# VR/AR in K-12 Science Education

Subjects: Education & Educational Research
Contributor: Zhuo Wang

virtual reality (VR) and augmented reality (AR) are increasingly capturing educators' and learners' attention. In particular, VR is defined as a real-time graphical simulation in which the user interacts with the system via analog control, within a spatial frame of reference and with user control of the viewpoint's motion and view direction. It first appeared in 1966 and was used in the design of US Air Force Flight Simulator. Developed from VR, AR is a technology used for improving users' perception of the real world by dynamically adding virtual elements to the physical environment. It made its debut in the 1990s, which was initially proposed by scientists from Boeing, an aircraft manufacturer, where they mixed virtual graphics with real environment displays to help aircraft electricians assemble cables.

Keywords: virtual reality ; augmented reality ; K-12 science education

## 1. Introduction

### 1.1. Augmented Reality/Virtual Reality(AR/VR) Applications and Beliefs

Science education for primary and secondary school students are facing a variety of challenges nowadays. On the one hand, scientific knowledge often contains a large number of abstract and complex concepts [1], which is difficult for children and adolescents to internalize, even with the help of words and 2D images [2][3]. For example, food digestion has been documented as an essential topic in many countries' primary school science curriculums [4][5][6], but without vivid animation, it can be overwhelming for students to obtain accurate understanding with their pure imagination. On the other hand, implementing real scientific experiments is often bounded by reality conditions, such as a lack of materials, high cost for necessary equipment, safety risks, or difficulties in geographical distance [7].

To tackle the above challenges, researchers have resorted to computing technologies, which are suggested should play a crucial role in student learning [8], comprehension of science concepts, as well as scientific reasoning skill development [9][10]. This is especially true for Generation Z, who have been born in the digital era, and have technologies permeated into virtually every aspect of their lives [11]. The way Gen Z processes information requires educators to not only teach with basic technologies, but capitalize the full potential of e-learning 4.0 [12], which is more personalized, data-based, and gamified [13]. For instance, instead of viewing pictures of digesting organs, students may use Google Board to view food digestion in action, and see clearly how food is processed in each organ with the naked eye. Among all advanced computing technologies, virtual reality (VR) and augmented reality (AR) are increasingly capturing educators' and learners' attention. In particular, VR is defined as a real-time graphical simulation in which the user interacts with the system via analog control, within a spatial frame of reference and with user control of the viewpoint's motion and view direction [14]. It first appeared in 1966 and was used in the design of US Air Force Flight Simulator [15]. Developed from VR, AR is a technology used for improving users' perception of the real world by dynamically adding virtual elements to the physical environment [16]. It made its debut in the 1990s, which was initially proposed by scientists from Boeing, an aircraft manufacturer, where they mixed virtual graphics with real environment displays to help aircraft electricians assemble cables [17].

As VR and AR technologies mature, they are gradually being applied in other domains, including education. For example, in order to teach the basic concepts of electromagnetism, researchers created an AR application so that students could explore the effects of magnetic fields [18]. Another example is that the system developed by VR technology simulated the movement of the Earth around the Sun, which could enable learners to better understand how seasons formed [19]. Since then, the positive effects of AR/VR integration have been documented in numerous studies, mainly including improved authenticity, increased animation, elevated interaction, enhanced student engagement, as well as reduced costs [20][21][22][23][24][25][26].

First of all, VR/AR can mimic authentic conditions to great extent, such as touring spots, planets or even body organs. For instance, they can enable learners to "reach" places that are difficult to reach in reality [20], and present the structure of cells, molecules and other microscopic objects [21], or the motion of large-scale cosmic objects right in front of their eyes [19]. Secondly, VR/AR can vividly demonstrate the occurrence of phenomenon or a process that may not be visible to naked eyes [22], and help learners better understand abstract scientific concepts with little or no oral explanation [23]. For example, while magnetic lines of force are real but invisible, VR/AR can help learners visualize the magnetic field line, and be aware of its existence and possible effects on human beings or everyday objects. Thirdly, VR/AR allows learners to manipulate objects to reflect authentic outcomes without suffering from real danger or risks of conducting experiments with especially hazardous or explosive chemicals [24]. For example, students can view the consequences of chemical mixtures in the environment created by VR without worrying about the danger of explosion. Fourthly, VR/AR provides richer sensory experience that is more attractive and interesting than pure narrative, text or pictures [22]. For example, students may not feel as excited or thrilled when watching a video of undersea scenes as those who experience with VR/AR equipment to explore creatures under the sea. VR/AR may also be used as a tool for game-based learning, which can stimulate learners' learning interest by presenting interactive games that they can navigate through using hand gestures, body movement, and other types of interactions [25]. In this way, their learning motivation would be greatly enhanced. Last but not least, compared with purchasing reality objects, VR/AR technology can greatly reduce such costs in the long term by presenting students with similar or lifelike experience with meticulous design [26].

## 2. Trends in the Integration of VR/AR in K-12 Science Education

First of all, there is a growing number of studies in VR/AR's integration in K-12 science education, indicating researchers' and practitioners' interest in using VR/AR to enhance learning science. For instance, 20 out of 60 papers were published in the last two years. Despite this, the majority of studies were published much more in generic educational technology journals, such as *Computers and Education* and *Educational Technology and Society*, which accounted for 85% of all. Contrarily, only few domain specific science education journals (i.e., *Journal of Science Education and Technology*) published such studies. This may be due to the fact that for most K-12 science teachers, VR/AR is an emerging technology that seems novel and inaccessible, and its effects on students is still ambiguous without conclusive findings or universal instructional design models [27][28]. Therefore, in future research more attention should be paid to the exemplary integration of VR/AR into teaching specific science topics, foster deep integration and enumerate the particular effectiveness of VR/AR application on students' learning outcomes, so that science teachers become more receptive of VR/AR uses.

Secondly, the theories involved appeared very diverse. On the one hand, this diversity demonstrates VR/AR's capacity of accommodating a multitude of theories; on the other hand, it also indicates the lack of an over-arching theoretical paradigm that could guide AR/VR-based science instructional design. Such a paradigm would not be possible without the collaborative effort from learning scientists, science teaching experts, instructional designers and VR/AR specialists. The absence of any of the stakeholders may lead to an ineffective design framework. It should also be noted that 45% of the reviewed papers did not cite any theory, which could lead to unsubstantiated interpretation of obtained results.

Thirdly, inquiry-based learning was the most adopted learning model (87.5%) among the reviewed studies, which is consistent with previous findings that inquiry-based learning was one of the most commonly used learning models [29][30][31][32]. Regardless, this learning model was not entirely gauged with the measured learning outcomes in the reviewed studies. That is, although students indeed used VR/AR devices, teachers did not necessarily capitalize on the benefits of inquiry-based learning, beside providing students with immersive or lifelike experiences. Previous studies have shown that inquiry-based learning without sufficient guidance is not significantly better than traditional textbook teaching [33]. Thus, it must be cautioned that there is a fine line between inquiry-based learning and simply asking students to explore or view an VR/AR object or environment. For example, Salmi et al. (ID19) developed a mobile AR application to enable students to explore the different reactions between a number of atoms and molecules, within which students only needed to interact with the AR system to view the structure of atoms and molecules; thus, it could be hardly deemed as inquiry-based learning [34].

Fourthly, in terms of the research methods, there were more quantitative studies (50.8%) than qualitative or mixed-method studies (42.6%), more experimental designs (77%) than investigation designs (23%). The emphasis on experimental studies could be because that those experimental studies were practically more welcomed than investigative studies in nearly all academic journals, owing to their more advanced statistical analysis measures and illustrations. Meanwhile, experimental studies help teachers make more instant and precise adjustment to their existing science teaching, such as integrating a certain VR/AR software, or a device. On the other hand, investigation studies are more suitable for understanding students' perceptions, attitudes or satisfaction toward the generic VR/AR technologies, the results of which may not be directly applied to specific instructional design or adaptation.

Last but not least, there were a variety of VR/AR technologies employed, such as location-based AR, image-or marker-based AR, immersive VR, and desktop VR, but the ratio of using advanced VR/AR technologies was very low. This is in direct contrast to Pellas, Dengel and Christopoulos's finding that 60% of the studies used high-end immersive devices, while nearly 30% used low-end solutions [35]. One major reason could be that school teachers were unlikely to purchase higher-end technologies, for experiment's sake without school's financial support. Moreover, considering K-12 students' cognitive ability and psycho-motor skills, it is not only appropriate but also safe for them to use less-advanced and -expensive devices, so as to avoid the risks of under-utilization or damage. In other words, to increase the diffusion of AR/VR use in K-12 science education, there is a need to develop more affordable and portable devices that can be easily operated, so that both science teachers and students can utilize them effectively and efficiently. Also, given that there were only four papers (ID8, ID11, ID17, ID34, accounting for 10%) that focused on learning with AR/VR in informal environment, it may be suggested that VR/AR technologies that can be easily transported from one place to another be developed, so that students can learn with such technologies seamlessly in and out of class. For instance, students who were instructed to observe planets with VR/AR devices in class may continue to learn this topic at home by using both VR/AR technologies and their personal microscope.

## 3. Issues in the Integration of VR/AR in K-12 Science Education

Despite its apparent advantages, VR/AR also has its limitations or issues. The first type of issues reflected in previous studies are technical issues, which refer to either the inherent limitations of VR/AR technologies, or the associated technological glitches, such as lack of mobility and inconvenience of using, especially for immersive VR. For example, HMD, trackers and other VR-related utilities like the Cave Automatic Virtual Environment could often cause such difficulties [14].

The second type of issues are pedagogical issues. Teachers who use VR/AR to teach science may have problems in using it effectively and efficiently, including identifying the most suitable resources, designing the most appropriate activities, or conducting the most precise assessments. For instance, VR/AR has been reported as distracting and visually overloading. Wrzesien and Raya (ID55) found that there was no significant difference between the results of the experimental group using virtual devices and the control group without virtual devices. Learners were easy to get lost in the virtual environment, and a lack of sufficient learning information was the main reason for this phenomenon [20]. Teachers thus are obligated to sift through various VR/AR resources, and identify those that are age-appropriate, visually comfortable, and mentally congruent. Also, as Charsky and Ressler (2011) point out, the lack of teaching methods and objectives can make students confused and depressed, and even increase their knowledge overload and reduce their learning motivation [36]. Some studies noted the limitations of VR/AR technology and sought to overcome them with supplementary activities. For example, Yoon et al. (ID8) used knowledge prompts, a bank of peer ideas, working in collaborative groups, instructions for generating consensus, and student response forms for recording shared understanding [37]. These scaffolds could promote collaboration within the peer groups by encouraging students to discuss their observations and reflections of their experience. Another pedagogical issue lies in the comprehensive and accurate evaluation of student learning outcomes. For instance, students' cognitive and affective outcomes were mainly measured, whereas behavioral change was less emphasized.

The third type of issues can be categorized as social issues. For instance, the price of VR/AR devices is considered a social issue, rather than a technical issue, because the price is not solely determined by the technical complexity or sophistication, but its relative novelty among other technologies as well as the income level of its targeted consumers. Meanwhile, whether teachers can integrate VR/AR into science teaching is greatly dependent upon the social perceptions of such technologies, as well as their school support, both of which constitute the context for our topic. For instance, according to Chih et al., not all schools were willing to pay a high price for virtual display devices and real-world devices [14].

There are also several research issues. In terms of the research length, about 62% of the studies observed usage for less than 10 h. Under such circumstances, probability factors like the novelty effect could hardly be eliminated. Also, while a multitude of variables were examined, including scientific reading, scientific process, scientific problem solving, scientific literacy and so on, most studies still focused on low-level cognition through knowledge tests; high-level thinking ability has not received adequate attention. According to Bloom's goal classification, memory, understanding, and application correspond with low-order thinking abilities, whereas analysis, evaluation and creation belong to high-order thinking abilities [38]. Academic research shows that "injection" mode is usually used to cultivate high-level thinking ability in science learning; that is, the learning of thinking skills is integrated with the learning of the science curriculum. In this mode, students are fully involved in thinking practice, focusing on the learning process and understanding of meaning. After solving certain challenging problems, high-level thinking skills can be developed [38]. However, the emphasis on higher-order thinking has been absent in most reviewed studies in this paper. This is consistent with previous research that the application of VR/AR in science education mainly focuses on the understanding of scientific concepts and phenomena [29][30]. For example, 85% of the studies focused on students' mastery of scientific knowledge or concepts, without mentioning critical thinking, social reasoning ability, innovation tendency and other high-level thinking ability. Moreover, the data analysis methods relied mostly on *t*-test (55.7%), which would be insufficient to analyze more complex relationships or phenomenon.

## References


1. Fidan, M.; Tuncel, M. Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. Comput. Educ. 2019, 142, 103635.
2. Parker, J.; Heywood, D. The earth and beyond: Developing primary teachers' understanding of basic astronomical events. Int. J. Sci. Educ. 1998, 20, 503–520.
3. Pena, E.M.; Quilez, M.J.G. The importance of images in astronomy education. Int. J. Sci. Educ. 2001, 23, 1125–1135.
4. Pettersson, A.J.; Danielsson, K.; Rundgren, C.J. 'Traveling nutrients': How students use metaphorical language to describe digestion and nutritional uptake. Int. J. Sci. Educ. 2020, 42, 1281–1301.
5. Carvalho, G.S.; Silva, R.; Clément, P. Historical analysis of Portuguese primary school textbooks (1920–2005) on the topic of digestion. Int. J. Sci. Educ. 2007, 29, 173–193.
6. Gil-Quílez, M.J.; Martínez-Peña, B.; De la Gándara, M.; Ambite, M.; Laborda, M. Constructing a model of digestion in a primary school using a theatrical performance. J. Life Sci. 2012, 6, 91–98.
7. Russell, T. Attitudes, identity, and aspirations toward science. In Handbook of Research on Science Education; Lederman, N.G., Abell, S.K., Eds.; Routledge: New York, NY, USA, 2013; Volume 2, pp. 361–393.
8. Russell, D.W.; Lucas, K.B.; Mcrobbie, C.J. The role of the microcomputer-based laboratory display in supporting the construction of new understandings in kinematics. Res. Sci. Educ. 2003, 33, 217–243.
9. Songer, N.B. Digital resources versus cognitive tools: A discussion of learning science with technology. In Handbook of Research on Science Education; Routledge: New York, NY, USA, 2007; pp. 471–491.
10. Dani, D.E.; Koenig, K.M. Technology and reform-based science education. Theory Pract. 2008, 47, 204–211.
11. Cilliers, E.J. The challenge of teaching generation Z. PEOPLE Int. J. Soc. Sci. 2017, 3, 188–198.
12. Pikhart, M.; Klímová, B. eLearning 4.0 as a sustainability strategy for generation Z language learners: Applied linguistics of second language acquisition in younger adults. Societies 2020, 10, 38.
13. Winstead, S. eLearning 4.0: Prospects and Challenges. 2016. Available online: https://elearningindustry.com/elearning-4-0-prospects-challenges (accessed on 7 November 2021).
14. Chen, C.-H.; Yang, J.; Shen, S.; Jeng, M.-C. A desktop virtual reality earth motion system in astronomy education. J. Educ. Technol. Soc. 2007, 10, 289–304.
15. Kavanagh, S.; Luxton-Reilly, A.; Wuensche, B.; Plimmer, B. A systematic review of virtual reality in education. Themes Sci. Technol. Educ. 2017, 10, 85–119.
16. Klopfer, E.; Squire, K. Environmental detectives: The development of an augmented reality platform for environmental simulations. Educ. Technol. Res. Dev. 2008, 56, 203–228.
17. Caudell, T.P.; Mizell, D.W. Augmented reality: An application of heads-up display technology to manual manufacturing processes. In Proceedings of the Hawaii International Conference on System Sciences, Kauai, HI, USA, 7–10 January 1992.
18. Ibáñez, M.B.; Di Serio, Á.; Villarán, D.; Delgado Kloos, C. Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. Comput. Educ. 2014, 71, 1–13.
19. Sun, K.T.; Lin, C.L.; Wang, S.M. A 3-D virtual reality model of the sun and the moon for e-learning at elementary schools. Int. J. Sci. Math. Educ. 2010, 8, 689–710.
20. Wrzesien, M.; Raya, M.A. Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the E-Junior project. Comput. Educ. 2010, 55, 178–187.
21. Ewais, A.; Troyer, O.D. A usability and acceptance evaluation of the use of augmented reality for learning atoms and molecules reaction by primary school female students in Palestine. J. Educ. Comput. Res. 2019, 57, 1643–1670.
22. Chen, C.J. Theoretical bases for using virtual reality in education. Themes Sci. Technol. Educ. 2009, 2, 71–90.

23. Ozkan, O. The Compatibility of Widely Used Presence Questionnaires with Current Virtual Reality Technology. Ph.D. Thesis, Bahcesehir University, Istanbul, Turkey, 2016.

24. Fernandez, M. Augmented virtual reality: How to improve education systems. High. Learn. Res. Commun. 2017, 7, 1–15.

25. Martín-Gutiérrez, J.; Ginters, E. Virtual and augmented reality in education preface VARE2013. Procedia Comput. Sci. 2013, 25, 1–3.

26. Sarioglu, S.; Girgin, S. The effect of using virtual reality in 6th grade science course the cell topic on students' academic achievements and attitudes towards the course. J. Turk. Sci. Educ. 2020, 17, 109–125.

27. Sitzmann, T. A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Pers. Psychol. 2011, 64, 489–528.

28. Vogel, J.J.; Vogel, D.S.; Cannon-Bowers, J.; Bowers, C.A.; Muse, K.; Wright, M. Computer gaming and interactive simulations for learning: A meta-analysis. J. Educ. Comput. Res. 2006, 34, 229–243.

29. Cheng, K.H.; Tsai, C.C. Affordances of augmented reality in science learning: Suggestions for future research. J. Sci. Educ. Technol. 2013, 22, 449–462.

30. Goff, E.E.; Mulvey, K.L.; Irvin, M.J.; Hartstone-Rose, A. Applications of augmented reality in informal science learning sites: A review. J. Sci. Educ. Technol. 2018, 27, 433–447.

31. Pellas, N.; Dengel, A.; Christopoulos, A. A scoping review of immersive virtual reality in STEM education. IEEE Trans. Learn. Technol. 2020, 13, 748–761.

32. Pellas, N.; Kazanidis, I.K.; Konstantinou, N.; Georgiou, G. Exploring the educational potential of three-dimensional multi-user virtual worlds for STEM education: A mixed-method systematic literature review. Educ. Inf. Technol. 2017, 22, 1–45.

33. Roth, K.J. Elementary science teaching. In Handbook of Research on Science Education; Lederman, N.G., Abell, S.K., Eds.; Routledge: New York, NY, USA, 2013; Volume 2, pp. 82–103.

34. Salmi, H.; Thuneberg, H.; Vainikainen, M.P. Making the invisible observable by augmented reality in informal science education context. Int. J. Sci. Educ. Part B 2017, 7, 253–268.

35. Luo, H.; Feng, Q.; Li, G.; Li, W. Review on the application of virtual reality technology in basic education (2000–2019). Audio Vis. Educ. Res. 2021, 42, 77–85.

36. Charsky, D.; Ressler, W. "Games are made for fun": Lessons on the effects of concept maps in the classroom use of computer games. Comput. Educ. 2011, 56, 604–615.

37. Yoon, S.A.; Elinich, K.; Wang, J.; Steinmeier, C.; Tucker, S. Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. Int. J. Comput.-Supported Collab. Learn. 2012, 7, 519–541.

38. Barak, M.; Shakhman, L. Fostering higher-order thinking in science class: Teachers' reflections. Teach. Teach. Theory Pract. 2008, 14, 191–208.