Augmented reality technology as a tool to support chemistry learning: a scoping review

I Sari1,2*, P Sinaga1, and Hernani1

1Program Studi Pendidikan Ilmu Pengetahuan Alam, Sekolah Pascasarjana, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung 40154, Indonesia
2Program Studi Pendidikan Kimia, Fakultas Keguruan dan Ilmu Pendidikan, Universitas Sultan Ageng Tirtayasa, Jl. Ciwaru Raya No.25, Serang 42121, Indonesia

*indahsari@untirta.ac.id

Abstract. The purpose of this scoping review was to provide a comprehensive overview of relevant research regarding the use of Augmented Reality, the links to pedagogy and educational outcomes, specifically in the context of chemistry learning. The scoping review is underpinned by the five-stage Arksey and O’Malley framework. First, research questions are identified. Second, the last ten years studies are explored by using the key word ‘augmented reality + chemistry learning.’ Third, studies are investigated through inclusion and exclusion criteria, and PRISMA model is utilized for article selection. PRISMA model used in the form of four-phase flow diagram, including: identification, screening, eligibility, and included. Fourth, selected articles are charted with respect to numerous dimensions and summaries. Finally, findings are reported in the light of research questions. The findings of the scoping review illustrated a set of studies that provide evidence of improved conceptual understanding, increase in students’ interest, engagement, motivation, and satisfaction through the educational environments that are enriched with AR applications. The findings of the scoping review are discussed with respect to multiple dimensions that are explored under research questions.

1. Introduction
Chemistry is a part of natural sciences that studies natural phenomena. Some basic concepts of chemistry are at the sub-microscopic level and require thinking about natural phenomena using three levels of representation namely macroscopic, sub-microscopic, and symbolic [1]. Chemists use symbols and chemical equations to present materials and describe chemical changes as the way to communicate their observations, and it becomes obstacles in chemistry learning [1, 2, 3]. Students consider chemistry as a difficult subject because it contains abstract concepts and technical language [4, 5]. Chemistry learners must be able to connect the macroscopic world that they can see with the sub-microscopic dan symbolic representation. AR can be one of the solutions to overcome these difficulties because this technology can help the visualization of abstract concepts. AR technology facilitates the realization of topics through enabling 3D representation of the invisible events, and provides an understanding of concept that students frequently find difficult [e.g. 6-10]. Applying AR applications in education especially in chemistry learning also have a positive impact on learning process and learners’ attitudes [11-15] and it can be integrated with pedagogical approaches to gain various learning outcome.

Looking from such a glimpse, this scoping review aims to capture the relevant studies in the literature about AR as a tool to support chemistry learning. This study may reveal the point that how AR
applications are integrated into the chemistry learning process, including the chemistry topics, pedagogical approaches/models, and learning outcomes/expected result.

2. Method
This study is a scoping review using Arksey and O’Malley’s five-stage framework including: identifying research questions, identifying relevant studies, study selection, charting the data, summarizing and reporting the results were utilized in this review [16]. The stages of identifying research questions, identifying relevant studies, and study selection will be presented in method section, but the stages of charting the data, summarizing and reporting the results will be presented in result and discussion section.

2.1 Identifying Research Questions
This review was focused on exploration about three aspects including: the chemistry topics that were presented in the AR applications; the pedagogical approaches/models were integrated with AR applications; and the learning outcomes/expected result that arose through chemistry learning with AR application as support tool. The following research questions are submitted to guide the research to capture literature that in line with the focus of this study: (1) What chemistry topics are presented in AR applications?; (2) What pedagogical approaches/models are integrated with AR applications?; (3) What learning outcomes/results are arising from the use of AR applications in chemistry learning?

2.2 Identifying Relevant Studies
The second step is identifying relevant studies. Keyword ‘augmented reality + chemistry learning’ is selected to capture literature regarding the use of AR in chemistry learning. The reason for selecting ‘augmented reality + chemistry learning’ as a search term was to reach out relevant studies as many as possible. Afterwards, inclusion and exclusion criteria were developed to get insights about the aspect that can be included to summarize the selected studies. Table 1 shows the inclusion and exclusion criteria.

| Criteria       | Inclusion                                                                 | Exclusion                                                                 |
|---------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Time period   | The last 10 years (2011-2020)                                             | Outside these time period                                                 |
| Study focus   | Studies relating to designed an AR application for chemistry learning or apply in educational purposes | Studies that designed an AR application not for chemistry learning         |
| Participant   | Students and teachers/lecturers in educational setting                     | Informal participant in which there is no educational purposes            |

2.3 Study Selection
The article selection process on this study followed the PRISMA model in the form of four-phase flow diagram, including: identification, screening, eligibility, and included [18]. Stages of the article selection process can be seen in Figure 1.
Figure 1 shows the fact that most of articles were irrelevant with inclusion criteria. Studies about designed an AR application for another subject are excluded, i.e. for medical and language despite having educational objectives. Moreover, full-text articles that not written in English and preview of thesis and dissertations are also exclude.

3. Result and Discussion

3.1 Charting the Data

The next step on this scoping review was charting the selected articles. The final articles included in review as many as 42 articles related to designed an AR application for chemistry learning or apply in educational purposes. After each study is perceived to be included in the inclusion criteria, summaries are developed for each article with several variables including the author, participant, chemistry topics, pedagogical approaches/models, and learning outcome/result as shown in Table 2.

### Table 2. Descriptive information related to the reviewed articles

| Participant | Chemistry Topics | Pedagogical Approaches/Models | Learning Outcomes/ Results | Author |
|-------------|------------------|------------------------------|---------------------------|--------|
| Undergraduate students | Complex molecules | Computer-based learning | Conceptual understanding | Eriksen, et al. [9] |
| Preliminary in-course student | Bio molecules | Computer-Based Learning | Conceptual understanding, interest/excitement | Sanii [8] |
| Students, teachers lecturers | Periodic table of elements, chemical reaction | Inquiry-based learning | Teambuilding, motivation, communication, engagement, enjoyment | Estudante & Dietrich [19] |
| Undergraduate students | Bio molecules | Multimedia-based learning | Conceptual understanding, self-efficacy, spatial awareness | Sung, et al. [10] |
| Undergraduate students | Laboratory equipment | Internet/Web-Based Learning | Students’ attitude toward chemistry instrumentation | An, et al. [12] |
| Undergraduate students | Analytical instrumentation | Internet/Web-Based Learning | Conceptual understanding | Naese, et al. [20] |
| Undergraduate students | Organic chemistry reaction | Multimedia-based learning | Conceptual understanding | Plunkett [21] |
| Undergraduate students | Chemical reactions | Internet/web-based learning | Conceptual understanding and attitude | Yang, et al. [13] |
| Undergraduate students | Biochemistry-laboratory Safety | Inquiry-based learning | Knowledge, memory, helpfulness, enjoyment | Zhu, et al. [22] |
| Undergraduate students | Colorimetric titration | Multimedia-based learning | Conceptual understanding, confidence in chemical handling | Tee, et al. [23] |
| Junior high school students | Chemical reaction | Collaborative learning | Conceptual understanding and science interest | Chen & Liu [24] |
| Junior high school students | The composition of substances | Inquiry-based learning | Students’ attitude and Conceptual understanding | Cai, et al. [25] |
| Undergraduate students | Stereochemistry | Not mention clearly | Students’ mental rotation ability, attitudes, conceptual understanding | Habig [11] |
| Preliminary students | Chemical reactions | AR-based learning | Students’ attitude | Ewais & Troyer [7] |
| Secondary school students | Redox reaction | Not mention clearly | Conceptual understanding, interactions understanding, | Wan, et al. [26] |
| High school students | Redox reaction | Experimental learning | Conceptual understanding | Gan, et al. [27] |
| Senior high school students | Electrochemistry | Not mention clearly | Conceptual intrinsic understanding | Huwer, et al. [28] |
| Participant | Chemistry Topics | Pedagogical Approaches/Models | Learning Outcomes/ Results | Author |
|-------------|-----------------|------------------------------|---------------------------|--------|
| 7th grade students | Composition of substances | Not mention clearly | Conceptual understanding, motivation, self-efficacy and self-determination | Chang & Chung [29] |
| Secondary school students | Periodic table of the elements | AR-based learning | Conceptual understanding, motivation, attitude | Pribeanu, et al. [30] |
| Students (not mention clearly) | Chemical reaction | Experimental learning | Conceptual understanding and lab experience | Tuli & Mantri [31] |
| Undergraduate students | Enzyme kinetics | Game-based learning | Conceptual understanding, engagement | Crandall, et al. [32] |
| Students (11-13 years old) | Periodic table of the elements | Game-based learning | Engagement, excitement, | Boletis & McCallum [33] |
| Second grade of lower secondary school | Acid-base reaction | Experimental learning | Students’ attitude | Wojciechowski & Cellary [34] |
| Secondary school students | Periodic table of the elements, chemical bonding, chemical reactions | AR-based learning | Conceptual understanding | Iordache, et al. [35] |
| Chemistry teacher | Chemical elements | Not mention clearly | Technology literacy | Astuti, et al. [36] |
| Undergraduate students | Molecular geometry | Not mention clearly | Conceptual understanding | Nazar, et al. [37] |
| Undergraduate students | Molecular geometry | Cooperative learning | Conceptual understanding, submicroscopic representation ability | Wulandari, et al. [38] |
| Teachers and senior high school students | Chemical bonding | Not mention clearly | Conceptual understanding | Fitriani, et al. [39] |
| Undergraduate students and lecturers | Alkanes and Cycloalkanes | Not mention clearly | Conceptual understanding, motivation | Masmui, et al. [40] |
| Undergraduate students | Molecular geometry | Not mention clearly | Conceptual understanding | Irvansyah, et al. [41] |
| Undergraduate students | Stereochemistry | STEM learning | Conceptual understanding | Behmke, et al. [42] |
| Secondary school students, chemistr teachers | Stereochemistry | Not mention clearly | Conceptual understanding | Swamy et al. [43] |
| Junior high school students | Chemical reaction | AR-based learning | Conceptual understanding | Ashida & Makino [44] |
| Secondary school students | Chemical bonding | AR-based teaching | Conceptual understanding | Abbasi, et al. [45] |
| Senior high school students | The making of oxygen experiment | Collaborative problem solving | Conceptual understanding, laboratory safety | Hou & Lin [46] |
| Students (not mention their level) | Chemical bonding | Not mention clearly | Conceptual understanding | Saidin, et al. [47] |
| Senior high school students | Hydrocarbon | Interactive 5E learning cycle-based AR system | Conceptual understanding, motivation, self-efficacy | Cheng & Chu [48] |
| Senior high school students | Electrochemistry | Experiential learning cycle | Conceptual understanding, motivation | Chen & Liao [49] |
| Senior high school students | Gases | Inquiry-based learning | Problem solving abilities, conceptual understanding | Yang, et al. [50] |
3.2 Summarizing and Reporting Findings

The last step of Arksey and O’Malley’s five-stage framework is summarizing and reporting findings. The use of AR in learning activities is an emerging trend aimed at improving students’ learning outcomes and affective factors [24, 17]. AR helps in bridging the gap between the theoretical knowledge acquired through analytical activities (such as reading text-books and listening to lectures) and the practical experience gained from constructive activities [54]. AR also help students to understand the abstract concept that require spatial ability about submicroscopic representation by 3D visualizing. It corresponds to findings (see Table 2) that AR is used for chemistry learning on the topics containing abstract concepts such as complex molecules [9], bio molecules [8, 10], periodic table of the elements [19, 30, 33, 35], chemical reaction [7, 13, 19, 24, 31, 35, 44, 52], laboratory equipment [12], analytical instrumentation [20], organic chemistry reaction [21], biochemistry-laboratory safety [22], colorimetric titration [23], the composition of substances [25, 29], stereochemistry [11, 42, 43], redox reaction [26, 27], electrochemistry [28, 49], enzyme kinetics [32], acid-base reaction [34], chemical bonding [35, 39, 45, 47], chemical elements [36], molecular geometry [37, 38, 41, 53], alkanes and cycloalkanes [40], the making of oxygen experiment [46], hydrocarbon [48], gases [50], acid-base titration [51]. Based on the findings, the most widely developed chemistry topic in AR application is chemical reaction. Chemical reactions are one of the topics that become a precondition for studying the next topic, i.e. acid-base, reaction rate, thermochemistry, and electrochemistry. The findings suggest that there are chemistry topics that can be presented in AR application in the future study because the topic has an abstract concept that requires visualization, i.e. basic chemistry laws, stoichiometry, thermochemistry, reaction rate, colligative properties of solution, and chemical equilibrium.

The findings (see Table 2) also expose that AR applications for chemistry learning are developed with certain educational approach/models, i.e. game-based learning [32, 33], AR-based learning [7, 30, 35, 44, 45, 51], computer-based learning [8, 9], internet/web-based learning [12, 13, 20], inquiry-based learning [19, 22, 25, 50], multimedia-based learning [10, 21, 23], collaborative learning [24], experimental learning [27, 31, 34], cooperative learning [38], STEM learning [42], collaborative problem-solving [46], experiential learning cycle[49], and interactive 5E learning cycle-based AR system [48], although some studies do not mention clearly about it.

The findings (see Table 2) also indicate that AR has the potential to effect a transformation in learning chemistry process. It can make positive impact to various learning outcome such as conceptual understanding, submicroscopic representation ability, spatial ability, problem solving abilities, motivation, interest/excitement, engagement, attitude toward lab safety, teambuilding, communication, self-efficacy, self-determination, and also technology literacy. AR also allowing users to use hands in a direct manipulation with real and virtual objects simultaneously and enables experimental learning/laboratory activities [e.g. 12, 13, 19, 46]. The findings also show that only study no. 39 which aims to improve students’ problem-solving abilities. In the future research, the development of AR application that aims to stimulate higher order thinking skills is a good opportunity.

4. Conclusion

This scoping review exploring the studies that aims to develop AR application that are integrated into the chemistry learning process which is focus on exploration about three aspects including: the chemistry topics that were presented in the AR applications; the kind of pedagogical approaches/models
were integrated with AR applications; and the learning outcomes/expected result that arose through chemistry learning with AR application as support tool. Based on findings, future research opportunities are to develop an AR application for chemistry learning on topics i.e. basic chemistry laws, stoichiometry, thermochemistry, reaction rate, colligative properties of solution, and chemical equilibrium because these topics have abstract concepts that requires visualization. Other opportunities in the future study is design AR app in chemistry learning to improve conceptual understanding and the higher order thinking skills (i.e. critical thinking skill, problem solving skill, creative thinking skill, and decision making) as learning outcomes.

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Acknowledgments
The author sincerely thanks Lembaga Pengelola Dana Pendidikan (LPDP), Kementerian Keuangan Indonesia, for providing me with the financial support during my study at Universitas Pendidikan Indonesia.