Research in Science & Technological Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/crst20

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RESEARCH IN SCIENCE & TECHNOLOGICAL EDUCATION
https://doi.org/10.1080/02635143.2022.2032629

Supporting informal science learning with metacognitive scaffolding and augmented reality: effects on science knowledge, intrinsic motivation, and cognitive load

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ABSTRACT

Background: Museums have been paying an increasing attention to the design of experiences conducive to informal learning. While spontaneous inquiries in museums often pique visitors' intrinsic motivation to learn, certain structures or scaffolds are needed to facilitate sense making in museum learning. Two promising approaches are identified: metacognitive scaffolding and augmented reality (AR) that offer on-demand content and interactions.

Purpose: This study aimed to answer the following research question: Compared with metacognitive scaffolding alone, how does the access to additional AR content affect informal learning experiences in a science museum in terms of science content knowledge, intrinsic motivation, and cognitive load?.

Sample: The sample of the study consisted of 63 sixth-grade students divided into two groups. The treatment group (31) received both metacognitive scaffolding and AR support in their museum visit, whereas the control group (32) received only metacognitive scaffolding.

Design and methods: A quasi-experimental research design was conducted. The independent variable was the treatment conditions, and the dependent variables were students' science knowledge test performance, learning motivation, and cognitive load. The research instrument for this study included a science knowledge test, a learning motivation survey, and a perceived cognitive load questionnaire.

Results: The results revealed that the combination of metacognitive scaffolding and AR led the treatment group to significantly outcome the control group in the science knowledge post-test, but the effect did not last in the 2-week delayed retention test. The control group perceived more importance in the museum learning activity. No difference was found in cognitive load.

Conclusions: Metacognitive scaffolding may have an enduring impact on science learning in museums. The long-term impact of AR needs further investigation. Balance should be maintained between structure and open exploration to sustain intrinsic motivation in informal learning settings.

KEYWORDS
Augmented reality; metacognition; scaffolding; museum learning; informal learning

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1. Introduction

Regarded as an important research topic in the field of informal learning, museum learning is a meaningful way of acquainting students with museum contexts and has long-term impacts on their learning and perception (Garcia 2012). Museum learning can be conceptualized as the construction of meaning in which students are immersed within the environment to make sense of culturally specific resources (Falk and Dierking 2000). To facilitate sense making in museum learning, Kim and Dopico (2016) argued that museums should shift from exhibitary to participatory. Two promising approaches are helpful with this transition to a participatory museum learning experience. First, learning in museums can be characterized as inquiry learning (Crowley, Pierroux, and Knutson 2014), and learners' metacognition has been shown critical in conducting science inquiries that lead to the acquisition of science knowledge (White and Frederiksen 1998). While the effect of metacognitive scaffolding has been investigated in formal science education (e.g. Huang, Ge, and Eseryel 2017; Peters and Kitsantas 2010), few empirically examined it in the context of informal learning in museums. Second, augmented reality (AR) has shown promise in formal education (e.g. Altinpulluk 2019) and has been increasingly used to offer content and interaction to support museum learning (Goff et al. 2018). Would the combination of the two approaches yield enhanced learning outcomes, or would it interfere with learning when learners pay simultaneous attention to both metacognitive scaffolding and AR while exploring the physical museum? In order to investigate the effectiveness of the two approaches, this study designed and implemented metacognitive scaffolds and AR content to support a science museum field trip in Taiwan, and investigated their effects on students' science knowledge, motivation, and perceived cognitive load.

2. Review of relevant literature

2.1. Informal learning in museums

Traditionally conceived as cultural institutions, museums have been increasingly fulfilling additional educational roles throughout the past century (Crowley, Pierroux, and Knutson 2014). With a wide range of artifacts, signs, tools, and discourses, museums offer informal learning experiences that complement and extend learning opportunities beyond the school (Russel, Knutson, and Crowley 2013). Students can learn various subjects from museum visits, ranging from art, history, to STEM areas (Falk and Dierking 2010; Mujtaba et al. 2018; Vavoula et al. 2009). Different from formal educational institutions that are often demanded by curricula, standards, and standardized tests, museums enable learners to pursue their own inquiry based on personal interests, goals, and knowledge (Crowley, Pierroux, and Knutson 2014). This type of free-choice learning often enhances visitors' intrinsic motivation to learn (Deci and Ryan 2000). Science museums, for example, support voluntary, self-directed science inquiries and often generate a sense of wonder that piques visitor's interest and eagerness to learn (Eshach 2007). Indeed, research has shown that children who engage more in informal science learning from places like science museums are more likely than their peers to show achievement, interest, and motivation in science (Bonnette, Crowley, and Schunn 2019; National Research Council 2009).

Despite documented advantages, museum learning is not without challenges. Cognitive psychologists questioned the educational effectiveness of the type of learning in museums, arguing that leaving learners to pursue open inquiries without guidance in a highly complex environment may generate a heavy cognitive load detrimental to learning (Kirschner, Sweller, and Clark 2006). Kim and Dopico (2016) observed that museums often focus on conveying science knowledge through visual representations and spatial organizations from the expert's perspective, but lack in engaging learners in active sense making. While research is abundant in designing conductive learning experiences in the formal school setting, empirical research is lacking in the design of museum learning experiences that facilitate open inquiries. One area of research that can shed light in this regard is the use of scaffolding to support science inquiry learning, which is introduced next.

2.2. Supporting science inquiries with metacognitive scaffolding

Science inquiries require not only content knowledge, but also the application of science process skills and metacognition (Mayer 1998). Metacognition is defined as the regulation of one's own thinking or cognitive processing (Flavell 1987). Metacognition is particularly important as learners engage in inquiry processes of questioning, formulating hypotheses, experimenting, making observations, collecting and analyzing data, interpreting and explaining, and reaching conclusions (Donnelly, Linn, and Ludvigsen 2014). Experts are distinguished from novices by high levels of metacognition (Schoenfeld 1985). In the context of science inquiries, experts or scientists deliberately monitor and negotiate their inquiry process. For example, they may consciously examine whether gathered data supports their hypothesis, whether and how findings address their research questions, and how their understanding is updated in light of new evidence. Comparatively, without intentional metacognitive thinking like a scientist, novice learners may complete an inquiry as a discrete series of activities without meaningful sense making.

Due to the importance of metacognition, researchers have experimented with interventions to scaffold learners' metacognition in inquiry-based science learning. For example, Huang, Ge, and Eseryel (2017) embedded metacognitive information and prompts to help students monitor their understanding during science inquiries. Peters and Kitsantas (2010) also embedded metacognitive prompts and checklists in a science inquiry that progressively developed learners' metacognition through self-regulation phases. Both studies found that the metacognitive scaffolding in science inquiries significantly enhanced students' acquisition of science content knowledge, and Huang, Ge, and Eseryel (2017) found that the effect remained even one month after the treatment. Scaffolding has the potential to promote not only learning in the subject area, but also motivation and engagement in learning (Shute 2008). Indeed, a recent study found that metacognitive scaffolding significantly improved learners' self-efficacy and learning motivation in addition to significant gains in content knowledge (Chen, Liu, and Huang 2021).

In the context of museum learning, metacognition plays an equally important role. Depending on the focus of their inquiry, learners need to selectively attend to elements of exhibits and generate meaning therein by constructing relations between new and previously acquired information, conceptions, and background knowledge (Falk and Dierking 2000). These metacognitive processes can be supported with appropriate metacognitive scaffolding to (1) assist learners to selectively attend to important aspects of learning and create meaningful understanding from the exhibition, and (2) prompt learners to highlight important knowledge, explain and synthesize what they have learned, and monitor the development of their understanding.

In recent years, museum educators have recognized the need for structure in museum learning. As such, in field trips to science museums, teachers often devise some kind of worksheet to facilitate the interactive relationship between learners and exhibits (Gutwill and Allen 2012; Yoon et al. 2013). An examination of students' behavior patterns in a museum trip revealed that worksheets helped them to better integrate learning activities and the exhibition (Hou et al. 2014). Gutwill and Allen (2012) found that structured museum inquiry activities that scaffolded cognition and metacognition led to significantly more learning gains than spontaneous trips without scaffolding. Yoon et al. (2013) compared the effects of different knowledge building scaffolds on informal learning in science museums, and the results generally suggested the effectiveness of the scaffolds. Despite the effort, there is a lack of research that empirically examines metacognitive scaffolding which is important in guiding learner inquiries at science museums. Accordingly, this study designed and investigated the effects of metacognitive scaffolding in museum science learning.

2.3. Augmented reality as a learning scaffold in museums

The fast development of technology in recent years has afforded museums with more tools to enhance visitor experience and learning beyond traditional multi-touch interfaces and worksheets. Mobile apps have expanded museum learning from a physical location to the virtual online space (Charitonos et al. 2012), and have been used to support such activities as exploration, information search, and communication (Chen, Xin, and Chen 2017; Vavoula et al. 2009). Among other technologies, AR has been increasingly used in museums.

AR technology uses electronic vehicles to connect virtualized objects and information with objects in the physical world (Bujak et al. 2013; Wong, Jamali, and Shiratuddin 2014). Due to its ability to provide on-demand multimedia content and interactions that are otherwise unavailable, AR has been used to support learning in multiple subject areas such as biology, physics, mathematics, and medical education (Akçayır et al. 2016; Chen et al. 2020; Ferrer-Torregrosa et al. 2015; Kamphuis et al. 2014; Lin, Chen, and Chang 2015). A recent review of the use of AR in education concluded that the 'most positive effect of AR is for academic success and learning motivation' (Altinpulluk 2019, 1089). Yoon et al. (2013) contended that the digital augmentation afforded by AR serves as a form of scaffold for learning, and found AR to be particularly helpful to conceptual learning in science (Yoon et al. 2012). AR has been used to support science inquiry learning. For example, Chiang, Yang, and Hwang (2014) found that AR enhanced students' learning achievement in science inquiry activities. In addition to cognitive impact, AR also appears to have an advantage in the affective dimension. Several studies have found that the incorporation of AR in learning promoted students' motivation, engagement, and attitudes (Chen et al. 2020; Cheng and Tsai 2013; Chiang, Yang, and Hwang 2014; Hsu, Lin, and Yang 2016).

Compared with the burgeoning research on AR in formal education, the use of AR in museum learning has received less attention. Many studies focused on the development, usability, and implementation of AR in museums (Wu et al. 2013). A review of studies that did examine AR's impact on science achievement in informal learning suggested that students generally demonstrated an increase in both science learning outcomes and motivation (Goff et al. 2018). For example, Yoon et al. (2012) used AR to provide visualization of electrical currents during a science museum field trip, and found that the groups that used AR exhibited significant learning gains. Further, Yoon and Wang (2014) found that learners who used AR to learn about magnets and magnetic fields interacted with the magnets significantly longer than those without access to AR.

Two potential issues are revealed in the literature regarding the use of AR in museum education. First, as students visit exhibits at museums while using AR devices to access additional content, their attention has to switch between the information on the device and the physical exhibits, which may cause extra cognitive load that interferes with learning (Liu et al. 2012; Wu et al. 2013). Second, several researchers have observed that learners' use of AR needs to be scaffolded in order to achieve deep learning (Ibáñez and Delgado-Kloos 2018; Kyza and Georgiou 2019; Yoon et al. 2012). To maximize the effectiveness of AR to support science learning in museums, more empirical research is needed.

2.4. The current study: supporting museum science learning with metacognitive scaffolding and AR

In light of the bodies of literature above, this study set out to implement and investigate metacognitive scaffolding and AR to support learner inquiries in informal science learning. To provide metacognitive scaffolding, we adopted the format of paper-based worksheets that have been 'traditionally' used to support museum learning (Gutwill and Allen 2012; Yoon et al. 2013). We were interested in how the additional provision of AR materials compares with the metacognitive worksheets alone in their effects on three types of outcomes: acquisition of science knowledge, motivation, and cognitive load.

Specifically, we would like to test whether the benefits of metacognitive scaffolding to formal science learning hold true in the informal learning setting. We were also interested in finding out whether additional access to AR content would lead to improved academic performance.

Due to the potential motivational impact of scaffolding and AR, we were interested in examining learners' motivation as the second outcome. We chose to focus on intrinsic motivation which is typically associated with informal learning situations (Deci and Ryan 2000; Eshach 2007). Ryan and Deci (2000) described intrinsic motivation as 'the inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, to explore, and to learn' (70). When an individual finds a museum visit inherently rewarding, he is likely to enjoy it, invest a lot of effort in exploring, and while doing so, would not feel a sense of pressure or tension (Ryan 1982).

Finally, we were interested in examining learners' perceived cognitive load in the museum experience. Open inquiries in museums can place a heavy cognitive load on learners (Kirschner, Sweller, and Clark 2006). While metacognitive scaffolds may ease some of the cognitive demand by offering guidance and structure, the additional availability of AR on mobile devices may split learners' attention among the exhibition, the scaffolds, and the mobile device, which may lead to a high level of cognitive load (Liu et al. 2012; Wu et al. 2013).

In summary, this study aimed to answer the following research question: Compared with metacognitive scaffolding alone, how does the access to additional AR content affect informal learning experiences in a science museum in terms of science content knowledge, intrinsic motivation, and cognitive load?

3. Method

3.1. Research design and participants

This study adopted a quasi-experimental research design. A total of 63 sixth-grade students were recruited from an elementary school in central Taiwan to participate in the study. The school had a partnership with local museums with the goal of empowering informal learning, offering authentic learning experience, and deepening students' STEM knowledge. At the beginning of the study, the students were informed of the purposes and procedure of the study. Subsequently, the students were randomly assigned to either an experimental or a control group based on their student ID numbers: those with an odd ID number were assigned to the experimental group (N = 31; male = 16 and female = 15), whereas those with an even ID number were assigned to the control group (N = 32; male = 15 and female = 17). The average age of the students was 11.

3.2. The museum context

The learning was situated in Chelungpu Fault Preservation Park, which is affiliated with the National Museum of Natural Science in Taiwan. The Park, in cooperation with the Taiwan Power Company of the Ministry of Economic Affairs, launched an *Electromagnetic Horizon* special exhibition. This special exhibition used a high-voltage electric tower for real-time electromagnetic science education. It also showcased basic electricity, electromagnetism, and energy in a real-life setting. As shown in Figure 1, the purpose of the exhibition was to not only demonstrate electromagnetic waves invisible to the human eye but also allow the public to explore the mysteries of power, electromagnetism, and energy. The electromagnetic exhibition included different showcases, some of which involved hands-on activities and observations. For example, in *Power Warehouse*, students could examine features of batteries and how they store energy. In *Mini Electromagnetic Train*, students could build mini electromagnetic trains by applying electromagnetic principles. In *Spark from Electric Shock*, students could recognize how electricity and magnetism enter human life and how electricity works. In *Current War*, students could understand how the war over electrical currents between Tesla and Edison influenced power transmissions in society.

3.3. Learning materials

The learning content in this study focused on electricity and magnetism, two phenomena that greatly influenced modern human civilization. The main learning goals were for students to (1) understand the principle of electricity, (2) recognize how electromagnetism works in daily life, and (3) identify the characteristics of electromagnetic waves.

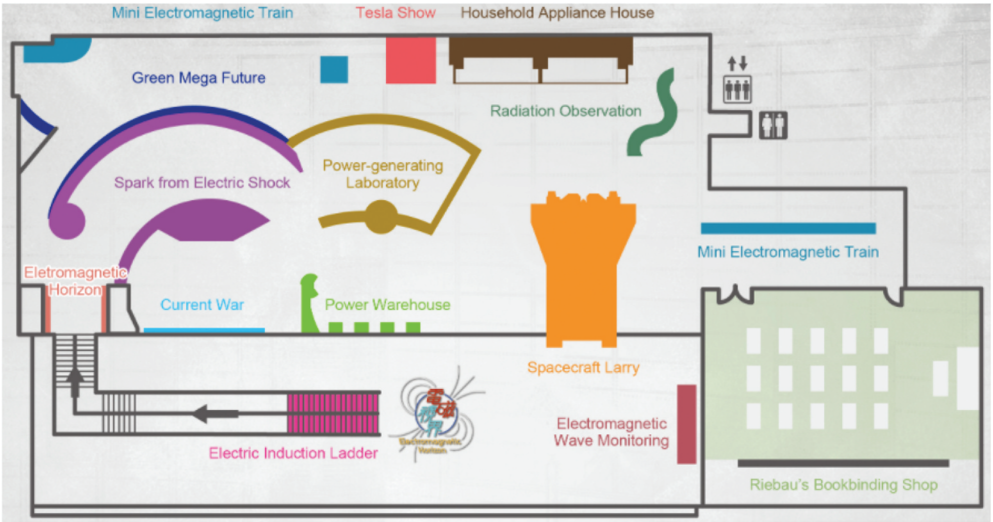

Figure 1. The electromagnetic exhibition showcases.

Students from both groups were given a paper-based worksheet intended to provide metacognitive scaffolding as they explored and tried to make sense of the various exhibits. The metacognitive scaffolds were adapted from Peters and Kitsantas (2010) that progressively scaffolded students' metacognition to think more like a scientist. While the subject area in Peters and Kitsantas (2010) was nature of science, ours was electromagnetism. Following Peters and Kitsantas (2010), the scaffolds prompted students' metacognitive thinking through Zimmerman's (2000) self-regulation phases: in the observation phase, students were prompted to compare their understanding of electromagnetism concepts with the scientific perspective; in the self-control phase, students were asked to reflect on their understanding of the major aspects of electromagnetism and their interrelationships; in the self-regulation phase, the questions prompted students to be more independently and adaptively applying their new understanding to different contexts. It should be noted that due to the emphasis on metacognition, the scaffolding questions did not directly address the aforementioned science learning goals. Instead, the questions were intended to prompt a metacognitive level of thinking like a scientist that would help students to achieve the learning goals. In addressing the prompts, students had to explore the exhibition, identify relevant information, connect new information with their own understanding, and monitor and reflect on how their ideas evolved as they proceeded. All students were required to complete the worksheet individually. The worksheet was also validated by the chief of the museum park who had been working in the park for over ten years. Sample questions in the worksheet are listed in Appendix A.

In addition to the metacognitive scaffolding, students in the experiment group had the additional access to the AR content developed using *Zappar*. When viewing a showcase, students were able to scan a nearby zap code with an iPad and access multimedia materials related to the showcase such as pictures, videos, web links, and audios.

Figure 2. Students in the experiment group who used iPad to access AR.

Figure 2 shows a picture of the students in the experiment group using AR to complete their worksheets. Students in the control group were only given the worksheet to explore the different exhibits (Figure 3).

3.4. Instruments

Three instruments were administered in this study: a science knowledge test, a learning motivation survey, and a perceived cognitive load questionnaire. The science knowledge test was developed by two experienced science teachers to evaluate students' understanding of the electricity and magnetism concepts covered in this study. The test consisted of 25 multiple-choice questions. The highest possible score was 100, with four points for each correct answer. Sample test questions are provided in Appendix B. The test was administered three times in this study before, immediately after, and two weeks after the intervention. Cronbach's alphas for pre-test, post-test, and retention test were .82, .80, and .82, respectively.

The learning motivation survey was adapted from the Intrinsic Motivation Inventory (Ryan 1982). A total of 11 Likert-scale items ranging from 1 (strongly disagree) to 5 (strongly agree) measured three subscales related to intrinsic motivation: interest (4 items; e.g. I enjoyed doing this activity very much; Cronbach's alpha = .86), perceived importance (4 items; e.g. I believe doing this activity could help me do better at school; Cronbach's alpha = .84), and tension (3 items; e.g. I felt very tense while doing this activity; Cronbach's alpha = .81).

The cognitive load questionnaire was adopted and modified from Sweller, van Merrienboer, and Paas (1998) and Hwang, Yang, and Wang (2013). The questionnaire measured cognitive load with two subscales. The first subscale, mental load, measured learners' perceived difficulty of the learning content (e.g. 'The instructional content in this activity was difficult for me'. The second subscale, mental effort, measured learners' reactions to the instructions of the learning task (e.g. 'The instructions in the learning activity were difficult to follow and understand'.) Cronbach's alphas for the two subscales were .87 and .85, respectively.

Figure 3. Students in the control group exploring museum with provided worksheet.

3.5. Procedure

A week prior to the museum field trip, students were informed that they would participate in an informal learning session outside the school, and were asked to complete the science knowledge pre-test which took about twenty minutes.

On the day when students arrived at the museum, they were randomly assigned to either an experimental or a control group. Each group was accompanied by a school teacher and an education guide from the museum. Students in both groups were informed of their learning goals for the museum visit and the voluntary nature of their research participation. Subsequently, all students participated in two required learning sessions. In the first session, both groups of students were guided through the electromagnetic exhibition showcases for about 30 minutes, and then watched a video about electricity and magnetism for approximately 10 minutes. The second learning session allowed students to freely explore the exhibition and engage in hands-on activities. Different scaffolds were provided to the two groups to support their inquiry. For the control group, students were provided the aforementioned worksheet to scaffold their metacognitive thinking. For the treatment group, in addition to the worksheet, the students were also able to access on-demand AR content using their iPads. Students in both groups were encouraged to complete the worksheet to the best of their ability and seek the teacher or education guide for help when questions arose. Upon their return to school from the museum visit, students completed the science knowledge post-test, the learning motivation survey, and the cognitive load questionnaire. Two weeks after the museum visit, students took the retention test.

3.6. Data analysis

The Statistical Package for Social Sciences (SPSS 20.0 for Windows) was used for data analysis, which included the computation of descriptive statistics, analysis of covariance (ANCOVA), and multivariate analysis of variance (MANOVA). The independent variable was the treatment conditions (Worksheet only vs. Worksheet + AR). The dependent variables were students' science knowledge test performance, learning motivation, and cognitive load. The alpha coefficient was established a priori at the .05 level, as suggested by Cohen (1977).

4. Results

To analyze the two groups' performance in the science knowledge tests, an independent sample t-test was first performed which found that the pre-test scores of the two groups did not reach a significant level ($t = .28$, $p > .05$), indicating that the two groups were equivalent in their content knowledge prior to their participation in this study. The analysis of homogeneity of the within-class regression coefficient showed that the two groups had no difference with $F = 2.99$ ($p > .05$), indicating that the homogeneity test was passed. Analysis of covariance (ANCOVA) was followed to analyze the post-test scores of the two groups with pre-test as a covariate. The post-test comparison between the two groups reached a significant level, $F(1, 62) = 6.23$ ($p < .05$), $n^2 = .10$, observed power = .69, showing a large effect size (Cohen 1977). For the retention test, ANCOVA did not find a significant difference between the two groups. Interestingly, while the treatment group (worksheet + AR) decreased from the post-test (57.17) to retention test (49.68), the control group (worksheet only) did not show a decrease, with the means of 51.13 and 52.25 for post-test and retention test, respectively. Table 1 summarizes the ANCOVA results.

Two examine the two groups' difference in intrinsic motivation, a multivariate analysis of variance (MANOVA) was performed on the three subscales of intrinsic motivation. Levene's test for homogeneity of variance was met ($p > .05$). The results revealed a significant difference between the two groups in intrinsic motivation, Wilk's Lambda = .85, $F = 3.55$, df = 3, standard error = .59, $p < .05$, $n^2 = .15$, and observed power = .76. Follow-up analysis showed a significant difference between the two groups in the subscale of perceived importance, $F(1, 62) = 6.57$, $p < .05$, $n^2 = .10$, and observed power = .71. Descriptive statistics and analysis results for intrinsic motivation are reported in Table 2. As

Table 1. ANCOVA results of the science knowledge post-test and retention test for the two groups.

Variance	Groups	N	Mean	SD	*F* value	n^2	Observed power
Posttest	Experimental group	31	57.17	17.56	6.23*	.10	.69
	Control group	32	51.13	17.77			
Retention test	Experimental group	31	49.68	12.10	.07	.01	.06
	Control group	32	52.25	16.48			

*$p < .05$.

Table 2. Descriptive statistics of learning motivation and cognitive load between the two groups.

Subscale	Group	N	Mean	SD	F	n^2	Observed power
Intrinsic motivation							
Interest	Experimental group	31	3.71	.71	.11	.01	.05
	Control group	32	3.64	.83			
Importance	Experimental group	31	2.77	.90	6.57*	.10	.71
	Control group	32	3.33	.85			
Tension	Experimental group	31	2.42	1.29	.02	.00	.01
	Control group	32	2.45	1.01			
Cognitive load							
Mental load	Experimental group	31	3.76	1.54	6.75	.05	.12
	Control group	32	3.10	1.35			
Mental effort	Experimental group	31	3.65	1.58	.63	.01	.12
	Control group	32	3.33	1.53			

*$p < .05$.

shown, the control group (M = 3.33, SD = .85) reported significantly higher perceived importance than those in the experimental group (M = 2.77, SD = .90). No significant difference was found in the subscales of interest and tension.

In regard to the students' perceived cognitive load, MANOVA results showed no significant differences between the two groups in mental load and mental effort, Wilk's Lambda = .94, F = 2.03, df = 2, standard error = 60, p = .14, n^2 = .05, and observed powered = .40. The descriptive statistics results of the cognitive load measures are shown in Table 2.

5. Discussion and implications

With a recognized importance of informal learning, museums have been paying an increasing attention to the design of experiences conducive to learning (Bonnette, Crowley, and Schunn 2019; National Research Council 2009). While spontaneous inquiries in museums often pique visitors' intrinsic motivation to learn, there is a consensus that certain structures or scaffolds have the potential to enhance museums' impact on learning (Eshach 2007; Gutwill and Allen 2012; Yoon et al. 2013). In light of documented benefits of metacognition in science inquiries and of AR in education (Altinpulluk 2019; Chiang, Yang, and Hwang 2014; Huang, Ge, and Eseryel 2017; Peters and Kitsantas 2010), this study implemented and investigated metacognitive scaffolding and AR to support student inquiries at a science museum.

Regarding students' performance in the science knowledge tests, the results showed that the treatment group scaffolded by both AR and metacognitive worksheet significantly outperformed the control group in the post-test. The finding corroborates with the findings by Yoon et al. (2013) and Chiang, Yang, and Hwang (2014) that AR enhanced students' science learning achievement. As students explored the museum exhibits and completed the worksheet, AR-enabled on-demand content might have helped them to develop a more in-depth understanding of given concepts (Yoon et al. 2012). Conversely, the worksheet served as a scaffold to help students explore AR content with more intention (Ibáñez and Delgado-Kloos 2018). The two scaffolds complemented each other to help students maximize their museum learning.

On the other hand, the benefits of the two combined scaffolds did not last in the retention test. In fact, the control group with only metacognitive scaffolding was able to maintain their level of understanding two weeks after the museum visit, while the treatment group that had both scaffolds showed a decline in the retention of their knowledge. The result demonstrated an enduring impact of metacognitive scaffolding on science learning in museums. In the context of formal science education, a similar effect was found by Huang, Ge, and Eseryel (2017), but few studies in the museum learning context examined knowledge retention. It can be reasoned that metacognitive thinking helped students to develop their own 'theories' and internalize what they have learned from the museum visit, and this meta-level of thinking beyond the cognitive scope might have a general impact on their science knowledge or even the use of learning strategies. Comparatively, the benefits of AR were mainly cognitive instead of metacognitive, thus having limited effect beyond the immediate impact.

Regarding students' intrinsic motivation, the finding is somewhat unexpected. Although the two groups felt the same levels of interest and tension, students in the control group perceived their museum learning experience to be more important and helpful. Research so far appears to suggest the motivational benefits of AR in both formal and informal learning environments (Altinpulluk 2019; Goff et al. 2018). The authors suggest two possible reasons for this result. First, the students in the treatment group had to consult both museum exhibition and AR to complete their worksheet, which might have left them little room for free exploration. Comparatively, the control group was able to focus on completing the worksheet while exploring the museum, which might have led them to recognize more importance in the learning activity. Secondly, the authors postulate that part of the reason for the finding might be the focus of this study on intrinsic motivation. Informal learning is traditionally driven by intrinsic motivation – the voluntary, unstructured setting invites learners to explore based on their personal interests and goals (Crowley, Pierroux, and Knutson 2014; Eshach 2007). However, as informal learning settings add more structure in the hope of improving educational effectiveness, the sense of spontaneous inquiry may simultaneously decrease. As such, learners' internal drive to learning may not be as strong. Indeed, Yoon et al. (2013) questioned 'how much is too much' in scaffolding learning in science museums and raised the concern of overformailization of museum learning (848). As Gutwill and Allen (2012) suggested, the most effective field trips might be those with intermediate levels of structuring while still allowing free exploration. More research is needed to empirically examine ways to maintain learners' intrinsic motivation with a balance between structure and free exploration.

Lastly, the two groups of students did not seem to experience different levels of cognitive load. It might be that the science content was not difficult enough that it requires a deep level of processing, thus not causing a high level of cognitive load among the students. It might also be that the work to complete the worksheet was demanding enough that AR did not impose additional significant load to the already heavy load. More research is needed to pinpoint the exact reason.

6. Conclusion

By comparing metacognitive scaffolding with or without additional support of AR in the context of museum science learning, this study simultaneously investigated the impact on science knowledge, intrinsic motivation, and cognitive load. The examination of students' retention performance yielded helpful insights into scaffolding in the museum context. The findings have implications for supporting learner inquiries in science museums and for using AR in museum learning.

The study could have been improved with a no-scaffolding control group to draw more helpful findings and implications. While this study focused on conceptual knowledge in science, future studies could examine scaffolding higher-order thinking in museums. Collection of qualitative data could also shed light on quantitative findings.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Ministry of Science and Technology, Taiwan [MOST108-2511-H-018-017-MY3].

References

Akçayır, M., G. Akçayır, H. M. Pektaş, and M. A. Ocak. 2016. "Augmented Reality in Science Laboratories: The Effects of Augmented Reality on University Students' Laboratory Skills and Attitudes toward Science Laboratories." *Computers in Human Behavior* 57: 334–342. doi:10.1016/j.chb.2015.12.054.

Altinpulluk, H. 2019. "Determining the Trends of Using Augmented Reality in Education between 2006–2016." *Education and Information Technologies* 24: 1089–1114. doi:10.1007/s10639-018-9806-3.

Bonnette, R. N., K. Crowley, and C. D. Schunn. 2019. "Falling in Love and Staying in Love with Science: Ongoing Informal Science Experiences Support Fascination for All Children." *International Journal of Science Education* 41 (12): 1626–1643. doi:10.1080/09500693.2019.1623431.

Bujak, K. R., I. Radu, R. Catrambone, B. MacIntyre, R. Zheng, and G. Golubski. 2013. "A Psychological Perspective on Augmented Reality in the Mathematics Classroom." *Computers & Education* 68: 536–544. doi:10.1016/j.compedu.2013.02.017.

Charitonos, K., C. Blake, E. Scanlon, and A. Jones. 2012. "Museum Learning via Social and Mobile technologies:(How) Can Online Interactions Enhance the Visitor Experience?" *British Journal of Educational Technology* 43 (5): 802–819. doi:10.1111/j.1467-8535.2012.01360.x.

Chen, C. H., J.-Q. Yang, K. Huang, and K.-C. Yao. 2020. "Augmented Reality and Competition in Robotics Education: Effects on 21st Century Competencies, Group Collaboration, and Learning Motivation." *Journal of Computer Assisted Learning* 36 (6): 1052–1062. doi:10.1111/jcal.12469.

Chen, C. H., T. K. Liu, and K. Huang. 2021. "Scaffolding Vocational High School Students' Computational Thinking with Cognitive and Metacognitive Prompts in Learning about Programmable Logic Controllers." *Journal of Research on Technology in Education* 1–18. doi:10.1080/15391523.2021.198389.

Chen, G., Y. Xin, and N. Chen. 2017. "Informal Learning in Science Museum: Development and Evaluation of a Mobile Exhibit Label System with iBeacon Technology." *Educational Technology Research & Development* 65: 719–741. doi:10.1007/s11423-016-9506-x.

Cheng, K.-H., and C.-C. Tsai. 2013. "Affordances of Augmented Reality in Science Learning: Suggestions for Future Research." *Journal of Science Education and Technology & Learning* 22 (4): 449–462.

Chiang, T. H., S. J. Yang, and G.-J. Hwang. 2014. "An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities." *Journal of Educational Technology & Society* 17 (4): 352–365.

Cohen, J. 1977. *Statistical Power Analysis for the Behavioral Sciences*. revised ed. New York: Academic Press.

Crowley, K., P. Pierroux, and K. Knutson. 2014. "Informal Learning in Museums." In *The Cambridge Handbook of the Learning Sciences*, edited by R. K. Sawyer, 461–478. Cambridge University Press.

Deci, E. L., and R. M. Ryan. 2000. "The "What" and "Why" of Goal Pursuits: Human Needs and the Self-determination of Behavior." *Psychological Inquiry* 11 (4): 227–268. doi:10.1207/S15327965PLI1104_01.

Donnelly, D. F., M. C. Linn, and S. Ludvigsen. 2014. "Impacts and Characteristics of Computer-based Science Inquiry Learning Environments for Precollege Students." *Review of Educational Research* 84 (4): 572–608. doi:10.3102/0034654314546954.

Eshach, H. 2007. "Bridging In-school and Out-of-school Learning: Formal, Non-formal, and Informal Education." *Journal of Science Education and Technology* 16 (2): 171–190. doi:10.1007/s10956-006-9027-1.

Falk, J. H., and L. D. Dierking. 2000. *Learning from Museums. Visitors' Experiences and the Making of Meaning*. Walnut Creek, CA: AltaMira Press.

Falk, J. H., and L. D. Dierking. 2010. "The 95 Percent Solution." *American Scientist* 98 (6): 486–493. doi:10.1511/2010.87.486.

Ferrer-Torregrosa, J., J. Torralba, M. Jimenez, S. García, and J. Barcia. 2015. "ARBOOK: Development and Assessment of a Tool Based on Augmented Reality for Anatomy." *Journal of Science Education and Technology* 24 (1): 119–124. doi:10.1007/s10956-014-9526-4.

Flavell, J. H. 1987. "Speculations about the Nature and Development of Metacognition." In *Metacognition, Motivation, and Understanding*, edited by F. Weinert and R. Kluwe, 21–29. Hillsdale, NJ: Erlbaum.

Garcia, B. 2012. "What We Do Best: Making the Case for the Museum Learning in Its Own Right." *Journal of Museum Education* 37 (2): 47–55. doi:10.1080/10598650.2012.11510730.

Goff, E. E., K. L. Mulvey, M. J. Irvin, and A. Hartstone-Rose. 2018. "Application of Augmented Reality in Informal Science Learning Sites: A Review." *Journal of Science Education and Technology* 27: 433–447. doi:10.1007/s10956-018-9734-4.

Gutwill, J. P., and S. Allen. 2012. "Deepening Students' Scientific Inquiry Skills during a Science Museum Field Trip." *The Journal of the Learning Sciences* 21 (1): 130–181. doi:10.1080/10508406.2011.555938.

Hou, H. T., S. Y. Wu, P. C. Lin, Y. T. Sung, J. W. Lin, and K. E. Chang. 2014. "A Blended Mobile Learning Environment for Museum Learning." *Educational Technology & Society* 17 (2): 207–218.

Hsu, Y.-S., Y.-H. Lin, and B. Yang. 2016. "Impact of Augmented Reality Lessons on Students' STEM Interest." *Research and Practice in Technology Enhanced Learning* 12 (2). doi:10.1186/s41039-016-0039-z.

Huang, K., X. Ge, and D. Eseryel. 2017. "Metaconceptually-enhanced Simulation-based Inquiry Learning: Effects on 8th Grade Students' Conceptual Change and Science Epistemic Beliefs." *Educational Technology Research and Development* 65 (1): 75–100. doi:10.1007/s11423-016-9462-5.

Hwang, G. J., L. H. Yang, and S. Y. Wang. 2013. "A Concept Map-embedded Educational Computer Game for Improving Students' Learning Performance in Natural Science Courses." *Computers & Education* 69: 121–130. doi:10.1016/j.compedu.2013.07.008.

Ibáñez, M.-B., and C. Delgado-Kloos. 2018. "Augmented Reality for STEM Learning: A Systematic Review." *Computers & Education* 123: 109–123. doi:10.1016/j.compedu.2018.05.002.

Kamphuis, C., E. Barsom, M. Schijven, and N. Christoph. 2014. "Augmented Reality in Medical Education?" *Perspectives on Medical Education* 3 (4): 300–311. doi:10.1007/s40037-013-0107-7.

Kim, M., and E. Dopico. 2016. "Science Education through Informal Education." *Cultural Studies of Science Education* 11: 439–445. doi:10.1007/s11422-014-9639-3.

Kirschner, P. A., J. Sweller, and R. E. Clark. 2006. "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-based, Experiential, and Inquiry-based Teaching." *Educational Psychologist* 41: 75–86. doi:10.1207/s15326985ep4102_1.

Kyza, E. A., and Y. Georgiou. 2019. "Scaffolding Augmented Reality Inquiry Learning: The Design and Investigation of the TraceReaders Location-based, Augmented Reality Platform." *Interactive Learning Environments* 27 (2): 211–225. doi:10.1080/10494820.2018.1458039.

Lin, H.-C. K., M.-C. Chen, and C.-K. Chang. 2015. "Assessing the Effectiveness of Learning Solid Geometry by Using an Augmented Reality-assisted Learning System." *Interactive Learning Environments* 23 (6): 799–810. doi:10.1080/10494820.2013.817435.

Liu, T. -C., Y. -C. Lin, M. -J. Tsai, and F. Paas. 2012. "Split-attention and Redundancy Effects in Mobile Learning in Physical Environments." *Computers & Education* 58 (1): 172–180. doi:10.1016/j.compedu.2011.08.007.

Mayer, R. E. 1998. "Cognitive, Metacognitive, and Motivational Aspects of Problem Solving." *Instructional Science* 26 (1–2): 49–63. doi:10.1023/A:1003088013286.

Mujtaba, T., M. Lawrence, M. Oliver, and M. J. Reiss. 2018. "Learning and Engagement through Natural History Museums." *Studies in Science Education* 54 (1): 41–67. doi:10.1080/03057267.2018.1442820.

National Research Council. 2009. *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington, DC: National Academies Press.

Peters, E., and A. Kitsantas. 2010. "The Effect of Nature of Science Metacognitive Prompts on Science Students' Content and Nature of Science Knowledge, Metacognition, and Self-regulatory Efficacy." *School Science and Mathematics* 110 (8): 382–396. doi:10.1111/j.1949-8594.2010.00050.x.

Russel, J. L., K. Knutson, and K. Crowley. 2013. "Informal Learning Organizations as Part of an Educational Ecology: Lessons from Collaboration across the Formal-informal Divide." *Journal of Educational Change* 14: 259–281. doi:10.1007/s10833-012-9203-4.

Ryan, R. M., and E. L. Deci. 2000. "Self-determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-being." *American Psychologist* 55: 68–78. doi:10.1037/0003-066X.55.1.68.

Ryan, R. M. 1982. "Control and Information in the Intrapersonal Sphere: An Extension of Cognitive Evaluation Theory." *Journal of Personality and Social Psychology* 43: 450–461. doi:10.1037/0022-3514.43.3.450.

Schoenfeld, A. H. 1985. *Mathematical Problem Solving*. Orlando, FL: Academic Press.

Shute, V. J. 2008. "Focus on Formative Feedback." *Review of Educational Research* 78 (1): 153–189. doi:10.3102/0034654307313795.

Sweller, J., J. J. G. van Merrienboer, and F. Paas. 1998. "Cognitive Architecture and Instructional Design." *Educational Psychology Review* 10: 251–296. doi:10.1023/a:1022193728205.

Vavoula, G., M. Sharples, P. Rudman, J. Meek, and P. Lonsdale. 2009. "My Art Space: Design and Evaluation of Support for Learning with Multimedia Phones between Classrooms and Museums." *Computers & Education* 53: 286–299. doi:10.1016/j.compedu.2009.02.007.

White, B. Y., and J. R. Frederiksen. 1998. "Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students." *Cognition and Instruction* 16 (1): 3–118. doi:10.1207/s1532690xci1601_2.

Wong, K., S. S. Jamali, and M. F. Shiratuddin. 2014. "A Review of Augmented Reality and Mobile-augmented Reality Technology." *International Journal of Learning in Higher Education* 20 (2): 37–54. doi:10.18848/1447-9494/CGP/v20i02/48690.

Wu, H.-K., S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang. 2013. "Current Status, Opportunities and Challenges of Augmented Reality in Education." *Computers & Education* 62: 41–49. doi:10.1016/j.compedu.2012.10.024.

Yoon, S., and J. Wang. 2014. "Making the Invisible Visible in Science Museums through Augmented Reality Devices." *TechTrends* 58 (1): 49–55. doi:10.1007/s11528-013-0720-7.

Yoon, S., K. Elinich, J. Wang, C. Steinmeier, and S. Tucker. 2012. "Using Augmented Reality and Knowledge-building Scaffolds to Improve Learning in a Science Museum." *International Journal of Computer Supported Collaborative Learning* 7 (4): 519–541. doi:10.1007/s11412-012-9156-x.

Yoon, S., K. Elinich, J. Wang, J. B. van Schooneveld, and E. Anderson. 2013. "Scaffolding Informal Learning in Science Museums: How Much Is Too Much?" *Science Education* 97 (6): 848–877. doi:10.1002/sce.21079.

Zimmerman, B. J. 2000. "Attaining Self-regulation: A Social Cognitive Perspective." In *Handbook of Self-regulation*, edited by M. Boekaerts, P. R. Pintrich, and M. Zeidner, 13–39. San Diego, CA: Academic Press.

Appendix A. Examples of metacognitive scaffolding in the worksheet

Observation phase

(1) Please explain in detail how we usually generate electricity.
(2) What do scientists understand about thermal power generation? How do your observations support this generalization?

Self-control phase

(1) Have you begun to think more like an expert about how the Tesla coil turns a low voltage into a high voltage?
(2) To observe the relationship between electricity and magnetism, what big ideas (i.e. theory) did you observe to make sense of your understanding of how electromagnetism produces a magnetic field?

Self-regulation phase

(1) How can you determine thermal power, hydropower, and nuclear power?
(2) How do your observations support people who use solar energy to generate electricity, and/or India's development of solar trees?

Appendix B. Sample questions in the science knowledge test

(1) Electromagnets are different from permanent magnets. What does the electromagnet and the permanent magnet have mainly passed before they have magnetic force? (A) Discharge (B) Conductivity (C) Storage (D) Static electricity
(2) Faraday uses the changing magnetic field to generate electric current. How does it work? (A) Electrokinetic magnetism (B) Electrostatic magnetism (C) Magnetism electromagnetism (D) Electromagnetic interaction
(3) V (Volt) is the unit of voltage, which represents the level of electric current, which is like water pressure. So which socket is not suitable for 110 V electrical appliances? (A) 220 V (B) 110 V (C) 100 V (D)80 V
(4) Thermal power generation is currently the most important power generation method in Taiwan. Which of the following is wrong in its description? (A) Most of the raw materials rely on imports. (B) Petrochemical fuels are depleted day by day. (C) Pollution is not high. (D) A lot of carbon dioxide will be emitted.