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Creating concept maps with augmented reality: a case of eclipse of the lunar and solar topic

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Abstract

Concept maps are the tools used to facilitate meaningful conceptual learning. In this study, an augmented reality (AR)-based concept map (AR-ConMAP) application was developed to facilitate the concept map creation process to overcome the challenges that students face when creating concept maps. The study was carried out as a case study. Observations via using video records and worksheets were used to examine the effect of this application on students' concept map creation skills and their evaluations about their experiences. The results suggested that using AR for creating concept maps provided more accurate results in associating the concept map components and supported students for meaningful conceptual learning. Students evaluated their experiences in using AR also as increasing their sense of enjoyment and curiosity which positively contributed to their motivation to create concept maps. Recommendations for future research and practices were also included.

Keywords: Augmented reality, Concept maps, Conceptual understanding, Knowledge representation

Introduction

Given the importance of conceptual understanding, previous studies suggested using concept maps to support meaningful learning (Briscoe & LaMaster, 1991; Drareni, 2020; Heinze-Fry & Novak, 1990; Kinchin, 2019; Machado & Carvalho, 2020; Ullah, 2019). Concept maps have been used as graphic organizers in the courses and navigational aids in computer-mediated instruction in which learners can represent knowledge (Haugwitz et al., 2010; Nesbit & Adesope, 2013). Researchers have considered the concept maps as an effective tool for integrating newly acquired knowledge into prior knowledge and enabling students to comprehend the relationships between concepts (Chiou, 2009; Heinze-Fry & Novak, 1990; Hwang et al., 2011). Although many studies have demonstrated their positive effects on learning outcomes, teachers still do not prefer concept maps in their courses. In this sense, some studies have shown that there are difficulties such as insufficient level of expertise about integrating concept maps into the courses, inability to design schemes smoothly, not to integrate maps, and visual complexity (Abadiano et al., 2001; Davies, 2011; González et al., 2008; Harrison & Gibbons, 2013; Trevisani et al., 2016). Some other studies asserted that many students usually memorize the creation ways and pushes them to search concepts and their interrelationships (Baig et al., 2016; Veronese et al., 2013). On the other hand, some other studies reported the benefits of concept maps highlighting challenges that students face in using them (Baig et al., 2016; Vadlapatla et al., 2014; Wankat & Oreovicz, 2015). Also, some students still cannot create concept maps due to the lack of understanding of the nature of concept maps. Therefore, a need exists to facilitate creating concept maps for students and offer some ways for instructional designers and teachers about how to use them effectively.

Knowledge representation via concept maps

Educators use various kinds of representations to make sense of the new knowledge for students. The representations make the information more understandable, regular, and evocative that has been linked to other information (Davies, 2011).

In this sense, teachers sometimes use concept maps to support students' conceptual learning performance and to correct students' misconceptions (Vanides et al., 2005). Concept maps are graphical materials that systematically organize and represent information (Novak & Cañas, 2008; Romero et al., 2017) and allow students to follow the relationships among the concepts in the form of a two-dimensional diagram (Marzetta et al., 2018). Using concept maps as an instructional strategy, Kamble and Tembe (2013) highlighted that concept maps greatly increase problem-solving skills over traditional teaching methods. Concept maps, organized as cognitive structures that support meaningful learning, also have the potential to encourage students to learn from superficial learning to meaningful and deep learning (Brinkerhoff & Booth, 2013). In addition, some researchers argued that concept maps can be used as a learning strategy or evaluation tool to identify concepts that are unclear or difficult to be understood (Pendley et al., 1994).

Previous research has demonstrated the beneficial effects of concept maps. For instance, Ariaga and Nwanekezi (2018) reported that students who used concept maps to represent knowledge had a better conceptual learning performance. Öner and Arslan (2005) also demonstrated that the recall levels of the students were significantly increased via using concept maps. In addition, Şan (2008) used concept maps in a high school biology course and reported that the students who used concept maps significantly outperformed the ones who did not use them. In some other studies, using concept maps improved reading comprehension, summarizing, and generating questions (Chiou, 2009; Kamble & Tembe, 2013; Nair & Narayanasamy, 2017). There are also some studies that documented negative results in learning outcomes. For instance; Sever et al. (2009) concluded that students could not create concept maps correctly. Thus, it was difficult to correct the misconceptions and to establish a logical relationship between previous and current knowledge for students. Along this line of reasoning, the fact that concept maps are not constructed to be easily created and to easily understand the underlying conceptual relationships between the concepts may negatively affect the conceptual learning process.

Creating concept maps

Concept maps can be structurally in the form of bars (non-hierarchical), spider map (central concept), form (hierarchical), and chain form (Kinchin, 2008). The links are used to present the relationships between concepts in different segments of the concept maps (Martinez et al., 2013). Although various ways have been implemented in the implementations so far to create concept maps, students generally struggle identifying and locating all possible relationships in concept maps (Harris & Zha, 2013; Kinchin et al., 2008; Long & Carlson, 2011; Novak & Gowin, 1984; Sachs, 2002; Tseng, 2020). In order to facilitate creation of concept maps, researchers suggest using collaboration, gap filling, scratch, or flowchart methods (Edwards & Fraser, 1983; Ruiz-Primo et al., 2001). In addition, some useful tools were also suggested to create concept maps such as spider map, classification map, flowchart, or fishbone. Using these tools, it is quite easy to associate items via arrows. However, these tools do not allow users to understand the concepts and also do not provide information on whether they are creating the concept map correctly or not.

One way to understand concepts, sub-concepts, and the relations between the concepts in the concept maps is visualization (Kwon & Cifuentes, 2009). In addition to visualizing the concepts, it is necessary to convey the meaning of the visuals to the students and reflect the real-world counterpart of the concepts. In this sense, augmented reality, as one of the emerging technologies, can be used to demonstrate the real-world counterpart of the meaning expressed by the visuals of concepts and to make a meaningful presentation of information.

Using augmented reality for knowledge representation

In order for the schemas in the mind to be formed correctly and effectively, different techniques such as constructing meaning by reducing the information, storytelling, poetry and song lyrics, and visualization have been used. Therefore, visual presentation of the structure and function of a piece of information enables an individual to construct a more permanent mental modeling of that information (Hoffler & Leutner, 2007). Concept maps, infographics, animation, simulation, etc., are used for visualization. In line with this, AR supports learning by allowing users to code the information in the memory via visualization and sense of reality while getting the information.

Over the past decade, AR has become increasingly common in our daily lives thanks to the prevalence of smart devices such as phones, tablets, and handheld game consoles, (Schiavi et al., 2022). AR adds computer-generated virtual items to the real world simultaneously, providing the feeling in human consciousness that these objects are real objects (Gül & Şahin, 2017; Sırakaya & Çakmak, 2018). Thus, AR applications have been widely used for learning complex and abstract concepts by enhancing interactivity. Researchers have proposed AR applications because they have highly interactive and tangible user interfaces, which enables the user to interact with virtual 3D objects in the real world (Fjeld 2003; Shelton & Hedley, 2002). By using AR, teachers can present abstract knowledge as visible, audible, and perceivable dynamic content (Cai et al., 2021). In this way, the content of AR learning presents relevant materials to assist students in immersion learning activities.

AR allows students to explore the world in an interactive way (Kraut & Jeknić, 2015). AR blends real and virtual components together to enhance learning experience with its ability to overlay images, text, video, and audio components onto existing images or space to enhance the learning experience. This learning experience includes bridging the gap between theoretical and practical learning practices and can be addressed in the context of constructivism (Wang, 2012). The constructivist learning theory emphasizes individual's interaction with the environment to construct knowledge. Constructivists suggest learning-by-doing and to be actively involved in constructing knowledge. Thus, a set of structured previous knowledge is needed that a learner can refer to construct new knowledge (Hein, 1991). In this sense, AR is aligned with constructivist approaches where learners control their own learning. On the other hand, AR allows to learn a piece of content in a short time when the students need information when they faced with a knowledge gap (Antonioli et al., 2014). This opportunity can be related to the just-in-time learning theory that AR can provide fast information through just-in-time format. These underlying theoretical views motivated this research effort.

In the educational context, a growing body of research indicated that using AR positively affected learning outcomes in various contexts. Researchers used AR in various contexts such as museum education (Damala et al., 2008), medicine (Thomas et al., 2010), biology (Balog & Pribeanu, 2010; Oh & Byun, 2012), physics (Lin et al., 2012), chemistry (Balog & Pribeanu 2010), mathematics and geometry (Liarokapis et al., 2002) for facilitating the learning process and improving students' cognitive skills.

Núñez et al. (2008) demonstrated the impact of a mobile AR system to engage students through the provision of active learning, helping student learning by reducing time spent on tasks. Gül and Şahin (2017) revealed the effectiveness of AR in getting feedback from instructors, making assumptions, learning to generalize, and drawing conclusions as higher-order thinking skills. By using AR, it is possible for students to gather their interest and engagement, trigger their feelings of curiosity, increase their motivation, and ensure their active participation, so these elements are among the biggest factors in the emergence of AR use in education (Kreijns et al., 2013; Shen et al., 2013). AR also includes a better learning experience, increased motivation, student engagement, and a positive attitude (Bacca Acosta et al., 2014). For instance, some studies concluded that AR enhances motivation and effective learning (Sumadio & Rambli, 2010; Wojciechowski & Cellary, 2013). Di Serio et al. (2013) pointed out that AR enriches interaction; Yuen et al. (2011) concluded that AR triggers creativity; Yuan et al. (2011) demonstrated that it develops imagination. AR is also noted for its aspects of visualization (Wu et al., 2013). Zhang et al. (2014) examined the effects of AR application in the field of astronomy involving visualization and motion-sensitive processes. The results showed that students' learning performance, observation skills, and cognitive and affective characteristics were increased by using AR. Yen et al. (2013) conducted training supported by AR about the topic of the phases of the Moon and found that AR applications increased students' conceptual learning and remedied misconceptions. In addition, Bower et al. (2014) highlighted that AR can be used in students' understanding of science, increasing motivation, contributing to many learning approaches. In a recent study, Fidan and Tuncel (2019) integrated AR into a problem-based learning model and found that it increased students' learning achievement and promoted students' long-term retention of physics materials.

In addition, AR-supported teaching plays a facilitating role in learning the concepts by embodying abstract concepts (Bujak et al., 2013). That is to say, AR materials can help clarify the conceptual understanding in which students directly interact with the virtual objects and students can change independently of their knowledge in terms of constructivism. In a study, a lunar-phase observation system was developed using AR. The questionnaire results revealed that it facilitated understanding the concepts about the moon and the lunar system (Tarng et al., 2016). Another study developed an AR-based application to enhance students' physics conceptions. The results suggested that integrating AR into physics classrooms can significantly enhance students' understanding of concepts and guide students to be more inclined to higher-level conceptions of learning physics (Cai et al., 2021).

One of the important roles of AR in the learning process is to provide three-dimensional visuals that allow various knowledge representations. Since AR has the potentials in providing more information about the concepts, it can be thought that using AR can support to construct the relationships among the sub-concepts related to the items when creating concept maps. In this sense, Kazanidis et al. (2021) asserted that AR can support meaningful learning, like creating concept maps, by visualizing concepts and contextualizing the content. By creating the concept map with AR, the creation process can be made more efficient by immediate feedback (Kazanidis et al., 2021). Due to the nature of the concept maps and the potentials of creating a concept map, using AR can further increase the effect of concept maps on meaningful learning. Accordingly, concept maps provide meaningful learning, predict and minimize difficulties, and are conditioned to work together with AR. Therefore, using AR in creating concept maps may provide a better conceptual understanding. AR can facilitate associating the sub-concepts and create relationships more correctly in the concept maps. Using AR can also support checking the incorrect relationships between the items of the concept maps that students generally provide more effort by trial and error. Creating concept maps with AR can also improve to test the accuracy of concepts and relationships of the concept maps in a short time. This can be done via audio-, video-, or text-based augmentation of the concepts in the concept map. Thus, this can provide valuable contributions for the use of concept maps in educational contexts. While creating concept maps with AR, the associating process is to be embodied by placing 3D models, videos, or images in the real world. Although studies have shown the effectiveness of creating concept maps via various technologies, research that has been conducted to explore the impact of the AR on student concept map creation skills is almost rare. With this in mind, in this study, we utilized AR for knowledge representation in creating concept maps.

Purpose of the study

AR embodies abstract concepts and provides convenience in learning the concepts correctly (Bujak et al., 2013). Increasingly popular mobile AR applications provide students with a flexible learning environment at any time and place. In this study, we hypothesized that students instantly observe the meaning of the concepts and the relationships between the concepts by controlling them with AR technology and correct their misconceptions by placing the misplaced concepts, relationships in a controlled manner in the appropriate places on the concept map. When misconceptions are controlled and corrected by using AR at the end of the activity, it supports meaningful conceptual learning. Thus, in this study, we investigated the effect of using AR in creating concept maps and enhancing students' conceptual learning.

This study aims to determine the effect of mobile AR application to visualize the concepts and relationships in concept maps to provide meaningful conceptual learning. By this way, we suggest a way to utilize AR to facilitate creating concept maps. The current study seeks to answer the following questions:

- How does using AR affect students' concept map creation skills?
- How does the AR-based concept map creation process affect students' academic achievements?
- How do students evaluate the benefits of using AR in creating concept maps?

In this section, research method, research tools, information about participants (age, computer proficiency level, and frequency of computer use), and data collection procedure are discussed.

Method

In this study, in the context of the topic of the lunar and solar system in Science and Technology course, we investigated the creating of concept maps with AR and its effects on the conceptual understanding. The study was carried out as a case study, in which observations and quantitative data were used to explain the influence of AR in creating concept maps. Approval was obtained from the local ethics committee.

AR-CONMAP application

In this study, we created an application called AR-ConMAP. In the Science and Technology course, a reference concept map was designed in accordance with the objectives of the solar and lunar topic. The objectives of the topic were as follows: Students could predict how the solar eclipse occurred, predict how the lunar eclipse occurred, and create a model representing the eclipse of the Sun and the Moon.

Basically, creating concept maps includes the following steps: Identify a concept, try creating a graphic organizer related to this concept, and focus on how concepts are related to each other (URL-1, https://learningcenter.unc.edu/tips-and-tools/using-concept-maps/). Accordingly, it can be helpful for students to provide hints about the starting concept. In this study, we implemented the creation process in two ways: AR with a reference which students start with one pre-placed concept (e.g., Sun) and AR without reference. In this study, it is aimed to use a reference point so that the student can easily remember, bring back and find the concept they are looking for. In short, referenced AR is creating a concept map using clues; AR without reference is creating a concept map without clues.

While creating the concept maps, first, images about the sub-concepts of the lunar and solar eclipses were prepared. Vuforia plug-in Unity application was used to create the QR code for each of the concepts. With the help of Unity software, the images were represented within each concept with the QR codes. The reference concept map consisted of the QR codes that enabled to display the images representing concepts using AR. When creating a concept map, the clues that students needed were added to the worksheet using the QR codes (see "Appendix 1").

While creating the concept map, the student kept the phone loaded with the application toward the QR code next to the related concept. Then, an augmented reality image was created, showing the 3D shapes of each concept and its connections with other concepts.

Process

The implementation process lasted 2 weeks, three lesson hours per week. In the first week, before implementing the mobile application in the classroom, the application was introduced to the students by a video about lunar and solar eclipses. The following week, the students were asked to create concept maps with the support of the AR application, taking into account the guidelines in the worksheets about the application. Figure 1 shows the concept map used via AR-ConMAP. During the implementation, students' behaviors while they were creating the concept maps and using AR application were recorded. In the first phase of the application, students were asked not to use QR codes located next to the concept boxes. They were first asked to use the tips found at the bottom of the worksheet when they needed them. Students were allowed to use the QR codes to check the accuracy of their answers (whether they placed the sub-concepts or the arrows associating the concepts correctly) when they think they have completed the concept map. The information we asked them to represent in the concept map was included in the statements. First, we discussed the topics for a short time, and then, they were allowed to create the concept maps to represent the following statements:

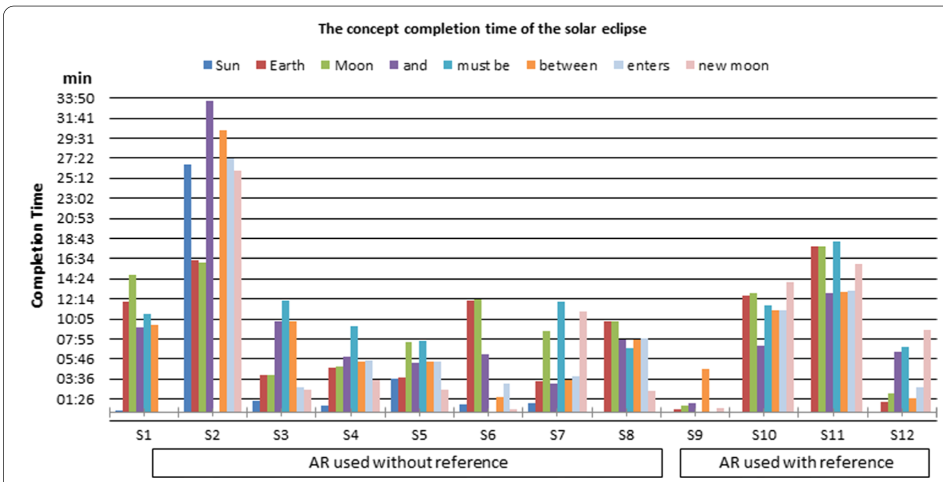


Fig. 1 Completion time of the Statement 1

1. Solar eclipse when the Moon enters between the Sun and Earth.
   1.1 The Moon must be the new moon

2. Lunar eclipse when the Earth enters between the Sun and Moon
   1.1. The Moon is in the full moon phase

Participants

Totally, 12 students (6 female, 6 male; age range 11–12) enrolled in the 6th grade Science and Technology Course at a public secondary school participated in the study. We randomly selected 4 students and used concept maps with reference to this group. In previous courses, the teachers presented various types of concept maps in the courses to teach some topics, but none of the students had experience in creating concept maps.

Data collection tools

Video records and worksheets were used to reveal the influences of AR to create the concept maps.

Video records

Students' actions in the concept map creation processes were recorded with a video recorder. The number of attempts to find correct relationships between the concepts and also the time spent in this process was calculated by analyzing these videos. The data were used to determine the influence of AR whether it facilitated the concept map creation process. Students' experiences were also gathered through these recordings in order to explain the influence of AR.

Worksheets

Worksheets were used to gather students' perspectives about the influence of conceptual understanding. The first page of the worksheet included guidelines for students about how to use the AR technology to create the concept map. The following instructions were included on the first page: "Run the AR application in your smartphones" (implemented in the first week). On the second page, the students were asked to remember the lunar and the solar eclipses. The second page was constructed to gather data about the students' experiences, behaviors, and feelings while they were working with the AR and the concept map components. The second page included two open-ended questions about the concept map creation process. These questions were "How did you feel while you were using AR app?" and "What difficulties did you experience while using the app?" The answers for these open-ended questions were also analyzed considering the video records.

Data analysis

Video records

To analyze the video records, meaningful analysis units were defined including a particular meaningful period. After a negotiation among the coders, the meaningful actions related to the concept map creating process were assigned as meaningful attempts in locating the arrows (links between the items) or items (sub-concepts). Coders noted the attempts to extract quantitative data about time and the number of attempts for associating the concepts when creating concept maps. The results were depicted on the graphics and interpreted with the benefits of the AR.

Worksheets

The open-ended questions in the worksheet were analyzed using the content analysis. In addition, students' perspectives in the worksheets about their performances and experiences during the process were presented as testimonials to explain their performances in creating the concept maps and their experiences about the contribution of the AR.

Results

The effect of using AR on the student concept map creation skills

Concept map creation skills were evaluated through the correctness of the relationships between the concepts and the time spent for finding the correct relationships between the sub-concepts. We implemented the creation process in two ways: AR with a reference which students started with one pre-placed concept (e.g., Sun) and AR without reference. While the students were creating the concept map, they encountered difficulties in locating the first concept. Also, looking at the concept map, it took a while for them to understand how to create the concept map. Therefore, if the concept is given as a reference, it is thought that the time it takes for the student to create and make sense of the concept map will be shortened and helping students by giving references may affect the way of AR support.

We determined the quantitative data for the completion time of concept creation.

The completion time during creating concept maps

By analyzing the video recordings, we determined the time that students correctly placed each of the concepts. Figure 1 shows the amount of time that students spent when creating a concept map using the AR-ConMAP application to find the right concept and relations about Statement 1.

> Statement 1: "Solar eclipse when the Moon enters between the Sun and Earth" and Sub statement 1: "Moon must be the new moon" -

Figure 1 shows that S2 spent more time than other students and could not complete the concept map. Students spent most of their time establishing relationships between concepts. They spent most of their time in the "and" relationship and "Moon" was the least time-consuming concept. All students (except S2), by using AR without reference, created accurate concept maps in a short time. The completion time of the main concepts "Moon" and "Earth" was significantly higher in the form of AR used with reference when compared to without reference. The results showed that the students correctly completed the basic concepts such as "Moon" and "Sun" in a short period of time and the sub-concepts such as "must be," "between," and "new moon" in a longer period of time. One interesting result in terms of the time spent is giving reference points for students to remind the starting point, which did not make it easier to place the items

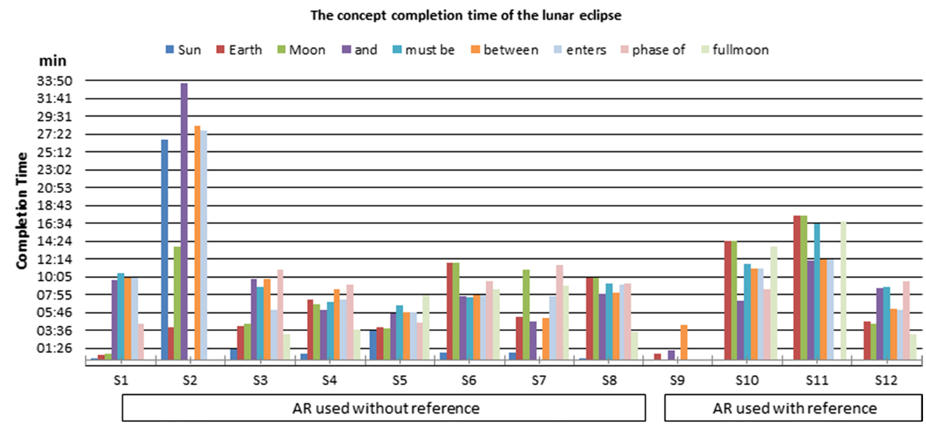


Fig. 2 Completion time in the Statement 2

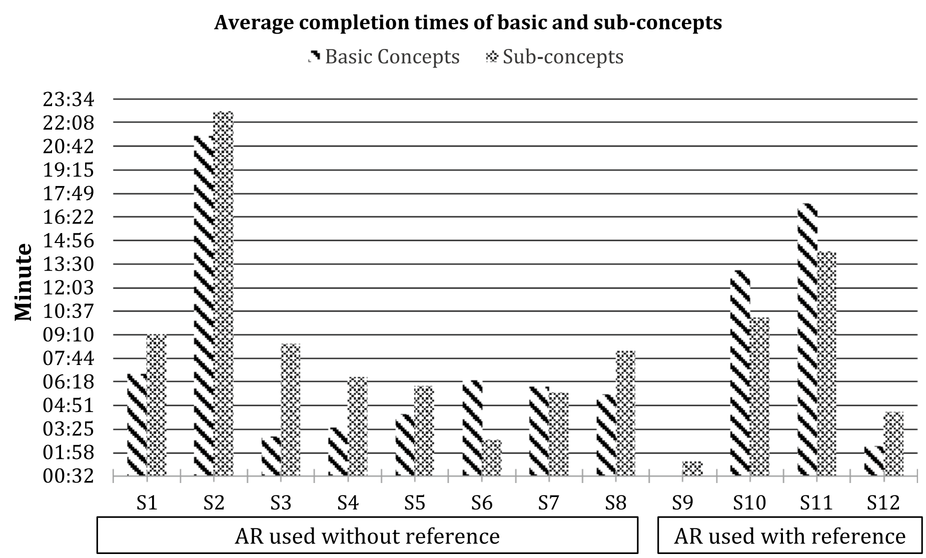


Fig. 3 Average completion times of concepts

correctly. Figure 2 shows the amount of time spent on creating a concept map using the AR-ConMAP application to find the right concept and relations about Statement 2.

> Statement 2: "Lunar eclipse when the Earth enters between the Sun and Moon" and Sub-Statement2: "Moon must be the full moon"

Students spent more time placing the relationships and sub-concepts correctly. The students spent most of their time placing the "shape of" relationship. Since the first concept of the concept map is "Sun," students first placed it. On the other hand, the correct completion time for key concepts such as "Moon" and "Earth" was higher while using the AR with reference than AR without reference. Figures 2 and 3 illustrate that the students first placed the main concepts and then the relationships and the sub-concepts.

Students' completion status of the statements is shown in Table 1. Table 1 shows that students who completed the application spent less time on average.

Table 1 Fully correct completions status and time (minute)

Student	Solar eclipse	Lunar eclipse	Both	Time (min.)
S1	X	X	X	14:51
S2	X	X	X	33:29
S3	✓	✓	✓	12:00
S4	✓	✓	✓	09:20
S5	✓	✓	✓	07:55
S6	X	✓	X	12:08
S7	✓	X	X	11:53
S8	✓	✓	✓	10:00
S9	X	X	X	04:43
S10	✓	✓	✓	14:27
S11	✓	X	X	18:20
S12	✓	✓	✓	09:31

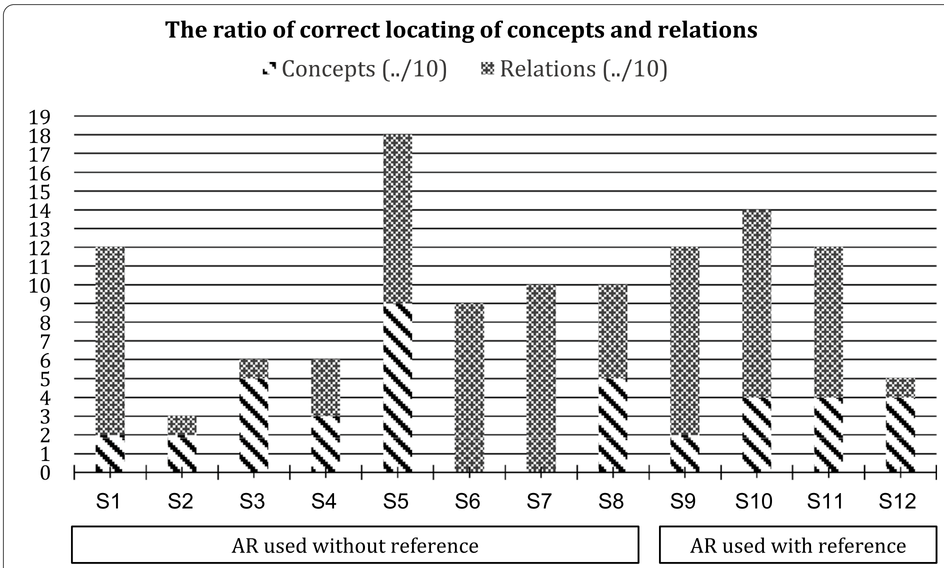


Fig. 4 The performance scores in locating concepts and relationships

In order to determine whether the main concepts and sub-concepts have different average completion times, we calculated the time spent on main concepts and sub-concepts. Average completion times of main-concepts and sub-concepts are shown in Fig. 3.

Figure 3 shows that S3, S4, S5, S8, S10, and S12 completed creating concept maps in a short time. Although S2 spent the longest time, he was unable to complete the concept. S9 had the shortest completion time, but he could not finish creating the concept map. We also associated percentages of the correctness of the concepts and the relations assigned to sub-concepts. The scores are shown in Fig. 4.

Figure 4 shows the correct placement of concepts and relationships before checking with the AR-ConMAP application when creating the concept maps. Figure 4 indicates that S5 showed the highest correct rate in locating concepts and relations. It is noteworthy that S6 and S7 could not locate the concepts correctly. The performances of S1,

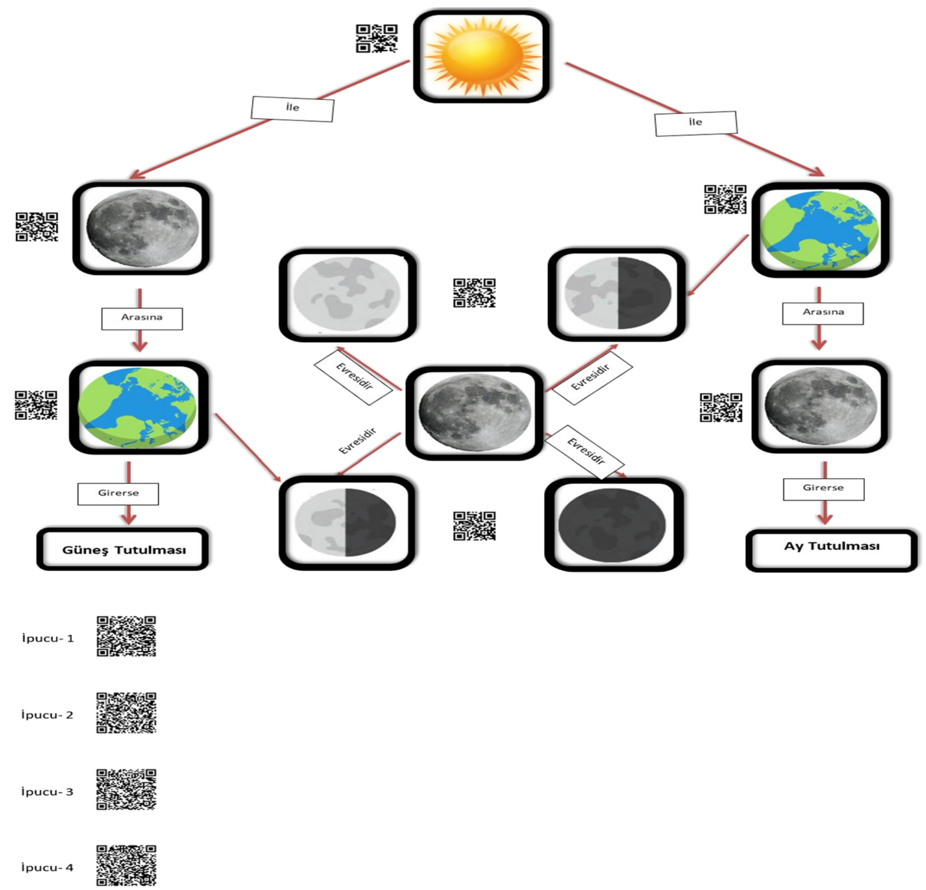


Fig. 5 A view from S11 having errors in sub-concepts

S2, and S9 in locating concepts correctly were very low, while those of S1 and S9 were high in locating relations. This indicates that students have different performances in creating concepts and creating relations. For example, one student located the relation, "between," correctly in his first attempt, but could not determine correctly whether the sentence describing the eclipses would be "If the Moon enters between the sun and the Earth, it would be an eclipse" or "If the Earth enters between the sun and the moon, it would be a lunar eclipse."

One remarkable finding is that the performance of S3 in creating concepts is higher than in relations. It is seen that the reference and non-reference groups' concept map creation performances were varied, but those of the referenced group were higher. However, the average values show that the without-reference group has a 6/10 ratio in relations and 3/10 in concepts, while the reference group has a 4/10 ratio in relations and 7/10 in concepts (3/10 when the referenced concept is removed).

In order to understand the contribution of the AR-ConMAP to the concept map creation skills, students' perspectives in their worksheets were also examined. The findings indicated that they could not see the main concepts stemming from the way they held the mobile phones and that the main concepts had slipped or appeared halfway.

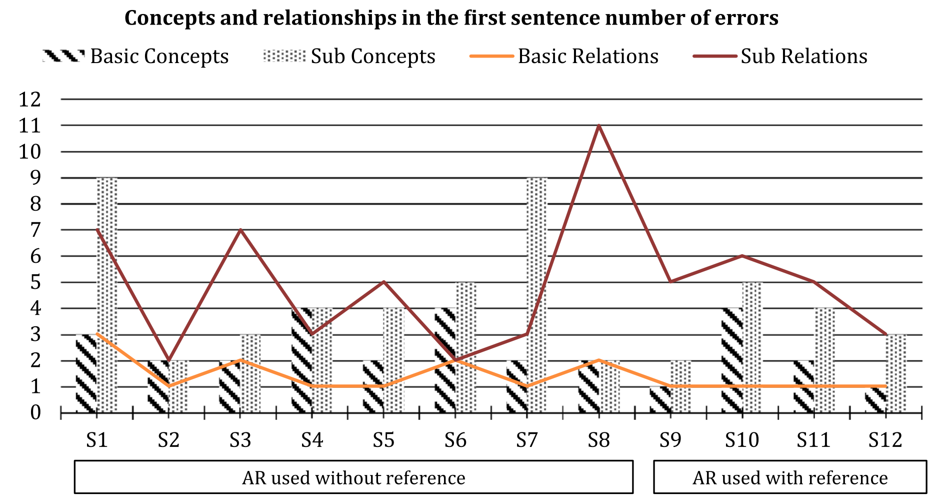


Fig. 6 Number of errors in concept and relationships in the first statement

Nevertheless, they stated that they were excited while using the application. The perspectives of the higher performed students who achieved the main concepts and sub-concepts correctly were generally positive about learning concepts easily with the application, and they also stated they enjoyed the application.

Figure 5 shows an example of incorrect placement. Here, the student confused "Solar Eclipse" with "Lunar Eclipse."

The students' perspectives could not see the main concepts stemming from the way they held the phone and that the main concepts had slipped or appeared halfway. Students who provided correct answers for the main and sub-concepts correctly stated that they were not forced to use the phone and that they enjoyed using this application for conceptual learning. Some of the students who used non-reference could not locate the concepts correctly.

Errors rates in finding the correct maps

The results indicated that using AR for creating concept maps reduced the number of errors. Thus, we considered the rates of errors in creating concept maps to reveal the contribution of AR in concept maps in Figs. 6 and 7.

Figure 6 shows that S9 and S12 completed the basic relationships with minimum error. S2, S8, and S9 performed best in correctly placing the sub-relations. S2, S4, and S8 completed both main and sub-concepts with similar rates of errors. In general, basic relationships appeared to make fewer errors. It is seen that more errors were made in sub-relationships than in basic relations.

The number of errors in the second statement is slightly less than in the first one. In the second statement, the number of errors of S9 and S12 was minimum. It is also seen that more errors were made in sub-concepts and sub-relations. Overall, we determined the average number of errors during the creation of concept maps in Statement 1 and Statement 2.

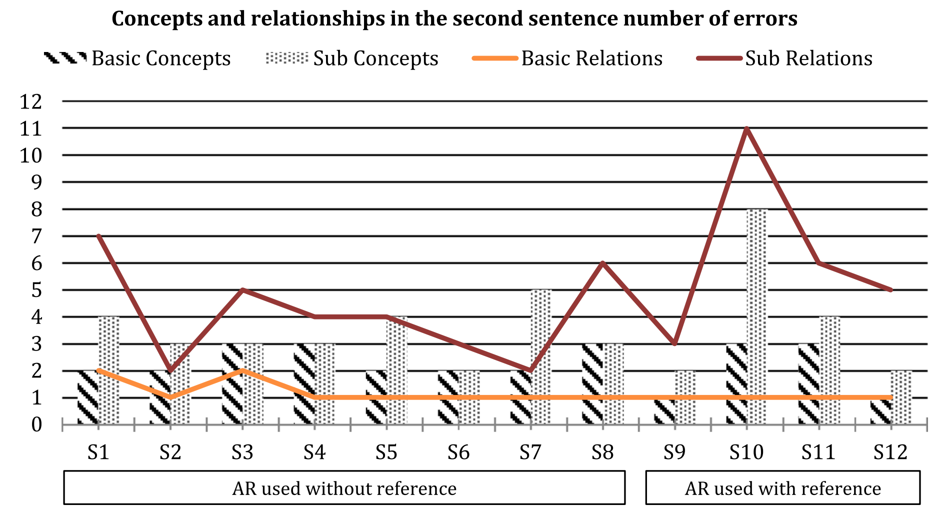


Fig. 7 Number of errors in concept and relationships in the second statement

Figure 8 shows that the students who used AR with reference made fewer errors than the ones who used AR without reference.

Students' academic achievements when using AR-ConMAP

The results of achievement test show that, except one, students' achievement scores were 100. In order to understand the contribution of AR on the acquisitions related to concepts, students' answers for the multiple-choice achievement test were analyzed through the correctness rates. The rates are shown in Table 2.

The achievement test results showed that students' scores were generally high and they were close to each other. Students' average score is 97 with the minimum score (S7 = 70, and S1, S3, S4, S5, S6, S8, S9, S11, and S12 = 100).

Students' evaluations about the effect of using AR in creating concept maps

In order to understand students' experiences in creating an AR-based concept map, two interview questions were directed to all of the students.

Students' explanations and responses about the first question "How did you feel while you were using AR app?" are shown in Table 3.

Three main codes were extracted from students' answers that are enjoyment, focusing, and curiosity. Both of these were noticed when students' were engaging with AR.

The second question was "What were the difficulties you experienced while using the app?" Students' responses were summarized in Table 4.

Table 4 shows that finding relationships and concepts was somewhat difficult. Most of the students expressed that they did not consider the application as difficult.

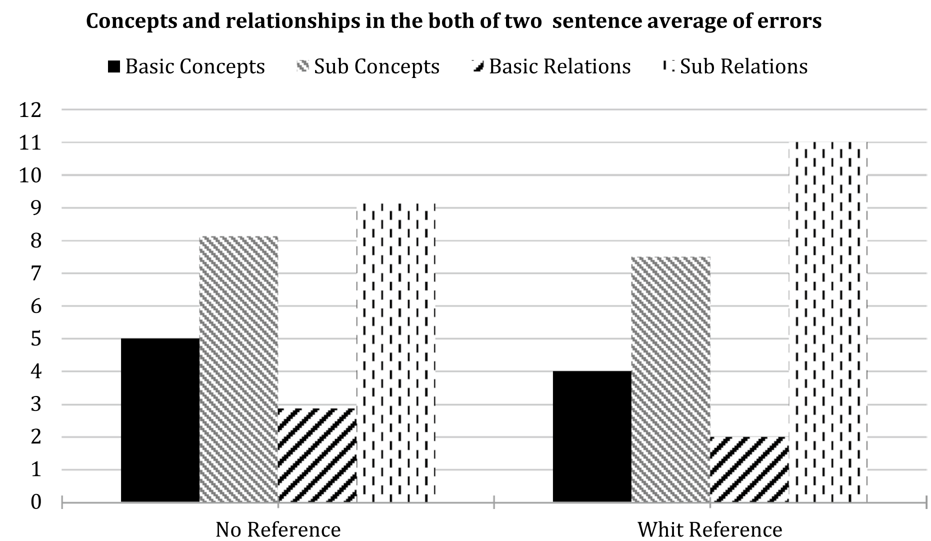


Fig. 8 Average errors in concepts and relationships

Table 2 Correctness rates on the achievement test

Questions	Correctness rate (%)
During a solar eclipse, the moon's shadow falls over the Earth	91
In order for a lunar eclipse to occur, the sun and earth must be in the same direction, and the moon must be in different directions	91
At what stage is the moon in when a lunar eclipse occurs?	100
Which of the following options shows a solar eclipse?	91
In which of the following events is a lunar eclipse observed?	75
At what stage does the solar eclipse occur on the Moon?	100
What regions do the students in the picture live in on earth?	100

Table 3 Student feelings when using AR application

Students' evaluations	*f*	Examples from students' views
Enjoyment	6	S10: "I was excited, I enjoyed following it and I looked to see if I could learn anything from the lesson."
Focusing	4	S5: "When I used it, it was different but wonderful. So it caught my attention and I focused on it."
Curiosity	4	S7: "It was very nice. I found everything very well. I tried to understand how it could help me"

Table 4 Difficulties when using AR app

Difficulties	*f*	Examples from students' views
Finding relations	3	S4: "It was difficult for me to place the writing."
Locating concepts	4	S3: "Locating pictures was difficult, but it was not difficult to locate the words."

Overall, students' evaluations were positive in using their experiences about learning concepts when creating concept maps in terms of enjoyment, focusing, and curiosity. Finding relations and locating concepts were the prominent difficulties in the process.

Discussion and conclusion

In this study, AR is used for creating concept maps to facilitate knowledge representation in the topic of the lunar and solar eclipse in Science and Technology course. Students experienced misconceptions or misunderstandings as they cannot establish the relationship between concepts. The misconceived concepts are difficult to correct, and the learning will be slowed down because of a misconception or misunderstanding experienced by the students. Concept maps are used to facilitate students' independent learning and thinking (Novak & Gowin, 1984).

The results indicated that creating concept maps with AR is more effective in supporting students' concept map creation skills. The students' feelings seem to be positive about the learning through the immersion of AR. In parallel to this finding, another study found that AR could create a highly immersive learning environment and gave students a stronger sense of relevance and allowed them to interact with the virtual objects, enhancing students' sense of identity with the observed phenomena (Cai et al., 2021).

The results suggested that creating concept maps supported with AR provided clues to find the correct locations for the relations and concepts when creating concept maps. AR supported students to create concept maps more accurately and faster by providing instant feedback to users when creating concept maps.

The results also showed that using AR with concept maps facilitated understanding the relationships and sub-concepts and reduced the number of attempts to find the correct locations of them in the concept maps. In this study, showing the relationships on three-dimensional images in text positively affected students' understanding of the relationships. One reason for this may be 3D animating the relationships in the concept maps by AR. This study shows that while creating concept maps, AR not only shows the correct location of a concept but also shows the relationship of this concept with other concepts. For example, in this study, the moon entering between the Sun and the Earth was shown as a relationship in the concept map. Observing this relationship with AR made it easier to understand this relationship. The findings of this study also supported by other studies demonstrated that students were able to shift from misconception to accurate explanation of the content after learning through AR (Danakorn Nincarean et al., 2019). In addition, the results concurred with another study that students who used the concept map via AR provide better learning outcomes in conceptual learning (Chen et al., 2016).

One positive contribution of the AR app in this study was in the emotional dimension. That is to say, focusing, curiosity, and enjoyment were the positive contributions when using AR. One can infer from the students' perspectives that students' emotions were positively influenced with their continuity on creating the concept maps. Similar results were also reported by other researchers about using AR technology for educational purposes in which students' interest and their attention were drawn in the lesson (Delello, 2014; Tomi & Rambli, 2013). Some other researchers also highlighted that using AR increased students' motivation by providing enjoyment (Kerawalla et al., 2006; Perez-Lopez & Contero, 2013; Tomi & Rambli, 2013). Previous studies similarly reported some positive effects of AR such as increasing motivation, providing an understanding of the given content, and ensuring the retention of the learned content (Danakorn Nincarean et al., 2019).

The results also showed that using AR when creating concept maps, visualization triggered schemas on constructing knowledge between previous and current knowledge. This finding was in accord with some previous studies that suggested visualization to learn by abstract concepts (Shelton & Stevens, 2004) and a better understanding of complex concepts (Kaufmann, 2003; Shelton & Hedley, 2002).

The current study concluded that using AR as a teaching tool in concept maps had a positive impact on knowledge acquisition. As a support to this finding, there are several studies in the related literature that reported the effects of AR use on academic success and perceptions of new technologies (Toledo-Morales & Sanchez-Garcia, 2018).

In this study, we implemented the creation process in two ways: AR with a reference which students start with one pre-placed concept (e.g., Sun) and AR without reference. It was aimed to use a reference point so that the student could easily remember, bring back, and find the correct item for the concept they were looking for. Four students were given reference points when creating concept maps, while eight students were not given reference points. Students who used references to compare them were given one concept, and, likewise, checked and compared whether they completed concept maps using clues and AR technology. The results showed that students who used references made fewer mistakes than students who did not use references and reached the correct result.

This study has a few limitations that should be noted. One was the small sample size; it is difficult to generalize the results because of the low number of participants and also the limited concepts included in the study. Notwithstanding, in this way, it was easier for researchers to observe and evaluate the effect of the intervention on small group of students. Due to the limited number of devices used to take screen recordings, a small number of participants were studied as the study focused only on solar and lunar eclipses.

For generalization, future studies to investigate similar constructs with a larger population in different learning contexts are warranted. With both findings and limitations that provide potential avenues for future conceptual understanding or knowledge representation research, this study moves us one step closer to understand that make the abstract concepts concrete by using AR.

Overall, the advantages of using the AR-ConMAP are providing an interesting interactive conceptual learning environment and creating concept maps as knowledge representation tools in a more accurate and understandable manner. As some prior research highlighted, the current study also confirmed that the characteristics of AR technology that can turn abstract learning content and concepts into lively and perceivable dynamic content phenomenon which cannot be directly observed in reality visualized in the classroom (Cai et al., 2021).

Implications and recommendations

In particular, AR supports students to learn the subjects that are abstract and difficult more easily, to increase interest and participation in class, and to correct misconceptions. The results showed that AR supported students to continue with instant feedback in the concept map creation process. Thus, students who did not use AR turned back to the beginning of the concept map and confirmed the relationships between the sub-concepts in their memory. When the students changed at least one concept in this process, they forgot the other parts of the relations between concepts and relations. It requires checking the concepts and hence takes time; therefore, the number of trials is also increased. By using AR, it becomes easier to recall the information in terms of time and the number of attempts.

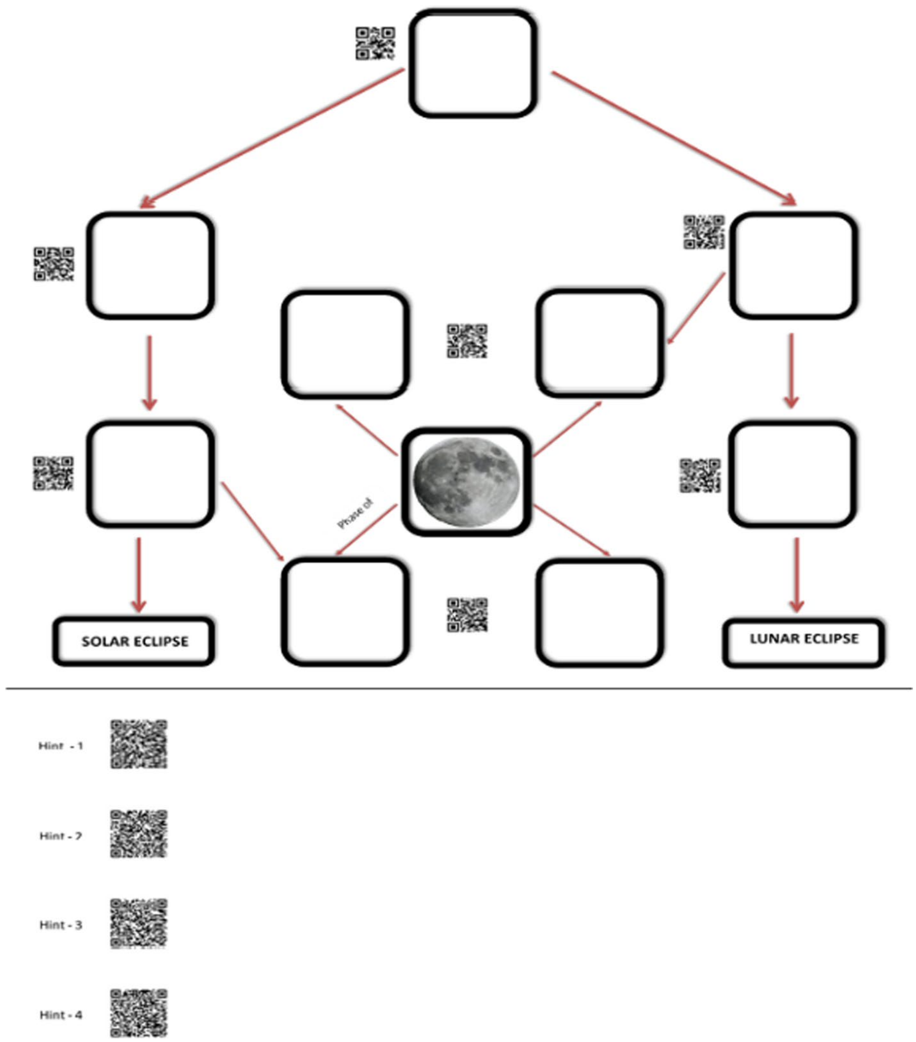
In order to use AR in creating concept maps, when concepts can be animated and the relationships can be easily organized via AR, concept maps can be easily adapted by students and teachers. Accordingly, they can easily be integrated into the science courses with the sense that they are not difficult. Using AR to create concept maps to improve students' conceptual learning is somewhat confirmed in this study. Thus, appropriate instructional packages including new concepts in technology-equipped classrooms can be implemented by teachers. In this study, using AR integrated with concept maps provided us more knowledge about using technology for concept teaching. Similar integration process could be applied when using AR in concept teaching. The context and the size of the concept maps derived from the concepts in the content should also be taken under consideration in order to prepare proper AR applications.

Consequently, some technological problems were noted during the application. It is important for using AR applications with adequate technology, especially to give instant feedback. Thus, poor technology may cause some problems in class management. For instance students without guidance, it was difficult for students to hold the mobile device in their hands and assigning correct QR codes when following the flow of concept maps. In such cases, students' concentrations should be negatively affected and they could be distracted. In particular, there are significant pedagogical issues (for example, the need for more classroom hours, unsuitability in crowded classrooms, instructors' insufficient experience with technology) can be considered as challenges with using AR in classrooms.

To conclude, the results of this study are hoped to provide implications for course designers and instructors who desire to use various knowledge representation ways such as using AR for teaching concepts to provide a better conceptual understanding.

Appendix

Concept map



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Author contributions
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Competing interests
The authors declare that they have no competing interests.

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