as internet, course book or conducting experiment and test the hypotheses. Finally, in the evaluation phase, they evaluate the problem scenario, the group members or the learning process (Lu et al., 2014).

While PBL has initially historical origins in medical education (Barrows & Tamblyn, 1980), it has started to draw attention of educators in various areas and levels of education such as science (Mundilarto & Ismoyo, 2017; Siew & Mapeala, 2017; Tosun & Şenocak, 2013) and maths (Uygun & Tertemiz, 2014) in K-12 and engineering (Hsieh & Knight, 2008; Yadav, Subedi, Lundeberg, & Bunting, 2011) or teacher training (Major & Mulvihill, 2018; Pourshafie & Murray-Harvey, 2013) in higher education with its advantages. According to the results from several emprical studies, PBL is a more effective learning approach which contributes to increasing academic achievement (Uygun & Tertemiz, 2014), provides the long-term retention of information (Hung, 2013; Uygun & Tertemiz, 2014), improves problem solving skills (Argaw et al., 2017) and critical thinking (Kumar & Refaei, 2017; Mundilarto & Ismoyo, 2017). It also has a positive effect on attitude (Akınoğlu & Tandoğan, 2007; Tosun & Şenocak, 2013) and motivation (Hwang, Hsu, Lai, & Hsueh, 2017; Siew & Mapeala, 2017) towards the course when compared with traditional method. Several meta analysis or synthesis studies examined the effects of PBL on learning outcomes such as cognitive and affective skills (Dağyar & Demirel, 2015; Dolmans et al., 2016; Merritt, Lee, Rillero, & Kinach, 2017; Strobel & Van Barneveld, 2009). These studies indicated that PBL may be disputatiously more or less effective than traditional methods in education. On the other hand, students may have difficulties in hypothesizing and coping with problems or get bored with long-running PBL activities and especially underachievers may experience a difficulty in internalizing the problem cases (Hung, 2011). Supporting PBL with technology can contribute to overcoming these difficulties.

In recent years, the researchers have investigated the role of emerging educational technologies in PBL (Donnelly, 2010; Savin-Baden, 2007; Uden & Beaumont, 2006). The results of some studies have shown that these technologies could enhance students' cognitive, affective, and social skills, provide effective learning environments by decreasing their cognitive loads and have a positive effect on their learnings (Beaumont, Savin-Baden, Conradi, & Poulton, 2014; Phungsuk et al., 2017; Roy & McMahon, 2012; Tomaz et al., 2015). Hung (2015, p. 88) stated that technology helps students to construct information by providing cognitive support in PBL. Specifically, instructional technologies are used as a tool of research, interaction, evaluation and collaboration by being integrated into the PBL process (Torp & Sage, 2002).

Hung, Jonassen, and Liu (2008, p. 498) emphasized that technology can be used in two ways in the PBL process. First, PBL can be integrated with online or distance learning technologies. Second, it can be supported with various multimedia such as sound, video or animation. More specifically, learning management system (Moodle, Sakai etc.), specific softwares (e.g., CMapTools), virtual learning environments (e.g., Secondlife), and three-dimensional (3D) modelling technologies can be used in PBL (Jin & Bridges, 2014). If PBL is not supported by various learning materials including visual and digital contents especially in such an information age, the current generation students also known as digital natives utilising the technology for their learning process (Prensky, 2001) can not focus on learning and the courses can be monotonous and boring (Lajoie et al., 2014). However, the use of technology helps students to build bridge with real-life environments and provides enriched learning experiences (Lu et al., 2014). Accordingly, it is considered important for effectiveness and productivity of learning as scaffolding to support the PBL especially with the emerging instructional technologies.

2.2. AR and its use in physics subjects as a part of science education

AR is an immersive and interactive technology that digital information generated by computers such as video, graphic, animation, text or sound interactively is integrated into the vision of the real-world (Craig, 2013; Dunleavy et al., 2009; Wu et al., 2013). As an extension or variation of virtual reality (VR), AR is a bridge that fills the gap between reality and virtuality (Azuma, 1997; Cai et al., 2014; Carmigniani et al., 2011). Different from VR, AR users interact with real world rather than completely a virtual environment (Cai et al., 2014; Fidan & Tuncel, 2018).

While the birth of AR dates back to 1950s (Carmigniani et al., 2011), it was entitled as a concept by Tom Caudell in 1990 (Lee, 2012). Azuma (1997) indicated core characteristics of AR: 3D visualization of objects, combination of real and virtual environments, interaction in real-time. In terms of recognition features, AR is divided into two categories: (i) image-based and (ii) location-based (Cheng & Tsai, 2013). While image-based AR uses methods of recognition of natural feature or specific marker, the features of device such as Global Positioning System (GPS), wireless or wave are used in location-based AR system. According to Pence (2011), types of AR are: (i) marker-based and (ii) markerless-based. Marker-based AR system uses an artificial marker (2D barcode, Quick Response -QR- code, graphic etc.). Another one uses the location detected by a device or the features such as surface texture, corner or edge of the objects. AR can be used indoors or outdoors on mobile devices and computers. Hence it allows to afford ubiquitous experiences as formal and informal settings (Wu et al., 2013).

In recent years, the use of AR in science education has been more widespread as well as in various fields of education such as language (Godwin-Jones, 2016; Küçük, Yılmaz, & Göktaş, 2014), maths (Bujak et al., 2013; Estapa & Nadolny, 2015; Sommerauer & Müller, 2014), geometry (Lin, Chen, & Chang, 2015), virtual arts (Chang et al., 2014; Di Serio, Ibanez, & Kloos, 2013). Fidan and Tuncel (2018) investigated the trends of AR in the fields of educational research in their study. The findings demonstrated that AR was used more frequently in the discipline of science than in other areas. AR has been implemented in the field of science education particularly in physics (Akçayır et al., 2016; Cai et al., 2017), biology (Küçük, Kapakin, & Göktaş, 2016; Marzouk, Attia, & Abdelbaki, 2013), chemistry (Cai et al., 2014), and astronomy (Yen, Tsai, & Wu, 2013). AR is suitable for the nature of science thanks to the realistic structure, concretization of subjects, facilitation of experiments and focusing on investigation or examination (Cheng & Tsai, 2013; Dunleavy et al., 2009; Yoon et al., 2017). Not only can AR promote students' achievement in learning process, but it can also stimulate their positive emotions in science education (Akçayır et al., 2016; Di Serio et al., 2013; Dunleavy et al., 2009; Hwang et al., 2016; Ibanez et al., 2014). More specifically, the results obtained from emprical studies have demonstrated that students who use AR technology have higher achievement (Hwang et al., 2016; Wu et al., 2017; Yen et al., 2013) attitude (Akçayır et al., 2016; Cai et al., 2013; Hsiao, Chen, & Huang, 2012), and motivation (Chiang et al., 2014; Di Serio et al., 2013) when compared with traditional methods in science education. Furthermore, AR facilitates understanding the science course by reducing learners' cognitive load (Küçük et al., 2016; Wu et al., 2017) and foster their attention towards it (Chiang et al., 2014).

AR technology has recently began to attract the attention of some researchers in teaching physics subjects as a part of science education (see Table 1). For example, Cai et al. (2017) developed a natural interactive application that supported the AR software for teaching magnetic fields or magnetic induction. The results of their study indicated that it could promote students' learning outcomes. The study of Cai et al. (2013) showed that AR application which was created for a convex imaging experiment in a physics course was an effective tool in enhancing the students' attitude, motivation, and attention. Likewise, Ibanez et al. (2014) investigated the potential of AR for improving the students' attitude in high school. They created AR apps related to the subjects of electromagnetics in physics course. According to the results of the study, the students who used these apps developed positive emotional features towards physics.

Dünser et al. (2012) presented an instructional material by creating interactive physics education books with augmented reality for high school students. Their study findings showed that the marker-based AR books were more effective for physics learning rather than traditional books. Based on the results of these and similar studies, it can be said that AR technology is a potential tool in developing students' cognitive and emotional states for physics subjects at different school levels. Furthermore, the findings of previous studies provide concrete evidences for the usability of AR in teaching physics subjects. Thanks to its realistic and immersive structure, AR facilitates the instruction of scientific concepts or subjects of the field in spite of challenges of physics science learning (Cai et al., 2013; Ibanez et al., 2017). Thanks to AR technology, the students can structure the abstract or difficult concepts more effectively in physics (Abdüsselam & Karal, 2012).

Table 1
The studies on the use of AR in physics.

Study	Subjects	School level	Variables[a]
Daineko et al. (2018)	Mechanics	Secondary	Practical tasks
Cai et al. (2017)	Magnetic fields and induction	Junior high school	Attitude, learning outcomes
Ibanez et al. (2017)	Magnetic field	University	Motivation, learning outcomes
Ibanez et al. (2014)	Electromagnetics	High school	Attitude
Wang et al. (2014)	Elastic collision	University	Learning outcomes
Cai et al. (2013)	Lens	High school	Attitude, motivation, attention
Enyedy et al. (2012)	Newtonian force and motion	Primary school	Learning outcomes
Dünser, Walker, Horner, and Bentall (2012)	Electromagnetism	High school	Achievement, motivation
Abdüsselam and Karal (2012)	Magnetism	High school	Achievement

[a] AR affected on these variables positively in physics education.

Table 2
Descriptive statistics of the groups' exam marks for science course in sixth grade.

Variable	Group	N	*M* (SD)
Learning achievement	EG-1	30	82.48 (2.29)
	EG-2	31	85.25 (2.93)
	CG	30	84.50 (2.06)

3. Research questions

In this study, the research questions (RQs) were as follows:

RQ1. Are there any significant differences between the pre- and post-test mean scores of each group (i.e., EG-1, EG-2, and CG) in terms of physics learning achievement and attitude in science course?
RQ2. Are there any significant differences between the post-test mean scores of EG-1, EG-2, and CG, respectively, in terms of physics learning achievement and attitude in science course?
RQ3. What are the opinions of the students who used AR about the impact of physics-related AR applications on their learning experiences?

4. Methodology

4.1. Participants

A total of 91 students (aged from 12 to 14, $M = 13.02$, SD = 0.47) from three classes of seventh graders of a junior high school at a province located in the north of Turkey, participated voluntarily in this study. Of the students, 50 (54.95%) were boys and 41 (45.05%) were girls. Prior to the experiment, the three classes were randomly divided into two experimental groups and a control group, consisting of 30 students in the Experimental Group-1 (EG-1), 31 in the Experimental Group-2 (EG-2), and 30 in the Control Group (CG). The groups were not different in terms of the mean value of learning achievement scores for science course in the spring semester of the 2015–2016 academic year, according to the one-way ANOVA test results ($F(2–88) = 2.62$; $p > .05$). Specifically, the averages of marks got by the students in these groups from science course exams in sixth grade were used for ANOVA. Table 2 shows that the mean scores of the students in the groups were close to each other in terms of science learning achievement for sixth grade.

4.2. Experimental procedure

A quasi-experiment, which includes pre- and post-test control group design was used in the study. The experiment lasted for 11 weeks in the fall semester of the 2016–2017 academic year. It had a workload of 5–9 h per week. While PBL assisted with AR was used in the EG-1 to teach the subjects of physics (Force and Energy Unit) in science course, PBL was solely used in the EG-2. In the CG, there was no intervention and the courses were carried out via teacher-based instruction. For all groups, the experiment was conducted in the science laboratory and the instructor was the same teacher in order to avoid some undesirable influences.

Both the achievement test (AT) and attitude scale (AS) were applied to all the groups before and after the implementation of this study. The maximum amount of time given for the completion of the AT was 45 min for both the pre- and post-test. AS was applied in 10 min in each of them, too. As the delayed post-test, AT was applied again to examine the students' long-term retention of physics concepts three weeks after the post-test. Following that, semi-structered interviews were applied to the students in the EG-1 in 45–75 min. Fig. 1 shows the procedure of experiment.

4.3. Design of the PBL activities and AR learning environment

Firstly, a total of 10 problem scenarios inspired by real-life contexts were created as ill-structured for the subjects of physics (see Appendix B for the examples of problem scenario). As to their appropriateness, the opinions of six experts were sought. In addition, the worksheets (pen-paper based) were prepared for collaboration and self-study on the basis of PBL. Secondly, all of the AR applications named FenAR, were designed by the researchers using the Unity 3D platform (game engine) and Vuforia SDK. These apps -based on marker based AR systems-can be used on Android-based devices and be adapted to other operation systems in terms of availability. 3D Max software was used to create the 3D model or animations. Some applications included the natural sounds (e.g., horse, elephant, plane) rather than digital ones in order to enhance the sense of reality and attract the students' attention. For example, for the problem scenario entitled "inseparable couple", the AR application was related to the Magdeburg experiment in physics. In this experiment, the horses try to separate the fitted hemispheres most of whose inner air was pumped out (see Fig. 2). The students can realistically endeavor to understand the air pressure. Hence, the horses' sound and their movements were added to the AR app. Similarly, another application included the sound of elephant to seem more realistic (See Fig. 2). In this way, it was intented to activate more senses of the students. In addition, the apps included specific interactive buttons to analyse or compare different situations. For example, the students could compare the varying weight measurements of an object in different celestial places such as

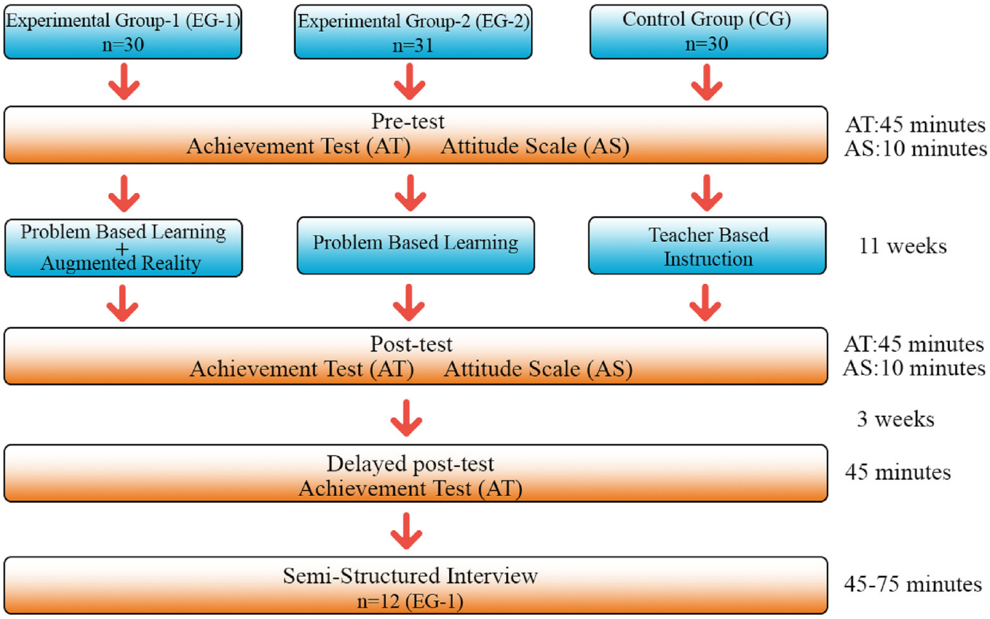

Fig. 1. Procedure of experiment.

Fig. 2. The examples from audible FenAR applications.

"Moon, Space, and Mars" (See Fig. 3). Thanks to the help buttons in the FenAR apps, necessary explanations and directives can be followed by students. FenAR applications have thoughtful and investigative learning contents for the students rather than direct information.

An inclusive main FenAR application includes a total of 36 different apps (see Table 3 for the distribution of the number of FenAR apps in terms of the problem scenarios and physcis concepts) was used with the EG-1. First, a link was shared through Google Drive for the students to download this main FenAR application file with ".apk" extension. The students in the EG-1 installed the main FenAR app on their tablet computers (See Fig. 4). Second, they installed the relevant sub-apps for each course from this main app file on their tablet computers under the guidance of the teacher. They used tablet computers for displaying the virtual objects with the special tracker cards which are called "marker". These objects can be displayed in detail by zooming and moving from different angles (see Fig. 4).

While 10 of FenAR apps were designed for the presentation of problem scenarios, the others were prepared for the stages of determining the un(knowns), data gathering, reflection and evaluation in PBL process. Based on the scenarios, activating their cognitive process, the students in experimental groups learned the physics concepts. Physics subjects are presented to the students, at early ages in Turkey, within the frame of elementary school science curriculum. For the teaching of these concepts, seventh grade is a critical transition phase (formal operational stage). Moreover, they are closely related to understanding the scientific logic of events in real life. Due to their context-based and realistic structures, the integration of AR and PBL can be suitable for physics education. The more similar the contents are to real life, the more effective the learning is in science education (Klopfer & Squire, 2008). Hence, the force, energy, pressure, and physical work -being the physical events in daily life-were selected as the main concepts in physics education in this study.

All of the PBL activities were same for both EG-1 and EG-2 in terms of learning contents in this study. Different from EG-2, these activities were supported with AR applications in the EG-1. The tablet computers (one tablet for each of EG-1 students) were used to run the apps in the classroom. The process of solving only one problem lasted an average of 1–1.5 week in the experimental groups. For instance, the implementation processes for the first problem scenario (see Appendix B, "The living space in the new planet") in

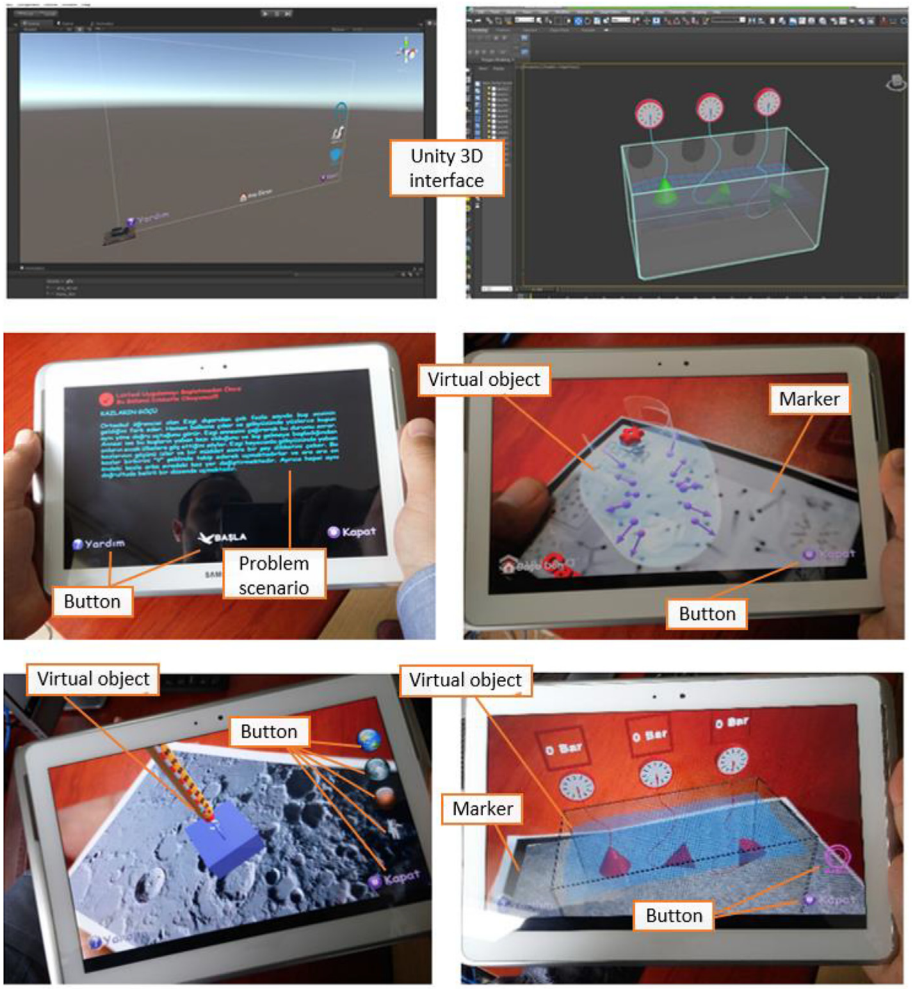

Fig. 3. Design of FenAR and the examples.

Table 3
The distribution of the number of FenAR apps in terms of the problem scenarios and physcis concepts on a weekly basis.

Time	Problem scenarios	Physics concepts	Number of FenAR apps
1st week	The living space in the new planet	Weight, mass, gravity, scales, dynamometre, Newton	3
2nd -3rd week	Resistance to nails	Solid pressure, force, surface	5
4th week	The migration of geese	Friction force, air resistance	3
5th week	Ceren's earache	Liquid pressure, density, height	4
6th week	Stucking in the muddle	Physical work, force, Joule, distance	4
7th week	Campfire	Friction force, thermal energy, transformation of energy	3
8th week	Newton's cradle	Potential energy, kinetic energy, transformation of energy	4
9th week	Wrong jump	Water resistance	3
10th week	Jumping shoes	The types of energy, transformation of energy	3
11th week	Inseparable couple	Gas pressure	4
	Total		36

experimental groups were as follows: The students in EG-1 firstly read the problem scenario text by running FenAR and then investigated the 3D visualization of the problem from FenAR app. But, the same scenario was showed on the projection by the teacher in the EG-2 . It was expected that the students would discover the variables such as concepts of gravity, weight, mass or their effects. After determining the problem status, the students in EG-1 gathered necessary information and made weight or mass measurements in different places (i.e., Moon, Mars, Space) through relevant FenAR (see Fig. 4). It was expected that they would learn the differences of weight and mass, dynamometre, force of gravity. The students used the buttons to compare or see different situations in the apps. Hence, the applications forced learners to do research on physics concepts or their relations with each other. After that, the students

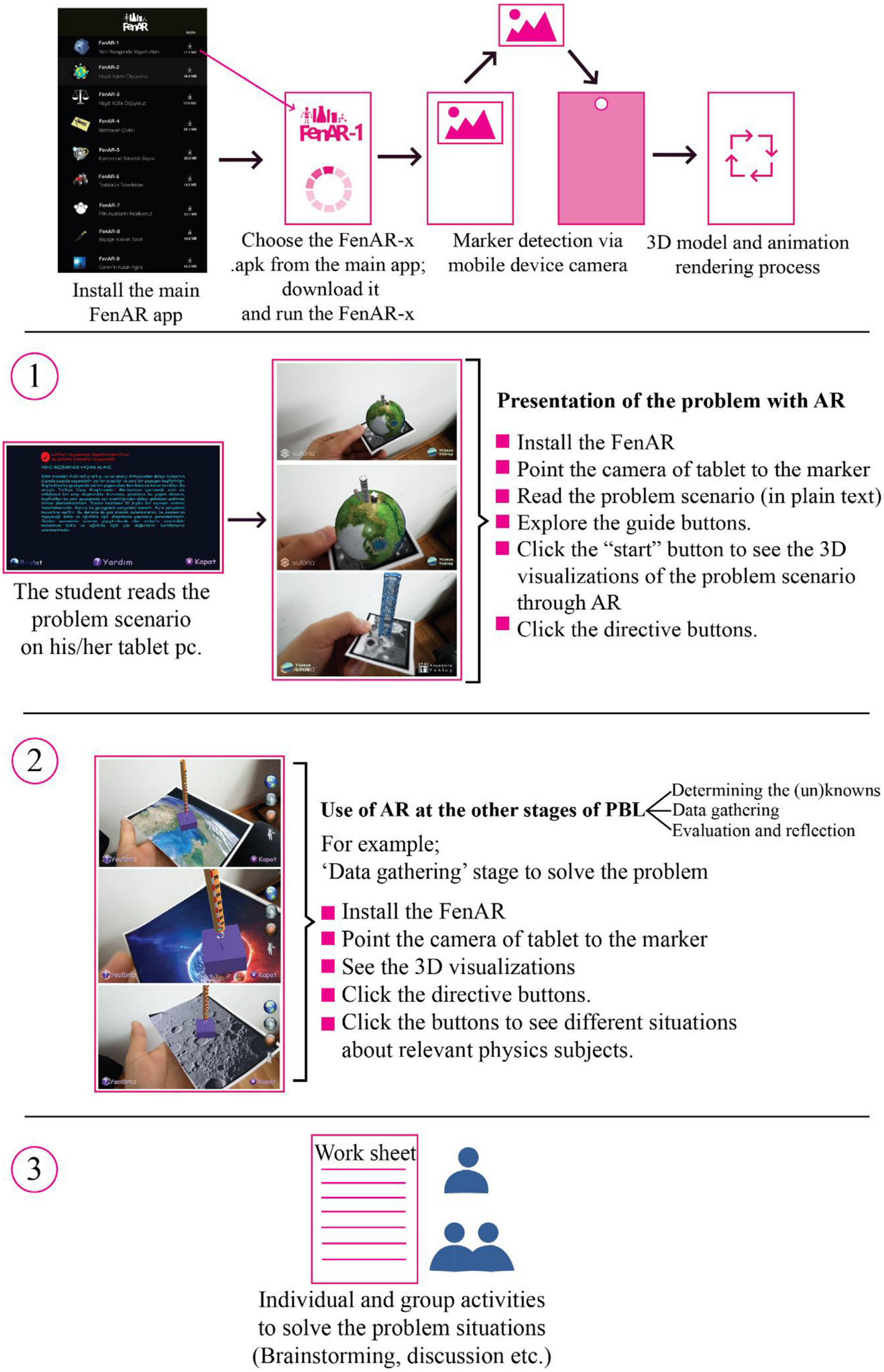

Fig. 4. The main framework for integration of FenAR and PBL.

discussed on the problem situation in the apps. Unlike EG-1, paper-pen activites were carried out in the EG-2 in PBL process. In addition, they also discussed on the problems in their groups and tried to reach the best solution . On the other hand, in the CG, the teacher-based methods (i.e., presentation, direct instruction technique) were used to explain the physics concepts without a specific

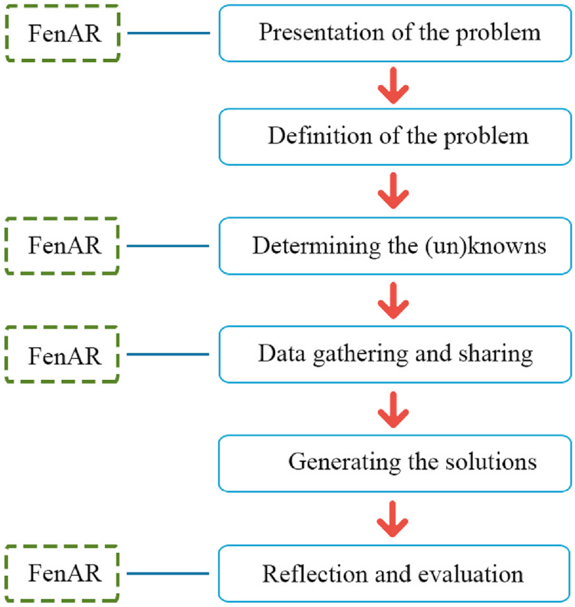

Fig. 5. Process of PBL assisted with AR.

technology. The students were mainly taught with the materials such as slides and course book under the supervision of the teacher.

4.4. *The process of integrating AR into PBL activities*

First of all, the students in the EG-1 used some AR apps (e.g., Anatomy 4D, Elements 4D) related to science course during two weeks before the experimental process. These apps were used as familiarization activities to reduce the novelty effect of AR on students. Following that, EG-1 was informed of both FenAR apps and PBL activities by the researchers. On the other hand, EG-2 was informed of only PBL activities. While the teacher was a guide in the process, students had an active learner role. The lessons in experimental process were conducted by adapting the steps to technology and PBL together (Donnelly, 2005; Lu et al., 2014; Torp & Sage, 2002; Uden & Beaumont, 2006). PBL activities were based on these six-stages: “presentation of the problem”, “definition of the problem”, “determining the (un)knowns”, “data gathering and sharing”, “generating the solutions”, “reflection and evaluation”. AR applications were integrated into some of these stages. The process of PBL assisted with AR is outlined in Fig. 5.

The “presentation of the problem” stage: The students in the EG-1 used FenAR applications to understand the problem scenarios. Firstly, they launched the relevant application by directing the tablet computer's camera to the marker cards and read the scenarios from the screen. After that, they examined in detail the AR application related to the problem by zooming and seeing from different angles. The problem was presented on projection in the EG-2. A student selected from the classroom, read aloud the problem scenario from the presentation (see Fig. 6).

The “definition of the problem” stage: There were some open-ended questions such as “*What is the problem situation in this scenario?*” and *“What is the problem that she encountered?”* in the worksheets. Each student tried to describe the problem clearly by evaluating the problem situation both individually and with group members. The techniques such as brainstorming and discussion were used in group works (see Fig. 7)

The “determining the (un)knowns” stage: The students in both experimental groups have written by listed (un)knowns about the problems onto the relevant area of the worksheets. Those in the EG-1 evaluated the leading questions about the unknowns related to the problem via FenAR and also produced the new questions. At this stage, the students in both groups determined the requirements regarding solution of the problem.

Fig. 6. Presentation of the problem.

Fig. 7. Students are evaluating the problem both individually and with group members.

The "data gathering and sharing" stage: There were some books about science, three desktop computers and internet connection in the laboratory room. At this stage, the students in both experimental groups searched for the unknown concepts or events by using these sources. The students in the EG-1 used the internet from their tablet computers to search the information. In addition, both groups also benefited from the school library to gather information (see Fig. 8).

The "generating the solutions"stage: The students shared the possible solutions with group members. Each group decided the best solutions and shared them with the other groups in the classroom.

The "reflection and evaluation" stage: The students in the experimental groups gave some examples similar to the problem situation from daily life in the reflection process. Following that, the students in the EG-1 answered the open-ended questions by examining the relevant FenAR application and wrote their answers on the worksheets. Thanks to these apps, it was aimed to help students better comprehend the questions related to physics. The students in the EG-2 answered the questions only by reading from the worksheets. The students in both experimental groups evaluated the process via self-assessment, the scenario of problem and in-group evaluation forms by selecting the emoji reflecting their emotions and scoring from 1 to 5 (see Fig. 9).

4.5. Measuring tools

4.5.1. Learning achievement test

In order to measure cognitive learning achievements of the students, AT was developed by the researchers in line with the learning objectives related to the subjects of "force", "weight", "mass", "pressure", "energy", and "work" in science curriculum. Firstly, a draft form of AT was composed of 54 multiple-choice questions. The opinions of experts were received in order to ensure the validity and reliability of the AT. The questions of the test were revised upon their feedbacks. Moreover, a pilot application of the test was conducted with 303 eighth graders. As item statistics, the difficulty index (*pj*) and discrimination index (*rjx*) were calculated by ITEMAN software. The incompatible items were excluded from AT. The final version of the test consisted of 38 questions (see Fig. 10 for an example question). The general discrimination value of AT was calculated as 0.42. Difficulty value of the test was calculated as 0.40. The internal consistency coefficient (KR-20) was 0.86. The contents of the pre-and post-test were same for the current study.

4.5.2. Attitude scale

The AS was developed by the researchers to determine junior high school students' attitudes towards the physics subjects in science course. Firstly, a comprehensive literature review was conducted on attitude and its dimensions, in addition to the attitude scales related to science. In line with the aim of this study, 54-items were formed for the draft form of the AS towards physcis subjects and the experts' opinions were received for content validity. Moreover, a linguist checked the items in terms of comprehensibility and grammar. Upon the experts' feedbacks, 14 items were excluded from AS which was structured as a 5-point Likert type (1-Strongly disagree, 2-Disagree, 3-Somewhat agree, 4-Agree, 5-Strongly agree). Afterwards, a pilot application of the AS was conducted with 1884 students attending 6th, 7th, and 8th graders from 11 different junior high schools in Turkey. The data obtained were analysed by Exploratory Factor Analysis (EFA) in order to determine the content of factors. According to the results of analysis, the items with

Fig. 8. Students are gathering information about unknowns.

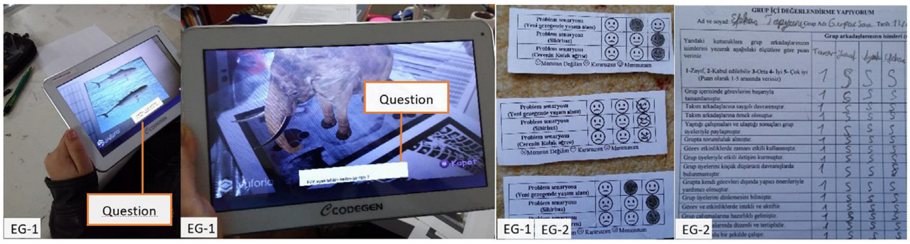

Fig. 9. The examples of evaluation.

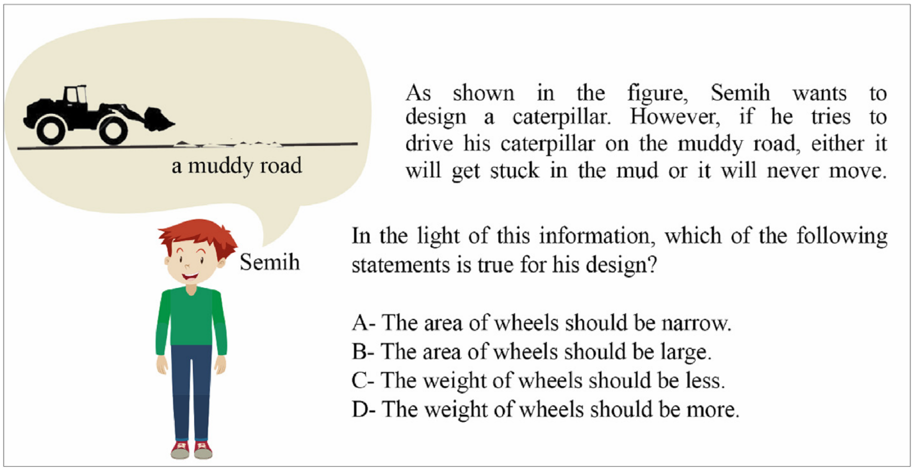

Fig. 10. An example of multiple-choice question.

less than 0.30 factor load and less than 0.10 difference of in factor loads between two factors were excluded from AS. After the analysis was repeated, AS consisted of four factors with 29 items (see Appendix A). 21 were including positive expressions while 8 items had negative expressions.

The total variance explained by these four factors is 49.94%. These four factors were named as “enjoyment the subjects of sound, light, heat” (9-items), “aversion the physics subjects” (8-items), “enjoyment the subject of electricity” (8-items), “enjoyment the subjects of force, movement, energy” (4-items). Confirmatory factor analysis (CFA) was performed to test whether the four-factor model was verified with 734 students attending 6th, 7th, and 8th graders. According to the results of CFA, the fit indexes were calculated (χ^2/df = 2.39; *TLI* = 0.93; *NFI* = 0.90; *GFI* = 0.92; *RMSEA* = 0.04; *SRMR* = 0.03). In addition, CFA results of the single factorial model also showed that fit indexes were acceptable. Cronbach's alpha reliability coefficient of the factors were calculated as 0.88, 0.85, 0.83, and 0.73 respectively. Cronbach's alpha for the whole scale used in this study was 0.92, suggesting that AS is reliable. In the current study, the AS was applied to groups as both pre- and post-test.

4.5.3. Interview form

A semi-structered interview form was prepared to determine the students' opinions about AR applications in the EG-1. An audio recorder was used to record the interviews. The examples of the interview questions included: “*What were the problems you experienced while using the AR applications?”, “What were the advantages of AR applications?”, “What did you feel, while using the AR applications?”, “What effects did the AR applications have on the development of your emotions and skills?”.*

4.6. Data analysis

Whether the data collected from AT and AS showed a normal distribution or not was tested via Shapiro-Wilk test in this study. The test results indicated that the values were calculated to be $p > .05$ for pre- and post-test. Hence, the analysis of covariance (ANCOVA) parametric test was conducted to determine the differences in post-test scores among the groups (i.e., EG-1, EG-2, CG) by using the scores of the pre-test as the covariate variable. The factors that showed a normal distribution and paired-sample *t*-test was used to compare differences between of pre- and post-test scores within the groups. The results of Shapiro-Wilk test for delayed post-test scores showed that the values were calculated to be $p < .05$. Hence, Wilcoxon signed-rank test was used for the pre- and delayed post-test comparisons within the groups.

The data obtained from the semi-structered interview were analysed by using content analysis. First, the data were encoded and the codes were grouped into themes according to their similar characteristics. Then, the direct quotations from the students were selected by coding them as S01, S02, and so on. In order to provide the reliability of qualitative data, three experts also recreated the

Table 4
Descriptive statistics of the pre- and post-test dependent variables.

Dependent variable	Group	N	*M* (Pretest-posttest)	SD (Pretest-posttest)
Learning Achievement	EG-1	30	10.59–29.23	3.33–4.56
	EG-2	31	12.29–25.96	4.41–4.67
	CG	30	12.43–22.73	5.03–5.42
Attitude	EG-1	30	107.66–122.40	22.98–17.44
	EG-2	31	111.56–106.23	20.09–22.00
	CG	30	109.36–98.60	17.25–14.07

codes and themes. Cohen kappa value was calculated respectively .80 and .87 for each theme in ensuring the consistency of opinions. After all, the qualitative findings were collected under two categories: students' opinions about "advantages of AR in learning physics" and "its limitations in learning physics".

5. Results

5.1. RQ1: are there any significant differences between the pre- and post-test mean scores of each group (i.e., EG-1, EG-2, and CG) in terms of physics learning achievement and attitude in science course?

To answer this, a paired-sample *t*-test was conducted to compare the scores before and after experiment in term of both learning achievement and attitude variables. Firstly, Table 4 shows the descriptive statistics for the dependent variables; learning achievement and attitude. For the variable of learning achievement, the post-test scores in all groups were higher than the pre-test scores. Specifically, the results of learning achievement variable indicated that the mean differences were significant in terms of the post-test scores of all groups, EG-1 ($t = 21.20$; df = 29; $p < .05$), EG-2 ($t = 19.10$; $p < .05$) and CG ($t = 14.45$; df = 29; $p < .05$). This means that the groups had significant improvements after the process.

On the other hand, the results of students' attitude scores showed that the mean differences between the scores of the pre- and post-test were significant for EG-1 ($t = 4.86$; $p < .05$), but not for EG-2 ($t = 1.81$; $p > .05$). Despite the fact that there was a significant difference between the scores of pre-test and post-test in the CG ($t = -5.62$; $p < .05$), the difference was not mainly in favor of the post-test scores. That is, the post-test scores did not increase or decrease significantly compared to the pre-test. This finding showed that teacher-based methods in the CG have not positively effected on students' physics attitude.

5.2. RQ2: are there any significant differences between the post-test mean scores of EG-1, EG-2, and CG, respectively, in terms of physics learning achievement and attitude in science course?

To answer this, ANCOVA (Table 5) was conducted to compare the differences of post-test scores between the groups by using pre-test scores as the covariate variable.

As shown in Table 5, there was a significant difference between learning achievement post-test scores ($F(2–88) = 34.870$, $p < .05$). Results of the pairwise test showed that the post-test achievement scores of students in the EG-2 (Adjusted $M = 24.48$) were more significantly higher than the scores of students in the CG (Adjusted $M = 22.75$), which shows that PBL method can contribute to the students' learning achievement more positively than the traditional method. More importantly, PBL assisted with AR was much more effective than both the traditional and only PBL method. That is, learning achievement increased even more when PBL method was supported by AR technology.

On the other hand, there was a significant difference between the attitude post-test scores ($F(2–88) = 30.68$, $p < .05$). The results of the pairwise test showed that the post-test attitude scores of the students in the EG-1 were more significantly higher than both the scores of the EG-2 and CG. That is, PBL assisted with AR had a positive effect on the attitudes of students in the EG-1. Moreover, it can be said that the PBL method used in the EG-2 had no effect on the attitudes of the students.

Lastly, the delayed post-test was applied to all groups three weeks after post-test to examine the students' long-term retention of physics concepts. This test was identical with the learning AT performed both as a pre- and a post-test. The delayed post-test showed

Table 5
ANCOVA results of the post-test dependent variables (between-groups).

Dependent variable	Group	N	*M* (SD)	Adjusted M	*F* (2–87)	Pairwise comparisons
Learning Achievement	EG-1 (a)	30	29.23 (4.56)	30.35	34.870*	a > b, a > c
	EG-2 (b)	31	25.96 (4.67)	24.48		b > c
	CG (c)	30	22.73 (5.42)	22.75		
Attitude	EG-1 (a)	30	122.40 (17.44)	123.59	30.68*	a > b
	EG-2 (b)	31	106.23 (22.00)	104.93		a > c
	CG (c)	30	98.60(14.07)	98.70		

*$p < .05$.

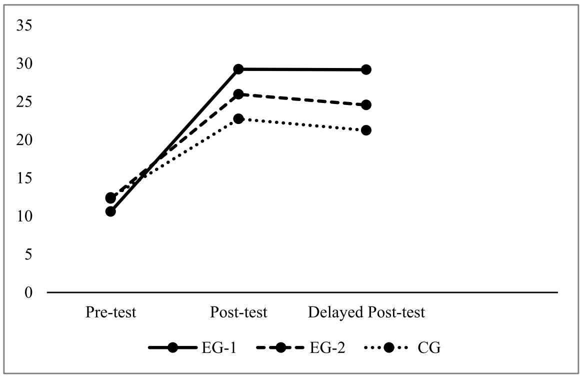

Fig. 11. The comparison of pre-test, post-test, and delayed post-test learning achievement scores.

that there was no significant difference compared to post-test achievement scores in the EG-1 ($t = 0.74$; $p > .05$). This means that AR had a positive influence on the retention of conceptual understanding. But, there was a statistically significant decrease in the scores compared to the post-test scores in the EG-2 ($t = 5.10$; $p < .05$). The analysis, made by using the Wilcoxon signed-ranks test showed that a statistically significant decrease occurred in the scores compared to the post test scores in the CG ($Z = -3{,}82$; $p < .05$). These results indicated that the students in both groups began to forget what they learned in contrast to the students using AR applications. Fig. 11 shows an overview of the learning AT scores.

5.3. RQ3: what are the opinions of the students who used AR about the impact of physics-related AR applications on their learning experiences?

To answer this, semi-structured interviews were carried out with 12 students from EG-1 about their learning experiences in using AR. The students reported mainly positive opinions about this technology in the educational contexts and their answers were grouped under two categories. First category was titled as the "advantages of AR in learning physics" by including positive cognitive and affective effects on students usefully (the codes: better understanding and analysing the problem scenarios; retention of physics concepts; facilitation and concretization in learning; autonomous learning; interesting, realistic, enjoyful, interactive as a learning environment). Some examples of the students' opinions related to the benefits of AR technology for learning physics are as follows:

S03: "It's easier to learn with the apps. I understand the problem scenarios better. Thanks to them, my skills of comparing and relating the subjects have improved. I don't forget what I learned with 3D models. Because I can examine the learning materials in more detail by zooming and seeing from different angles …"

S09: "I have learned by having fun and without getting bored. The apps have made learning easier for me. I use to get tired earlier, but now FenAR was interesting, funny and I'm coming willingly to learn …"

S11: "I think, I can see the apps from every angle because of 3D modelling … I was curious about the solution of the problem. Some apps were challenging, but this is good for learning and studying …"

S02: "It offers a realistic and more effective learning environment … There is interaction with learning …"

S10: "They were useful for remembering the information …"

Apart from the advantages of AR, few students had some difficulties during the experimental process. Accordingly, the other category was titled as the "limitations of AR in learning physics" by including common challenges related to physical health and technical difficulties in learning activities. The examples of their comments with respect to the problems are as follows:

S05: "Sometimes, we looked at the screen of the tablet computers too long. Therefore, our eyes might be damaged …"

S07: "I have experienced neck stiffness … I had pain in my arms and hands because of holding the tablet …"

S02: "The apps were running slowly …"

S12: "While introducing the marker cards, I occasionally experienced the problems …"

6. Discussion and conclusions

The experimental results of this study demonstrated that the students who used AR technology in the PBL process had significantly higher learning achievement scores when compared with both only PBL and teacher-based instruction in the classroom. This finding, which was parallel to the findings of some studies that used PBL assisted with technology (Beaumont et al., 2014; Lajoie et al., 2014; Virtanen & Rasi, 2017), indicated that AR technology developed the students' learning capabilities in physics subjects by enhancing the effectiveness of PBL. The immersive and realistic contexts offered by well-designed AR environments profoundly provide the development of students' cognitive skills and more importantly, the transfer of knowledge to real-life environments.

Moreover, the present study's results indicated that only PBL activities had also significant positive effect on students' learning achievement in comparison to teacher-based instruction. Contrary to this, the findings of Yılmaz and Batdı's (2016) meta analysis study, which synthesized the findings of previous studies, demostrated that the impact of AR on academic achievement was found to be low as effect size. Cai et al. (2013) investigated that the efficacy of AR for a convex imaging experiment in a physics course. The experiment applied with a pretest-posttest control group design indicated that there appeared to be no significant difference between the experimental and the control groups in terms of post-test scores. Similarly, Yen et al. (2013) developed AR materials related to the phases of the moon in astronomy. The study findings showed that there was no significant difference between the post-test academic achievement scores of the experimental and control groups. Some researchers investigated the use of AR to enhance the students' learning achievements in science education and found consistently similar results (Cai et al., 2017; Chiang et al., 2014).

Interestingly, when PBL activities are supported with AR technology the students' achievement increase considerably -even more in the current study. It may be the reason that AR has an activating effect on cognitive processes in PBL. Considering AR and PBL positively interact with each other in learning process, PBL -stimulates the students' cognitive activities-may also be a strong method that support the emerging technologies such as AR to enhance their achievement scores. Other important experimental results showed that PBL activities assisted with AR were more effective in promoting the learner's attitude towards physics subjects than teacher-based instruction. This finding is consistent with the results from similar studies which found that AR can improve the attitude towards science education (Akçayır et al., 2016; Cai et al., 2013, 2017). One more remarkable finding was that AR contributed to students' long-term retention of physics concepts. This may be caused by several factors such as the realistic and sense-stimulating 3D structure of AR and the quality or other features of the application design. 3D design of AR allows the students to examine learning materials in detail from different angles and envisage the concepts. Hence, a deeper or more permanent learning takes place for them (Ibanez et al., 2014; Radu, 2014). Furthermore, AR applications have an interactive learning environment including multimedia contents such as voice, video, 3D objects, animation, and buttons rather than a stagnant appearance (Cai et al., 2014). Some researchers pointed out that AR enhances attention and focus time for learning (Akçayır & Akçayır, 2017; Yen et al., 2013). Attention is a substantial variable in the transfer of information from short-term memory to long-term memory for ensuring the permanence of learning (Chang, Kinshuk, Chen, & Yu, 2012).

On the other hand, amazingly, PBL activities had no significant effect on students' attitudes compared to teacher-based instruction. Contrary to this finding, the majority of previous studies have pointed out that PBL can alone (without a specific technology support) enhance the attitude towards science course (Akınoğlu & Tandoğan, 2007; Tosun & Şenocak, 2013; Yoon, Woo, Treagust, & Chandrasegaran, 2015, pp. 217–233). In the present study, it was seen that PBL when used alone did not have an important effect on learning attitude. This may be because long-term PBL activities can be boring for early-age students without instructional technologies (Donnelly, 2005) and they can feel incompetent because of the difficulties in hypothesizing, analysing or understanding the problem in PBL process (Dolmans et al., 2005; Hung, 2011). Another reason can be the fact that changes in attitude can occur in a long period of time different from the academic achievement (Bohner & Dickel, 2011).

Following the empirical study, the qualititave results of this study revealed that interviewees who used the FenAR applications had positive views and lively welcomed this technology in terms of learning and teaching process. They pointed out that FenAR can be helpful to understand, analyse or solve the problem scenarios. FenAR may have helped the students to cope with difficult tasks and eased the challenges such as complicated problem scenarios, difficulty of adaptation to this process at an early age and lack of resources or instructional technologies in accessing information within the PBL process. The other qualititave results revealed that there were some (backache etc.) limitations of marker-based AR mostly regarding health. This finding is similar to the finding of the study by Ibanez et al. (2014) who found out that the students had posture problems and were getting tired after using AR because of holding the tablet computer to marker cards for a long time. To sum up, it was seen that AR technology could be a potential pedagogical tool because it supports the PBL process. The students' views are also consistent with the emprical findings of the current study which points out that AR has a positive impact on cognitive and emotional improvement in science education.

Based on the findings of the current study, the several educational implications can be highlighted in terms of instructional design. As the design process of AR has a crucial role in the effectiveness of learning, the apps should be developed meticulously on the basis of cognitive and emotional design standards in multimedia learning (Plass & Kaplan, 2015). AR designs with 3D modelling allow the learners to have realistic experiences compared to the ones with two-dimensional modelling. Moreover, the various components (buttons, sensors, modules for cooperation, etc.) should be integrated into the design both to construct better the concepts as neural and to increase the interaction. The tactile and motion-sensing designs are important as well as visual and auditory factors. Hence, the more senses of the learners can be stimulated and their attention concentrates for autonomous learning (Akçayır & Akçayır, 2017; Yen et al., 2013). The apps should be combined with the learning strategies (inquiry or problem based etc.) that stimulate or compel students' cognitive processes. Such integrations seem to be future trends in science education. Considering these explanations, well-designed AR applications help to facilitate the learning by enhancing their reality perception (Wu et al., 2017). However, the main concern is that it can be difficult for teachers to create the professional AR contents (with 3D objects). The platforms where they can design and share their own AR-based teaching-learning contents, should be developed. A specific data warehouse open to access by teachers through a common educational platform can also be created. There is another concern in socio-economic context that each student may not have enough display devices such as mobile phone, monitor, and specific glasses. The instructional technologies may also be inadequate for the use of AR systems in the classroom. To ensure the equality of opportunity in terms of instructional technologies, the necessary equipments should be provided to all public schools.

The current study showed interestingly that only PBL did not have a significant effect on physics achievement and attitude in the

EG-2. On the contrary, some researchers have underlined that it is an effective method in terms of cognitive and affective variables (Hmelo-Silver, 2012; Hung, 2013). For this opposite finding of our study, there may be some subjective reasons such as the quality of instructional design and methodological limitations in teaching process. To be more precise, the emerging technologies nowadays have attracted the attention of students, especially of these digital natives. If PBL is combined with these technologies, its effect on learning may increase positively as in the findings of current study. Theoretically, AR can be integrated into the processes of PBL such as understanding the problem, data gathering, evaluation in accordance with the structure of authentic learning. Physics concepts or subjects may be boring and incomprehensible for students because of its abstract or complex structure (Argaw et al., 2017). Considering PBL is selected for teaching of these concepts or subjects, its combination with emerging technologies may be effective coupling for learning rather than traditional PBL approach (especially the one based on paper-pen activities). This integration provides the emergence of a powerful model for learning by minimising the limitations of AR and PBL approach. In addition, marker-based applications can give rise to physical disorders such as backache, neckache or hand pain among early-age students. The educators or researchers will need to consider the physical skills and ages of students in using AR. For instance, various physical exercises should be performed periodically by the students under the supervision of the teacher in the class to prevent such disorders.

This study has a number of limitations; first, the learning content was designed for only the seventh graders and learning contents of “force and energy” unit as physics subjects. Hence, generalizability of the findings seems difficult in comparison to other populations since the current study is based on experimental research. Therefore, the combination of AR and PBL may be applied to other physics subjects (electricity, light etc.). It should also be worth trying to explore in other STEAM fields (technology, engineering, art, maths) or more diverse courses' subjects as well as the disciplines such as biology, chemistry, and astronomy in science education. In particular, we solely focused on students' achievement and attitude in physics in this study. It would also be interesting to investigate their cognitive and emotional features (e.g., motivation, high-order thinking skills, cognitive load). Second limitation is that the AR applications designed as marker based, can be affected technically by light or dark to recognize the marker. It is suggested that further studies may investigate whether the use of AR with markerless (location, gesture, etc.) tracking techniques can effect the students' learning in physics education in accordance with the structure of this field. Another limitation is that it can be difficult to use FenAR especially with specific learners with visual (e.g., color blindness) impairments or tactile disorders; even if there were no such cases among the participants of the current study. Thanks to its potentials (e.g., the zooming of virtual objects on the screen), AR actually provides an opportunity for users with poor vision to see the objects in more detail by perceptually enhancing the existing vision capabilities. But, the accessibility issues in AR designs are also crucial to person with disabilities (Stearns, Findlater, & Froehlich, 2018). From this point, assistive wearables (i.e., head-worn, finger-worn, hand-held) can be used to enable hard of touching, hearing or seeing accessibility. For instance, the specific smart glasses -to better visualize the differences between colors- can be solution for color blindness. Furthermore, they can focus on the other learning approaches (e.g., project-based, inquiry-based) which can be integrated with AR technology like PBL and a comparative experimental study can be carried out to determine which approach will be more effective on learning when combined with AR. Together with the findings of similar studies, a comprehensive theoretical model can be designed on the integration of PBL with immersive technologies such as AR. It would be worth exploring.

\Conflicts of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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Appendix A. The items of attitude scale

1. I like studying the working principles of the tools that make our daily tasks easier.
2. I enjoy listening to the life stories of famous physicists such as Newton and Einstein.
3. I am eager for investigating the reasons for the weight of an object on other planets.
4. Topics about the movement of an object in space are fun for me.
5. *I get bored while learning topics related to force.
6. *I am not willing to participate in experiments and activities about the impact of force on objects.
7. Designing simple electrical circuits entertains me.
8. I like learning the working principles of electric vehicles.
9. I like using what I have learned about electricity in daily life.
10. I enjoy doing assignments about electricity.
11. *I am not willing to participate in electrical activities.
12. I like following the developments in electricity production from natural sources.
13. What I have learned about electricity leads me to a related field in the future.

14. I like learning new information about electricity.
15. What I have learned about electricity saving is useful in everyday life.
16. *I do not enjoy solving problems related to electricity.
17. *I do not feel comfortable in experiments and activities about electricity.
18. I like doing experiments about sound propagation.
19. I like following new developments in audio technologies.
20. I have fun doing experiments on the subject of light.
21. I am willing to participate in projects and activities aiming to reduce sound pollution.
22. I enjoy experimenting with the formation of the shadow.
23. I enjoy producing new ideas on sound insulation.
24. It is enjoyable for me to explore how the voice is transmitted on the phones.
25. *Topics about light are unnecessary to me.
26. *I do not want to participate in experiments and activities about sound.
27. I like solving problems about heat and temperature.
28. *Topics about heat and temperature are boring to me.
29. I like doing experiments about heat and temperature.

*Negative items.

Appendix B. The examples of problem scenarios

THE MIGRATION OF GEESE

Ezgi, a secondary school student, realizes the sounds of too many birds coming from outside.She goes out to the balcony at once and sees hundreds of birds flying in the same direction in the sky. She calls her mum and asks why the birds fly in this way. Her mother says that these birds are graylag geese and they migrate to warm countries because winter is approaching. Ezgi enthusiastically watches the migration of the graylag geese in the sky and after a while something catches her attention: These geese are flocking by drawing a simple "V" shape in the sky and occasionally the goose in the top spot is displaced by the goose in back spot. All of them are also flying in a certain order in the same direction.

1-What is the incident that attracts the attention of Ezgi in this scenario?

2-What are the reasons behind this incident?

THE LIVING SPACE IN THE NEW PLANET

Due to the rapid population growth and the needs for water and energy, scientists have searched for livable places in space, outside the Earth, and discovered a new planet. On this planet, they have decided to establish a living space. For this purpose, a team in which you are also included has been created by the Center of Turkey Space Research. It is planned to build this living space in the form of a skyscraper due to the space constraint on this newly discovered planet. You are expected to design a 10-person elevator system. The force of gravity on this planet is equal to the gravitational force of the Moon. Considering this fact, you should make arrangements about the mass and weight that this elevator will carry. You are asked to determine (or give an opinion about) values for the maximum mass and weight on the label to be glued onto the elevator.

What do you think is the problem situation in this story?

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