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MOBILE AUGMENTED REALITY IN SOCIOSCIENTIFIC ISSUES-BASED LEARNING: THE EFFECTIVENESS ON STUDENTS' CONCEPTUAL KNOWLEDGE AND SOCIOSCIENTIFIC REASONING

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ABSTRACT

This research investigated the impact of newly developed instructional materials that integrate mobile augmented reality technology called Mobile Augmented Reality of Respiratory System (MARRS) in socioscientific issues-based biology learning. A quasi-experimental research with a nonequivalent pretest-posttest control group design was employed to compare the MARRS and conventional SSI instructional materials using PowerPoint and students' worksheets. Two classes with 72 eleventh-grade students were randomly assigned to experimental or control groups. This research evaluated two outcome variables: conceptual knowledge and socioscientific reasoning. Results indicated no significant difference in the overall conceptual knowledge, but a significant difference was found in socioscientific reasoning between the two groups. Moreover, MARRS is shown to be better in promoting students' analyzing skills and their perspectives and inquiry of socioscientific reasoning. Overall, it can be concluded that MARRS positively impacts being integrated into socioscientific issue-based biology learning.

Keywords: augmented reality; biology learning; conceptual knowledge; socioscientific issue; socioscientific reasoning

INTRODUCTION

Scientific literacy has always been the ultimate goal of science education. Another equally important goal has been promoting students' experiences with contemporary social dilemmas related to or based on science to enhance their appreciation for the interdependence of society and science (Sadler et al., 2004; Sadler & Fowler, 2006). This goal is relevant to one of the main goals of the 2013 curriculum to prepare Indonesian to have the ability to live as individuals and citizens who can contribute to the life of society, nation, state, and world civilization (Permendikbud, 2014). Therefore, learning in schools, including biology, is expected to be a tool so that students are not only able to master knowledge well but also be able to apply what they have learned in school to the community and use the community as a learning resource. However, in reality, science learning, including biology, which has been happening, still tends to separate knowledge and real-life problems (Çimer, 2012; Nida et al., 2020).

Implementing the 2013 curriculum can be supported by creating a learning experience where students are actively involved in understanding, evaluating, and making decisions related to real problems or issues in life. One of them is by involving them in a current social dilemma related to science to explain the relationship between science and its close relationship with society. Because of the central roles of social and scientific dimensions in these dilemmas, they have been termed socioscientific issues (SSI) (Sadler, 2004). SSI has become essential in science education since they

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are relevant to promoting scientific literacy, that science students require the ability to make informed decisions regarding scientific issues of particular social import (Sadler & Zeidler, 2005). Negotiating SSI involves understanding the content of an issue, processing information regarding the issue, attending to the moral and ethical ramifications and creating social debate or controversy by adopting a position on the issue (Sadler et al., 2004; Sadler & Zeidler, 2005). Engaging students in inquiry activities using SSI as a context can situate important science content and processes and create more meaningful learning to develop more integrated and valuable concepts. Many educational researchers have proven the advantages of implementing SSI in the classroom. It creates more meaningful learning (Sadler et al., 2007), enhances students' science knowledge (Chang et al., 2013; Chiang et al., 2014) and motivation (Chiang et al., 2014), develops informal reasoning (Sadler & Zeidler, 2005; Jansong et al., 2022), decision-making (Lee, 2007; Gutierez, 2015), socioscientific reasoning (SSR) (Sadler et al. 2011; Chang et al. 2018), reflective judgment (Subiantoro et al. 2013), critical thinking (Cahyarini et al., 2016; Pratiwi et al., 2016) scientific literacy (Arizen & Suhartini, 2020; Widiyawati, 2020; Widodo et al., 2020) and argumentation (Martini et al. 2021).

SSI differs from other issues in science since they are typically debatable problems and ill-structured, which implies that they are open-ended and subject to multiple perspectives and solutions (Sadler & Donnelly, 2006). Current socioscientific issues frequently stem from dilemmas involving biotechnology, such as genetic engineering, cloning, stem cells, genome project, genetically modified foods, and environmental problems such as local pollution issues, global climate change, land-use decisions, alternative fuels, and the introduction of exotic substances (biotic and abiotic) (Sadler, 2004; Sadler & Zeidler, 2004, 2005; Sadler & Donnelly, 2006). Today, science education researchers have made significant advances in using SSI as context to make science learning more relevant to students' lives. Many studies have been conducted and used more varied topics of SSI. For example, health issues related to COVID-19 (Subiantoro et al., 2021), nuclear energy use and radiation pollution (Chang et al., 2013), and smoking issues (Bell & Lederman, 2002; Lee, 2007).

As an example of SSI, smoking is very closely associated with Indonesian. Holipah et al. (2020) reported that Indonesia is a developing country with the highest cigarette consumption of 40,3% of current smokers. To control cigarette consumption, the Indonesian government introduced some policies such as defining tobacco products as excise items, establishing policies on smoking in open spaces, marketing tobacco products, and selling tobacco products (Amalia et al., 2019; Holipah et al., 2020; Rasyid & Ahsan, 2020). However, these policies are not enough since the smoking issue also positively impacts the government. Cigarettes contribute to the macroeconomic (Rasyid & Ahsan, 2020). The economic value of cigarettes is used for planning health services provisions and other public expenditures (CISDI, 2021), and cigarette companies provide considerable employment (Rasyid & Ahsan, 2020). Since many decades ago, smoking has been a cultural habit in Indonesia that is not easily changed. Therefore, effective cigarette consumption control requires addressing all possible health, economic, social, and commerce domains of tobacco (Kosen et al., 2017). This is consistent with the SSI movement that school science should reflect the dynamic interactions of science and society, which not only emphasizes the scientific background behind the issue and social, political, economic, and moral challenges (Sadler & Fowler, 2006).

Considering the smoking issue as described, it can serve as a functional SSI context for teaching and learning science content, particularly on the respiratory system. The respiratory system is included in the biology curriculum for senior high school eleventh graders and is considered complex by students (Pahlifi & Fatharani, 2019; Myanda & Riezky, 2020). Referring to the Ministry of Education and Culture Regulation number 37 of 2018, the basic competencies that students should internalize from the topic of the respiratory system are stated in 3.8, which is "analyzing the relationship between the structure of tissues that build the respiratory system organ about the bioprocess and functional disorders that might occur within the human respiratory system." It is paired with 4.8, which is "presenting the analysis results about the effect of air pollution on the abnormalities of respiratory system organs' structure and function based on the literature review" (Permendikbud, 2018).

Engaging students in SSI instruction will not isolate them on the focused issue only, but they will also involve in activities that promote their knowledge about science's products and processes related to the issue, as explained in the beginning. It will help students to acquire the basic competency 3.8. Furthermore, according to Cao et al. (2020), tobacco particles within the smoke are an example of air pollutants that harm the human body and are mainly reflected in the respiratory system. This is relevant to basic competency 4.8. Overall, using the smoking issue as a platform to learn the respiratory system within the SSI instruction is relevant to academic discipline under the Indonesian biology curriculum. However, it must be recognized that using SSI in science classrooms may consume a significant increase in lesson time and preparation (Sadler et al., 2007; Friedrichsen et al., 2020; Genisa et al., 2020).

Teachers usually develop a well-designed lesson plan to overcome the problem, including the instructional materials for their classroom activities. Common instructional materials to maximize learning are students' worksheets and PowerPoint slides. Although technology integration is essential for supporting active, motivating, and meaningful learning, teachers must choose the best technology for their classes. PowerPoint, as one of the technology commonly used around the globe, PowerPoint is still considered less effective since the students usually remain passive in the learning process (Singhal et al., 2012). With this technology, students will passively consume information by only sitting in the classroom without much engagement in the learning process, listening to lectures, taking notes, and memorizing it for the exam (Hill et al., 2012). Consequently, an alternative technology is required to improve learning.

Augmented reality (AR) is one of the fastest-growing modern technology that has proven potential for teaching and learning (Bacca et al., 2014; Akçayır & Akçayır, 2017; Sirakaya & Sirakaya, 2018; Kalana et al., 2020). AR enables users to interact with virtual and real-world applications in real time (Azuma, 1997). This unique ability supports an interactive, exciting, unforgettable experience and active participation opportunities (Kiryakova et al., 2018). AR technology is suitable for studying science (Wu et al., 2013) and is mainly used for learning abstract concepts or concepts that are not visible before students' eyes (Bacca et al., 2014; Kalana et al., 2020). Therefore, AR integration into biology learning on the respiratory system is relevant and facilitates more effective learning. Moreover, this will transform the conventional classroom environment where the common activity is merely memorizing and reciting the concepts rather than learning them meaningfully.

Although many researchers have examined AR potential in many biology topics (Kalana et al., 2020), relatively little has been done regarding how to incorporate this technology into an instructional design of learning. It is, therefore, noteworthy that technology is not essential for educational researchers (Bronack, 2011), rather than when and how innovative technology promotes the learning process by considering the interplay among technology design, instructional method, and learning context (Chang et al., 2014). As Aydin (2019) reported, AR integration into an expository or inductive strategy could reduce its learning potential. On the contrary, many studies have concluded that a combination of AR and inquiry-based strategy is more potent in promoting learning.

The main potential of AR in inquiry-based learning is as a visualization tool. AR visualization can help students understand concepts related to material that does not allow them to experience it directly (Chang et al., 2013). It can also help students understand abstract (Kamarainen et al., 2016) or concrete science concepts (Chiang et al., 2014; Ahmed et al., 2017) more profoundly and ground those concepts in relevant contextualized phenomena. A more complex AR design enables an authentic task presentation for the inquiry process and increases students' engagement as the actuality of students' affective domain (Chang et al., 2014). AR technology with context and assignments equipped with various representations, such as text, image visualization, and SSI simulation, can support students in developing their Socioscientific Reasoning (SSR) (Chang et al., 2018). AR technology capitalized on virtual-physical interaction in inquiry-oriented activities can retain learned knowledge and is more motivating for students (Chang et al., 2016). AR integration into an inquiry-based strategy using the Jigsaw learning method can improve learning achievements and develop collaboration skills (Rezende et al., 2017). The framework of AR in combination with a virtual laboratory based on the 5E model has also recently been developed and is reported to have the ability to provide opportunities for increasing learning outcomes (Purwaningtyas et al., 2022). Overall, it can be concluded that AR integration into an inquiry-based strategy can facilitate the visualization of abstract and concrete concepts and support the enhancement of students learning achievement from the cognitive, affective, and psychomotor.

In the previous study, we developed a new mobile augmented reality called Mobile Augmented Reality of Respiratory System (MARRS), which was proposed for conducting SSI-based biology learning on the respiratory system. We took advantage of the AR technology described to provide students with new learning experiences and facilitate the visualization of the issue. Experts, practitioners, and users have evaluated the MARRS. From the results, it can be concluded that the MARRS is appropriately implemented in teaching and learning the respiratory system. In this study, we engaged students in an SSI regarding smoking issues. The AR technology is used to develop students' science knowledge related to the smoking issue, for example, about the structure and function of the human respiratory system and the harmful effects of smoking on the human respiratory system. Students were provided with a dilemma requiring them to consider the arguments for and against a new government policy to ban smoking for someone aged 24 and under completely. It means that someone aged 24 and under will never be able to legally purchase, possess, and smoke cigarettes. This dilemma was used to support the development of Socioscientific Reasoning (SSR) as one of the essential learning outcomes of SSI.

We evaluated the impact of the MARRS by focusing on how well-designed SSI instruction can enhance students' conceptual knowledge and socioscientific reasoning (SSR) as an essential outcome in learning SSI. In previous research, interpreting the relationship between students' scientific knowledge and their decisions has always been debated. In SSI, decision-making and SSR are related in that the decisions are made through the socioscientific reasoning processes. Some researchers reported that students with better science performance will show better reasoning and be able to use multiple sources of evidence in making decisions. On the other hand, researchers also argue that students' decision-making ability is irrelevant to their knowledge of science content (Jho et al., 2014). The irrelevant results are also reported by Sadler and Donnelly (2006) and Chang et al. (2018). Consequently, additional research that can more robustly describe the relationship between conceptual knowledge and SSR is needed.

This research relies on the MARRS as a new innovative technology for SSI-based biology learning, particularly in Indonesia, since research focusing on SSI-based instructional materials remains limited. Moreover, this research supports the scientific studies about SSI that have evolved and as additional evidence to describe the relationship between conceptual knowledge and SSR. Therefore, the research questions that guide this study are: (1) How is the effectiveness of SSI-based biology learning supported by MARRS as instructional materials of the human respiratory system toward students' conceptual knowledge?; (2) How is the effectiveness of SSI-based biology learning supported by MARRS as instructional materials of the human respiratory system towards students' socioscientific reasoning (SSR)?

METHODS

This research employed a quasi-experimental with nonequivalent pretest and posttest design to investigate the effectivity of MARRS on students' conceptual knowledge and SSR. It involved two classes of 72 eleven-graders from a public senior high school in Yogyakarta. The two classes were randomly assigned as the experimental group (n=36) and control group (n=36) with the same teacher within the same curriculum and teaching procedures based on SSI instruction. Each student took pretests before and posttests after the intervention.

The pretests and posttests had the same questions and were administered to the students. They did a 20-minutes conceptual knowledge test and a 20-minutes SSR test with 5 minutes of time tolerance. The conceptual knowledge test contains 20 multiple-choice items to measure students' conceptual knowledge based on Krathwohl's (2002) definition, including knowledge of classifications and categories, principles and generalizations, and theories, models, and structures regarding the human respiratory system. The SSR test contains ten multiple-choice items using a two-tiered ordered multiple choice (OMC) format with a brief scenario describing a smoking issue to measure the four dimensions of SSR based on Sadler et al.'s (2007) definition, including complexity, perspectives, inquiry, and skepticism. The SSR test was constructed by adopting and modifying the Quantitative assessment of Socioscientific Reasoning (QuASSR) format developed by Romine et al. (2016). Both conceptual and SSR tests went through revisions to ensure their content validity. Only the data from students that finished both the pretest and posttest were collected and analyzed.

The intervention was engaging students in SSI instruction within the smoking issue to situate the learning of the human respiratory system. SSI instruction was conducted through six stages: 1) issue orientation and analysis; 2) clarifying the biology background of the issue; 3) resuming the socioscientific dimension; 4) discussing and evaluating different points of view through role-playing activity; 5) reflection, and 6) evaluation. This SSI instruction was adopted and modified from Feierabend & Eilks (2010) and Subiantoro et al. (2021). In the practical work, the experimental group students used the instructional material in the MARRS application, while the control group students used the worksheet and PowerPoint as commonly used by the teachers. The learning activities for each group were conducted four times of learning with 60 minutes each, including pretests and posttests. The experimental group was introduced to the MARRS application before the learning activities. The students learning activities were guided by a worksheet that can be downloaded from the MARRS application. This worksheet contained a task that required students to clarify the biological background of the smoking issue through AR technology. The control group used the same worksheet, but the clarification task was asked through PowerPoint. AR and PowerPoint had the same information. However, AR was equipped with research conflicts about the smoking issue from some publications summarized in diagrams, charts, and tables, while PowerPoint presented the information as teachers usually do without publication summaries. Figure 1 displays the diagram of the experimental design. The time excluded from Figure 1 was used for other purposes, such as opening, apperception, motivation, explanation, conditioning of students, and giving assignments.

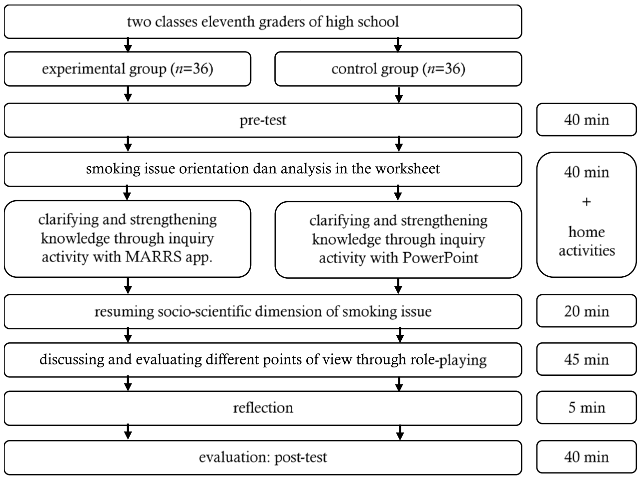

Figure 1. Diagram of Experimental Design

The data obtained in the study were analyzed via IBM SPSS Statistics 27. The P-value tests were carried out to examine the MARRS by comparing the results statistically. The t-test and Mann-Whitney U test were applied in this study to conduct data analyses. We decided to analyze the dependent variables separately rather than simultaneously using one-way MANOVA since previous research reported that both variables are not correlated (Sadler & Donnelly, 2006; Jho et al., 2014; Chang et al., 2018). MANOVA test is justified only when the researchers have reason to believe that correlation exists among the dependent variables (Küçük et al., 2016).

RESULTS AND DISCUSSION

With the help of a developer team competent in AR technology, an AR system called Mobile Augmented Reality of Respiratory System (MARRS) has been developed. MARRS was designed using a markerless AR system in the form of Android-based smartphone software. Although the marker-based AR system was primarily preferred in educational AR studies (Sirakaya & Sirakaya, 2018), markerless AR is more beneficial than marker-based AR (Abdinejad et al., 2021). Since the virtual objects do not need to be attached to any marker in the real world, this eliminates the user from printing any distinctive shape, picture, or barcode (markers) to view the AR objects, which can minimize the technical problems about perceiving the marker. Android operating system was chosen based on a preliminary survey that revealed that >90% of students use Android smartphones. Figure 2 provides a view of MARRS.

Although many educational studies have examined AR technology in many biology topics (Kalana et al., 2020), research aimed to investigate its effectiveness when integrated with specific instructional learning designs is still very limited. In recent years, SSI instruction has gained much attention since it has been proven to have many positive impacts on learning (Sadler & Zeidler, 2005; Lee, 2007; Sadler et al., 2007; Chang et al., 2013; Subiantoro et al., 2013; Chiang et al., 2014; Gutierez, 2015; Pratiwi et al., 2016; Chang et al., 2018; Arizen & Suhartini, 2020; Martini et al., 2021). Some controversial issues have been introduced in AR-based SSI instruction, including nuclear power plants (Chang et al., 2013) and global warming (Parvathy et al., 2016), but no study has been conducted on smoking issues. Based on that, we developed a new AR technology app called MARRS to support SSI-based biology learning within the issue of smoking, and this present study will focus on the evaluation of the MARRS towards students' conceptual knowledge dan sociosientific reasoning (SSR).

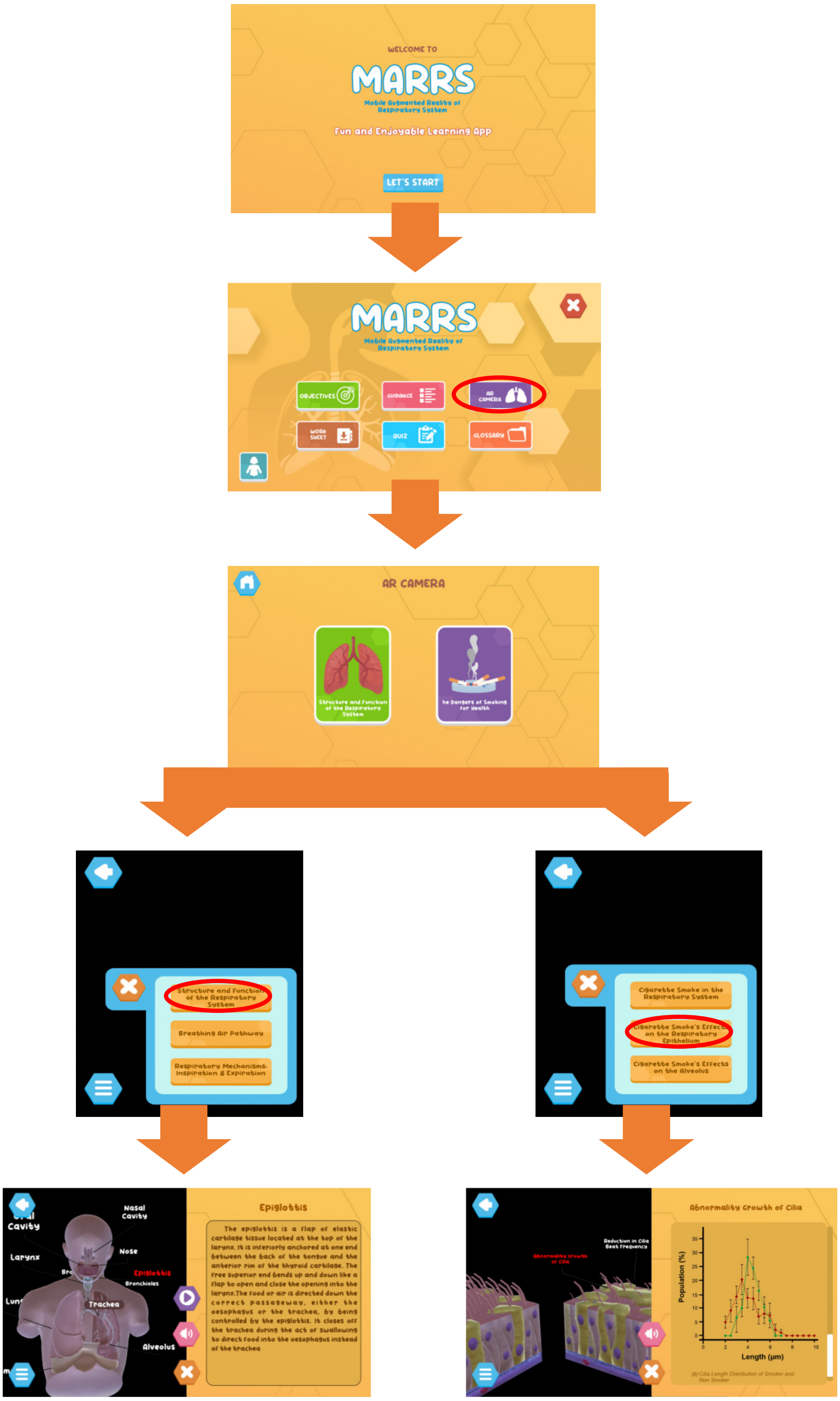

Figure 2. Flowchart of Markerless AR App

As shown in Figure 2, the AR camera menu is used in the second stage of SSI instruction to clarify the biological background of smoking issues and strengthen students' knowledge. Before further engagement in SSI instruction, students need to understand the scientific background of the issue. Within smoking issues, we assumed that most students were non-smokers, so providing them with an indirect smoking experience was worthwhile so they could be better at figuring out what would happen to smokers' respiratory systems (Lee, 2007). AR technology in the clarification stages of SSI instruction will support this in a more realistic human anatomy learning environment since AR visualizes not only the organs' shape but also the position and the relationship between them (Yeom, 2011). Thus it can promote students' knowledge acquisition. It involves understanding the content knowledge behind the issue, and negotiating in SSI requires students to adopt a position on the issue (Sadler et al., 2004). This entails students' participation in dialogue, discussion, and debate (Parvathy et al., 2016). In our work, students discussed different points of view regarding the smoking issue through a role-playing activity. Role-playing is an example of SSI learning methods in which students assume the roles of characters based on a scenario regarding the issue, implying students' participation and active engagement to defend their points of view behind the decision on the issue they made. Some previous research has suggested this method since it can help students become more interested and involved in learning and encourage a deeper understanding of content and the development of collaboration, communica-tion, and argumentation skills (Agell et al., 2015). Because it promotes students' ability to argue, role-playing is essential in supporting the development of students' reasoning skills. It is reported that contributing factors to students' reasoning about SSI remain uncertain, where students' scientific knowledge may or may not relate to it (Sadler et al., 2004; Sadler & Donnelly, 2006; Chang et al., 2018). This study may provide evidence to support the uncertainty.

Description of the Implementation Process

The control group learned using instructional materials of printed worksheets assisted by PowerPoint, while the experimental group learned using MARRS assisted by AR technology. The scope of materials presented in both PowerPoint and MARRS is mainly sourced from anatomy and physiology of human respiratory system books, considering both the width and depth of content in adaptation to the high school biology curriculum. PowerPoint and MARRS are different regarding visualization ability since AR technology can make content concrete by visualizing abstract structures in 3D and clarifying complex topics (Küçük et al., 2016). Moreover, MARRS in this study was designed with the application of a more complex multimedia principle that combines words and pictures and 3D objects, animations, videos, and voice. Another difference between PowerPoint and MARRS lies in diagrams, charts, and tables regarding the conflicting research results about smoking issues from some publications presented in MARRS.

The study was split into two sessions as designed in the worksheet. Each participant participated in all two sessions within the biology class schedule for about two weeks. Before the learning sessions started, students were divided into six study groups where they needed to collaborate to finish the sessions. The first session incorporated two initial stages of SSI instruction in which students learned the essential biological background related to the issue. When the necessary foundational knowledge was mastered, the second session began. It incorporated the third and fourth stages of SSI instruction and aimed to teach students about the societal dimension of debates and the inherent interplay between science and society.

In the first session, students were introduced to the smoking issue with an article titled 'Protecting the Lungs by Quitting Smoking.' This article was selected to provoke a preliminary discussion and identify the students' level of knowledge about smoking and the potential consequences (Feierabend & Eilks, 2010). After that, students were asked to clarify their knowledge about the issue using PowerPoint for the control group and AR for the experimental group. The second session resumed the socioscientific debate, where students were asked to mimic societal or political decision-making (Feierabend & Eilks, 2010). This study used role-playing as a panel discussion, which was adopted and modified from Sagmeister & Kapelari (2021). Study groups were divided into six expert roles based on various potential stakeholders in society, including the minister of health, scientist, tobacco industry representative, minister of finance, tobacco farmer representative, and hawker representative that participated in the role-based panel discussion. The provocative scenario, in this case, is a bill proposing to ban smoking for someone aged 24 and under completely. It means that someone aged 24 and under will never be able to legally purchase, possess, and smoke cigarettes. The scenario is a fictitious constitutional act that deliberately created to enhance motivation. A similar act was done by Feierabend & Eilks (2010) in their research. Some basic scientific knowledge students gain from the first session will allow students to understand the debate better (Feierabend & Eilks, 2010).

Compared with the control group, students in the experimental group appeared much more eager in each session. In the first session, it was observed that students using the AR technology showed excitement in the clarification stage. Students were seen actively exploring the 3D objects in the MARRS. We did not observe the same thing for the students using PowerPoint, and they tended to be silent while reading the PowerPoint prepared by the teacher. This could indicate that AR technology could better promote students' interest and enjoyment in studying biology. This observation result is not surprising, as most AR studies in the literature also reported that AR technology can be used to construct a learning environment that supplies students with much fun (Chang et al., 2016; Weng et al., 2020).

Referring to the role-based panel discussion, each role from the control and experimental groups used supporting information to represent their roles' positions. Nevertheless, in general, the experimental group showed better performance. Perhaps their interest and enjoyment in the first session had given them external motivation since they seemed more prepared. Some roles even brought print-outs or written notes of arguments they had prepared beforehand for the panel discussion. This indicated that they dealt with oral and written arguments. Moreover, the well-prepared arguments were evidence that the experimental group students' applied their reasoning skills and utilized their newly acquired knowledge more than the control group.

Overall, the implementation process showed that both groups were slow in responding to the SSI learning instruction. This is because students were accustomed to the teacher's traditional learning setting. For example, they did not fully understand the activity instruction within the worksheet. In the first session, students did not present a good analysis of the biological background behind the smoking issue in relevance to their clarification. They only wrote down the scientific facts behind the smoking issue related to the respiratory system without giving in-depth thoughts and only clarified the facts without relating them to the analysis results. Only a small number of students carefully read and understood the worksheet's tasks, while the others only read a particular section to find the solution to the problem discussed in the worksheet. This was shown from the students' arguments during role-based panel discussions, where most of the arguments were taken from provided information within the worksheet. Furthermore, this study was carried out during the COVID-19 pandemic after almost two years of remote learning. Since this study's targets were eleven graders, it means that participating students were middle school students before. Perhaps they were still transitioning from middle to high school learning level. This could be a limitation in kind.

Analysis of Students' Conceptual Knowledge

This section compares the two learning conditions regarding how the students' overall conceptual knowledge improved. The improvement in conceptual knowledge was determined by comparing the pretest and posttest scores of the experimental and control groups using the paired-sample t-test. Table 1 indicates that there is a significant difference between the pretest and posttest in the experimental and control groups ($t = -11.305$; $p < .05$ and $t = -14.832$; $p < .05$). It means that the intervention of SSI instruction had similar effects on students' overall conceptual knowledge in both groups. Students in both groups exhibited much better overall conceptual knowledge after the intervention.

Table 1. Paired-Sample T-Test of the Conceptual Knowledge

Group	Pretest			Posttest			*t*	*d*
	N	***M***	**SD**	***N***	***M***	**SD**		
Experimental	27	44.44	13.107	27	75.74	11.743	-11.305*	2.176
Control	27	43.89	9.129	27	73.33	9.707	-14.832*	2.854

*$P < .05$; *d* means the effect size

The comparison results of students' conceptual knowledge using an independent sample t-test are summarized in Table 2, Table 3, and Table 4. Table 2 provides the students' overall conceptual knowledge comparison results. None of the pretest and posttest results differed significantly between the two groups ($t = -.181$; $p > .05$ and $t = -.821$; $p > .05$). The insignificant pretest results indicated that the participating students in the two groups had the same initial basic conceptual knowledge. The insignificant posttest results indicated that the two versions of SSI instruction had the same effectiveness on the students' overall conceptual knowledge improvement.

Table 2. Independent Sample T-Test of the Conceptual Knowledge

Test	Experimental Group			Control Group			*t*	*d*
	N	*M*	SD	*N*	*M*	SD		
Pretest	27	44.44	13.107	27	43.89	9.129	-.181	.049
Posttest	27	75.74	11.743	27	73.33	9.707	-.821	.223

*$P < .05$; *d* means the effect size

Other tests were conducted to further understand the effect of AR integration into SSI on conceptual knowledge. Table 3 provides the results of students' conceptual knowledge comparison based on different cognitive levels.

Table 3. Mann-Whitney U Test of the Conceptual Knowledge based on Cognitive Level

Level	Experimental Group				Control Group				*Z*	*d*
	N	*M*	SD	Mean rank	*N*	*M*	SD	Mean rank		
Remember	27	2.81	.834	27.44	27	2.81	.786	27.56	.028	.004
Understand	27	3.19	.834	26.31	27	3.33	.734	28.69	.600	.082
Apply	27	1.44	.506	26.28	27	1.52	.580	28.72	.653	.089
Analyze	27	4.70	1.068	31.57	27	4.15	.949	23.43	1.977*	.269
Evaluate	27	2.93	1.035	28.43	27	2.85	.864	26.57	.453	.062

*$P < .05$; *d* means the effect size

Table 3 shows that the students' analyzing level in the experimental group (*M* = 4.70; SD = 1.068) was significantly higher (*Z* = 1.977; $p < .05$) than in the control group (M = 4.15; SD = .949). It indicates that the MARRS app was more effective in promoting students' conceptual knowledge at the level of analyzing (*d* = .269). Table 4 provides the results of students' conceptual knowledge comparison based on conceptual knowledge's aspects according to Krathwohl (2002).

Table 4. Mann-Whitney U Test of the Conceptual Knowledge based on Its Aspects

Aspect	Experimental Group				Control Group				*Z*	*d*
	N	*M*	SD	Mean rank	*N*	*M*	SD	Mean rank		
Knowledge of classifications and categories	27	2.48	.975	26.04	27	2.67	.784	28.96	.728	.099
Knowledge of principles and generalizations	27	7.48	1.626	28.46	27	7.26	1.745	26.54	.460	.063
Knowledge of theories, models, and structures	27	5.19	.962	32.11	27	4.74	.656	22.89	2.308*	.314

*$P < .05$; *d* means the effect size

Table 4 shows that students' knowledge of theories, models, and structures in the experimental (*M* = 5.19; SD = .962) was significantly higher (*Z* = 2.308; $p < .05$) than the control group (*M* = 4.74; SD = .656). It indicates that the MARRS app was more effective in promoting students' conceptual knowledge of theories, models, and structures than the conventional method, though they were relatively small effect sizes (*d* = .314).

From the results, we conclude that using the MARRS app in SSI instruction and the conventional SSI instruction method with PowerPoint had a similar effect on students' overall conceptual knowledge. A few researchers have started comparing AR technology with other teaching materials to identify unique AR features that benefit learning. In comparison with picture books and physical interaction (Hung et al., 2017), textbooks (Weng et al., 2020), digital video (Chang et al., 2016), and interactive simulation technology (Chang et al., 2016), AR has similar effectiveness in facilitating students' gains of knowledge. In this study, the two conditions required the same cognitive tasks through the rest of the learning session guided by worksheets. This may be why there is no significant difference between both groups, as was hypothesized in the AR comparison with interactive simulation technology.

Although there is no evidence showing that the use of MARRS is more effective than the conventional method with PowerPoint in order to promote students' overall conceptual knowledge, we can at least infer that AR integration in SSI instruction can provide a new alternative to an attractive, engaging, and fun learning experience. Moreover, this study shows that integrating AR technology into SSI instruction was particularly more effective in promoting students' analyzing level than PowerPoint. Relevant results were provided by Chien et al. (2019) and Weng et al. (2020). In the MARRS app, the AR system was designed to stimulate real objects using virtual objects in an integrated manner and equipped with narrated explanations. Thus, students could observe the objects while understanding the explanation simultaneously, contributing to the decrease of students' cognitive load. This allows students to use higher-order thinking skills since they require less effort to organize the information (Chiang et al., 2014; Weng et al., 2020). Unfortunately, this study failed to record the same result for the evaluating level. Based on Hsu & Lin (2017), students' evaluation levels can be developed using visualization tools to visualize complex information. The less realistic visuals in the MARRS app may contribute to the insignificant difference between students' evaluation level in the two groups since the information received by students become less comprehensive and accurate. On the other hand, the insignificant results for the basic cognitive levels could be related to the design of the teaching plans with the same learning objectives (Chien et al., 2019) and the less realistic object visualization (Weng et al., 2020). As suggested by Erbas & Demirer (2019), AR systems with more realistic visuals and design are essential so that the students can engage in better interactivity and focus more on the content rather than the technology.

This study also shows that integrating AR technology into SSI instruction was particularly effective in promoting students' conceptual knowledge in terms of their knowledge of theories, models, and structures. This result is supported by AR's ability to present the human respiratory structures in 3D models, allowing students to gain knowledge of human structures more efficiently than conventional teaching methods (Marzouk et al., 2013). In this study, the MARRS app presents 3D models of the human respiratory system that can be seen from various points of view, which cannot be obtained through learning with static 2D images. With MARRS, students can rotate the 3D models to various angles and zoom in and out the models. Each part of the human respiratory structure is clearly labeled, allowing students to touch the label for explanations. Animations and videos are also provided to support the learning. 3D models, animation, and videos are examples of multimedia that are often used to visualize anatomical structures (Hegarty, 2004; Nicholson et al., 2006; Küçük et al., 2016).

Analysis of Students' Socioscientific Reasoning (SSR)

The paired-sample t-test results of the SSR are shown in Table 5. The results show that the posttest of the experimental group (M = 59.75; SD = 15.217) was significantly higher (t = –3.651; $p < .05$) than the pretest (M = 49.13; SD = 15.460) with a medium effect size (d = .603). Meanwhile, the control group did not show the same result since the test indicates there is no significant difference (t = –1.371; $p > .05$) between the posttest (M = 50.37; SD = 17.864) and pretest (M = 44.57; SD = 15.612). These results indicate that using the MARRS app in SSI instruction impacted students' SSR improvement but the exact opposite in using the conventional SSI instruction method.

Table 5. The Paired-Sample t-test of the SSR

Group	Pretest			Posttest			*T*	*D*
	N	*M*	SD	*N*	*M*	SD		
Experimental	27	49.13	15.460	27	59.75	15.217	-3.651*	.603
Control	27	44.57	15.612	27	50.37	17.864	-1.371	.264

*$P < .05$; d means the effect size

The comparison results of students' overall SSR of the experimental and control groups using an independent sample t-test are summarized in Table 6. The pretests between the two groups were not significantly different (t = –1.080; $p > .05$), indicating that participating students in the two groups had the same initial SSR. The posttests show that the difference between the SSR of the two groups was significant (t = –2.078; $p < .05$) with a medium effect size (d = .565). Moreover, the mean value of the experimental group (M = 59.75; SD = 15.217) was higher than that of the control group (M = 50.37; SD = 17.864), indicating that MARRS is more effective than the conventional SSI instruction method in order to promote students' SSR.

Table 6. Independent Sample T-Test of the SSR

Test	Experimental Group			Control Group			*T*	*d*
	N	*M*	SD	*N*	*M*	SD		
Pretest	27	49.13	15.460	27	44.57	15.612	-1.080	.294
Posttest	27	59.75	15.217	27	50.37	17.864	-2.078*	.565

*$P < .05$; d means the effect size

To further understand the effect of AR integration on SSR, another test was conducted by allocating research data based on the aspects of SSR, according to Sadler et al. (2007). The results in Table 7 indicate that only two over four aspects show a significant difference. The two aspects are perspectives (t = 2.072; $P < .05$) dan inquiry (Z = 2.097; $P < .05$), with the higher means value in the experimental group (EG: M = 4.44; SD = 1.783 | CG: M = 3.48; SD = 1.909 for perspectives and EG: M = 4.48; SD = 1.868 | CG: M = 3.37; SD = 2.022 for inquiry). It can be concluded that the MARRS app is more effective in promoting perspective and inquiry of SSR rather than the other two aspects, complexity and skepticism.

Table 7. Independent Sample T-Test/Mann-Whitney U Test of the SSR Based On Its Aspects

Aspect	Experimental Group (EG)				Control Group (CG)				*t/Z*	*d*
	N	*M*	SD	Rank mean	*N*	*M*	SD	Rank mean		
Complexity	27	3.81	1.272	25.96	27	4.11	1.050	29.04	.752	.102
Perspectives	27	4.44	1.783	31.83	27	3.48	1.909	23.17	2.072*	.282
Inquiry	27	4.48	1.868	-	27	3.37	2.022	-	2.097*	.571
Skepticism	27	5.19	3.151	30.41	27	4.15	2.769	24.59	1.368	.186

*$P < .05$; d means the effect size

We conclude from the results that the MARRS app in SSI instruction is more effective on students' SSR than the conventional SSI instruction method with PowerPoint. Further statistical tests show significant differences in the perspectives and inquiry aspects, not in the complexity and skepticism aspects.

Advanced practice of SSR is demonstrated by the ability and tendency to conceptualize the complexity associated with SSI and avoid simplifying the issue by focusing on a single factor. Students' awareness of an issue's complexity is supported by their understanding of the issue itself (Sadler et al., 2007). In this study, the lack of ability of MARRS to visualize complex information through 3D models could be contributed to reducing students' understanding of the smoking issue so that awareness about the complexity of the issue decrease. For example, visualization of the cigarettes' effects on the human respiratory system is only visualized by the changing color after cigarette smoke is inhaled. Meanwhile, airway epithelium damage due to cigarette smoke is visualized in the other 3D model. This may cause the students to have difficulty drawing connections between the information since it is separately visualized.

SSI is a controversial issue since it involves various perspectives. Moreover, SSI is also an unstructured issue that requires ongoing investigation and is often based on fragile and sometimes contradictory (scientific) evidence (Sadler et al., 2007; Eggert et al., 2017). Students involved in SSI were asked to adopt different but reasonable solutions based on differences in personal priorities, principles, and biases of the issue. The solution made is an open solution that is still uncertain. Thus, an SSI must be conceptualized as an open field of inquiry from scientific and social perspectives (Sadler et al., 2007). The role-playing activity could develop this. Role-playing can increase students' contextual understanding of the issue's scientific and social background (Sagmeister & Kapelari, 2021).

In this research, both the experimental and control groups were involved in role-playing, which means that the significant improvements in perspectives and inquiry were supported by the research conflicts about smoking issues added to the MARRS app. In addition to the students' perspectives based on their roles and priorities, conflicting scientific research results could strengthen students' perspectives regarding the issue's bias. As indicated in Karahan & Roehrig (2017), the position taken by students related to SSI can influence their perspectives ability. For example, students who take a biased position tend to explain the problem from one perspective (for example, from scientific study or personal experience), while other students who take a neutral position on an issue can explain the problem from different perspectives. Furthermore, when giving statements about the scientists' research, learners realize that further investigations into an issue are needed (inquiry). A well-documented example of a unique perspective from the experimental group was observed from the scientist's role, where they argue against the proposed bill to completely ban smoking for someone aged 24 and under because the research results on the effects of smoking are still conflicting. Thus they recommend conducting further investigation. Unfortunately, the conflicting results were not enough to develop students' skepticism about the smoking issue.

The advanced practice of SSR should include showing skepticism in the face of potentially biased information for rational decisions. Less sophisticated practices tend to accept information without recognizing potential bias (Sadler et al., 2007). The role-playing activity in this research was designed by adopting the implementation of role-playing in previous studies by Agell et al. (2015) and Sagmeister & Kapelari (2021). In this activity, students were divided into character groups that opposed or supported the dilemma in scenarios involving a problematic issue. Students were then asked to find information and prepare arguments to support their position (Agell et al., 2015). The argument was then presented as a panel discussion (Sagmeister & Kapelari, 2021). In the panel discussion, the group of students was alternately asked to introduce the characters they played, followed by the delivery of arguments from various perspectives according to the characters they played.

One of the important points noted during the activity implementation was that each group of learners only focused on preparing their arguments. This happened in both the experimental and control groups. Supposedly, arguments must also be prepared to argue against the other roles and defend their role position. As a moderator responsible for guiding the panel discussion, the teacher occasionally asked the panel members, gave the floor to someone, or called them to provide feedback. However, this was not entirely successful since their preparation was not optimal. Although the conflicting scientific results presented in the MARRS app emerged as an argument in the experimental group, there was also no debate from the other group.

Overall, all roles from the experimental and control groups did not show different levels of skepticism during the role-based panel discussion, which may contribute to the SSR test. Sagmeister and Kapelari (2021) suggested that teacher mentoring in developing and preparing arguments may be a solution to developing skepticism more optimally. In this study, the school's policy to reduce effective learning hours during the pandemic situation is a limitation for doing so. The reduction caused not all SSI instruction stages could be fully implemented in the classroom but also become independent learning activities at home, one of which was the argument preparation for the role-based panel discussion.

CONCLUSION

The results of this study show that the combination of AR technology and SSI instruction positively impacts science learning. The MARRS app in SSI instruction and the conventional SSI instruction method with PowerPoint had similar effects on students' overall conceptual knowledge. However, the MARRS app can specifically promote students' conceptual knowledge about the human respiratory system at the analyzing level and their knowledge of theories, models, and structures compared with PowerPoint. In addition, the MARRS app is more effective in promoting students' SSR about smoking issues compared to PowerPoint, according to the higher average score of the experimental group relative to the control group with significantly different results. Moreover, this study indicates that students' SSR of SSI is unrelated to their scientific knowledge.

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