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Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis

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ABSTRACT

The aim of this study was to reveal research trends over the last six years by content analysis and to examine bibliometric results of articles related to the use of augmented reality (AR) in science education. For bibliometric mapping analysis, a total of 147 articles were accessed and for content analysis, a total of 79 articles published between 2013 and 2018 years were included from the Web of Science. From this, a total of 62 articles were selected for analysis. Our results revealed that mobile learning, science education, science learning and e-learning were the most used keywords in articles, while the focus of more recent articles tended to be on mobile learning. The results showed that recent articles have mostly focused on mobile learning and e-learning environments. The most-used words in the abstracts were education, knowledge, science education, experiment and effectiveness. It is evident that recent articles have focused mostly on students' knowledge and achievement. Azuma, Dunleavy and Klopfer are the most cited authors in this field. This is not surprising as they are probably the leading authors on AR in the literature. The most cited journals are Computers & Education, Journal of Science Education & Technology, Educational Technology and Society, Computers in Human Behavior, and British Journal of Educational Technology. These are the most prominent journals on the use of technology in education. Content analysis results showed that "Learning/Academic Achievement", "Motivation" and "Attitude" have been the most examined variables in the articles. Since academic achievement is highly influenced by motivation and attitude, it is understandable that these variables are considered together in reviewed studies. It was found that mobile applications and marker-based materials on paper have been the most-favored types of materials for AR because these types of materials are easy to use and they can be developed easily and practically. Quantitative studies were the most used research design type but there have been only a limited number of qualitative studies in the last six years. This may be due to the increased tendency to use quantitative and mixed studies in recent years.

1. Introduction

One indication of the increasing impact of science and technology on education is the rapid development of augmented reality (AR) applications. AR is a technology which uses real-world camera images and virtual objects placed at specific points,

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simultaneously providing for interactions and interpretations through the resulting programs (Azuma, 1997; Kye & Kim, 2008). In an AR application, the real environment is not directly encroached upon: it is an interaction between real world and virtual objects (Erbas & Demirer, 2014). According to the Horizon reports published each year, AR Technology is likely to have a considerable influence on education in the foreseeable future (Cai, Wang, & Chiang, 2014). This was also highlighted in a report published in 2012 which stated that the use of AR in education can make a significant impact during the next 4–5 years. Similarly, others have stated that AR has the potential to effect a transformation in education (Johnson, Adams & Cummins, 2012).

In recent years, AR technology has come to the fore in areas such as mathematics and science, since it enhances students' activity and takes them into an individual learning environment. The combining of virtual and real objects, providing real-time interaction, and presenting 3D objects which are important features of AR technology, results in a different learning experience in which the sense of reality is created (Azuma, 1997; Moreno, MacIntyre & Bolter, 2001). In this way, a permanent learning environment is created which makes the information concrete (Walczak, Wojciechowski & Cellary, 2006). Other benefits of AR technology highlighted in research studies include: the opportunity for experiences which are not available to people in real life (Wojciechowski & Cellary, 2013; Wu, Lee, Chang, & Liang, 2013); increased student participation (Wojciechowski & Cellary, 2013); learning by entertaining (Yoon, Elinich, Wang, Steinmeier & Tucker, 2012); saving time and space (Li, 2010; Ab Aziz, Ab Aziz, Paul, Yusof, & Noor, 2012); raising motivation and attention levels (Ab Aziz et al., 2012; O'Brien & Toms, 2005; Sumadio & Rambli, 2010) and increasing cooperation (Billinghurst, 2002; Yuen, Yaoyuneyong & Johnson, 2011). Another factor is that AR supports approaches such as constructivism, learning by doing, and authentic learning, which serve to make students active in the learning environment (Yilmaz & Goktas, 2017; Kirner, Reis & Kirner, 2012; Wojciechowski & Cellary, 2013; Yuen et al., 2011).

Science is an area of education where AR technology is particularly prominent. Students often have difficulty in learning science subjects because of the abstract concepts they contain (Palmer, 1999). Science lessons enriched with technologies which include visuals for the teaching of phenomena that cannot be easily examined in the class are more effective than traditional science lessons. As a result, students' interest in science is increasing and concrete knowledge of the field of science is provided (Rehmat & Bailey, 2014). Furthermore, simultaneous use of virtual objects and real environments in AR technology makes it easier for students to understand complex abstract concepts (Arvanitis et al., 2009). AR technology, by enabling three-dimensional representation of invisible and difficult-to-visualize events, facilitates the realization of topics and provides an understanding of subjects that students normally find difficult (Wu et al., 2013).

When the literature on AR applications in science education is examined, a number of educational benefits are claimed, such as: positively affecting the attitudes of the students (Cai, Chiang, & Wang, 2013; Sumadio & Rambli, 2010); increasing students' motivation in the lesson (Cai et al., 2013; Sumadio & Rambli, 2010; Wojciechowski & Cellary, 2013); presenting an effective and efficient learning environment (Iordache, Pribeanu, & Balog, 2012) and ensuring the course is fun and achieving the active participation of students (Wojciechowski & Cellary, 2013; Yoon et al., 2012). Other advantages include: providing a sense of reality when learning a subject (Lin & Wang, 2012); providing students with a natural experience in the learning environment (Sumadio & Rambli, 2010) and facilitating learning (Shelton & Stevens, 2004). When comparing the benefits of AR technology in general use in all areas of education and the benefits of its use specifically in science education, it can be seen that many benefits are shared. These are: enhancing students' activity, providing a sense of reality, learning by entertaining, raising motivation and providing an efficient learning environment. This situation reflects the value of using AR technology in science education. For this paper, 62 articles indexed over the last six years in the Web of Science are summarized in Table 1.

Many review studies on AR have been published in recent years. However, there have been only a limited number focused on science with AR. This study set out to provide a review of the literature relating to the use of AR in science education. Bacca, Baldiris, Fabregat, Graf, and Kinshuk (2014) reviewed studies of the use of AR, exploring such aspects as its advantages, limitations, effectiveness, challenges and characteristics in educational environments. Hackett and Proctor (2016) studied anatomy education. Icten and Bal (2017b) examined the AR technology field, highlighting specific aspects of the latest developments and applications. Içten and Bal (2017a) looked at software and hardware features and identified trends in academic studies on AR. Korucu, Usta and Yavuzaslan (2016) focused on studies of AR technology and the determination of fields of study, content, usage, purposes and trends using content analysis. Mortara et al. (2014) examined studies relating to the analysis of complex relationships between type, usage context, technological solutions and learning activity, highlighting the educational objectives of games. Radu (2014) looked at studies examining the influence of AR on learning. Santos et al. (2014) studied learning experiences in relation to AR. Saltan and Aslan (2017) provided a comprehensive overview of the emergence of AR and relevant research on pedagogy and educational output, particularly in the context of formal education. Suárez, Specht, Prinsen, Kalz and Ternier (2018) analyzed work on research-based mobile AR learning applications. A summary of these studies is presented in Table 2.

Table 1
Aims and results of reviewed articles in science education.

Authors & Year	Aim of the Study	Results of the Study	Discipline
Georgiou & Kyza (2018)	To investigate impact of immersion on students' learning and motivation in location-based Augmented Reality settings	Motivation was positively predicted by immersion. Also, conceptual learning gains were positively related to level of immersion.	Biology
Chang & Hwang (2018)	To examine the effectiveness of AR-based learning for science learning activity.	AR-based flipped learning promoted students' project performance and also developed their learning motivation, critical thinking tendency, and group self-efficacy.	Science
Yang, Mei, & Yue (2018)	To explore pre-service chemistry teachers' perception of mobile AR applications for chemical education.	Pedagogical thinking in developing similar educational apps is important factor.	Chemistry
Tom Dieck, Jung, & Rauschnabel (2018)	To examine whether educational, esthetic, escapist and entertainment experiences using AR affect visitor satisfaction and memorable experience.	Users' experience influences satisfaction, memory and the tendency to engage visitors.	Science
Chang, Hsu, Wu, & Tsai (2018)	To determine whether mobile AR technology supported students' socio-scientific reasoning.	Results show the impact of the learning environment on students' scientific knowledge and attitude change. Also, students' post-learning attitudes toward socio-scientific reasoning were dominated by their pre-learning attitudes.	Science
Ozdamli & Karagozlu (2018)	To examine the opinions of pre-school teachers on the use of AR technologies in science education.	AR technology positively influenced learning and teaching processes in preschool education. It also served to draw their attention to the lesson.	Science
Wan, Sun, & Omar (2018)	To evaluate the effectiveness of using mobile AR material for science students in secondary school.	Positive results were obtained in terms of learning, therefore AR can be used as an effective tool in courses.	Science
Ibáñez & Delgado-Kloos (2018)	To investigate the effect of STEM applications on learning by using AR technology.	AR applications offer discovery and simulation activities which stimulate STEM learning.	STEM
Yoon, Anderson, Park, Elinich & Lin (2018)	To investigate the effects of digital, text-based and collaborative designs on learning by interacting with a device.	The AR scaffold has the capacity to access hidden information. Text-based scaffolds have the ability to provide instructions on how to interact with the exhibit. Collaborative scaffolds offer the ability to receive feedback on one's own understanding.	Science
Nuanmeesri (2018)	To develop an AR application to teach the structure of the human heart.	Use of an AR application was found to produce more successful results in terms of learning.	Science
Cheng (2018)	To develop a questionnaire with a view to revealing students' ideas about science learning using AR, through consideration of scientific epistemological beliefs.	AR increases students' motivation and interaction with the course and it has a positive effect on learning.	Science
Gazcón, Nagel, Bjerg, & Castro (2018)	To develop a mobile application that provides a fully virtual 3D terrain of the surrounding environment which can be superimposed onto the real world without an internet connection.	The feasibility of the application was confirmed in the Geology field, and also its potential value to other Earth Science-related fields.	Science
Karagozlu (2018)	To determine the impact of AR applications on the achievement and problem-solving skills of students.	AR applications were found to increase student achievement. Also, the self-control level of students was improved.	Science
Chen & Wang (2018)	To determine students' degree of presence and levels of perception while using AR.	A more satisfactory level of AR perception leads to a higher level of learner presence in the AR environment.	Science
Abdusselam, Kilis, Sahin Cakir, & Abdusselam (2018)	To introduce a sample 5E learning model for middle school students in science laboratory with an AR microscope (named "MicrosAR") to examine microscopic organisms based on inquiry-based learning.	Results indicated that students prefer to use the MicrosAR application and that it can be effectively applied in science lessons.	Science
Oh, So & Gaydos (2018)	To articulate and test a new hybrid AR environment for conceptual understanding.	The results indicated that learners who experienced the game-based simulation before the non-game simulation performed better than where the order was reversed.	Science
Chang & Yu (2018)	To explore the impact of AR on learning outcomes of college freshmen and their knowledge of the biology lab course	Results showed that by integrating AR technology into the instruction, the students took on a more positive autonomous learning attitude; they were able to gain a better grasp of basic biology lab knowledge through the interactive operation as well as cooperative learning	Biology
Wu, Hwang, Yang & Chen (2018)	To develop a mind-tool AR system and determine students' learning achievements, cognitive loads and satisfaction.	The results indicated that the implemented approach can effectively improve students' learning achievements and they rated their own AR learning systems as being highly satisfactory.	Science
Goff, Mulvey, Irvin, & Hartstone-Rose (2018)	To investigate the role of AR in exhibit-based ISE settings (e.g., museums, zoos and aquariums)	It was observed that there was an increase in acquisition, retention and collaboration compared to previous studies. In addition, some studies also observed changes by gender.	Science
Mumtaz et al. (2017)	To compare students' learning and motivation using AR technology in the contexts of blended and classroom learning respectively.	The use of AR had a positive effect on students' learning experience, raising levels of confidence and motivation.	Science

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Table 1 (*continued*)

Authors & Year	Aim of the Study	Results of the Study	Discipline
Moro, Štromberga, Raikos & Stirling (2017)	To evaluate the effects of using Virtual Reality and AR in the field of structural anatomy on student learning, engagement and performance.	There was found to be no significant differences in students' learning between groups. Both virtual reality and AR were beneficial in teaching anatomy using tablet devices. These technologies increased learner immersion and engagement.	Biology
Hung, Chen, & Huang (2017)	To determine the usefulness of AR in teaching. Also, to explore which form of aid (AR graphic book, picture book, or simply physical interaction) serves best to help students' learning.	The AR graphic book was found to offer a practical, hands-on way for students to discover and learn about bacteria. This was their strong preference over other forms of aid.	Biology
Yoon, Anderson, Lin & Elinich (2017)	To examine whether using AR in physics education helps students develop a more accurate conception of Bernoulli's principle.	It was found that students using AR demonstrated greater gains in knowledge.	Science
Montoya, Díaz & Moreno (2017)	To examine effects of AR material using static and dynamic content on students' learning perception and performance.	When using dynamic content, students' learning performance was found to improve and their perception was positive.	Science
Cai, Chiang, Sun, Lin, & Lee (2017)	To investigate the effect of using natural interaction on students' physical learning, attitudes and understanding, compared to traditional learning tools.	AR- based motion detection software was found to improve students learning attitude and learning outcomes.	Physics
Salmi, Thuneberg & Vainikainen (2017)	To reveal the effect of AR on motivation and cognitive aspects of learning and on informal learning.	Using AR in education provides advantages to everyone, particularly groups who previously showed least success, including girls.	Science
Bidarra & Rusman (2017)	To propose a design framework to support science education through blended learning, based on a participatory and interactive approach supported by ICT-based tools, referred to as the Science Learning Activities Model (SLAM).	This study suggested that the use of the SLAM framework as a tool to aid the design of science courses had a high motivational impact on students. The framework is concerned with the assumption that science learning activities should be applicable and relevant to contemporary life and transferable to 'real-world' situations.	Science
Fokides & Atsikpasi (2017)	To learn outcomes from the use of a tablet and an application as content delivery methods for teaching the parts of plants, reproduction types and organs, photosynthesis, and respiration.	Results showed that there were no differences between the groups with regard to students' misconceptions.	Biology
Atwood-Baline & Huffman (2017)	To study the impact of a mobile game on student interactions in a science center.	The results of this study indicate that male and female students achieved and perceived gameplay differently. It was seen that females outperformed males on every measure of game achievement.	Science
Liou, Yang, Chen, & Tarng (2017)	To compare the influence of 2D image-based VR and AR in an inquiry-based astronomy course.	Results indicated that the real objects presented in the AR system reduced mental load because students were able to take the real objects of the AR system as the reference objects for the movement of the moon. Also the sense of immediacy is increased due to the fact that peers are featured on the AR system.	Astronomy
Karagozlu & Ozdamli (2017)	To examine the development process of AR content and student evaluations.	It was concluded that the AR content of science teaching developed during the design-based research process was good, easily applicable and useful.	Science
Garzon, Magrini, & Galembeck (2017)	To evaluate whether the application offered the tools to assemble a metabolic pathway and provided the necessary skills to understand the basic concepts of metabolism.	Several desirable skills were observed in students (such as academic debate, peer review, collaborate learning, meaningful learning etc.)	Biochemistry
Liou, Bhagat & Chang (2016)	To evaluate the highly interactive cloud-classroom system, which incorporates AR and virtual reality in teaching basic materials for science courses.	This study showed that participants in the experimental group who used the highly interactive cloud-classroom system outperformed the control group, in both the post-test and delayed post-test, across three learning dimensions.	Science
Techakosit & Nilsook (2016)	This study aimed to develop the learning process of Scientific Imagineering through AR in order to enhance STEM literacy.	It was concluded that the development of the learning process of Scientific imagineering to enhance STEM literacy was achievable through integration with the AR learning environment.	STEM
McMahon, Cihak, Wright & Bell (2016)	To investigate use of AR for teaching science vocabulary to college students with intellectual disability and autism spectrum disorders	All students successfully learned descriptions and labeling terms using the new science vocabulary.	Science
Chang, Hsu, & Wu (2016)	To compare the effectiveness of AR versus interactive simulation	No significant differences in knowledge and attitude were found, but a significant difference was found between groups' perceptions.	Science
Chang, Chung, & Huang (2016)	To contrast the effect of the ARFlora system and digital video on students' learning about plants (retention, motivation).	ARFlora and digital video were found to have an equal effect on students' learning outcomes. Relatively, ARFlora was more effective in helping students retain learned knowledge and in motivating students to learn.	Biology

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Table 1 (*continued*)

Authors & Year	Aim of the Study	Results of the Study	Discipline
Ferrer-Torregrosa et al. (2016)	To compare the effect of using notes about images, videos and AR applications in terms of students' time spend, learning, metacognitive perception and prospects for future use of AR	AR was found to be effective in all aspects.	Biology
Chen, Chou, & Huang (2016)	To integrate AR with concept maps and examine whether concept-mapped AR helped to improve learning, motivation and attitude in mobile learning activities.	Students using concept-mapped AR performed significantly better than other groups. They also stated that it helped them to organize their learning.	Science
Huang, Chen, & Chou (2016)	To develop an eco-discovery AR-based model (EDALM), based on Kolb's experiential learning theory.	The Eco-discovery AR-based model (EDALS) produced positive emotional responses from the students and better results.	Biology
Hwang, Wu, Chen, & Tu (2016)	To reveal whether an AR-based gaming approach improves students' achievements and attitudes.	The AR- based game approach was found to enhance students' attitudes and learning achievements.	Biology
Akçayır, Akçayır, Pektas & Ocak (2016)	To investigate the effect on students' laboratory skills and attitudes of the use of AR technology.	Students' laboratory skills were found to be positively affected by the use of AR technology.	Science
Martin-Gonzalez, Chi-Poot & Uc-Cetina (2016)	To explain the development and evaluation of an AR system for Euclidean vectors.	Participants displayed a positive attitude towards the use of the AR system to enhance their learning.	Biology
Ibáñez, Di-Serio, Villarán-Molina, & Delgado-Kloos (2016)	To examine methods of improving students' focus on meaningful learning activities.	Learners in the experimental group showed a higher level of learning achievement than the control group.	Physics
Matcha & Rambli (2015)	To investigate how students spend their time when interacting with AR- based systems in a cooperative learning environment.	Students were found to spend more than ninety percent of their time concentrating on task- related activities. They also appreciated opportunities for group learning using AR material. AR's potential to engage and motivate students was confirmed.	Physics
Laine, Nygren, Dirin & Suk (2016)	To contribute (1) concept and architecture of Science Spots AR, (2) design and implementation of the Leometry game prototype, and (3) mixed-method formative evaluation of Leometry.	They confirmed that the platform's concept is feasible, and that there is potential for building science learning games. The results also indicated that AR can be a powerful motivator	Science
Hsiao, Chang, Lin, & Wang (2016)	To enhance students' academic achievement in a natural science course and improve their learning motivation when using the MAR system to carry out inquiry-based learning activities.	Integrating the MAR system into inquiry-based field study made a greater positive impact on students' academic achievement and motivation, compared to the multimedia teaching resources installed on a tablet PC.	Science
Tarng, Ou, Yu, Liou, Liou (2015)	To develop a virtual butterfly ecological system using AR and mobile learning technologies.	This project raised levels of student motivation and interest through close observation activities.	Biology
Ferrer-Torregrosa, Torralba, Jimenez, García & Barcia (2015)	To create a new tool using AR to help investigate the anatomy of the lower limb.	The use of AR in anatomical education was found to be helpful for student motivation, allowing opportunities for autonomous work and for spatial interpretation.	Biology
Stoyanova, Kafadarova & Stoyanova-Petrova (2015)	To clarify the practical use of Mobile Augmented Reality (MAR) applications in transferring knowledge in education.	AR technology triggers students' interest in learning content and encourages their cognitive activity. AR offers a more attractive and fun educational experience.	Science
Chen & Wang (2015)	To develop AR- embedded extensive instruction and to examine its effect on learning in earth sciences.	AR-embedded extensive instruction can enhance adaptability and act to resolve disparities caused by individual differences among learners.	Astronomy
Ibáñez, Di-Serio, Villarán-Molina, & Delgado-Kloos (2015)	To investigate effects of using AR-based simulation on student interaction and learning performance.	It was found that AR simulations were successful in helping students to learn the main principles of electricity.	Physics
Crandall et al. (2015)	To test an AR game focusing on basic enzyme kinetics in food chemistry	AR games can be used to provide learners with multiple perspectives, situated learning, and transfer of learning. It facilitates the transfer of learning from the game to the real world.	Chemistry
Wang, Wu, Chien, Hwang & Hsu (2015)	To identify educational functionalities of TPCs and generated guidelines to design educational apps for science learning.	The test results showed a significant improvement in students' conceptual understanding of the projectile motion and collision of moving objects. It was also found that implementation of the apps was particularly useful for students' understanding of advanced concepts.	Science
Tscholl & Lindgren (2016)	To investigate the social learning affordances of a room-sized, immersive, and interactive AR simulation environment designed to support children's understanding of basic physics concepts in a science center.	The results were in contrast with studies on high-interactive immersive environments that have typically shown that children tend to isolate themselves from their social surroundings, Mixed-reality environments, in contrast, appear to support significant social interaction, while still offering children playful and engaging experiences.	Science
Barma, Daniel, Bacon, Gingras, & Fortin (2015)	To focus on AR as a technological innovation embedded on a tablet.	Conclusions were drawn and discussed in the paper on the thematic interpretation of students' written responses to the evaluation questionnaire, as well as the lessons and observations derived from the in-class experimentation.	Physics

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Table 1 (*continued*)

Authors & Year	Aim of the Study	Results of the Study	Discipline
Gopalan et al. (2015)	To determine the users' perception towards the use of the e− STAR application which combines the existing science textbook and the AR technology.	Outcomes indicate that the users agreed on all the dimensions. Moreover, the experts found that the e-STAR application complies with all the required standards both in terms of the contents as well as the functionality and interface. This study highlights the value of innovative and creative methods for science learning through the utilization of the e-STAR application.	Science
Chiang, Yang, & Hwang (2014a)	To evaluate the effectiveness of AR in an elementary school natural science course.	The AR-based inquiry learning activity was shown to occupy students in more interactions relating to knowledge construction.	Biology
Chiang, Yang, & Hwang (2014b)	To carry out inquiry-based learning activities using an AR-based mobile learning system.	It was shown that the proposed approach can develop students' learning achievements.	Biology
Kamarainen et al. (2013)	To facilitate students' understanding and interpretation of water quality measurement using AR technology.	The use of AR in education presents many advantages for teaching and for learning. Teachers reported that the technology encouraged student interaction and learners showed a deeper understanding of the principles of water quality measurement.	Biology
Yoon, Elinich, Wang, Schooneveld & Anderson (2013)	To ascertain ways of improving learning, conceptual and cognitive results in the context of a science museum using augmented tools.	Results showed that posted questions, together with attendance in cooperative groups, may be the optimal design for improving conceptual learning in this context	Physics
Bressler & Bodzin (2013)	To investigate factors related to student engagement, as characterized by flow theory, during a collaborative AR, involving a forensic science mystery game using mobile devices.	The findings demonstrated a potential for mobile AR science games to increase science interest and help students learn collaboration skills.	Science

This study focuses on uses of AR in science education articles published between 2013 and 2018. These articles have been analyzed in terms of examined variables, used material types for AR, method trends, data collection tools, sampling methods, sample populations, sample sizes and data analysis methods. In addition, a bibliometric mapping analysis was conducted in respect of the most-used keywords, words in abstracts and the most-cited authors and journals in published articles to date. Within the scope of the study, the form of the data collection tool is the determining factor for the handling of the variables examined in content analysis. When trend studies in the literature are considered, it can be seen that the variables examined are similar to those in this study (Akçayır & Akçayır, 2017; Bacca et al., 2014; Baydas, Kucuk, Yilmaz, Aydemir, & Goktas, 2015; Goksu, Ozcan, Cakir, & Goktas, 2017; Goktas et al., 2012; Hwang & Tsai, 2011; Kucuk, Aydemir, Yildirim, Arpacik & Goktas, 2013; Solak & Erdem, 2015; Wu et al., 2012). In addition to the content analysis, the number of variables was increased by the bibliometric mapping analysis. All articles published on the use of AR in science education up to 2019 were examined, and a general evaluation presented. The variables in the bibliometric mapping analysis were limited to the analysis provided by the VOSViewer program. The aim of this study was to reveal any missing or necessary factors by examining methodological research trends over the last six years and the bibliometric mapping analysis results of all related published articles. Through this comprehensive content and bibliometric mapping analysis, it is hoped that our findings will provide a valuable contribution to researchers studying AR applications in science education. It is hoped that this work will prove to be a useful resource for researchers in this field in future. The research questions set out in this study, all of which relate to entries in the 'Web of Science' online literature source, are listed below:

1. What is the distribution of the most used keywords in articles on the use of AR in science education?
2. What is the distribution of the most used words in abstracts of articles on use of AR in science education?
3. Who are the most cited (citation and co-citation) authors in articles on use of AR in science education?
4. Which are the most cited (citation and co-citation) journals publishing articles on the use of AR in science education?
5. What were the variables examined in articles on use of AR in science education?
6. Which material types were used for AR applications in science education?
7. What were the methodological trends in articles on use of AR in science education?
8. What were the most preferred data collection tools in articles on use of AR in science education?
9. What were the most preferred sampling methods, sample populations and sample sizes in articles on use of AR in science education?
10. What were the most preferred data analysis methods in articles on use of AR in science education?

Table 2
Review studies relating to AR in the literature.

Authors	Title of Research	Aim of Research
Cheng & Tsai (2013)	Affordances of Augmented Reality in Science Learning: Suggestions for Future Research	To understand how image-based AR and location-based AR technology could help science learning.
Radu (2014)	Augmented reality in education: a meta-review and cross-media analysis	To analyze papers comparing student learning in AR versus non-AR applications.
Bacca et al. (2014)	Augmented Reality Trends in Education: A Systematic Review of Research and Applications	To review studies focused on investigating such factors as: use of AR, its advantages, limitations, effectiveness, challenges and features in educational settings.
Santos et al. (2014)	Augmented Reality Learning Experiences: Survey of Prototype Design and Evaluation	To review applications intended to complement traditional curriculum materials for K-12.
Koutromanos, Sofos & Avraamidou (2015)	The use of augmented reality games in education: a review of the literature	To examine the use of AR games in education and specifically in the context of formal and informal environments.
Korucu, Usta, & Yavuzaslan (2016)	Using Augmented Reality in Education: A Content Analysis of Studies in the 2007–2016 Period	To investigate studies on use of AR technology in education in terms of their contents, aims and research trends.
Içten & Bal (2017b)	Review of Recent Developments and Applications in Augmented Reality	As stated, to examine the latest developments on AR technology
Içten & Bal (2017a)	A Content Analysis of the Academic Works on the Augmented Reality Technology	To investigate software and hardware features of AR
Agrawal & Patel (2017)	A Review: Augmented Reality And Its Workings	To show how AR works and what the different technologies involved are.
Chen, Liu, Cheng, & Huang (2017)	A review of using Augmented Reality in Education from 2011 to 2016	To review literature on AR in education with regard to its uses, advantages, and effectiveness.
Akçayır & Akçayır (2017)	Advantages and challenges associated with augmented reality for education: A systematic review of the literature	To present a systematic review of the literature on AR as used in education.
Saltan & Arslan (2017)	The Use of Augmented Reality in Formal Education: A Scoping Review	To provide a comprehensive overview of studies related to AR and to focus on pedagogy and educational outcomes.
Altinpulluk (2018)	Examination of theses on augmented reality in turkey through bibliometric analysis method	As stated, to examine theses on augmented reality in Turkey via the bibliometric analysis method
Goff, Mulvey, Irvin & Hartstone-Rose (2018)	Applications of Augmented Reality in Informal Science Learning Sites: a Review	To review applications of AR in informal science learning sites with a view to promoting additional rigorous research in future.
Ozdemir, Sahin, Arcagok, & Demir (2018)	The Effect of Augmented Reality Applications in the Learning Process: A Meta-Analysis Study	To investigate the effect of AR applications in the learning process
Ibáñez & Delgado-Kloos (2018)	Augmented reality for STEM learning: A systematic review	To review the literature on the use of AR technology to support science, technology, engineering and mathematics (STEM) learning.
Palmarini, Erkoyuncu, Roy, & Torabmostaedi (2018)	A systematic review of augmented reality applications in maintenance	To reveal the advantages and disadvantages of AR in this field.

2. Method

2.1. Article selection process

In this study, content and bibliometric mapping analysis was used. The article selection process for both types of analysis is presented under separate headings.

2.1.1. Article selection process for content analysis

Published articles relating to the use of AR in science education between 2013 and 2018 were searched. The literature source was selected as Web of Science and SSCI, SCI-EXPANDED, A&HCI, CPCI-S, CPCI-SSH, and ESCI indexes, as these offer the opportunity to reach easily all SSCI, and other important indexed journals (Akcayir & Akcayir, 2018). The time span was limited to the period from 2013 to 2018. The language was selected as "English" and the document type was determined as "journal articles" for consistent quality. The keywords selected were "*augmented reality*" and "*science*" in the topic section, using the advanced search function. In the first search, a total of 79 articles relating to the use of AR in science education, in the *"education/educational research category"* were reviewed (Access date: May 2019). Full texts of all articles were downloaded. Each article was checked by four researchers, taking inclusion and exclusion criteria into consideration. The first inclusion criterion was that the article was related to science education. The second was whether science-based AR applications featured in the articles. Some articles were not specifically related to science education. Some were review articles or technical articles and these were not included in the scope of the study. Consequently, 62 articles were selected for analysis in this study, from many different journals. The content analysis therefore covers published articles spanning the period 2013 to 2018. The article selection process for this study is summarized in Fig. 1.

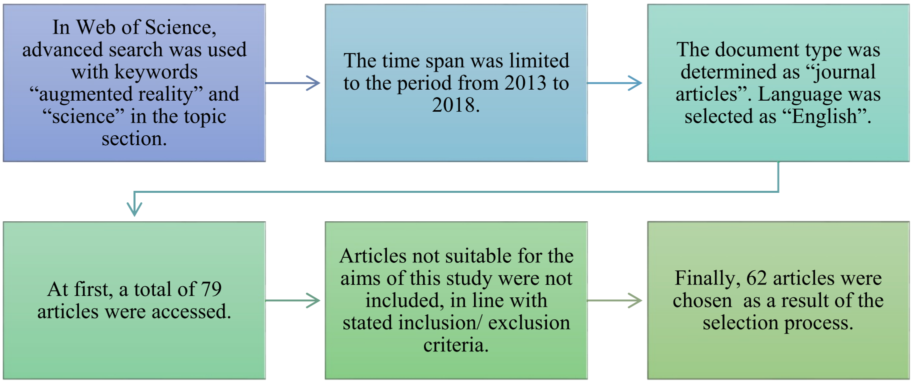

Fig. 1. Article selection process for this study.

2.1.2. *Article selection process for bibliometric mapping analysis*

In order to carry out the bibliometric mapping analysis, the literature source was selected as Web of Science, using the same indexes. However, no particular time span was used. The keywords used for the content analysis were not adopted in this case, as the word "science" is too all-enveloping. Because it would not be possible to examine the articles one by one, all keywords related to science education were used. Using the advanced search function, the keywords entered were "*augmented reality*" in the topic section, a range of commonly-used terms, listed as follows: *"learning for science" OR "education in science" OR "scientific project*" OR "science reading" OR "science center*" OR "science game*" OR "teaching science" OR "elementary science" OR "science class*" OR "earth science" OR "natural science" OR "Museum Science*" OR "science education" OR "science course*" OR "science learning" OR "learning science" OR "science teaching" OR "science content*" OR "science laborator*"*. A total of 147 published articles relating to the use of AR in science education were accessed (Access date: May 2019). Then, full records and cited references were downloaded in tab-delimited (Win) file format. The file was uploaded to the VOSViewer programme. The reason for the difference in the number of articles for the content and the bibliometric analysis is a year limitation in content analysis and the use of more specific keywords in the bibliometric mapping analysis without year limit. The bibliometric mapping analysis covers published articles across all years.

2.2. *Data coding and analysis*

In this study, Goktas et al.'s (2012) Publication Classification Form was used to analyze the selected articles. This form consists of five sections: (1) name of the study, author(s), and title of the journal, (2) methodologies, (3) data collection tools, (4) samples and (5) data analysis methods. For bibliometric analysis, the VOSViewer programme was used in order to reveal network visualization of the most used keywords, words used in abstracts, citation analyses and co-citation analyses in the articles. The data analysis procedure was conducted by four researchers (three doctoral students and one PhD). They studied and discussed the data together during the content analysis process. Consequently, descriptive statistics were used to analyze the findings.

3. Findings

3.1. *Bibliometric mapping analysis findings*

3.1.1. *Most used keywords in the articles related to use of AR in science education*

In order to create a map based on text data for the most used keywords, co-occurrence analysis was used and author keywords were selected. The minimum number of occurrences of a keyword was set as 5 and the number of keywords to be selected was automatically given as 7. The map created is illustrated in Fig. 2. It shows there are three clusters and the most used keyword is 'augmented reality' ($f = 95$). In addition, it is revealed that 'mobile learning' ($f = 18$), 'science education' ($f = 19$), 'science learning' ($f = 8$) and 'e-learning' ($f = 6$) are the most used keywords. These results indicate that the articles mostly focus on mobile learning and e-learning environments. It can be seen that AR studies in science education began to grow in number in 2013, though the first study was published in Web of Science much earlier, in 1999. When the distribution of the number of articles using the keywords by year is shown, it can be seen that recent articles focus mainly on mobile learning. The distribution of the number of the articles by years is presented in Fig. 3.

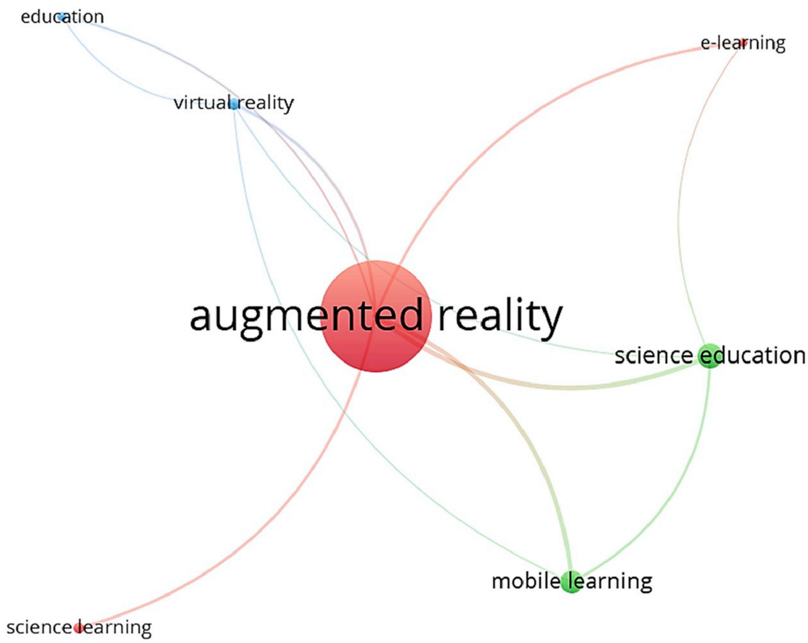

Fig. 2. The most used keywords in articles relating to the use of AR in science education.

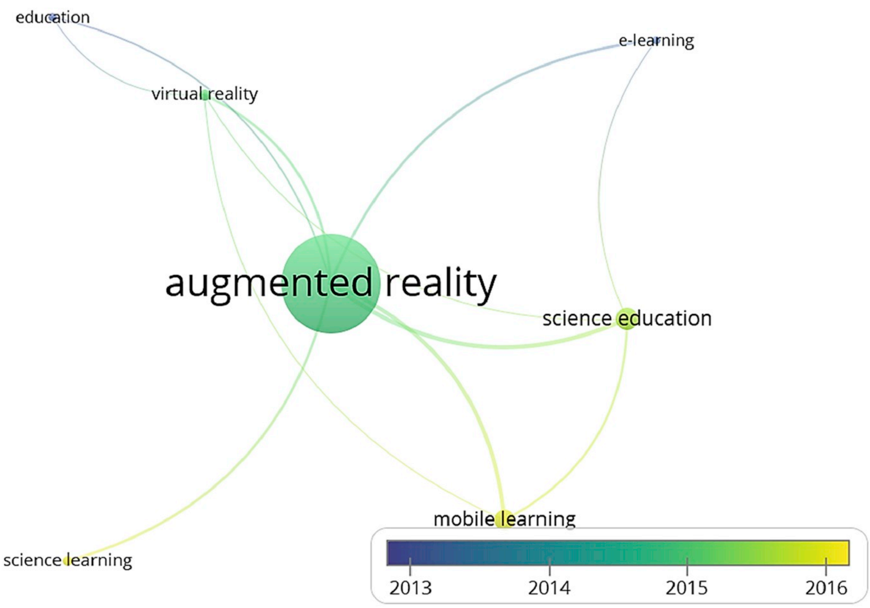

Fig. 3. Distribution of the number of articles using the keywords by year.

3.1.2. Most used words in abstract sections

In order to create a map based on text data for the most used words in the abstracts of articles, the Web of Science bibliographic database file was uploaded into the programme. Then, abstract and binary counting method was selected as field. The minimum number of occurrences of a term was set as 10 and the number of terms to be selected was automatically stated to be 47. The map created from this is given in Fig. 4. It shows three clusters and the word 'reality' is the most used word found in the abstracts ($f = 112$). The most used keywords were found to be: education ($f = 38$), knowledge ($f = 32$), science education ($f = 31$), experiment ($f = 30$) and effectiveness ($f = 20$). These results indicate that the articles mostly focus on students' knowledge, experimental research designs and the effectiveness of AR technology. When the distribution of these words is shown on a year-by-year basis, it is evident that more recent articles tend to focus on students' knowledge and achievement. The distribution of the most used words in abstracts by year is presented in Fig. 5.

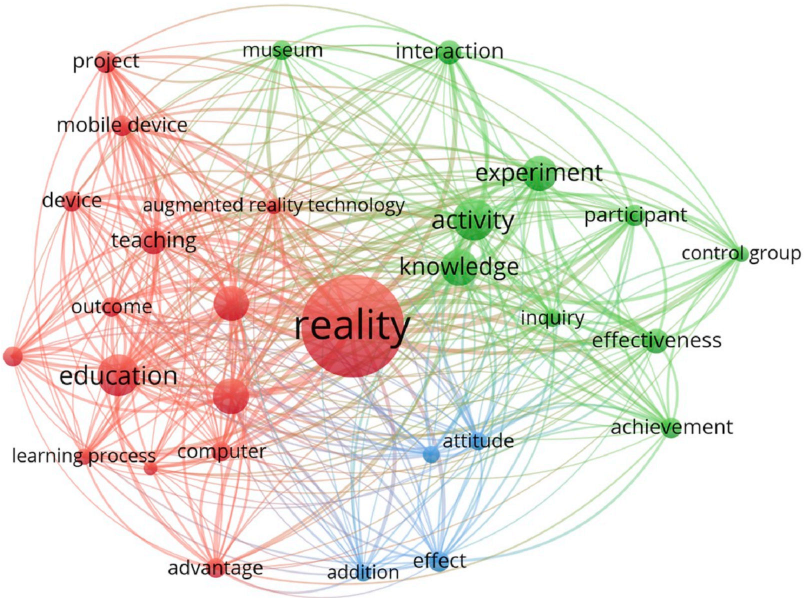

Fig. 4. Most used words found in article abstracts.

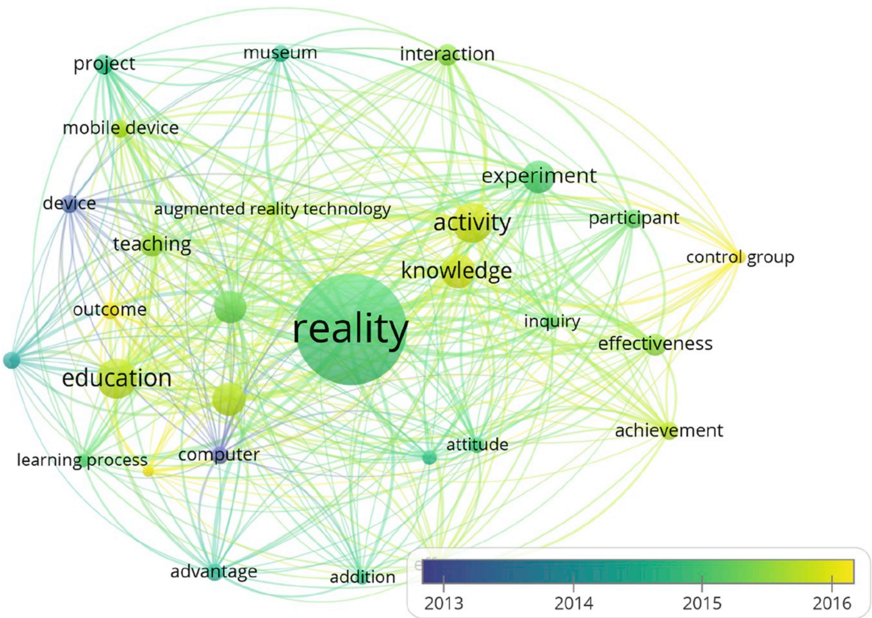

Fig. 5. Distribution of most used words in article abstracts by year.

3.1.3. Most cited authors

In order to create a map for most cited authors, citation analysis and authors were selected. The minimum number of documents by a particular author was set as 3 and the minimum number of citations of an author was determined as 10. The number of authors to be selected was automatically given as 13. The map created is shown in Fig. 6. This indicates that Hsin-Kai Wu (*323 citations*) and

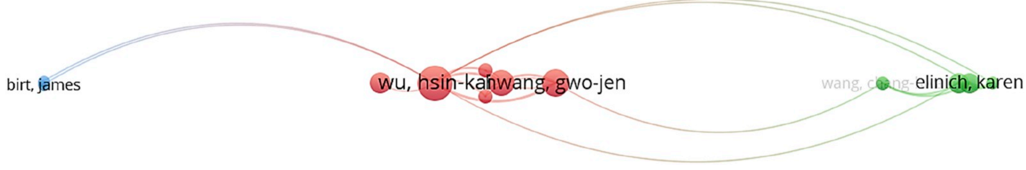

Fig. 6. Most cited authors (Citation analysis).

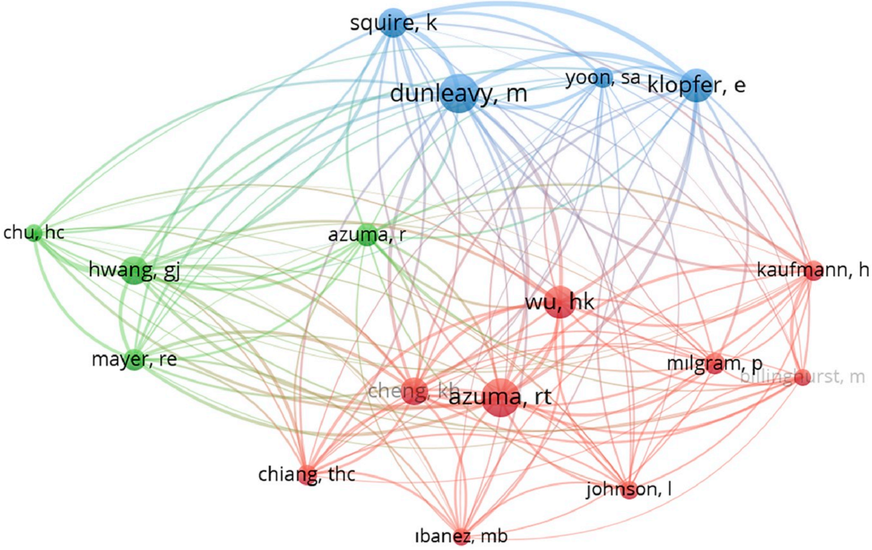

Fig. 7. Most cited authors (Co-citation analysis).

Hwang Gwo-Jen (*148 citations*) were the most cited authors in this field.

In addition, co-citation analysis and cited authors were selected. The minimum number of citations of an author was set as 20 and the number of authors to be selected was automatically given as 17. The map created is stated in Fig. 7. It shows that Azuma (80 *citations*), Dunleavy (53 *citations*) and Klopfer (44 *citations*) are most cited (co-citation) authors in this field.

3.1.4. Most cited journals (citation and Co-Citation)

In order to create a map for most cited journals, citation analysis and sources were selected. The minimum number of documents of a source was set as 3 and the minimum number of citations of a source was also set as 3. The number of sources to be selected was automatically given as 6. The map created from this is presented in Fig. 8. It shows that the most cited journals are Computers & Education (*541 citations, 5 documents*), Educational Technology & Society (*147 citations, 4 documents*) and The Journal of Science Education and Technology (*143 citations, 4 documents*).

In addition, co-citation analysis and cited sources were selected. The minimum number of citations of a source was set at 20 and the number of sources to be selected was automatically stated to be 24. Fig. 9 shows the resulting map. It shows that the most cited journals are Computers & Education (*397 co-citations*), The Journal of Science Education & Technology (*123 co-citations*), Educational Technology and Society (*95 co-citations*), Computers in Human Behavior (*73 co-citations*), and British Journal of Educational Technology (*60 co-citations*).

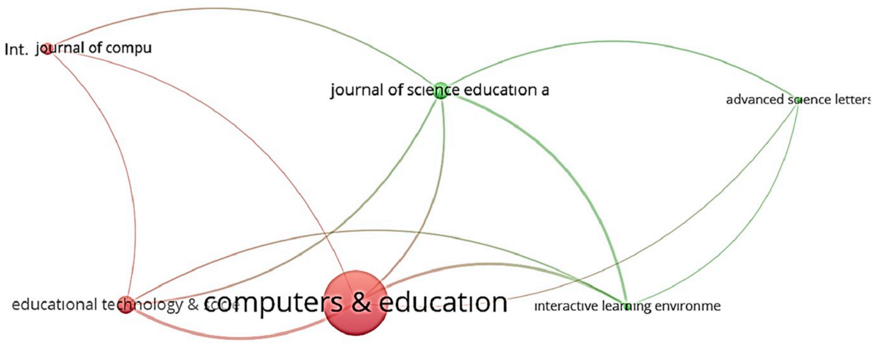

Fig. 8. The most cited journals (citation analysis).

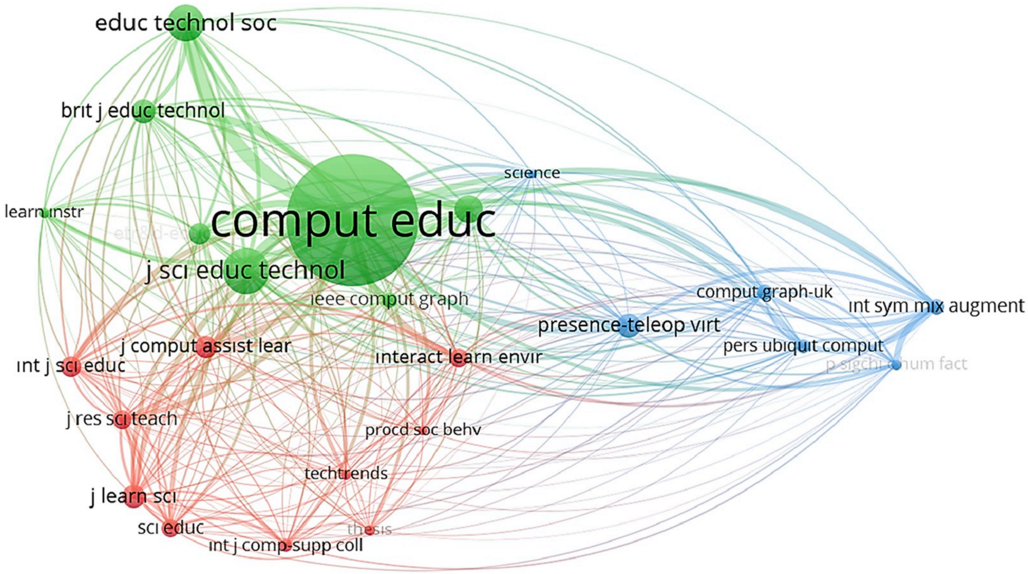

Fig. 9. Most cited journals (co-citation analysis).

3.2. Content analysis findings

3.2.1. Examined variables in the articles on the use of AR in science education

The examined variables were explored as a category in this review and the results are shown in Table 3. Because one study can indicate more than one advantage, the total frequency is high. The results show that the major advantages indicated in the articles are: “Learning/Academic Achievement” (*f* = *32*), “Motivation” (*f* = *12*) and “Attitude” (*f* = *9*). Also, many other variables such as social factors, emotional improvement, retention, behavior analyses, learning styles, laboratory skills, engaging time, ease of use, engagement, enjoyment and fun were all examined in the reviewed articles.

Table 3
Frequency of the examined variables in the articles.

Examined Variables	Number of articles	Percentage (%)
Learning/academic achievement	32	51.61
Motivation	12	19.35
Attitude	9	14.52
Cognitive aspect	3	4.84
Perception	3	4.84
Usability	3	4.84
Self-regulation	1	1.61
Flow	2	3.23
Immersion	1	1.61
Critical Thinking	1	1.61
Group Self-Efficacy	1	1.61
Engagement	1	1.61
Interest	1	1.61
Scientific Epistemological Beliefs	1	1.61
Problem-Solving Skills	1	1.61
Presence	1	1.61
Scientific Imagineering	1	1.61
Misconceptions	1	1.61
Interaction	1	1.61

3.2.2. Used material types for AR

Used material types for AR in science education were examined in the reviewed articles. Mobile applications (*f* = *42*) and marker-based materials on paper (*f* = *10*) were the most-preferred options. Also, some articles referred to the use of AR picture books, Kinect and AR game systems. Related results are indicated in Fig. 10 below.

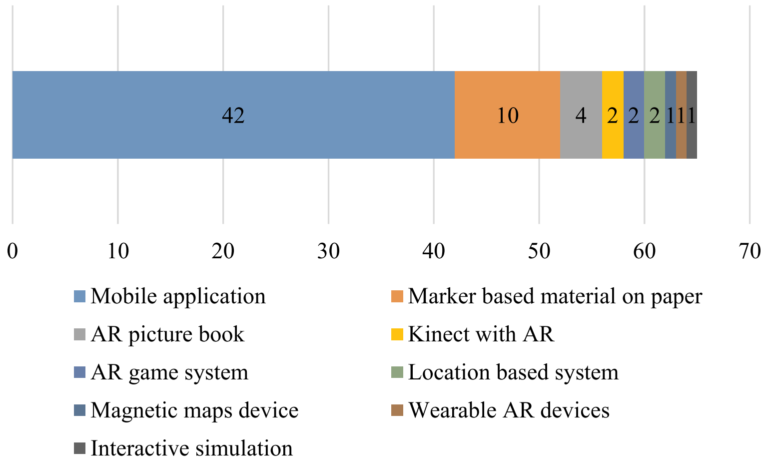

Fig. 10. Frequency of material types used for AR in science education as stated in the articles.

In Fig. 10, 'Mobile application' means AR applications used in mobile phones, 'AR picture book' means AR applications that are designed in book form, defined virtual objects are based on the visuals in the book, and 'AR game system' means AR applications placed in a computer or mobile game. Also, "Marker based material on paper" refers to AR applications developed using images on paper and "Location based system" denotes AR applications using location with the help of GPS. Although many material types in Fig. 10 are developed with mobile systems, these are labelled differently because these material types are mentioned specifically in articles. For example, if the article says mobile AR application is used, the mobile application material type is mentioned. If the article says AR picture book is used, the AR picture book material type is selected. The Magnetic Maps device is an AR application which enables students to see how the magnetic field responds to their various actions, allowing users to adapt the device to their own requirements. "Kinetic with AR" indicates AR applications developed using motion-sensing technology. Finally, 'Wearable AR device' means AR applications adapted for use with wearable technologies and 'Interactive simulation' refers to simulation applications supported by AR technology.

3.2.3. Method trends

According to Fig. 11, 81% of the articles used quantitative design, 3% used qualitative design, 10% used mixed design and 6% preferred review/meta-analysis research. Quasi-experimental (55%) and pre-experimental designs (11%) were most preferred among experimental quantitative methods. Among the mixed methods, triangulation was the most preferred design (8%). Between 2013 and 2018, there were only two articles published which used qualitative design. Methodological trends are presented in Table 4.

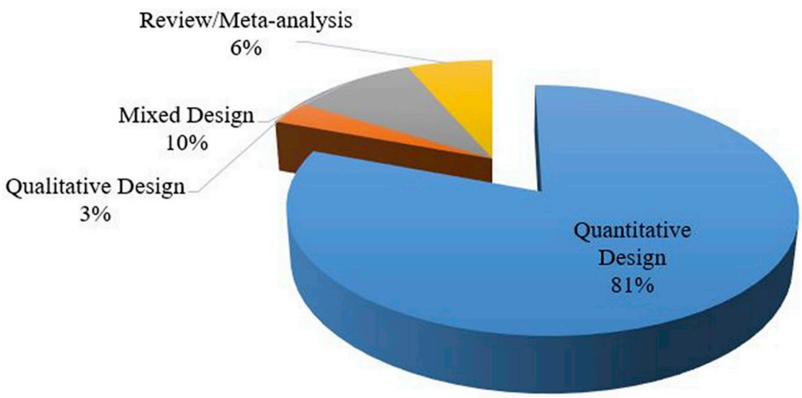

Fig. 11. Frequency of use of research methods in last six years.

Table 4
Method trends in articles on use of AR in science education by year.

Research Methodologies		Research Methods	2013–2015	2016–2018	2013–2018	
			f	f	f	%
Quantitative	**Non-experimental**	Descriptive		2	2	3.23
		Correlational		2	2	3.23
		Total		**4**	**4**	**6.45**
	Experimental	Quasi-experimental	9	25	34	54.84
		True experimental		4	4	6.45
		Pre experimental	4	3	7	11.29
		Single Subject		1	1	1.61
		Total		**33**	**46**	**74.19**
Qualitative		Phenomenological Study		1	1	1.61
		Case Study		1	1	1.61
		Total		**2**	**2**	**3.23**
Mixed		Triangulation	1	4	5	8.06
		Explanatory	1		1	1.61
		Total		**4**	6	9.67
Other		Literature review		4	4	6.45
		Meta-analysis			0	0.00
		Total		**4**	4	6.45
Total			**15**	**47**	**62**	**100**

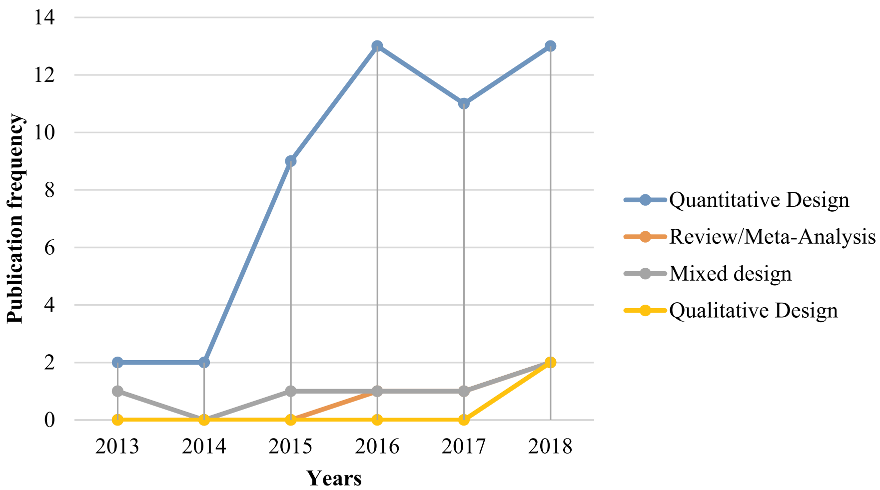

Fig. 12. Distribution of research method by year.

With regard to the distribution of research methods over the years, the use of quantitative methods increased in the period from 2014 to 2016. Fig. 12 shows quantitative design was used most commonly between 2016 and 2018. Review and mixed design showed no variation in distribution over time. Qualitative design began to be used after 2017. In 2018, the most used research method found in articles is quantitative design.

3.2.4. Data collection tools

The findings show that achievement tests (74%), questionnaires (47%), surveys (44%), and interviews (34%) were commonly used in the articles. Regarding the distribution of data collection tools over the years, achievement tests have been used throughout

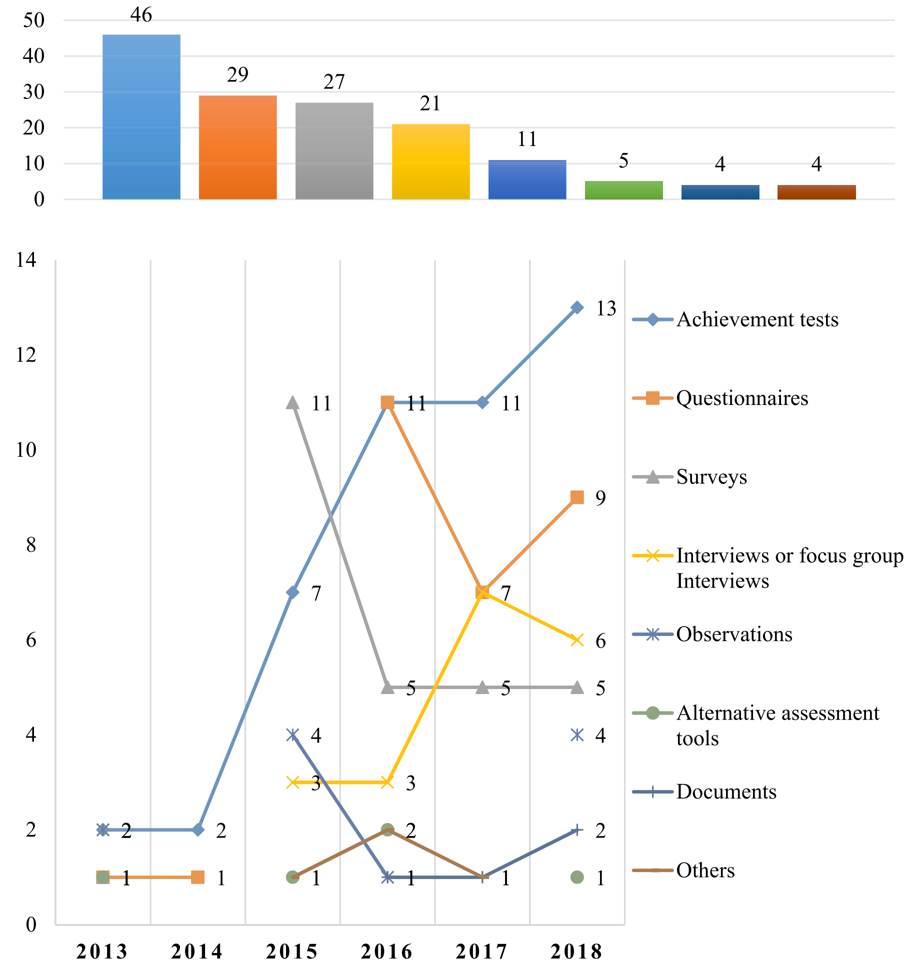

Fig. 13. Frequency of use of data collection tools and their distribution by year.

the period. The use of interviews increased in the period from 2016 to 2017. Surveys were used most commonly in 2015. The frequencies of the data collection tools and their distribution by year are given in Fig. 13.

3.2.5. Sampling methods, sample populations, and sample sizes

As can be seen in Fig. 14, the most commonly used sampling method is convenience sampling (56%). With regard to the distribution of sampling methods over the years, convenience sampling has been used throughout. The use of the random sampling method began to increase in 2017. The 31-100-person group (50%) was the most preferred sample size in articles published between 2013 and 2018, as stated in Fig. 15.

Primary (5–8th grade) students (31%) and primary (1–4th grade) students (23%) were commonly preferred as sample groups. Undergraduate students (3%), documents (5%), teachers (2%) and faculty members (2%) were the least chosen as sampling groups. Detailed information on frequency of use of sampling groups is given in Table 5. The distribution of the sampling groups by year is indicated in Fig. 16. This shows that studies with primary (5–8th grade) students began to increase from 2016 to 2018. Graduate students were used most commonly in 2016.

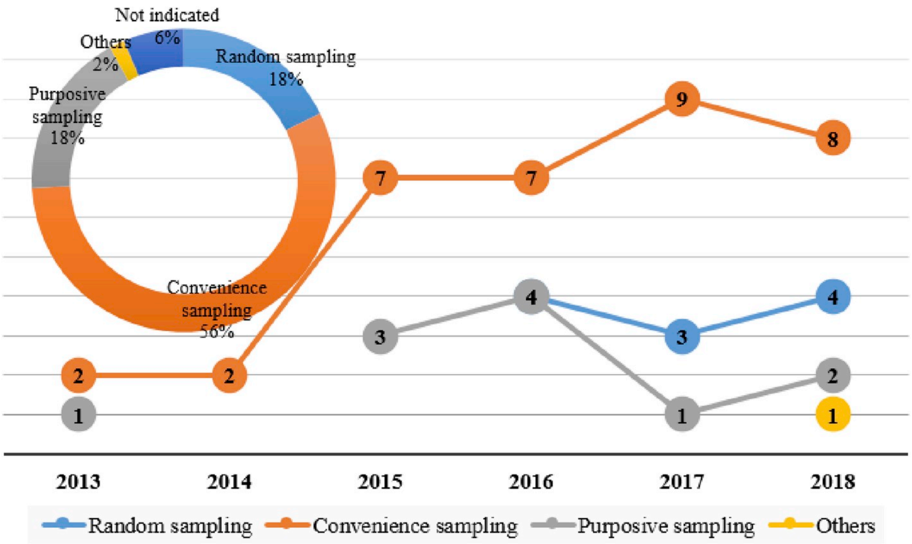

Fig. 14. Frequency of use of sampling method in articles and their distribution by year.

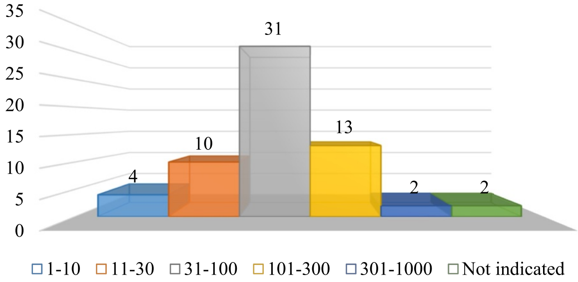

Fig. 15. Frequency of use of sample sizes in articles.

Table 5
Frequency of use of sampling groups in articles.

Sampling groups	2013–2018	
	N	%
Primary (5–8th grade) students	19	30,6
Primary (1–4th grade) students	14	22,6
Graduate students	13	21,0
Secondary (9–12th grade) students	10	16,1
Documents	3	4,8
Undergraduate students	2	3,2
Faculty members	1	1,6
Teachers	1	1,6

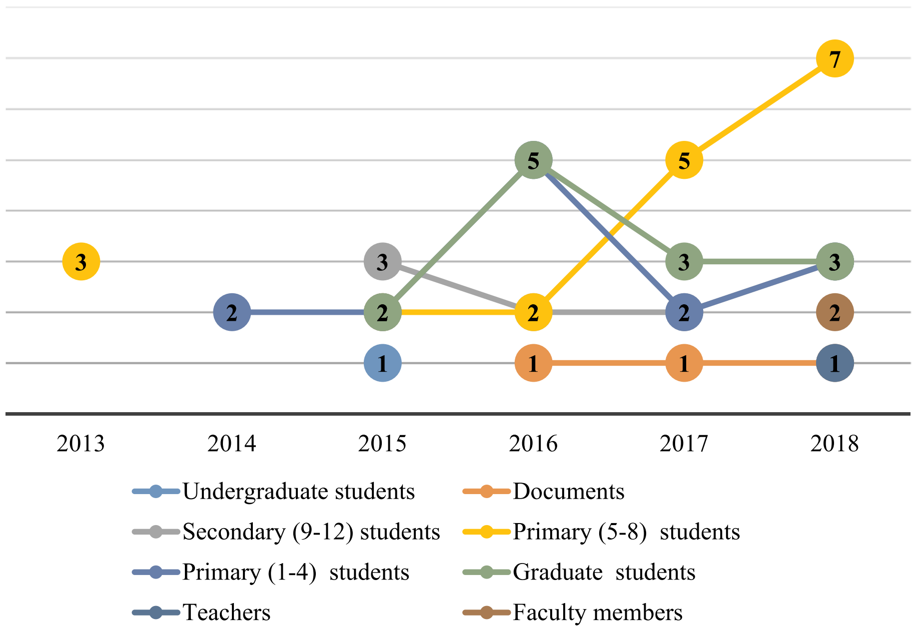

Fig. 16. Distribution of sampling groups by year.

3.2.6. Data analysis methods

The study shows that the most conducted data analysis methods were use of frequencies, percentages, tables (47%) and means, standard deviations (44%). The most commonly-used inferential techniques were T-tests (34%), ANOVA/ANCOVA (26%) and non-parametric tests (16%). The most used qualitative data analysis methods were content (26%) and descriptive analysis (21%). Detailed information regarding data analysis methods is presented in Table 6.

Table 6
Distribution of data analysis methods in articles.

		2013–2015	2016–2018	2013–2018	
		f	f	f	%
Descriptive analyses	Frequencies, percentages, tables	5	24	29	46.77
	Means, standard deviations	4	23	27	43.55
	Graphs	2	9	11	17.74
Inferential analyses	T-tests	4	17	21	33.87
	ANOVA/ANCOVA	5	11	16	25.81
	Non-parametric tests	3	7	10	16.13
	Correlations	1	6	7	11.29
	Others	0	3	2	3.23
	Regression	1	2	3	4.84
	MANOVA/MANCOVA	0	2	2	3.23
	Factor Analysis	0	1	1	1.61
Qualitative Analyses	Content Analysis	4	12	16	25.81
	Descriptive Analysis	3	10	13	20.97
	Others	1	1	2	3.23

4. Discussion

In this study, methodological research trends over the last six years were revealed, together with the results of bibliometric analysis of articles related to the use of AR in science education. This involved bibliometric mapping analysis and content analysis. Bibliometric analysis results showed that the most used keywords in articles relating to the use of AR in science education were: augmented reality, mobile learning, science education, science learning and e-learning. The results showed that the articles mostly focused on mobile learning and e-learning environments. When the distribution of the number of articles using the keywords was considered on a year-by-year basis, it was apparent that recent articles were mainly focused on mobile learning. These findings can be explained by the increase in the availability of mobile technologies everywhere in the world. This is confirmed by Traxler (2009), who asserts that the use of these technologies has increased and has also improved mobile learning. Chen et al. (2017) found similar results in their study and stated that mobile technologies are mostly used for AR technology. In addition, Goff, Mulvey, Irvin and Hartstone-Rose (2018) stated that mobile technologies have an advantage in terms of cost and benefit. This explains why there are so many studies on mobile learning and e-learning. Also, the most used words in abstracts were reality, education, knowledge, science education, experiment and effectiveness. This indicates that the articles mainly focus on students' knowledge, experimental research designs and the effectiveness of AR technology. When distribution of these words is examined on a yearly basis, it is evident that recent articles focus mainly on students' knowledge and achievement. When the review study by Yilmaz (2018) on the use of AR in education between the years 2016 and 2017 is examined, it can be seen that the articles frequently focused on the effectiveness of AR and that academic achievement was the most studied variable. This is to be expected since experimental studies of this kind are generally carried out when investigating effectiveness. According to Cheng and Tsai (2013), AR technology in the field of education is not yet well-developed, so experimental studies are preferred. This explains why the words obtained from bibliometric analysis are repeated more. According to the citation and co-citation analysis, Azuma, Dunleavy and Klopfer were the most cited authors in this field. This is not surprising as they are probably the leading authors on AR in the literature. The most cited journals were Computers & Education, The Journal of Science Education and Technology, Educational Technology & Society, Computers in Human Behavior and British Journal of Educational Technology. These are the most prominent journals on the use of technology in education. Chen et al. (2017) reviewed articles relating to the use of AR in Education in these journals.

Content analysis results showed that “Learning/Academic Achievement”, “Motivation” and “Attitude” were the most examined variables in the articles. This is as expected since these are the variables most often featured in research (Chang, Chung, & Huang, 2016; Chang, Hsu, & Wu, 2016; Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015; Hwang et al., 2016; Mumtaz et al., 2017; Tarng et al., 2015). Therefore, the findings obtained in this study are supported by the literature (Borrero & Marquez, 2012; Cai et al., 2013; Hsiao, Chen, & Huang, 2012; Hwang et al., 2016; Foncesa, Martí, Redondo, Navarro & Sánchez, 2014). Since academic achievement is highly influenced by motivation and attitude, it is understandable that these variables are considered together in reviewed studies (Boyd, 2002; Klomegah, 2007; Wang, 2004; Yenilmez & Özabacı, 2003). As AR is a newly-emerging technology, it is important to understand attitudes towards it. Furthermore, motivation and attitude are important factors affecting intention to use new technologies (Baydas & Goktas, 2016). There are many studies in the literature examining the effect of AR applications on motivation and attitude. The findings obtained in this context are supported by the literature (Sirakaya & Alsancak Sirakaya, 2018; Pérez-López & Contero, 2013; Delello, 2014; Furió, Juan, Segui & Vivó, 2015; Akçayır et al., 2016; Hsiao et al., 2012; Hwang et al., 2016). A crucial question when introducing any new technology into education is whether or not it contributes to academic achievement (Middleton & Murray, 1999). A number of studies investigating the effects of AR applications on academic achievement can be found in the literature, and they tend to support the findings obtained in this study (Cai et al., 2014; Chen & Wang, 2015; Núñez et al., 2008; Zhang, Sung, Hou & Chang, 2014). This study also showed that mobile applications and marker-based materials on paper were the most-favored material types for AR, probably because these types of materials are easy to use and they can be developed easily and practically.

Quantitative studies (81%) were the most used research design type. The reason for using quantitative methods is likely to stem from researchers' concern to test objectively the effects of AR technology on students learning (Hranstinski & Keller, 2007). This assumption is supported by the further result that quasi-experimental (55%) and pre-experimental design (11%) were the most preferred methods in the articles. Experimental studies are used in situations where the effect of a particular factor is examined. Since educational studies, by its nature, is more appropriate for quasi-experimental studies (Mcmillan & Schumacher, 2014), it is thought that experimental studies have been conducted to investigate the effect of AR in the last six years of research. In addition, the use of quantitative methods is generally time and cost-effective. Therefore, quantitative methods might be preferred for this reason. The percentage for the use of mixed methods studies was low, reflecting the fact that these studies are difficult to conduct and take time (Küçük et al., 2013). One important finding was that there have been few qualitative studies in the last six years. This may be due to the increased tendency to use quantitative and mixed studies in recent years (Bacca et al., 2014; Chen et al., 2017). In addition, fulfillment of qualitative studies related to AR can also be a cause of this situation (Hew, Kale, & Kim, 2007; Ross, Morrison, & Lowther, 2010).

According to the findings, achievement tests, questionnaires, surveys and interviews, were the most used data collection tools. The tendency for mostly quantitative designs to be used meant an increased preference for these tools. The relatively high popularity of interviews was due to the extensive use of mixed methods in the studies. With regard to the distribution of data collection tools over the years, achievement tests were used throughout this period. Academic achievement emerges as the most examined variable in articles in this study. Also, it was among the most studied variables in the literature (Chang, Chung, et al., 2016; Chang, Hsu, et al., 2016; Ferrer-Torregrosa et al., 2015; Hwang et al., 2016; Mumtaz et al., 2017; Tarng et al., 2015). Correspondingly, the widespread use of achievement tests is no surprise. The use of interviews increased in the period from 2016 to 2017 and surveys were used most commonly in 2015. These findings are similar to those of the study conducted by Altınpulluk (2018). Bacca et al. (2014) observed that the most used data collection tools were surveys and interviews. Chen et al. (2017) found that tests, interviews, video observations and surveys were mostly preferred in studies. Korucu et al. (2016) stated that, respectively, the most used tools were documents, surveys, interviews and achievement tests. The differences in results in these studies may be assigned to variations in such factors as databases, sampling, and time intervals. The most preferred sampling method was convenience sampling (56%). This method is preferred as researchers can easily access the sample group (Baydas, 2015). Regarding the distribution of the sampling method over the years, convenience sampling has been used throughout the period, while use of the random sampling method has increased since 2017. As quasi-experimental studies are generally the most used, it is expected that the convenience sampling method will be preferred. Also, the 31-100-person group (50%) was found to be the most preferred sample population. This may be due to the preference for using quantitative designs in studies. Primary (1–4th grade) students (23%) and primary (5–8th grade) students (31%)

were commonly preferred as sample groups. This can be explained by the fact that AR applications attract more attention from primary school students (Joo-Nagata, Abad, Giner & García-Peñalvo, 2017; Kamarainen et al., 2013; Obregón, 2014, pp. 65–66; Ramirez & Cassinerio, 2014). Studies with primary (5–8th grade) students showed an increase in the period from 2016 to 2018. However, graduate students were most commonly used in 2016. In contrast to our study, Altınpulluk (2018), Chen et al. (2017) and Korucu et al. (2016) found that graduate students were the most used sample group. With regard to data analysis methods, frequencies/percentages/tables and means and standard deviations were the most commonly used over the last six years. T-tests (34%), ANOVA/ANCOVA (26%) and non-parametric tests (16%) were commonly used as inferential techniques. These results can be explained by the frequent use of quasi-experimental designs in quantitative research (Baydas, 2015). The most used qualitative data analysis methods were content (26%) and descriptive analysis (21%). Content analysis may be preferred as it tends to give more detailed results than descriptive analysis (Creswell & Clark, 2017). In this case, it may be that the researchers concentrated on the content analysis method in order to explain in depth the data they obtained.

Some suggestions based on the findings of our study are presented below:

- As past studies on the use of AR in science education have often focused on learning/academic achievement, motivation and attitude, it is thought that examination of these variables may now be reaching saturation point. It may be more beneficial in future to focus on cognitive issues, interaction and collaborative activities beyond these variables.
- There are many applications made with mobile technologies and material types of marker-based on paper in the literature. Interactive AR applications using technologies such as Kinect, the internet of things, and virtual reality make a useful contribution to AR science studies in the literature.
- Studies of mobile learning and e-learning should be focused in future on AR supported science education since these issues are appearing more frequently as trend topics in recent years.
- Experimental studies have become increasingly used in the last six years and it is expected that this trend will continue in future. In addition, it is likely that there will be significant benefits if the number of studies using mixed designs is increased in the field of science education.
- A key finding is that there has been a very limited number of qualitative studies in the last six years. It is suggested that more qualitative research should be conducted in future in order to obtain more in-depth information on the use of AR in science education.
- Achievement tests, questionnaires and surveys are often used as data collection tools. It is recommended that alternative assessment techniques are used in future.
- AR studies in science education are generally carried out at primary, secondary and university level. However, pre-school education is an area which has been largely neglected. This may be an important sample group for future studies, particularly with regard to the teaching of basic science concepts. Students with disabilities are another group which may benefit greatly from participation in AR-based learning. Further studies are needed to evaluate opportunities for these groups in future, particularly with regard to science education.

Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical approval

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

Informed consent

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

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