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A comparison study of augmented reality versus interactive simulation technology to support student learning of a socio-scientific issue

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We investigated the impact of an augmented reality (AR) versus interactive simulation (IS) activity incorporated in a computer learning environment to facilitate students' learning of a socio-scientific issue (SSI) on nuclear power plants and radiation pollution. We employed a quasi-experimental research design. Two classes (a total of 45 ninth-grade students) were randomly assigned to either the AR or IS treatments. We compared three outcome variables of the AR and IS groups: knowledge of and attitude towards the SSI, and perceptions of the AR or IS feature. We also examined the interplay among the three variables within each of the two groups. The results indicated no significant differences in knowledge and attitude, but a significant difference in the perceptions between the two groups. Moreover, different patterns of correlations among the variables were identified. The implication includes educational impact of emerging AR technologies to support affective aspects of student learning of SSIs.

Keywords: augmented reality; simulation; socio-scientific issue

Introduction

The advent of innovative technology makes it possible for designers of learning environments to bring new technology into an environment to facilitate learning. However, a debate regarding whether it is the technological medium or the instructional method that matters (Clark, 1983, 1994; Kozma, 1991, 1994) points out the importance of studies critically examining when and how innovative technology benefits learning, considering the interplay among technology design, instructional method, and learning context. Moreover, with the diverse technological resources now available, designers of interactive learning environments often need to choose among competitive technologies. What is needed is research providing solid evidence of what does and does not work in what conditions among different types of technologies.

As an initial step towards discerning the benefits of competitive technologies in possibly different domains of learning, in this study we focus on augmented reality (AR) and compare the impact of a learning environment incorporating AR with the impact of another learning environment incorporating interactive simulations (IS), with a focus on the learning outcomes in the conceptual and affective domains. AR technologies have

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been identified as one type of the key emerging technologies for education over the next five years (Johnson, Levine, Smith, & Haywood, 2010). AR enables the use of virtual objects or information overlaying physical objects or environments, resulting in a mixed reality in which virtual objects and real environments co-exist in a contextualized way to augment learning experiences (Dunleavy, Dede, & Mitchell, 2009). The recent development of mobile devices even makes it possible for mobile AR environments to support outdoor learning enhanced by computer simulations and virtual objects with the focus on real environments (Dunleavy et al., 2009). The theoretical foundation for AR in education includes situated cognition, but more research is needed to understand AR's mechanism for supporting learning. For example, a study which reviewed recent research on AR applications in education found that the majority of the AR articles focused on development, usability, and initial implementation of AR tools. Comparison studies are needed to identify unique AR features that benefit learning (Wu, Lee, Chang, & Liang, 2013).

To understand the educational value unique to AR environments, a few researchers have started to compare AR learning environments with virtual learning environments. For example, a qualitative examination of students in an AR versus a virtual environment revealed that the AR environment seemed to prompt students to make more informed decisions considering not only scientific evidence but also all environmental-related factors such as ecological, political, and psychological factors (Klopfer, 2008). Another study found that an AR environment might have an advantage of presence over a simulated or virtual environment (Tang, Biocca, & Lim, 2004). However, these two studies did not quantitatively compare the effects of AR versus virtual learning environments. A study quantitatively compared students' achievements and attitudes in three types of learning environment, one involving AR technology, another involving desktop computers, and the other involving only traditional face-to-face teaching methods, as students learned the topic of ecosystems (Hsiao, Chen, & Huang, 2012). The AR environment was designed specifically to provide students with opportunities to do physical exercise, such as boxing or jumping in the real environment to generate gesture input to answer questions about ecosystems on the computer. Since the AR activities focused more on physical exercise than on the content, the results showed that no difference was found among the three types of learning environments in terms of facilitating the students' achievements of learning the concepts. Nevertheless the students in the AR group demonstrated higher scores for their attitude, indicating that the students perceived that the AR environment was more useful for learning ecosystems than the other two environments.

Another study evaluated virtual reality (VR) and AR training for industrial maintenance and assembly tasks (Gavish et al., 2013). The study found that, compared to the control group in which participants watched an instructional video and performed the physical tasks, the AR group, which performed the physical tasks using a platform incorporating AR features, had fewer unsolved errors. However, there was no significant difference between the VR and another control group. As noted by the authors, the study was not able to directly compare the AR and VR groups because the two platforms were different with respect to several pedagogical features. The authors pointed out the need for such comparison in future studies in which the pedagogical features are more similar.

In this study, we explore the impact of an AR versus an IS activity on students' learning of a socio-scientific issue (SSI). SSIs are controversial social issues with conceptual ties to science and are open-ended problems requiring consideration of multiple perspectives and solutions (Sadler & Donnelly, 2006). Promoting student learning of SSIs has gained much attention in recent research of science and environmental education (Lee et al., 2013), as the current global society is facing an increasing number of complex issues such as global warming that require decision-making informed by scientific evidence and multi-perspective reasoning. It is critically important to educate future citizens so that they develop adequate knowledge, skills, and even values when confronting complex social environmental issues.

We engaged students in an SSI regarding the issue of nuclear power plant development, and a dilemma requiring them to suggest remediation for a campus site on which part of the soil was slightly polluted by the nuclear accident at the Fukushima Daiichi Nuclear Power Plant after the 3.11 earthquake in Japan. We developed the unit starting with the AR activity in which the students were provided with tablet computers to actually go to their campus (assumed to be a middle school 12 km away from the Fukushima Daiichi Nuclear Power Plant the first day after the hydrogen gas explosion) to collect simulated radiation values using the scanning function on the tablet (Figure 1, the AR application can be downloaded to Android tablet computers at http://twise.nknu.edu.tw/VESL/curriculum.html, in Chinese). This is a type of mobile AR activity since virtual information (the radiation values) is superimposed on physical environments (locations at the school). We designed the mobile AR activity because it is out of the question to expose students to a real radiation-polluted environment (Chang, Wu, & Hsu, 2013). The following activities scaffolded students to learn proper actions to protect them from radiation pollution and science concepts including definitions of radiation, nuclear pollution, and the impact of nuclear pollution on ecology through biological diffusion and biomagnification. A decision-making activity asked students to select between two proposals for the remediation of the polluted soil in that middle school (details of the activities are summarized in Table 1).

In addition to the AR version, we developed an IS version (Figure 2). The IS version replaced the AR activity, with the students using the simulation and clicking on spots at different locations on the computer screen (Figure 2) to virtually collect data of simulated radiation values on the first day after the hydrogen gas explosion at a middle school about 12 km away from the Fukushima Daiichi Nuclear Power Plant. The rest of the activities were the same in both versions. Compared to the AR version, the IS version seemed more practical to the teachers because it took less time since it did not require the students to go outside to collect data, and required no mobile devices which the school might not be

Figure 1. A photo showing students in the AR group using tablet computers to scan simulated radiation values at a location on campus (from a total of 10 locations with conditions the same as the IS activity).

Table 1. Summary of activity sequence and content for the AR and IS versions.

Theoretical perspective	Activity sequence and content	
	Activity 1 Introduction ● Introductory video showing what happened as a result of the earthquake on 11 March 2011 in Japan ● Embedded reflection note: Why would the great earthquake on 11 March 2011 in Japan cause the explosion of the nuclear power plant? Write down your opinions	
	Activity 2 Contextualization	
Situated cognition: authentic data; authentic inquiry	AR version ● Suppose today is the first day after the hydrogen gas explosion of the Fukushima Daiichi Nuclear Power Plant, and your school is located about 12 km away from the power plant. ● Your task is to use the tablet to go to 10 different locations on campus to collect radiation values of the 10 locations (also see Figure 1).	IS version ● Suppose today is the first day after the hydrogen gas explosion of the Fukushima Daiichi Nuclear Power Plant, and your school is located about 12 km away from the power plant. ● Your task is to use the detector in the computer simulation to detect radiation values for 10 spots in the simulation that represent different locations on the campus (also see Figure 2).
	(More authentic inquiry) (Affective orientation)	(Less authentic inquiry) (Cognitive orientation)
	● Embedded reflection note: Look at the radiation values you have collected. What did you find?	
Constructivism: reflection notes and dilemma questions to promote active learning	Activity 3 The basics ● Web-pages providing information including text and images depicting the difference between ionizing and non-ionizing radiation, radioactive contamination, and how it may affect living things, and how people can limit contamination and prevent radiation exposure ● An embedded reflection note asking students to suggest the best equipment and practices to help prevent radiation exposure Activity 4 Dilemma ● A decision-making activity regarding a dilemma which requires the students to suggest remediation for the campus site on which part of the soil was slightly polluted by the radiation elements. The students are asked to select between two proposals, one of which is an environmentally friendly proposal to grow plants which gradually absorb the radiation elements (i.e. the growing plant proposal), and the other is a complete removal proposal using giant machines that might physically damage the environment and threaten the neighbourhood, but which would bring about more instant remediation (i.e. the removal proposal) ● Embedded reflection note: Which proposal would you choose? Explain your choice	
Multimedia design principles: cognitive load considered; visual and verbal modes of multimedia allocated	Activity 5 Visualization ● An animation showing biological diffusion at the cell and molecular levels	

(*Continued*)

Table 1. Continued.

Theoretical perspective	Activity sequence and content
	• A video explaining the concept of biomagnification and how radioactive contamination may affect ecosystems through biomagnification • Embedded drawing activities: Using the drawing tools embedded in the environment, students are asked to draw their ideas of how radioactive contamination may affect humans through biological diffusion and biomagnification

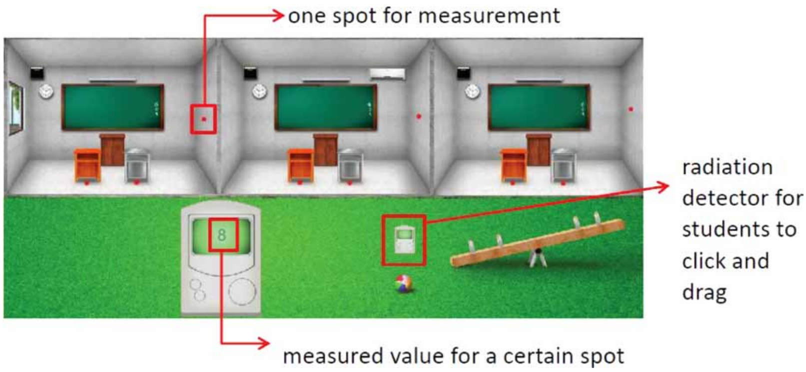

Figure 2. A screenshot (with annotations) of the IS activity for the IS group to measure simulated radiation values at 10 spots.

equipped with. However, we wondered whether the IS version could actually replace the AR version in terms of the impact on student learning of the SSI. In this study, we examined the conceptual and affective aspects of the students' learning outcomes to investigate how AR and IS might have different effects on student learning of an SSI.

Theoretical background of the design and our hypotheses

The theoretical perspective of situated cognition emphasizes learning in authentic activities so that learning is situated in socially and culturally meaningful contexts through practices (Brown, Collins, & Duguid, 1989). "Authentic" here is judged by the extent to which the objects and data in a learning environment are consistent with the actual data in the real environment, and the extent to which the tasks that the students are required to perform are consistent with the ordinary practices of the target community (Brown et al., 1989; The Cognition and Technology Group at Vanderbilt, 1990). Learning in authentic activities should lead to useful knowledge, as opposed to inert knowledge in which knowing and doing are separated. Moreover, a learning environment designed based on the perspective of situated cognition should enculturate students to become more centrally involved in the practices of a community and to develop identities as effective participants in the community (Greeno & The Middle School Mathematics Through Application Project Group, 1998). Both involvement and identity relate to the affective outcomes of learning.

Considering the two versions of our designed unit (a summary of the content and activity sequence is presented in Table 1), we believe that both the AR and IS versions are authentic since they target real SSI and data. However, the AR version of the unit is more authentic than the IS version in terms of inquiry as the students used a mobile device to actually collect data on the campus. In comparison, the students in the IS group only virtually collected data using a computer simulation. Therefore, based on the situated cognition theory, we hypothesize that the AR version would have more impact on the affective aspect of the learning outcomes. As an initial step, we measured students' perceptions of the AR/IS feature, and their attitudes towards the SSI, to indicate the affective aspect of their learning.

We hypothesized that the students' gains in conceptual knowledge would be the same in the two groups since both versions required the same cognitive tasks through the rest of the unit such as the reflection notes and dilemma question embedded in the unit (Table 1) that serve as prompts to elicit the students' ideas and link between personal ideas and science concepts. The design of the prompts in both versions followed the constructivist perspective of promoting active learning by requiring students to respond to prompting questions and reflection notes. The constructivist perspective acknowledges learners' pre-existing knowledge and experience and emphasizes learning building on learners' own ideas and learners' reflection for active learning (Linn & Eylon, 2011; Piaget, 1977).

In addition, in both versions, we provided the students with visualizations showing the concepts of biological diffusion and biomagnification at different levels: the microscopic, cell, and macroscopic levels. We also asked the students to use the drawing technology embedded in the online learning platform to draw their ideas of how radioactive contamination may affect humans through biological diffusion and biomagnification after they observed the visualizations. The design of the visualization and student drawing activities followed the multimedia design principles which consider learners' cognitive load and use both visual and verbal channels for optimal learning (Chandler, 2004; Mayer, 2005). Moreover, the presented content in the visualizations was specifically considered to reduce extraneous and increase germane cognitive load by tailoring the fit between the students' prior knowledge and the presented content. Again, since the visualization activity is the same for both versions, we hypothesized that there would be no difference between students' understanding of the concepts of biological diffusion and biomagnification.

In summary, the AR and IS versions only differed in the technology used, but otherwise were the same for the rest of the unit. The use of the AR technology enabled authentic data and tasks for student inquiry. Based on the theory of situated cognition, it would increase learners' involvement and identity with the community, which belong to the affective domain of learning. Therefore, in the current context of the AR technology, we hypothesized that the AR technology would have an impact on the students' affective domain. In comparison, the use of the simulation technology was more oriented as a cognitive resource. We hypothesized that the IS would therefore be more associated with the learners' knowledge gains, and less associated with their affective domain, such as attitudes towards the SSI.

Given the explorative nature of this study, we compared two classes using the different versions and addressed the hypothesized differences and similarities. We revealed similar and different patterns between the two groups, treating them as two cases rather than aiming to generalize the results to other settings.

Methods

Participants

Two classes (a total of 45 ninth-grade students, aged 15–16, 53% male) taught by the same science teacher at a public middle school in southern Taiwan were randomly assigned to use either the AR version ($n = 23$, http://twise.nknu.edu.tw:8888/webapp/vle/preview.html?

projectId=246, accessible in Chinese and only for Firefox) or the IS version ($n = 22$, http://twise.nknu.edu.tw:8888/webapp/vle/preview.html?projectId=245, accessible in Chinese and only for Firefox). The two groups of students did not differ in their pre-test knowledge scores ($t(42) = 0.33$, $p = .75$; for the AR group: $M = 10.00$, SD = 4.97; for the IS group: $M = 10.71$, SD = 3.13) or in the scores of their attitudes towards nuclear power plants before the unit ($t(35) = 0.68$, $p = .50$; for the AR group: $M = 3.77$, SD = 0.75; for the IS group: $M = 3.99$, SD = 0.38), indicating comparable prior knowledge and attitudes. Tests of normality indicated that the pre-test knowledge scores for both groups were normally distributed (AR: $W = 0.95$, $p = .69$; IS: $W = 0.91$, $p = .10$), and that the pre-attitude scores were also normally distributed for both groups (AR: $W = 0.86$, $p = .06$; IS: $W = 0.92$, $p = .16$). Due to absence on the days the tests were administered, few random students did not take the pre- or post-tests or surveys, but all students participated in the learning of the unit. The students who did not take the tests were excluded from the statistical analyses of the test results.

Treatments

We developed both versions of the unit using an open-source online platform, the Web-based Inquiry Science Environment (WISE; Slotta & Linn, 2009). The details of the activities in the two versions are summarized in Table 1. The two versions only differed in the AR or IS activity as described in the preceding section and remained the same for the other activities in the unit. The IS group spent 3 and the AR group spent 3.5 class periods (45 minutes each) completing the unit. Since the AR group spent more time on the logistics (e.g. assigning tablets and travelling on campus), the instructional time for the AR group was slightly more than that of the IS group. The students in both groups worked in dyads to complete the learning tasks in the unit. The teacher guided the learning of the two groups in similar teaching routines including allowing the majority of the time for group learning tasks, assisting with whole class discussions to clarify learning tasks.

Instruments

Knowledge tests

The pre- and post-knowledge tests are identical, including 13 multiple-choice and 2 constructed-response items to measure the students' conceptual understanding of the science concepts, including definitions of radiation, nuclear pollution, biological diffusion and biomagnification. The test items went through several rounds of revision by science educators to ensure content validity. Cronbach's α for the items is 0.77. The students took pre-tests before and post-tests after the unit.

Attitude questionnaires

We used the questionnaire with 14 5-point Likert scale items developed and validated by Yang (2011) to probe the students' attitudes towards nuclear power plants. Cronbach's α for the nuclear attitude items is 0.78. The students completed pre-questionnaires before and post-questionnaires after the unit. The pre- and post-questionnaires are identical. For the attitude scores we averaged the students' scores on the 14 items to obtain mean attitude scores towards nuclear power plants. A higher score indicates that the student is more opposed to the operation of nuclear power plants.

Perceptions of curricular features

A survey was conducted right after the post-tests that required the students to indicate their perceptions of six curricular features in the unit in terms of liking and facilitating learning, including the first mobile AR or IS activity along with the other five features such as the biological diffusion animation and the ecology impact drawing activities in the unit. For example, the first item in the survey for the AR group was “Please indicate how you liked the AR activity.” Students could choose from a 5-point Likert scale ranging from 5 (like it very much) to 1 (does not like it at all). The other part of the item asked “Please indicate how much the AR activity helped your learning” with another 5-point Likert scale ranging from 5 (very helpful) to 1 (very unhelpful). We summed the students’ scores in the two parts of the item (a total of maximum score is 10) to indicate students’ perceptions of the AR feature.

Data coding and analysis

We developed scoring rubrics to code the students’ responses to the pre- and post-knowledge tests. In general, for multiple-choice questions, one point was given for an appropriate response and zero for an inappropriate one. For constructed-response questions that required explanations, two points were given for a complete response, one point for a partially complete response, and zero for an incomplete or irrelevant one.

We used *t*-tests to examine the mean differences between the AR and IS groups on the students’ post-knowledge scores. We used the Mann–Whitney *U* tests to compare the post-attitude and perception scores between groups since the post-attitude and perception scores were not normally distributed. In addition to the comparisons across the groups, we examined the interplay among students’ perceptions, attitude changes and knowledge gains within each of the two groups to discern any pattern of learning demonstrated similarly or differently between the two groups. We used Wilcoxon signed-rank tests to examine whether the students’ attitudes towards nuclear power plants changed significantly after the unit for each of the groups respectively.

Results

Treatment effect on knowledge, attitudes, and perceptions

Overall, the two versions of the unit were both effective in facilitating students’ gains of knowledge about nuclear radiation and its possible impact on the environment. Students in each treatment group made significant gains from the pre-knowledge test to the post-knowledge test. For the AR group: $t(15) = 2.83$, $p = .01$; $M_{pre} = 10.00$, $SD_{pre} = 4.97$; $M_{post} = 11.44$, $SD_{post} = 5.88$. For the IS group: $t(20) = 3.41$, $p < .01$; $M_{pre} = 10.71$, $SD_{pre} = 3.13$; $M_{post} = 12.86$, $SD_{post} = 3.63$.

Another *t*-test result of the post-test knowledge scores between the treatment groups reveals no significant differences between treatments ($t(36) = 0.92$, $p = .36$), indicating that both conditions were as effective in facilitating students’ learning of the science concepts in the SSI context. This result supports our hypothesis that both versions are effective in promoting conceptual learning. Moreover, such a result is encouraging as we are exploring the educational value of AR instructional activities. A review on computer simulations in science education in more than 40 studies indicates solid evidence that computer simulations have more positive impacts on student learning than traditional lecture-based instruction without simulations (Rutten, van Joolingen, & van der Veen, 2012). In this study, we provide evidence from a case of two classes of students that incorporating AR activities can be as effective as incorporating simulation activities in an instructional unit to facilitate students' learning of the science concepts.

In terms of the students' attitudes towards nuclear power plants, there is no significant difference between the two treatment groups on the post-attitude scores ($Z = -0.62$, $p = .53$). The result indicates that, after the unit, whether engaging in the AR or IS activity, on average the two groups of students possessed similar attitudes towards the nuclear power plant issue after the unit.

However, the students' perceptions of the AR or IS feature in the unit are significantly different between the two groups ($Z = -2.31$, $p = .02$), with the AR group having higher mean scores ($M = 7.6$, SD = 0.89) than the IS group ($M = 6.6$, SD = 1.50). The results partially support our hypothesis regarding the affective aspect of learning. We found that, compared to the IS activity, the AR activity could better enhance students' perceptions of the curricular feature in terms of how much they liked the feature and how helpful they thought the feature was for learning. However, the treatment effect on the students' attitude towards the nuclear power plant issue seemed not to be significant.

Research points out that students' reasoning and decision-making for an SSI are complex. A qualitative study found that students' reasoning in SSIs is influenced by their personal beliefs and scientific knowledge (Sadler, Chambers, & Zeidler, 2004). On the other hand, a quantitative analysis found no significant relationships among students' content knowledge, moral attitudes or argumentation quality (Sadler & Donnelly, 2006). It seems that multiple factors from individual traits might confound the result when we try to discern the effect of the technological feature. With this limited sample size, controlling for those potential confounders would be impossible. Rather, we treated each group as a case and examined associations among the affective and conceptual aspects of learning to explore if there are different patterns between the AR and IS groups, as detailed in the following two sections.

Interplay among knowledge gains, attitude changes, and perceptions of the AR group

Although the AR group demonstrated significant gains in knowledge after the unit, as has been revealed in the foregoing section, the AR group's attitudes towards nuclear power plants did not significantly change after the unit (pre-questionnaire attitude: $M = 3.81$, SD = 0.68; post-questionnaire attitude: $M = 3.67$, SD = 0.59; Wilcoxon signed-rank test: $Z = -1.03$, $p = .30$). The majority of the students tended to show attitudes that were opposed to the operation of nuclear power plants. It seems that the AR group gained knowledge after the unit, but the trend of their attitudes still showed opposition to nuclear power plants.

We further examined correlations between any two of the three variables and listed the results in Table 2: students' knowledge gains (post-test knowledge scores minus pre-test

Table 2. Correlations between each two of three variables for the AR group.

Variable	Knowledge gain	Attitude change	Perception of AR
Knowledge gain	1	−0.18	−0.24
Attitude change	−0.18	1	0.51*
Perception of AR	−0.24	0.51*	1

*$p < .05$.

knowledge scores), nuclear attitude changes (post-test attitude scores minus pre-test attitude scores, with a higher score indicating being more opposed to the operation of nuclear power plants), and perceptions of the AR activity (ranging from 0 to 10, with a higher score indicating more positive perceptions in terms of liking and facilitating). The correlation results of Table 2 support the result that the students' gains in knowledge were not associated with their attitude changes for the AR group.

However, the AR students' attitude changes were significantly associated with their perceptions of the AR activity. That is, the more a student liked the AR activity, the more the student's attitude changed to oppose the operation of nuclear power plants. In the AR activity, the students were physically immersed and contextualized in the hypothetically polluted environment, which in turn might strengthen their attitudes against nuclear power plants. The pattern of this AR group shows that, compared to knowledge gains, the experience in the AR activity plays a more significant role in students' change of attitude towards the SSI.

Interplay among knowledge gains, attitude changes, and perceptions of the IS group

The IS group demonstrated significant gains in knowledge after the unit, as has been discussed. Moreover, the IS group's attitudes towards nuclear power plants changed significantly after the unit (Wilcoxon signed-rank test: $Z = -2.97$, $p = .003$), from a mean of 3.99 (SD = 0.38) before the unit, which shows a trend of opposition to nuclear power plants, to a mean of 3.67 (SD = 0.40) after the unit, with Cohen's $d = 0.82$, which shows a large effect (Cohen, 1988). The changes in mean scores indicate a trend of changes towards a more neutral attitude. It seems that after the unit, as the students were more knowledgeable about nuclear power plants, their attitudes became milder and more neutral.

The correlations between any two of the three variables, students' knowledge gains, nuclear attitude changes and perceptions of the IS group, are summarized in Table 3. It appears that the associations among the variables for the IS group were different from those we found for the AR group. The results indicate that for the IS group, the students' gains in knowledge were significantly associated with their changes in attitude. This statistical significance supports our conjecture that when students become more knowledgeable about an SSI, they change their attitude to be more neutral or not opposed to it. However, this relationship only applied to the IS group, and not to the AR group in this study.

On the other hand, the IS students' perceptions of the IS activity were not significantly associated with their changes in attitude towards the SSI. The IS group demonstrated a different pattern from the AR group. It seems that for the IS group, knowledge gains play a more important role than the perception of the IS activity in changing the students' attitudes towards the SSI.

Table 3. Correlations between each two of three variables for the IS group.

Variable	Knowledge gain	Attitude change	Perception of IS
Knowledge gain	1	0.46*	−0.06
Attitude change	0.46*	1	−0.22
Perception of IS	−0.06	−0.22	1

*$p < .05$.

Discussion and conclusion

SSIs require current and future global citizens to make informed decisions which consider multiple perspectives, scientific evidence, and moral and ethical aspects. Research calls for instruction focusing on SSIs to promote character and values for global citizens (Lee et al., 2013). Weighing multiple perspectives, and considering moral and ethical aspects and values all involve the affective aspect. Therefore, the learning of SSIs should stress learning outcomes, not only in the conceptual but also in the affective domain.

As a pioneering study incorporating innovative technology to support student learning of SSIs, we compared two types of technology, AR and IS, and investigated the associations among technology use and conceptual and affective learning outcomes. We identified two different patterns of the students using the different types of technology, and conceptualized the differences in Figures 3 and 4.

The results of this study indicate that, compared to the simulation technology, the AR technology appears more likely to address the affective aspect of learning an SSI. For example, in this study we observed that the students' perceptions of the AR technology were significantly related to their changes in attitude towards the SSI. In comparison, we did not observe the same pattern for the students using the simulation technology, which is not surprising, since, as with the majority of the studies reported in the literature, we used the simulation as a cognitive rather than an affective resource to support student learning. In the IS group we found that the students' gains in knowledge of the SSI were significantly associated with their changes in attitude towards the SSI. In comparison with the AR group, it is the students' perceptions of the AR technology that were significantly associated with their changes in attitude towards the SSI. It needs to note that in the unit we did not aim to shape the students' attitude towards a certain position about the SSI. Rather, we observed how the students might develop their own attitude with the science content and technology provided in the environment. Overall the results of the study indicate that students' gains of science knowledge or the use of technology can play a role in supporting students in developing their attitude towards an SSI.

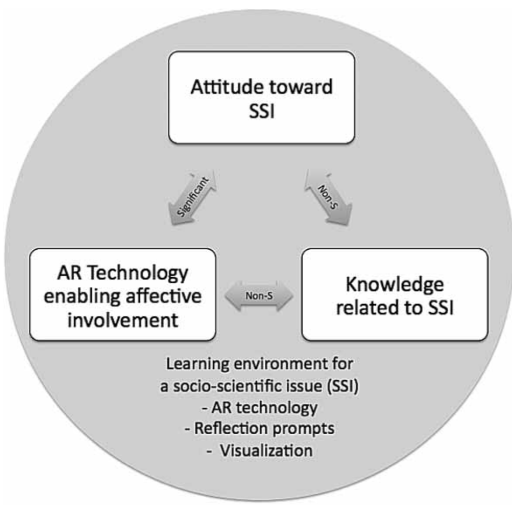

Figure 3. The pattern of learning demonstrated in the AR learning environment (Non-S: non-significant relationship).

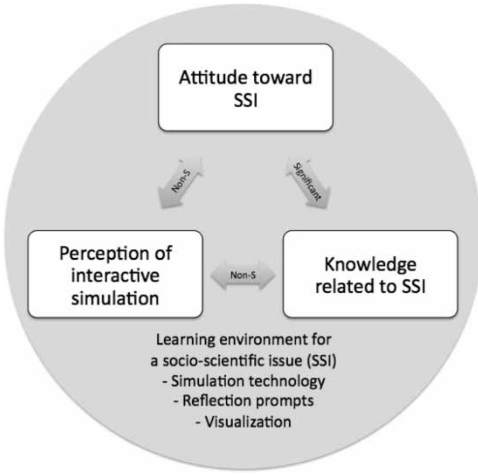

Figure 4. The pattern of learning demonstrated in the IS learning environment (Non-S: non-significant relationship).

Given the affordance of AR to enhance learners' sense of presence, immersion, and contextualization (Bronack, 2011), the results of this study provide evidence supporting the educational value unique to AR, not in the conceptual but in the affective domain, such as the students' perceptions and attitude changes. Supporting students' development of the affective domain is especially important for instruction on SSIs (Sadler, 2004, 2009). Our study provides a case of using AR technology as affective resources to support student in developing the affective domain as they learn SSIs.

In terms of supporting conceptual learning, we found that, when combining AR with constructivist and visualization learning activities, this combination of activities is as effective as another combination of activities in which the AR activity was replaced with a simulation to support students' conceptual knowledge of the SSI. However, in this comparison, the randomization of sampling was at the class level. Also, the study involved a limited number of students. This result may only apply to the context of the current study. The added value of AR technology on promoting students' conceptual learning seems to depend on designs exploiting other AR affordances.

Based on the two cases of using either AR or IS technology, we propose two design principles to spur future research and discussion. First, simulation and visualization technology that serves as cognitive resources for student learning of SSIs can possibly affect learners' attitude towards the SSI by student development of knowledge about the issue. Second, AR technology aligns well with the emphasis of SSI instruction on developing learners' involvement, beliefs and values, and can serve as affective resources for immersive contextualization.

Future studies can further explore how AR can foster students' engagement and involvement in SSIs that require participation as global or local citizens. In addition, a comparison study extending this research can investigate whether students engaging in AR activities would develop useful knowledge by examining their knowledge and actions. Nevertheless, the different learning patterns found in this study suggest that AR and IS may lead to different learning patterns and therefore are not interchangeable in terms of their educational value of benefiting student learning of SSIs.

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