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Chinese pre-service chemistry teachers' perception of augmented reality-assisted secondary chemistry learning

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Abstract

This research aims to explore the functional characteristics of Augmented Reality (AR) supported teaching in secondary chemistry learning, based on the theoretical framework of AR research in science education proposed by (JSET 22:449-462, 2013). Grounded theory and interview were used to construct AR related functional models. In the study, pre-service teachers were first asked to experience organic chemistry AR teaching app—"Meet Organic", and then semi-structured interview was conducted. Secondly, Nvivo12 was used to encode the interview results and finally relevant functional models were obtained. According to the results, AR education functions in science education are mainly divided into three parts: *"Visual Presentation"*, *"Concept Understanding"* and *"Thinking Construction"*, and each function is divided into 2–3 sub-functions based on the interview depth coding. Exploring the functional differences of AR between male and female meanwhile. The results of this research are of great importance to promote the in-depth understanding of the essence of augmented reality supported teaching, and the deep integration of AR teaching with science education. It also provides suggestions for future teachers to design teaching methods based on AR.

Keywords Augmented reality, Organic chemistry leaning, Chinese pre-service teachers

Introduction

The British Computer Society defines augmented reality (AR) as "the technology of digital combination, which allows users to combine real-life sensory experiences with digital environment perceptions". It combines human senses with virtual objects to facilitate real-world environment interactions, enabling users to achieve an authentic perception of the virtual environment, which is identified with three characteristics: (1) combining real and virtual, (2) interactive in real time, and (3) registered in 3D (Azuma, 1997). Since 2002, the year when Billinghurst of The University of Washington, Poupyrev of Sony Computer Science Laboratory and others used AR technology to develop and design children's reading Book Magic Book (Magic Book), the application of AR technology in education and teaching has been gradually popularized and perfected (Billinghurst, 2002). Moreover, based on the characteristics of AR technology, researchers are more likely to apply it to scientific learning (Linn, 2003).

Chemistry, as one of the scientific disciplines, is considered to be a complex field of scientific research, and many students struggle with it (Thomas & Schwenz, 1998). One of the most challenging topics for students and educators is the three-dimensional (3D) visualization of molecules and their stereo-chemistry (Jones & Kelly, 2015), and the presentation of AR images can solve the problem of chemistry structure visualization precisely. Therefore, a large number of researchers have applied AR to chemistry teaching. For example, Yu-Chien Chen compared the

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AR model of "amino acid molecule" with the real model in teaching chemistry "Amino Acid", so that students could have a deeper understanding of related concepts and realize the visual construction of the model (Chen, 2006b). Augmented Chemical Reactions Patrick Maier teaches Augmented Chemical Reactions (ACR), which visualizes atoms and molecules to visually characterize spatial structural relationships (Maier, 2009). Therefore, it can be known that the introduction of AR teaching in chemistry class is prevailing, and it's an important way to support science teaching. As future chemistry teachers, pre-service normal university students play a vital role in the educational development, combining technology with teaching&learning. Existing literature reviews on augmented reality learning have pointed toward AR's usefulness in training pre-service teachers' cognitive skills (Hamilton et al., 2021).On April 18, 2022, EDUCAUSE released *The Horizon Report 2022 (Teaching and Learning Edition)* (Pelletier et al., 2022), which analyzed the current trend of educational development, promoting a variety of technologies and emphasizing the importance of educational technology. In China, *"The Ministry of Education on the opinions of the excellent teacher training scheme 2.0"* clearly put forward information technology reform to deeply boost educational teaching as one of excellent normal teachers' team construction tasks, which emphasizes "make full use of virtual reality and augmented reality, promoting new technology and combination of educational curriculum". It follows that it is necessary for normal university students to integrate AR technology into the current education in China.

Augmented reality technology was originally developed and developed in Western countries, and with the maturity of the technology, the application field of AR is gradually extensive. Since 2002, Billinghurst of the University of Washington in the United States and Poupyrev of Sony Computer Science Laboratory have developed and designed children's reading Book Magic Book with AR technology, the application of AR technology in education and teaching has gradually become popular and perfect (Billinghurst & Kato, 2002). At present, foreign AR teaching research focuses on science classroom (Jorge et al., 2014). Researchers use questionnaires, interviews, classroom observation and other methods to explore the impact of AR technology in science education on learners' conceptual understanding and conceptual transformation (Chen, 2006a), spatial ability (Nunez et al., 2008), practice and interaction ability (Andujar et al., 2011), learning attitude and motivation (Bursztyn et al., 2017), so as to pave the way for realizing the maturity of AR classroom teaching. Meanwhile, researches on whiteboard, intelligent classroom and VR in Chinese high school chemistry class are far more than those on AR. Furthermore, many people studied AR software development or AR review, but few focused on AR learning process or AR educational function. Hence, this study is to conduct semi-structured interviews with pre-service teachers (normal students of undergraduates and postgraduates) to summarize the functional characteristics of AR teaching, since normal students represent both teachers and students, whose feelings contain teachers' and students' (Deng et al., 2011).

Therefore, this study further explores the educational functions of AR depending on current AR researches:

1. Refine the contents of the three functions through interviews
2. Explore the functional differences of AR between male and female
3. Get inspiration from current AR teaching application through AR function exploration

Theoretical underpinnings

This study is based on a theoretical framework in AR science education proposed by Tsai (Fig. 1), including *Mental Models, Spatial Cognition, and Social Constructivist Learning* (Cheng & Tsai, 2013). Based on the analysis of 12 articles related to AR, Cheng and Tsai (2013) systematically summarized the technological characteristics, key themes, participants, and insights for scientific learning of these studies. Drawing on the dimensions of VR learning model (Salzman et al., 1995), including technological features, scientific concepts, learner characteristics, interaction experience, learning experience, learning process, and learning outcomes, selected articles were discussed. During the analysis process, researchers systematically summarized the cognitive levels of learners in their understanding of scientific concepts through AR-based instruction. They extensively examined advanced AR technologies such as handheld devices and virtual reality to investigate the spatial capabilities of AR and its ability to facilitate spatial relationships within a spatial context. Additionally, they explored the impact of AR on social interaction and collaborative learning. This was achieved by surveying learners about their experiences engaging in group activities and interacting with virtual characters or peers within an AR environment. The aim was to evaluate how these interactions facilitated knowledge construction and the development of scientific understanding (Cheng & Tsai, 2013).Ultimately, based on the results of investigation and analysis and a summary of scientific practice,the theoretical foundation of AR science education was categorized into three critical aspects: cognitive modeling, spatial cognition, and social constructivist learning, this theoretical framework provides guidance for designing interview

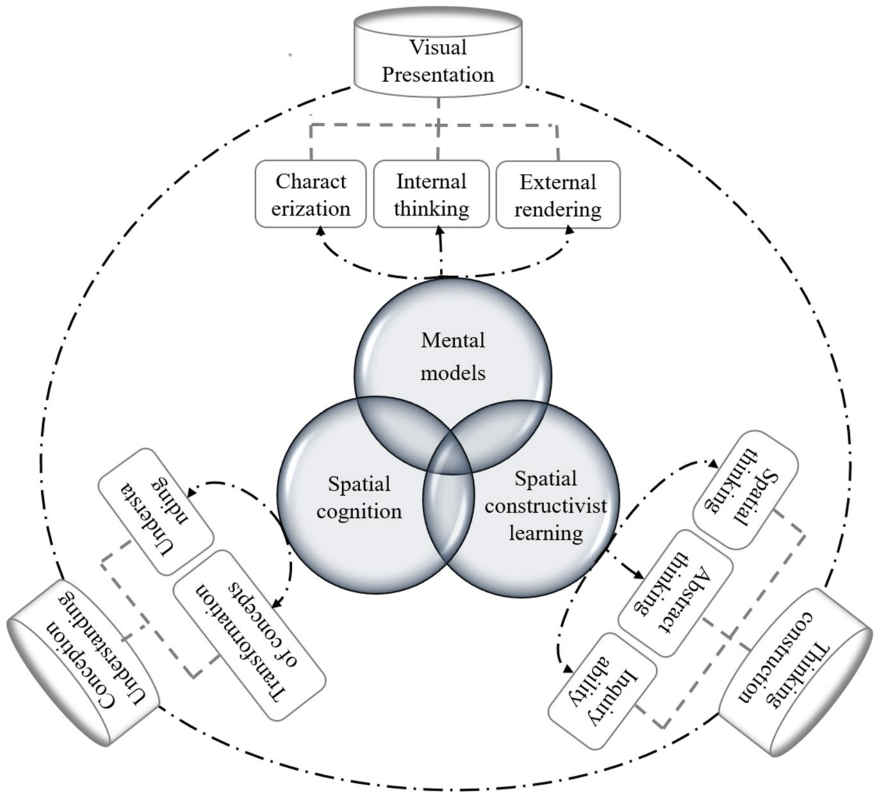

Fig. 1 A framework of theories guiding AR research in science education

guidelines and offers a direction for exploring the potential of AR in science education (Cheng & Tsai, 2013). First, Johnson-laird's *Mental Model* involves internal thinking processes and representations about something working in the external world, that is, the presentation of reality will affect people's internal understanding or cognition(Johnson-Laird, n.d.). On the basis of that, it can be known that AR can provide a visual image that is a process of converting abstract data into visual representation, enhancing or replacing texts to explain specific scientific concepts, so the first component of mode theory is *"Visual Presentation"* (Zollmann et al., 2021). Second, *Spatial Cognition*, which concerns knowledge about spatial properties of objects in the world, can be an essential theory to guide AR research (Montello, 2001), and it refers that integrating AR into learning can promote the learners' understanding and transformation of concept (Mathewson, 1999). Therefore, *"Conception Understanding"* is seen as the second functional component, which means that AR images can build a bridge between students' existing and scientific concepts, increasing the level of knowledge understanding. Finally, *Social Constructivist Learning* initiated by Vygotsky emphasizes the social and collaborative learning (Vygotsky, 1978), it is related to the application of Augmented Reality (AR) technology in the development of literacy. In AR, students gain a deeper learning experience by using AR tools together with others or participating in collaborative activities within AR scenes. This learning environment promotes interaction, discussion, and cooperation among students, stimulating their collaborative and creative abilities. At the same time, AR technology provides personalized learning support by offering customized resources and guidance based on students' needs, fostering their ability for independent thinking. During learning, thinking is defined as "an organized mental process where individuals confront with a problem" (Aziz & Ahmed, 2013). Therefore, teachers need to pay attention to cultivating students' thinking and constructing thinking modes. In sum, AR education can promote students' spatial thinking (Nunez et al., 2008), abstract thinking (Maier, 2009) and inquiry ability (Aldalalah et al., 2019), because of that, *"Thinking Construction"* is the last one of mode theory to guide the interview. In conclusion, by analyzing related theories, it can gain the coding frame, including *"Visual Presentation"*, *"Conception Understanding"* and *"Thinking Construction"*, guiding the design and analysis of AR interview.

Methodology

The survey method was used to probe pre-service chemistry teachers' perception of mobile AR technology into teaching process. This research uses Grounded Theory as the main analyzing method, which is a qualitative research methodology proposed by Charmaz, which combines Glaser's classical grounded theory with Strauss and Corbin's programmed grounded theory. It seeks to develop theory that is grounded in data systematically gathered and analyzed (Glaser & Strauss, 1967). On the grounds of that, it is helpful to gain core thinking and depth meaning of individuals' perspectives, contributing to construct a theory model to lead further researches. At the same time, in order to see the impact of AR on students with different levels of chemistry teaching knowledge, the research results are presented in a quantitative manner, making the survey results more intuitive and the theoretical construction more scientific.

"Meet organic" app

"Meet Organic" app developed by our research team is an AR software, which can help students learn organic chemistry well in high school. Fifty-two representative organics are selected and classified into four groups: alkanes, alkynes, oxygen-containing organic compounds and aromatic compounds and cards were chosen as AR triggers, four colors corresponding to four kinds of organics (Fig. 2). Besides, the ball-and-stick model of organic molecule is a main part of the card, integrating the Chinese and English name and structural formula of organics, which helps students build connections between knowledge and symbol.

The app can be downloaded to mobile phone by scanning the QR code on the card. Finishing installation, the users can scan the cards and the AR images will appear on the phone screen. Moreover, the AR images can be zoomed and rotated through operation, so that organics' structure and model can be carefully observed (Fig. 2).

Participants

The study investigates pre-services by a semi-structured interview and uses stratified sampling. In all, 8 chemistry pre-service teachers (4 males and 4 females) are selected from a normal university in China, containing sophomores, juniors, seniors, and postgraduates. Each grade chooses two students (male and female) (Table 1). All participants would use the app by themselves for two weeks. Among them, sophomores are just beginning to learn chemistry teaching courses, juniors are practicing teaching in middle schools, seniors are about to finish their undergraduate studies, and postgraduates are studying and researching chemistry teaching theories at a higher level. In short, the characteristics and functions of AR teaching can be further explored by investigating the views of pre-service teachers at different levels.

Procedure

The research procedure of this study is mainly divided into three steps, namely App Presentation; Interview and Data Collection; Data Analysis.

App presentation

In the early stage, the researcher introduced the AR teaching software – *"Meet Organic" app* to all participating pre-service teachers in detail. At first, AR and the

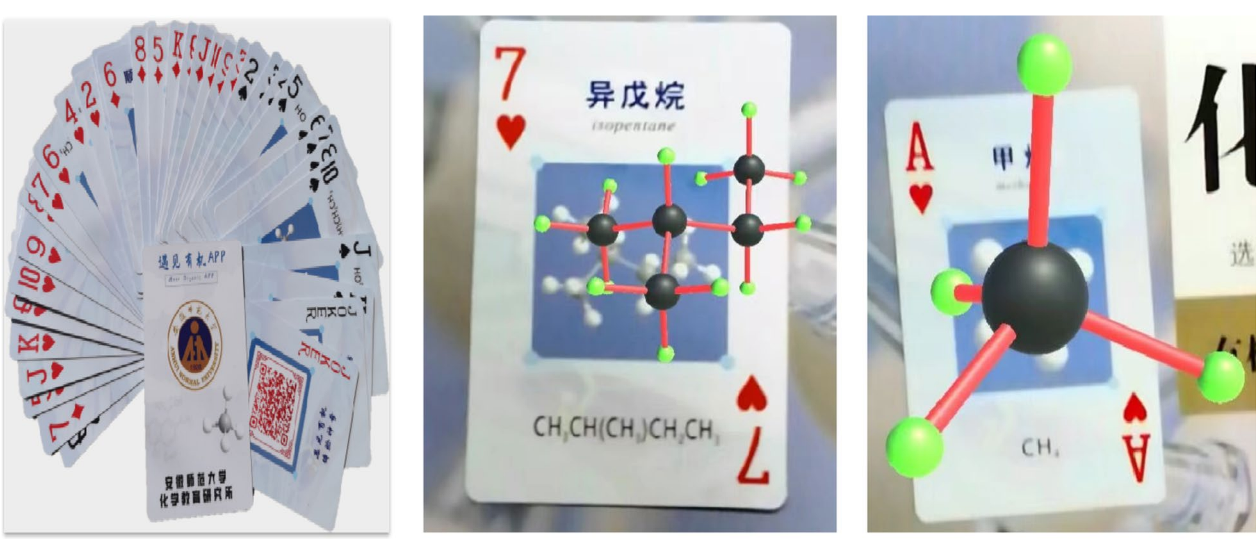

Fig. 2 Function card and AR scan image of "Meet Organic" app

Table 1 Participant identity information

Grades	Gender	Age	Major	Chemistry school age	Chemistry learning hierarchy
Sophomores	male	19	Chemistry (teacher-training)	5	beginning to learn chemistry teaching courses
	female	20			
Juniors	male	21	Chemistry (teacher-training)	6	practicing teaching in middle schools
	female	21			
Seniors	male	22	Chemistry (teacher-training)	7	finishing their undergraduate studies
	female	21			
Postgraduates	male	24	Subject teaching (Chemistry)	8	Studying and researching chemistry teaching theories at a higher level
	female	23			

status of AR teaching research were introduced, and our research product- *"Meet Organic" app* was presented and explained its introduction. Then, each student can scan the QR code to download it and try to get the AR images. After two hours learning, all participants had a comprehensive understanding and could skillfully use the app skillfully. Finally, all participants would use the app by themselves for two weeks, during which, they would have an in-depth exploration about app and prepare for the later interview.

Interview and data collection

Due to the complexity and recessive nature of cognitive research, this study intends to use grounded theory to carry out qualitative research. Different from the traditional survey research method, this study is based on the perspective of the participants and uses semi-structured interview to conduct in-depth communication with them from their ideas. Through communication, we can directly understand the views of pre-service chemistry teachers on the integration of AR into chemistry teaching, instead of guessing or analyzing. In this way, the obtained data is more real and can better reflect the inner views of all interviewees.

The survey adopted a semi-structured interview. The researchers made an outline of the interview in advance according to the theories "*Visual Presentation*", "*Conception Understanding*" and "*Thinking Construction*". Meanwhile, the three aspects are formulated in correspondence to the outline, namely, "Feeling of Experience", "AR &Organic Chemistry Learning", and "AR &Organic Chemistry Teaching", then, each theme was designed with 2–3 questions (Appendix 1).

Afterwards researcher A conducted the one-to-one semi-structured interviews with 8 participants respectively, and when it comes to other topics, interviewers will ask further questions. The interview, was recorded and transcribed by the researcher B. and checked by researcher A.

Data analysis

In order to analyze the data in depth and condense features highly, researchers use grounded theory as a methodology. The specific analysis process uses deep detail coding, requiring researchers to ask analytical questions for the collected data, and the whole process draws the cocoons to construct relevant theoretical models from coarse-to-fine. Finally, Nvivo12, an advanced qualitative research software in the world, is used as an auxiliary tool to realize the theoretical construction of the cognitive function of AR learning in high school chemistry.

Before coding, we set the word minimum length as 4, the words number as 60 and grouping as "generalizations". Then it obtains the word frequency list and word cloud. Later, we began to code based on Grounded Theory in three stages: (1) coding subthemes; (2) focused coding using Charmaz's interpretation of Grounded Theory (CMT); and (3) constructing the theoretical framework. Firstly, based on literature reviews, coding topics are divided into three major themes: *Visual Presentation*, *Conceptual Understanding* and *Thinking Construction* and each topic is roughly subdivided and further focused. Then, the three themes are subdivided into 8 sub-themes (Appendix 2), and different views compared by the genders and grades (knowledge learning level), so as to draw conclusions (see Fig. 3). Finally, the characteristics and functions of AR teaching are summarized, which can lay a foundation for further theoretical construction. (Consistency test was conducted on the coding results in this study, and the final Kappa coefficient was 0.873, with good consistency and high external reliability.)

Furthermore, the study aimed to compare the views of different groups of participants, specifically gender and knowledge learning level (grades). To better illustrate the differences in their understanding of AR teaching, a bar chart was created. The chart could help readers easily visualize the variations in perception among the participants, which can be useful for drawing conclusions and constructing theoretical frameworks.

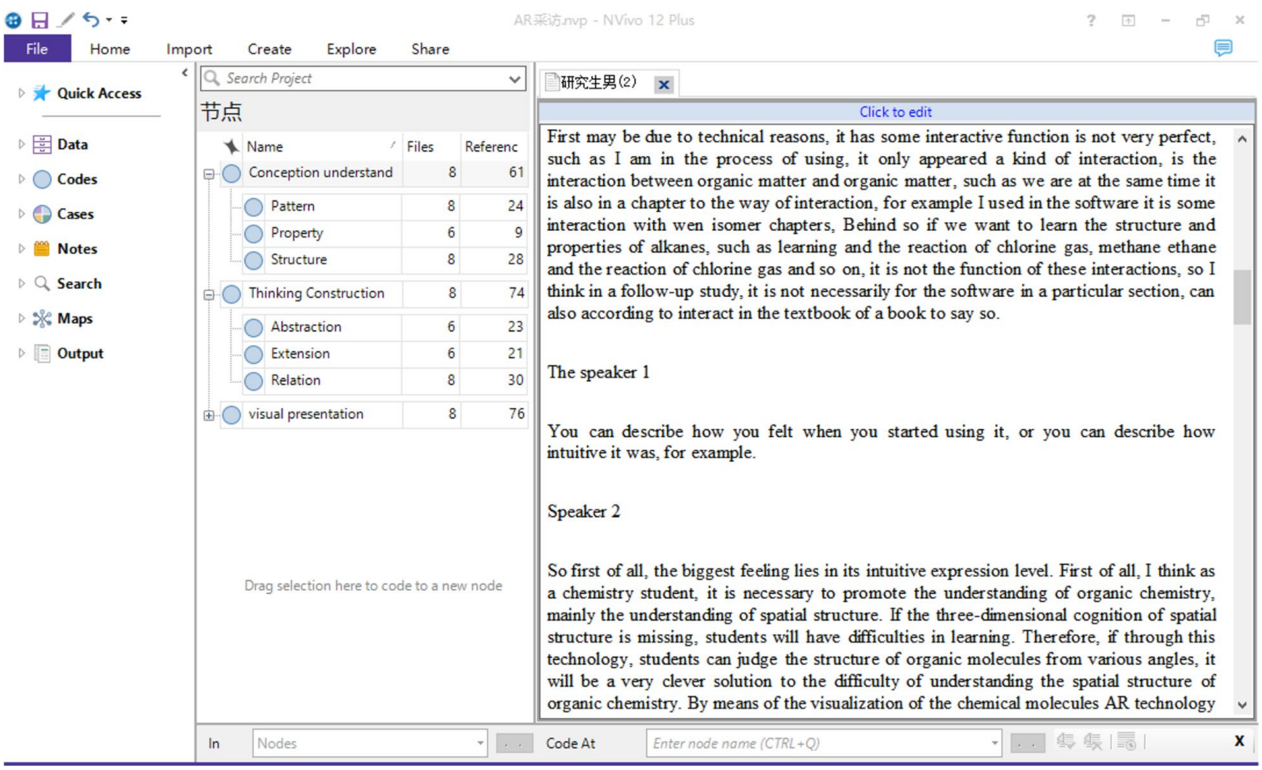

Fig. 3 Specific coding process in NVIVO 12

Overall, the use of visual aids such as word clouds and bar charts can help researchers to present their findings in a more accessible and understandable way. It can also aid in identifying patterns and trends in the data, which can further inform the research process and lead to more accurate and reliable results.

Results and discussion

Through the research process and analysis, the final results are presented from three aspects: word cloud, grade and gender.

Word cloud

Word cloud is text-based visual representations that display word significance in terms of popularity and importance by using different font sizes and colors (Chi et al., 2015). It refers to the use of computer language to carry out intelligent tag capture, classification statistics, statistical characterization of text symbols, and use software to analyze key issues in massive texts and capture their contents. The size of the words in the word cloud map reflects the word frequency of the phrase, and indirectly indicates the hot spots and themes that the public pays attention to, which is an important way for data display. It builds a bridge between qualitative and quantitative, reflecting qualitative views, quantitative characterization, visual results and other characteristics, which is helpful to reveal the implicit attitude. According to the map (Fig. 4), the words most mentioned are: 'student', 'thinking', 'construction', 'organic' and 'knowledge'. That is, from the dual identities of teachers and students, the normal university students express more viewpoints on the students side. They believe that AR teaching is more focused on students and students can learn independently.

For example, they believe that when students learn organics through AR, they will operate the APP by themselves, and generate new questions by exploring. On this basis, they will conduct in-depth exploration, and form a thinking mode gradually, which can help them build a connection between the multiple representations. After that, students can have an imagination about micro world and construct a strong three-dimensional model.

Grades

The interviewees in this study are sophomores, juniors, seniors and postgraduates. Due to their different learning degrees, their opinions on AR teaching are also different. All the students' viewpoints are analyzed on three main themes, demonstrating the relevant functional characteristics of AR teaching.

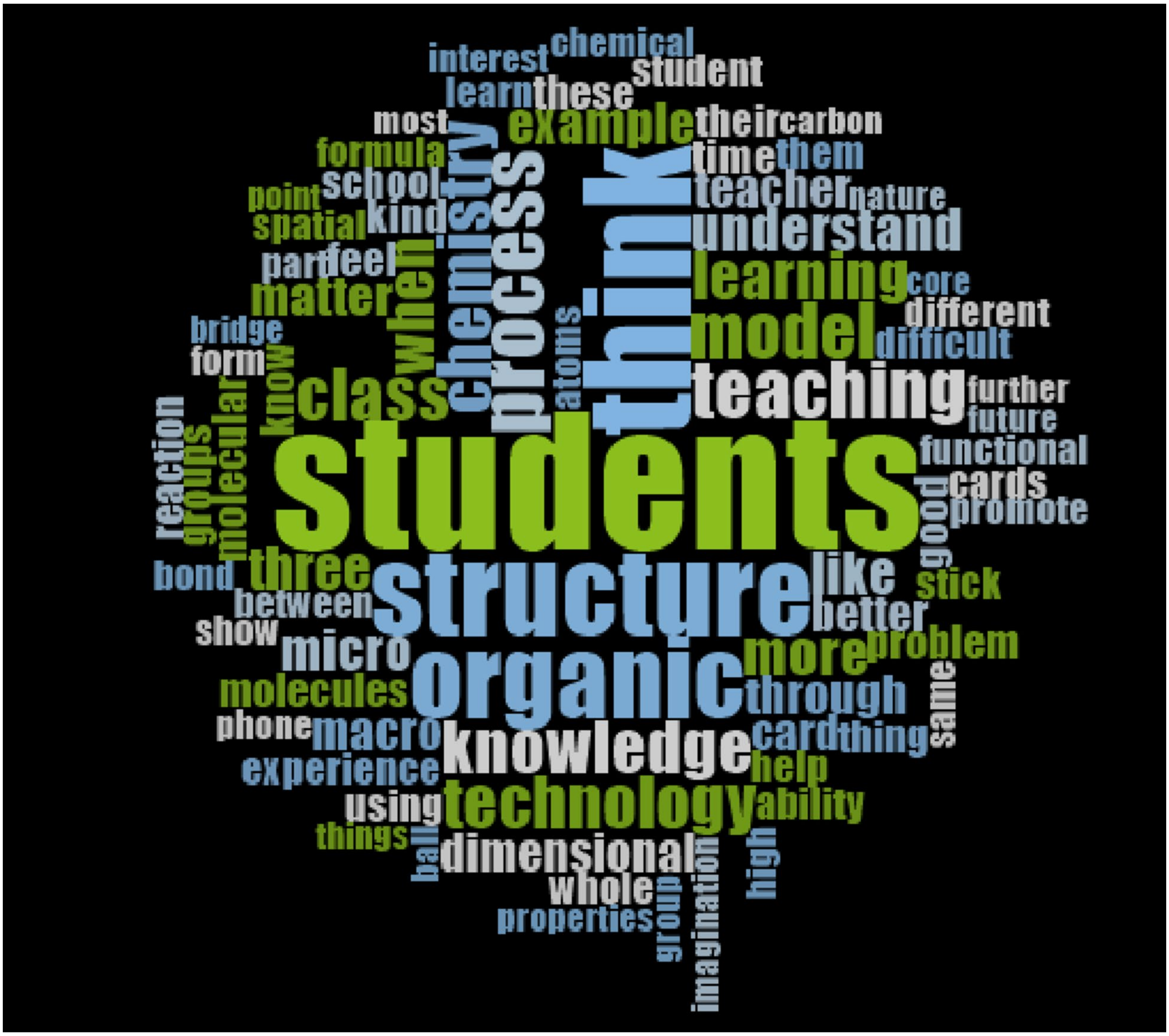

Fig. 4 Word Cloud

Visual presentation

According to coding, the *"Visual Presentation"* category is mainly divided into two sub-functions: *Motivation* and *Perception*. As Fig. 5, the total number of codes in *Visual Presentation* is increasing with grades, which is due to the improvement of learning and deepened understanding of organics. Therefore, they will be more approved of the AR teaching application, which can also illustrate the use of AR *Visual Presentation* in many aspects. Based on Grounded Theory, researchers find that pre-service teachers' visual presentation mainly focuses on two aspects, namely *"Motivation"* and *"Perception".* And students of different grades have different perspectives on *Visual Presentation* (Fig. 5).

Motivation In the education field, motivation can be defined as "the student's desire to engage in a learning environment" (Keller & Litchfield, 2002). At present, a large number of studies have proved that "motivation affects students' academic performance in the learning process" (Serio et al., 2013).

Through the interview text (Table 2), the study finds that each interviewee has built a connection between AR teaching and improving motivation, and discusses how it affects the motivation. Firstly, every pre-service teacher mentioned "sensory stimulation" as the sense of curiosity and excitement, and it will trigger students' desire for exploration and learning, leading to the deeper

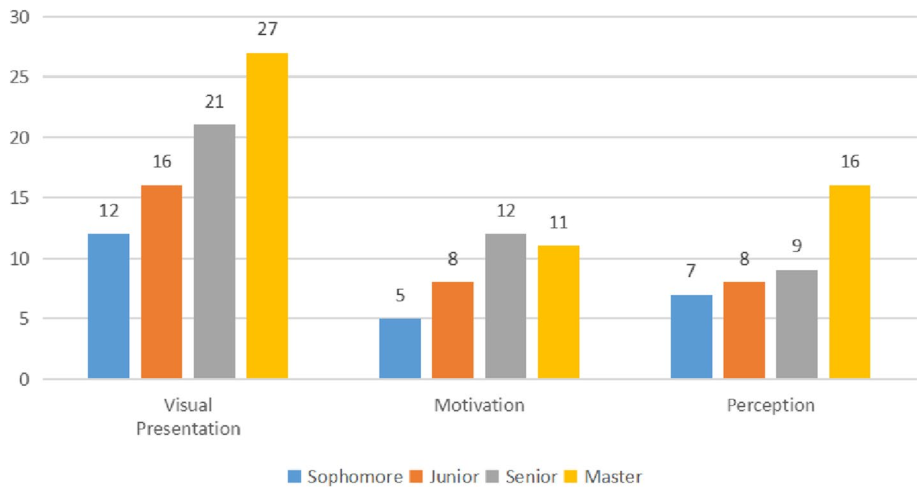

Fig. 5 Total and partial details of *Visual Presentation*

Table 2 The interview text about motivation

Sophomore F	*When students understand and enjoy learning, they will love it gradually and their learning initiative will be improved*
Sophomore M	*The appearance of AR is easy to attract others, and students will feel amazed. They will think that chemistry is a magical subject, so they can learn better during enjoying*
Junior F	*Through combining cards with advanced AR technology, it can quickly arouse students = interest in organic chemistry learning*
Junior M	*AR images show students three-dimensional molecular structures and colorful atoms, which attracts students instantly and deepen their impression*
Senior F	*Sensory stimulation will enhance students' learning enthusiasm, and they may be interested in computer technology, so that they'll learn knowledge on their own*
Senior M	*Seeing a plane model in three dimensions, we will have a desire to explore. We can't help thinking the objects we usually see in three-dimensional way and we want to observe them from different angles, which is an active learning*
Postgraduate F	*Students have not heard of the AR technology, so the introduction can not only improve students' learning chemistry enthusiasm, but also reduce their learning fear*
Postgraduate M	*Due to the introduction of AR teaching, students can reduce their chemistry fear and perceive the charm of chemistry gradually*

understanding. Secondly, Junior M and Senior M both mentioned "three dimensions". Students can viewed the images from different angles, seeing flat structure in details. Meanwhile, because we live in a 3D-world, the stereoscopic structure of AR can be linked to our life and create a familiar atmosphere, which can help to improve our motivation. Finally, Postgraduate F and Postgraduate M referred to "reducing the fear of learning chemistry". Due to the abstraction and three-dimensional characteristics of chemical knowledge, it is difficult for students to understand knowledge and they may fear the whole subject. However, realistic presentation of AR makes knowledge visualized, which helps reduce their fear and is conducive to the later learning.

In a word, pre-service teachers of all grades agree that AR can promote students' learning motivation. Among them, seniors and postgraduates have a more comprehensive grasp of chemical knowledge, so the motivation discussed in the interview is not limited to images, but also based on knowledge learning. For example, seniors and postgraduates not only mentioned reasons such as "interesting" and "vivid", but also covered aspects like "learning fear" and "building connections with life". In short, boosting motivation is one of important AR visual functions, which lays a foundation for the other two functions.

Perception In the interview, pre-service teachers mainly mentioned four aspects of "*Perception*" about AR teaching: impact, intuitive, space and operation (Table 3), which plays an essential role in AR learning.

By scanning, the AR images have a strong visual impact on students, which is not only a sense of astonishment, but also stimulates them to further explore, and they'll be full of enthusiasm for the organics study. In addition, different from planar molecules in textbooks, the images of

Table 3 The interview text about perception

Impact Sense	***Sophomore M:*** *When I first opened and scanned it, I was astonished, since I could touch it closely. And students can operate and experience it subjectively, which makes students learn independently*
	Senior M: *I can imagine the students will get excited, because scanning the cards, the images popped up surprises me*
Intuitive Sense	***Senior F:*** *The ball-and-stick model shows a three-dimensional structure, which can display the connections between carbon, single bond, double bond and triple bond intuitively*
	Master M: *I think this technology can help students see the molecular structure without imagination intuitively, which is conducive to the organic chemistry learning*
Spatial Sense	***Junior F:*** *If you look at cards carefully, there are chemical formula and molecular structures. If you scan them,they can show the three-dimensional model and three-dimensional molecular structure, which makes you havea sense of space*
Operational Sense	***Senior M:*** *Through their own scanning, observation and hands-on operation, students will observe every detail carefully. And they will become a learner gradually, which is useful to the later organics learning*
	Senior F: *The students were able to see the stick models from different angles by operation*

AR present a stereoscopic and intuitive conformation on the screen, presenting the molecular structure that students perceived only through imagination before. Based on it, the AR organics learning gives students a sense of space, which allows them to further imagine molecular structures, especially for those with poor spatial ability. Finally, the whole process of inquiry learning is operated by students themselves. They are the main operators of "scanning", "rotation" or "scaling", which makes learners become teaching subjects and further strengthens their perception of patterns.

In short, due to the interaction of the four aspects of AR "*Perception*" function, learners can observe and experience the molecular structure of organics more deeply. And the "*Perception*" and "*Motivation*" functions promote each other, making the whole organics learning more scientific and interesting, and also making students full of expectations for chemistry learning.

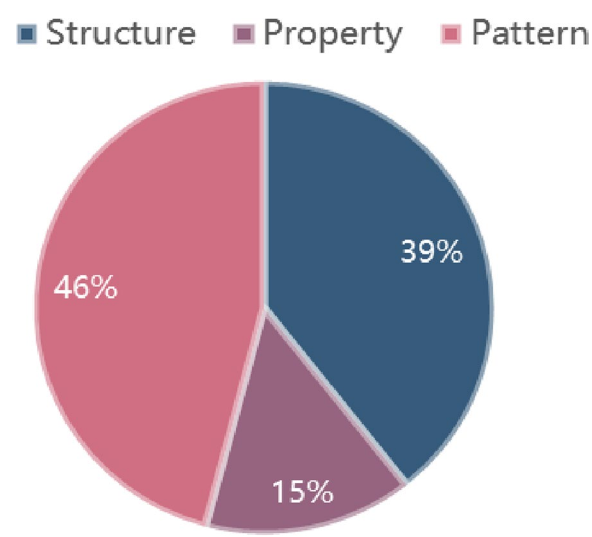

Fig. 6 Total and partial details of *Conception Understanding*

Conception understanding

The "*Conception Understanding"* category is divided into three sub-functions: "*Structure*", "*Property*", and "*Pattern*". It can be seen from Fig. 6 that pre-service teachers mentioned "*Structure*" and "*Pattern*" more frequently than "*Property*". Meanwhile, as Fig. 7 indicates, juniors mentioned "*Conception Understanding*" most frequently during the interview, because they are now in the internship period, and they have same personal experience in the teaching, which is more appropriate for students' cognition and learning. The following is a detailed discussion of relevant research results from three sub-functions.

Structure Chemistry learning relies heavily on structural representations (Peragovics & Biró, n.d.). However, interpreting, manipulating, and switching between the numerous structural representations is a complicated task for many students (Graulich, 2015). During the interview, pre-service teachers of all grades have expounded the "*Structure*" function of AR to different degrees (Table 4), while students mainly elaborated from three aspects: "*Global Micro-structure*" "*Functional Group*" and "*Bond Length and Bond Angle*".

Firstly, AR images can present the overall structure of organic molecules in detail, and students can understand the specific molecules structure at macro level through scanning, observation and operation, which is difficult for them in traditional class. Secondly, AR images can specifically show the size and characteristics of various functional groups, and students can understand organics reaction, bond breaking and other related issues by observing the size and location of functional groups. Finally, through zooming and rotation, students can see the bond lengths and angles inside molecules, especially the bond angles. Comparatively speaking, classes with

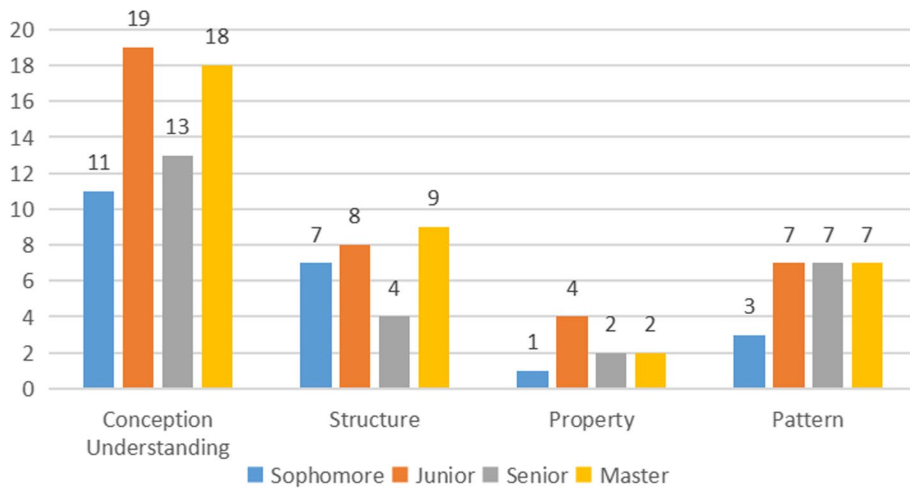

Fig. 7 Total and partial details of *Conception Understanding*

Table 4 The interview text about structure

Global Micro-structure	***Sophomore M:*** *Learning organic chemistry requires mastering the microscopic structure of molecules. The process is focused on introducing the appearance and characteristics of molecules. However, many students have a problem that is difficult to imagine the molecules at learning beginning, but AR teaching solves it well*
	Junior M: *Organic molecules are very invisible, but I can see their various groups and structures by scanning their AR images*
Functional Group	***Junior M:*** *When an AR image is presented, the detailed structure of organic functional groups can be seen. We present the structure of functional groups to students in a large, scientific and intuitive way, so that students can have a deeper understanding*
Bond Length and Bond Angle	***Sophomore F:*** *We can see the microscopic structure of organics intuitively, and also see the size of individual atoms, even the bond lengths and bond angles between atoms*
	Postgraduate ***M:*** *Comprehensive operation and positioning of organic bond length, bond Angle and spatial position can further help students to develop spatial cognition*

AR presentation is more conducive to knowledge learning than traditional classes.

In short, AR teaching has the function of "*Structure*", and students can feel the microscopic structures of organics by observing and manipulating, thus it can promote learning, lower the level of knowledge difficulties, help students understand related concepts and lay a foundation for *Thinking Construction*.

Property *In terms of the organics study, mastering properties is also an important part of knowledge understanding* (*Tümay*, 2016). *Based on the Grounded Theory, pre-service teachers didn't mention the "Property" function more* (*Fig.* 7), *juniors mentioned the "Property" function most, while sophomores mentioned it least. This is partly because junior students are in the internship stage through which they may get a better command of students' thinking while sophomore students just began to learn chemistry teaching theories.*

> ***Junior M:*** *Structure determines properties, through the macroscopic and microscopic structure, it can help students understand the molecular structure, and better grasp the knowledge of organic matter, so as to master the conditions of organic reaction*

> ***Postgraduate F:*** *Through this three-dimensional model, the characteristics of the structure are explained to students in detail, so as to further explain the property knowledge behind the characteristics of the structure, so students can not only master the structure, but also understand the related reactions and the reasons for breaking bonds*

"Structure determines properties" is so significant in the study of organic chemistry that only when students master the molecular structure can they further understand the related properties and reaction process. According to the research results, AR teaching can help students understand molecular structure better and have a perfect mastery of knowledge- “structure”. On this basis, the problems (organics reaction, the principle of bond formation and bond breaking and related mechanisms) can be easily solved.

Pattern Model construction is very critical in organic chemistry. Only by imagining and building a structural model in their minds can students master the knowledge smoothly. To solve this problem, AR teaching has a positive function to help students understand and develop cognition.

> ***Junior M:*** *The pattern is more scientific, students don’t need too much time to assemble, and they can see the overall pattern of organic matter with scanning.*

> ***Senior F:*** *Instead of a straight line, like n-butane, it’s a staggered chain of carbons. Regarding carbon and hydrogen of coplanar problems, such as cyclohexane, we can see three hydrogen atoms are in the above and three hydrogen atoms are in the following. Through AR images, we can intuitively see which atoms are in common plane, the connection mode and configuration between atom, which can solve problems that students can’t imagine. Therefore, I think AR is a useful teaching tool.*

It’s concluded that in terms of solving model problems, the most difficult ones for students are the common plane of atoms and the configuration of molecules, and students can reach conclusions through their own operation, observation and exploration. Therefore, with AR teaching, teachers should try their best to make students think and learn independently, so as to promote knowledge acquisition.

Thinking construction

The “*Thinking Construction*” function is divided into three sub-functions: “*Abstraction*”, “*Extension*” and “*Relation*”. As Fig. 8, the three sub-nodes are mentioned in the same frequency. Besides, with grades increasing, the number of pre-service teachers mentioning “*Thinking Construction*” gradually increases, and the number of postgraduates reaches the highest 33 times (Fig. 9), because postgraduates pay more attention to the construction and transformation about students’ thinking and the formation of scientific literacy during the learning.

Abstraction “*Abstraction*” function refers to the ability of students to build models and space in their minds through imagination. In traditional class, it is difficult to form abstract thinking because there is no three-dimensional reference. However, AR teaching overcomes this problem and helps students form construction of abstract things in their minds.

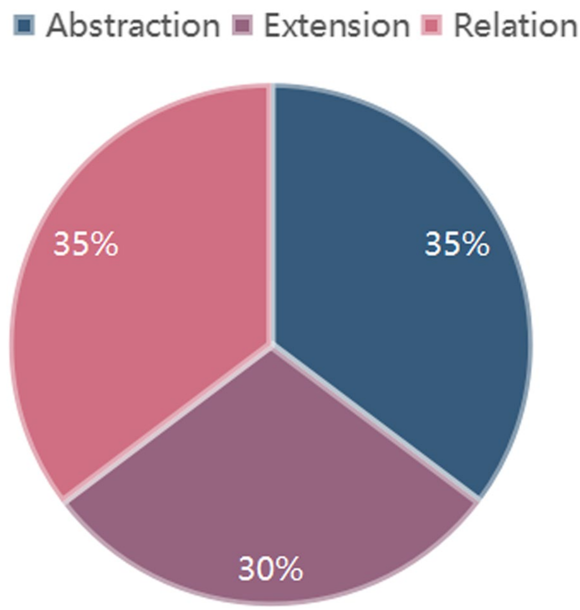

Fig. 8 Total and partial details of *Thinking Construction*

> ***Postgraduate F:*** *Through AR learning, students can see the three-dimensional configuration of planar molecules, which cultivates their sense of space and further develops their spatial abstraction ability.*

> ***Postgraduate M:*** *Due to the stereoscopic nature of AR images, the learning process is no longer just relying on imagination, but more on stereoscopic presentation, which is conducive to the development of abstract stereoscopic thinking and greatly improves spatial ability*

As is shown in the interview texts above, when learning AR organics, students are given visual stereoscopic models presenting stereoscopic molecular structures. By observing the learning operation, students will form abstract concepts in their minds gradually. The concept development will boost formation about abstract thinking, which is conducive to developing spatial imagination and cognition.

Extension About interview results, the interviewees focused on the extension of thinking, such as concept change and inductive reasoning. A few pre-service teachers pointed out that AR teaching was beneficial to the development of innovative thinking and the cultivation of students’ practical ability due to their own operation and observation.

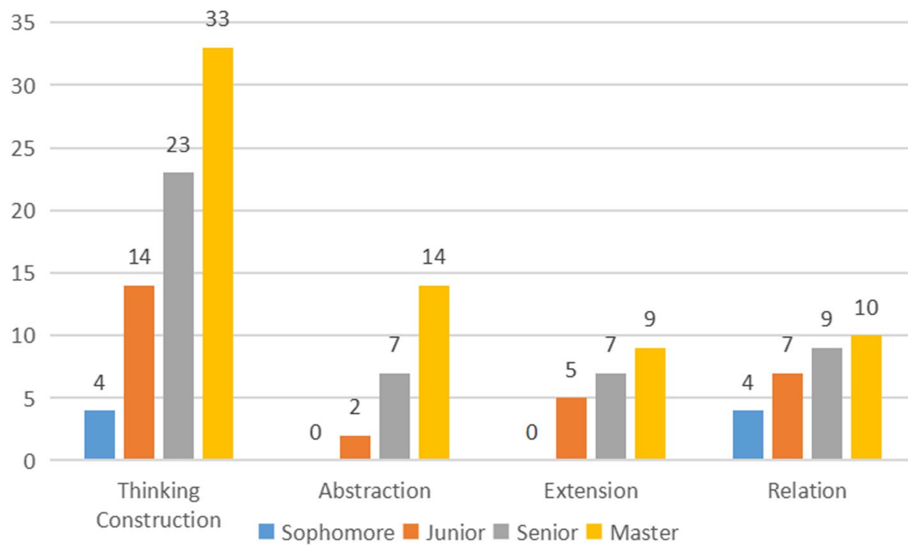

Fig. 9 Total and partial details of *Thinking Construction*

> ***Postgraduate F:*** *Basic learning is carried out first, then complex content is gradually mastered. Because of its three-dimensional structure, the learning process is from simple to complex, so as to achieve the inductive reasoning ability.*

> ***Postgraduate M:*** *Students can intuitively see the molecules three-dimensional structure, which may differ from what they imagined before. Students gradually complete concept transformation and form critical thinking through exploration.*

Due to the intuitiveness and operability of AR images, students will form cognitive conflicts through independent inquiry. To solve this problem, they need to think and change, which cultivates inductive reasoning and makes concepts transformation possible, paving the way for the cultivation of science thinking. Besides, because of personal operation, it also cultivates students' hands-on and brain-based inquiry ability and collaborative ability developed through group collaboration inquiry.

Relation The "*Relation*" function are mainly building bridges between the same contents and realizing transformation. For organic chemistry, it is key to mastering the macroscopic, microscopic and symbolic representations of substances, and build a connection between them to achieve mutual transformation. Pre-service teachers of every grade mentioned the "*Relation"* function, and all examples were based on "triple representation transformation" (Table 5), indicating that AR teaching can solve this problem and build relevant thinking (Fig. 9).

Gender

Male and female mentioned the three educational functions of AR in similar frequency (Fig. 10). Among them, *"Visual Presentation"* and *"Thinking Construction"* are mentioned slightly more frequently by females, while *"Conceptual Understanding"* is just the opposite. For further exploration, this study plots the differences between male and female views on each AR education sub-function (Fig. 11).

There are no differences between male and female on AR education sub-function "*Structure*", "*Property*", "*Abstraction*" and "*Extension*", and there are minor differences on "*Motivation*", "*Pattern*" and "*Relation*". However, "*Perception*" differed greatly between male and female. It can be seen that stereoscopic images are perceived more strongly by the females, which means images are more helpful for the females to construct a spatial sense in their mind, and help them better understand the abstract and three-dimensional nature of chemical knowledge. In contrast, the males are interested in freshness about AR presentation, knowledge can be visualized through AR presentation, which can enhance the interest and vividness of learning and reduce students' fear of learning chemistry, prompting their learning motivation. Hence, AR teaching is more helpful to the females than the males about the problem-triple representation switching.

Table 5 The interview text about relation

Sophomore F	*I think it's a good way to build macro characters*
Sophomore M	*At beginning, the app should be presented to the students so that they can feel. In this process, they will form an impression in their mind, then they can build connections with discussion quickly*
Junior F	*Organics teaching focuses on students to build a bridge between macro phenomenon, micro phenomenon and symbol, so AR images skillfully combine micro phenomenon and symbol*
Junior M	*It has an important strengthening effect on triple representation*
Senior F	*In particular, AR plays a good role in the process of microscopic and symbolic transformation, which can help students build a knowledge bridge and promote learning*
Senior M	*When teaching the molecular and structural formula, the cards are presented to the students. When they see the molecular formula and microscopic structure plan on the cards, they cannot connect directly, but through scanning, they will have a more intuitive view of this structure, so that they'll have a deep grasp of knowledge*
Postgraduate F	*Students are able to make better connections between molecular micro-structures and symbols*
Postgraduate M	*In inquiry learning, I think you can also use AR technology. With integrating these technologies into teaching, the association between images and knowledge can promote the transformation of thought*

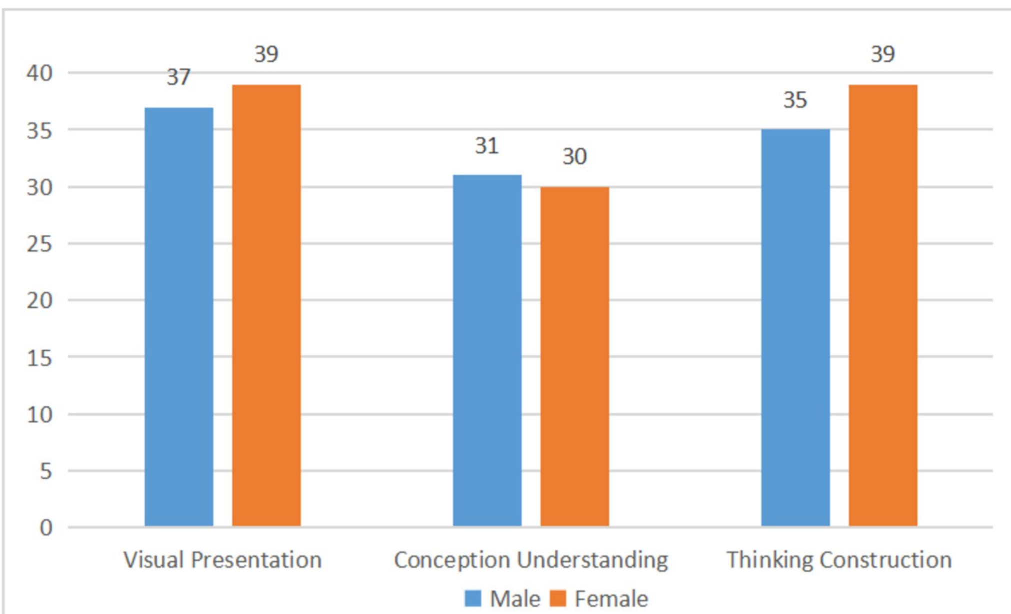

Fig. 10 The whole and part of the gender perspective

Conclusion and recommendations

In conclusion, this study constructs a theoretical models of AR educational functions (Fig. 12). Firstly it is divided into three major functions: *"Visual Presentation"*, *"Conception Understanding"*, *"Thinking Construction"*, and each function can be respectively divided into 2–3 subfunctions. By interacting and promoting with each other, the function of AR can be completed, which means the three functions can be implemented and the organics chemistry learning can be promoted.

Therefore, teachers should design the way of teaching based on the three AR functions in the future. For example, in order to attract students' attention, teachers can change the introduction ways or insertion positions, which help students explore and develop various thinking modes and construct an AR teaching environment with developing the multiple thinking. Only such teaching mode can get modern teaching reformed, promote the informational education, and explore the contemporary education.

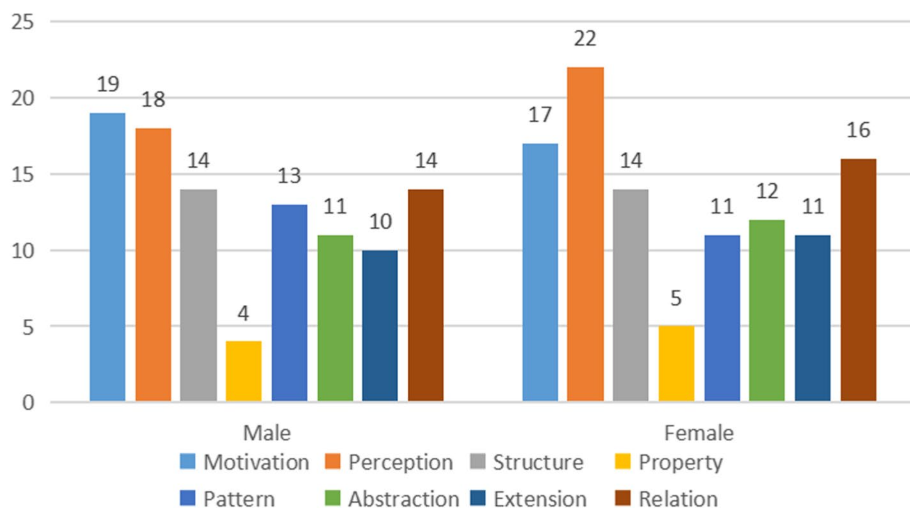

Fig. 11 The whole and part of the gender perspective

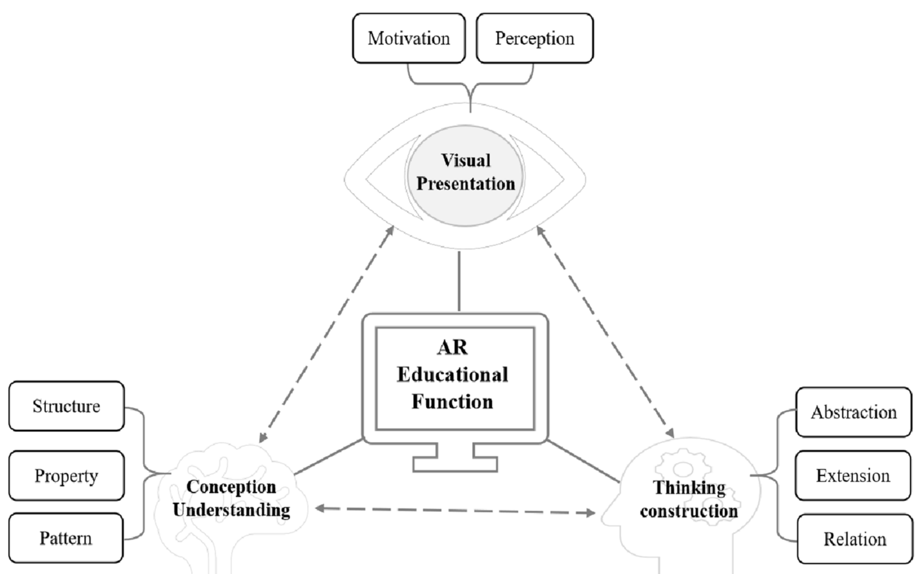

Fig. 12 Theoretical model construction of AR education function

Appendix 1

Interview Outline	
Feeling of Experience	(1) What did you think of the experience you just had?
	(2) What did you enjoy most about the experience?
	(3) What did you like least the experience?
AR &Organic Chemistry Learning	(1) During organic chemistry learning, what knowledge do you think it's difficult to understand?
	(2) Can the AR app promote to solve it ? Why?
AR &Organic Chemistry Teaching	(1) Are you willing to try AR in your future teaching process? Why?
	(2) If you have chance to use it, which way will you choose to mix AR with organic chemistry teaching? Why?

Appendix 2

Code Table	
Visual Presentation	Motivation
	Perception
Conception Understanding	Structure
	Property
	Pattern
Thinking Construction	Abstraction
	Extension
	Relation

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Authors' contributions

SZ and CZ developed the augmented reality software of "Meet Organic" App, developed the concept, wrote the manuscript. CZ and JZ conducted the investigation, analyzed and interpreted the data.SZ contributed by consulting on all sections of the manuscript, also revising and proof-reading it. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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