International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

An exploration of primary school students' perceived learning practices and associated self-efficacies regarding mobile-assisted seamless science learning

Xiao-Fan Lin, Dandan Tang, Xuanjun Lin, Zhong-Mei Liang & Chin-Chung Tsai

To cite this article: Xiao-Fan Lin, Dandan Tang, Xuanjun Lin, Zhong-Mei Liang & Chin-Chung Tsai (2019): An exploration of primary school students' perceived learning practices and associated self-efficacies regarding mobile-assisted seamless science learning, International Journal of Science Education, DOI: 10.1080/09500693.2019.1693081

To link to this article: https://doi.org/10.1080/09500693.2019.1693081

Published online: 21 Nov 2019.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2019.1693081

Routledge
Taylor & Francis Group

An exploration of primary school students' perceived learning practices and associated self-efficacies regarding mobile-assisted seamless science learning

Xiao-Fan Lin [a,b], Dandan Tang[a], Xuanjun Lin[a], Zhong-Mei Liang [a] and Chin-Chung Tsai [c,d]

[a]School of Education Information Technology, South China Normal University, Guangdong Provincial Engineering and Technologies Research Centre for Smart Learning, Guangzhou, People's Republic of China; [b]Guangdong Provincial Institute of Elementary Education and Information Technology, Guangzhou, People's Republic of China; [c]Program of Learning Sciences, National Taiwan Normal University, Taipei, Taiwan; [d]Institute for Research Excellence in Learning Sciences, National Taiwan Normal University, Taipei, Taiwan

ABSTRACT

This study aimed to explore the relationships between students' perceived learning practices and associated self-efficacies regarding mobile-assisted seamless science learning. The learning practices for mobile-assisted seamless science learning questionnaire was developed with three scales that denote learning supported by mobile technology. These scales included authentic learning, self-directed learning, and collaborative learning with information and communication technology. Associated self-efficacies promoted by mobile-assisted seamless science learning could include authentic problem-solving, creative thinking and academic self-efficacy. A sample of 312 primary school students from China responded to the mobile-assisted seamless science learning questionnaire. Confirmatory factor analyses indicated that the mobile-assisted seamless science learning questionnaire had high reliability and validity. The path analysis results analysed via a structural equation modelling technique implied that primary school students' perceived self-directed learning and authentic learning were important as positive predictors for authentic problem-solving efficacy, which may function as a partial mediation variable in the effect of students' perceptions of learning practices on the academic self-efficacy of mobile-assisted seamless science learning. The findings highlighted that learning practices (i.e. authentic learning and self-directed learning) and authentic problem-solving efficacy are both indispensable and mutually reinforcing. This can provide some insights for promoting mobile learning in science learning in the future.

ARTICLE HISTORY
Received 4 February 2019
Accepted 10 November 2019

KEYWORDS
Science learning; mobile learning; self-efficacy; primary school

Introduction

Facilitated by the advancement of information communication technology (ICT), the trend in modern education has shifted more in favour of student-centred learning

CONTACT Zhong-Mei Liang 351632147@qq.com Office 214, School of Distance Education, South China Normal University, #55 Zhongshan Dadao Xi, 510631, Guangzhou, P.R.China

(Saavedra & Opfer, 2012). In particular, many researchers have mentioned that incorporating empowering mobile learning technologies and strategies in science learning practices could increase teachers' tendency to employ these technologies and strategies and improve students' competencies (Crompton, Burke, Gregory, & Grabe, 2016; Delen & Krajcik, 2015; Hwang, Tsai, Chu, Kinshuk, & Chen, 2012). Researchers have highlighted the crucial role of incorporating mobile-assisted, real-world learning contexts into science learning practices (Chang, Hsu, Wu, & Tsai, 2018; Hwang et al., 2012).

To become scientifically literate, students should learn to apply the scientific knowledge they have learned to situation-specific phenomena (Chu, Hwang, Tsai, & Tseng, 2010), communicate with peers for reasoning or analysing (Hsi, 2007), deal with problems in authentic situations (Hwang, Wu, & Ke, 2011), and develop new ideas like a scientist (Hung, Hwang, & Huang, 2012) during learning practices. Furthermore, several studies have reported that students' collaboration (Burden & Kearney, 2016; Wu, Hwang, Kuo, & Huang, 2013) and problem-solving performance (Gu, Chen, Zhu, & Lin, 2015; Sung, Hou, Liu, & Chang, 2010) could be improved by well-designed mobile learning activities. However, attempts to bring mobile technology into science learning without careful consideration of subject ecology and personal characteristics would not contribute much to learning for science-savvy students (Fu & Hwang, 2018; Looi, Sun, Kim, & Wen, 2018). Moreover, researchers have indicated that it is crucial to take students' self-efficacy into account when developing learning practices in order to engage them in higher-order thinking processes and improve their creativity and learning achievements (Bonsignore, Quinn, Druin, & Bederson, 2013).

However, a recent review of the literature indicated that the current research on mobile learning still focuses more on the design of mobile learning and discussion of its effects on learning (Wu et al., 2012). From the perspective of Sharples, Taylor, and Vavoula's (2010) framework, most mobile learning research focuses on operational interfaces, mediating tools, and context, and there has been comparatively little discussion of science learners' self-efficacy, deep conception changes, cognitive processes, and learning practices. It seems that students' perception of mobile science learning is a complicated context, which may involve the interaction of varied factors (Chang et al., 2018).

We developed an authentic mobile learning environment to facilitate primary school students' science learning on the life of plants and the essential conditions of seed germination. This environment took advantage of mobile augmented reality technology to develop an immersive context to enhance students' conceptual understanding and impress upon them the possible everyday applications of scientific concepts. Moreover, a systematic review regarding the use of mobile learning in science showed that 51% of current studies focus on designing a system for learning and that research on the effects of mobile learning in science were relatively insufficient – only 16% employed quantitative and quasi-experimental methods; most employed case studies and qualitative methods (Crompton et al., 2016). Since the relationships between the multiple factors contributing to students' perceptions of mobile science learning are still unclear, this study conducted a structural equation model to understand the relationship between students' self-efficacies and their perceived learning practices with mobile-assisted seamless science learning (MASSL).

Literature review

Self-efficacy

'Self-efficacy' refers to an individual's perceptions of his/her ability to implement a task; it also predicts how much effort a person will exert to accomplish a task and how far they will persevere with the endeavour (Bandura, 1996). Previous studies in science education have indicated that students who have positive beliefs about whether they are qualified for scientific activities (i.e. they possess a high level of self-efficacy in this regard) usually have a significant preference for such activities. They are also more likely to devote themselves to completing learning tasks and less likely to feel frustrated when facing difficulties (Britner & Pajares, 2006; Zeldin & Pajares, 2000). Conversely, students with a low level of self-efficacy will often abort the learning tasks they have to face and are less likely to devote themselves to these tasks even if they are made to do so by their teachers or parents. When they encounter difficulties, they often give up because of the pressure they feel (Kıran & Sungur, 2011).

Science educators and researchers are convinced that self-efficacy is crucial for promoting students' achievement and participation in scientific learning-related activities (Britner & Pajares, 2006). Previous studies have indicated that self-efficacy can be used to predict outcome variables of scientific learning (Areepattamannil, Freeman, & Klinger, 2011; Capa Aydin & Uzuntiryaki, 2009; Kupermintz, 2002; Lau & Roeser, 2002). In Barak, Ashkar, and Dori's (2011) empirical study, 1,335 students' self-efficacy was used as a predictor to examine their science learning achievement through animated videos. Further, Areepattamannil et al. (2011) revealed a significant positive relationship between self-efficacy and science learning achievement in a large-scale survey involving 13,985 middle school students in Canada.

Some researchers (Bandura, 1997; Pajares, 1996) have proposed that studies examining students' self-efficacy should develop measures that can be adapted to domain-specific contexts and account for individual characteristics within these different domains, so as to avoid examining students' self-efficacy in a general way. Some researchers (Capa Aydin & Uzuntiryaki, 2009; Lin & Tsai, 2013; Uzuntiryaki & Capa Aydin, 2009) have tried to develop multidimensional scales to understand students' self-efficacy in science learning domains. Uzuntiryaki and Capa Aydin (2009) developed chemistry learning self-efficacy questionnaires consisting of four scales: knowledge/comprehension skills, higher-order thinking skills, psychomotor skills, and everyday application of learning. Further, a questionnaire was developed for evaluating Taiwanese high school students' science learning self-efficacy, involving five scales: conceptual understanding, higher-order cognitive skills, practical work, everyday application of learning, and science communication (Lin & Tsai, 2013). The above research demonstrates how studies focusing on domain-specific contexts (e.g. chemistry learning in a given school) result in different sets of measurements and findings than studies that focus on general science learning.

Influential factors explaining MASSL may be deduced by analogy, and students may hold multiple, layered perspectives of self-efficacy in MASSL contexts rather than one predominant one (Lin, Deng, Hu, & Tsai, 2019). Previous studies have employed several multidimensional scales to understand students' self-efficacy in MASSL contexts (Chai, Wong, & King, 2016; Kuo, Hwang, & Lee, 2012; Vinu, Sherimon, & Krishnan, 2011). Researchers have advocated examining four common dimensions of mobile-assisted seamless learning and practices: students' perceived authentic experiences and/or contexts for everyday life applications of science concepts and skills (Song, 2018; Sun & Looi, 2018); students' willingness and confidence regarding self-directed and/or self-regulated scientific learning (e.g. mobile devices which provide support for students' self-management of their science learning or provide goal-directed access to science learning; Lai, Hwang, & Tu, 2018; Teo et al., 2010); students' confidence in their ability to collaborate with peers (e.g. mobile technologies offering new approaches for group or community communication/argumentation/discussion and fostering collective understanding of science-related issues or themes; Chai, Deng, Tsai, Koh, & Tsai, 2015; Chang, Chen, & Hsu, 2011); and students' self-efficacy regarding higher-order skills (e.g. confidence in their problem-solving skills or expression of creative thinking by elaborating, refining, and analysing in science learning activities; Kim, Suh, & Song, 2015; Kuo et al., 2012). As mentioned above, examining students' self-efficacy regarding MASSL as a monolithic entity may provide limited information. Instead, MASSL can be conceptualised along the following dimensions: authentic learning (AL), self-directed learning with technology (SDL), collaborative learning with ICT (CoL), authentic problem-solving confidence (APS), and creative thinking confidence (CreT). These dimensions are fully explained in the research framework below.

The context of MASSL

As mentioned above, students may perceive multiple layers of self-efficacy regarding MASSL rather than one predominant one. This makes significant differential contributions to students' science learning. A better, more nuanced understanding of self-efficacy may help teachers and educators develop and implement instruction which can enhance MASSL. To ensure that all participants and teachers received the same level of MASSL experience and instruction, they were required to complete mobile science courses in order to qualify for a series of more advanced courses. Through this process all participants were exposed to learning projects where projects involving mobile devices occupied more than one-third of class time.

Furthermore, the teachers were trained to design mobile-learning scientific activities according to four recommended activities, which integrate scientific learning and knowledge both in the classroom and outdoors. In the first activity, students learn in a conventional school environment, which helps their knowledge comprehension. In this environment students can form a sense of scientific knowledge and problems that require scientific knowledge in order to be solved. In this activity the teacher presents animations which depict either scientific knowledge or problems requiring scientific solutions, and then organises students to propose investigation plans and collaborative learning. For instance, 3D models or videos regarding the concept of seed germination were presented via augmented reality on smartphones. Teachers guided students' proposals of plans to investigate that process to verify that seed germination does not require sunlight, which helped overturn students' misunderstanding and previous knowledge.

The second activity involves individual extracurricular authentic learning. Here, students watch animations or videos on mobile devices before or after class. They would then be required to explore and elaborate the scenes about scientific knowledge or problems – for instance, they could capture photos or videos of the real-life context and inquiry process using their devices and then upload those to the community website (e.g. a Wiki) which contains photos and text. This might help them compare notes with their classmates and specify the connection between variables and hypotheses and learning scientific knowledge or solving scientific problems.

Activity three involves extracurricular collaborative learning online. Using mobile devices, students would comment on and/or modify their classmates' posts to a Wiki. The online sharing, discussions, and interpretation with peers based on the evidence occurring through this activity might facilitate students' science learning processes and foster conceptual understanding.

The fourth activity is meant to strengthen and enhance students' scientific knowledge. In this activity the teacher chooses a topical, issue-based scientific problem or realm of scientific knowledge which is related to the above activities. Students would then talk about these issues together, developing new ideas and solutions to the problems as they go.

We took the scientific issue of 'exploring the essential conditions of seed germination' as the example to express actual questions regarding the actual learning. Questions regarding the actual learning for the students are comparing the difference between their experience and science knowledge. 3D models or videos regarding the concept of seed germination were presented in a Networked Learning Space via smartphones to help teachers build an authentic learning context and immersive experience for their students (see Figure 1). This can facilitate students to think deeply about the relationship of seed germination to photosynthesis and allows teachers to check whether students properly understood the concept of seed germination. Teachers presented the augmented reality videos of seed germination a second time, so that students could discover or repair their misunderstanding of seed germination through observation and reflection. Then, the reasons for seed germination not requiring sunlight were proposed to correct the misconceptions.

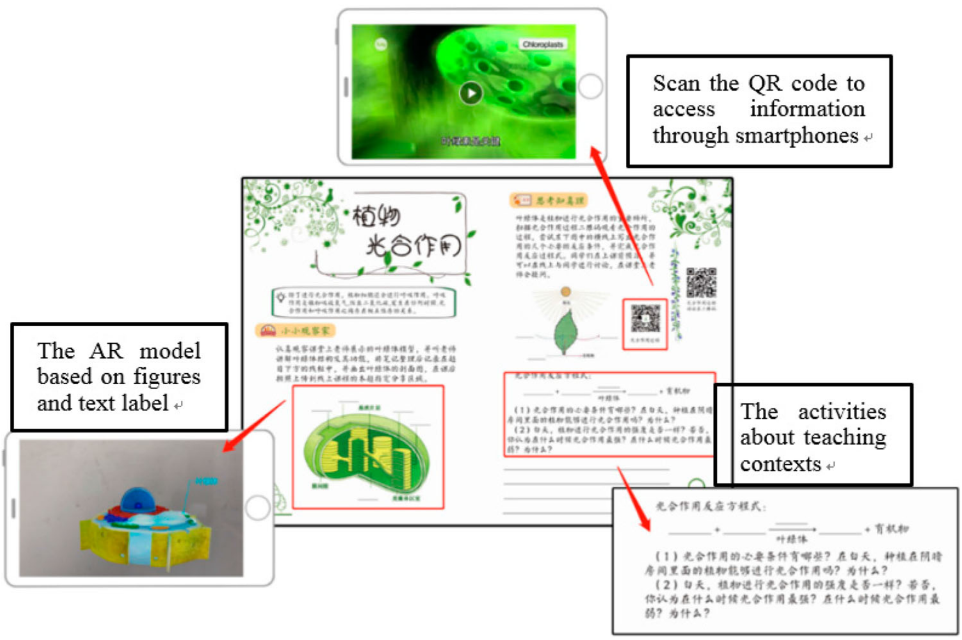

Figure 1. The function of Networked Learning Space in smartphones.

To emphasise the importance of sunlight for plant life, teachers guided students' exploration of that process and verified that seed germination does not require sunlight, which helped overturn students' misunderstanding and previous knowledge. In short, teachers and researchers developed augmented reality models containing figures and texts to explain the process of seed germination and other biological phenomena which are difficult to observe in reality. These tools can help students understand the nature science of seed germination and photosynthesis.

Research framework

Chai et al. (2015) examined students' perceptions and associated self-efficacies regarding MASSL through a more appropriate (i.e. less general) framework that measured students' learning practices and higher-order thinking efficacy. Thus, AL, SDL, and CoL measure students' perception that their scientific knowledge is gradually improved and gained through contexts, objects, or peers, which taken together form the latent construct 'learning practice'. On the other hand, APS, and CreT focus more on students' self-efficacies regarding thinking, judging, analysing, and developing innovative ideas in science learning – taken together, they form the overarching construct 'higher-order thinking efficacy' in this study. In sum, this study will examine MASSL regarding learning practices and higher-order thinking efficacy.

In addition, this study developed the MASSL framework from three aspects, namely learning practices, higher-order thinking efficacy, and academic self-efficacy (as shown in Figure 2).

The 'learning practices for MASSL' aspect refers to a MASSL process that engages students in individual autonomy, self-regulation, and collaborating-to-learn in an authentic context. In this study, AL involves connecting what is learned to one's real world learning context or everyday life (Howland, Jonassen, & Marra, 2012). AL refers to students' perceived authentic experiences or contexts for everyday applications of scientific concepts and skills. AL leveraged mobile technology to facilitate knowledge of scientific concepts and motivate perpetual learning experiences, bridging real-world environments and

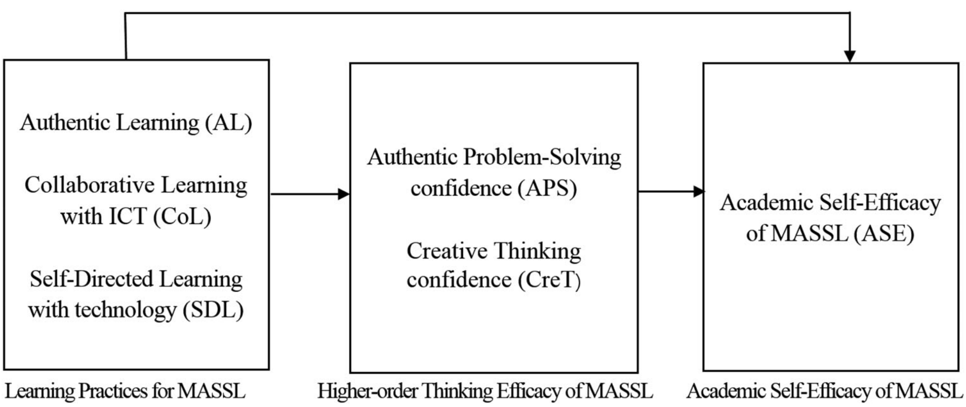

Figure 2. The framework for the relations among students' learning practices, higher-order thinking efficacy, and academic self-efficacy of MASSL

cyberspace by utilising mobile devices (e.g. augmented reality technology) in learning environments (Hwang et al., 2012). Teacher-centred traditional instruction in a science class is administrated by teacher initiation of scientific knowledge, student response, and then teacher provision of feedback (Wells, 2006). However, in AL and seamless science learning, the teacher assists students' self- or group-directed exploration of concepts with the help of smartphones (Harley, Poitras, Jarrell, Duffy, & Lajoie, 2016), which stimulates students' interest and participation. For instance, students understand the natural science of seed germination and photosynthesis through a Networked Learning Space, and can access via smartphones authentic 3D models or videos of the process of seed germination (see Figure 1).

In this study, the concept of SDL advocates students' conscious choice and implementation of learning strategies with certain mobile devices to achieve their personal science-learning goals and/or to form their own ideas and approaches toward learning tasks (Hwang et al., 2011). Several studies have implied that self-directed learning may be a relatively vital part of students' learning outcomes (Chu, Chu, Weng, Tsai, & Lin, 2012; Lin, Liang, Tsai, & Hu, 2018), especially for science learning that incudes inquiry and exploratory activities (Hwang et al., 2011). For example, the students utilised SDL strategies to fulfil the task of studying the essential conditions of seed germination in extracurricular and outdoor learning via smartphones.

CoL refers to a learning approach that facilitates learners' achieving their learning objectives or accomplishing learning assignments through exchanging ideas and communicating with partners (Kuo et al., 2012; Osman, Duffy, Chang, & Lee, 2011). It may facilitate a deeper understanding of science subjects for students through timely and convenient collaboration supported by ICT (Manathunga & Hernández-Leo, 2018; Wang & Lin, 2007). In this study, students had discussions with each other and asked for help with the inquiry into the essential conditions of seed germination via email, wiki, SMS, WhatsApp, etc.

The gap in theoretical or empirical links between the above-reviewed learning practices and higher-order thinking efficacy in MASSL is likely to result in reproductive learning with mobile technology, which leaves students lacking higher-order thinking efficacy. APS refers to an individual's belief in his/her ability or tendency to identify problems, collect and analyse associated data or information, propose legitimate solutions, and select the most sure-fire solution to the problem (Akcaoglu & Koehler, 2014; Lazakidou & Retalis, 2010; Pantiwati, 2013). Akcaoglu and Koehler (2014) revealed that well-designed learning game (e.g. system analysis and design, decision-making, and troubleshooting) could promote improved problem-solving skills. However, as others have highlighted (e.g. Farmer, Leonard, Spearman, Qian, & Rosenblith, 2016; Qian & Clark, 2016), Akcaoglu and Koehler's (2014) work relied too heavily on game-based learning and problem-solving skills. They critiqued the experimental procedure that their design rested on other twenty-first century skills such as creativity and collaboration as learning outcomes. In addition, it cannot isolate the effects of their specific instructional interventions on students' problem solving skills and other higher-order thinking skills (e.g. a designed after-school programme), which may involve the interaction of multiple factors. CreT highlights an individual's expectations of his/her ability to propose innovative solutions, methods or devices through more effective exploration, elaboration, corroboration, verification and evaluation (Carbonaro et al., 2008; Kuo, Chen, & Hwang, 2014).

The results of Chai et al. (2015) and Kuo et al. (2012) offer powerful evidence that students' collaborative and self-directed learning can facilitate higher-order cognition, such as creative thinking, critical thinking, and complex problem-solving procedures. Moreover, AL is commonly advocated as a fundamental factor in MASSL practices, especially when applied in field science learning (Börner, Kalz, & Specht, 2014). Thus, this study assumed that students' perceived learning practices (i.e. AL, SDL, and CoL) and the fundamental practices of MASSL could predict and explain higher-order thinking efficacies, including APS and CreT.

This study also attempted to employ AL, SDL, CoL, APS, and CreT to account for general academic self-efficacy, which was regarded as the outcome variable in the current framework. An additional study by Sung, Hwang, Liu, and Chiu (2014) implied that an active learning process integrating SDL, AL, and CoL could positively influence students' self-efficacy in science courses. Along this line, the present study assumed that learning practices might predict academic self-efficacy.

Other studies have recorded a significant, positive connection between higher-order thinking efficacy and students' academic self-efficacy (Dunlap, 2005; Sung et al., 2010; Tierney & Farmer, 2011). It is recommended that research on science issues should be taken in the interaction of higher order thinking, learning performance, and self-efficacy (Fu & Hwang, 2018). Moreover, according to Chai et al. (2015), the 'learning practice' construct and 'higher-order thinking efficacy' construct can predict academic self-efficacy. Taking these observations together, this study hypothesised that in MASSL, learning practices (AL, SDL, and CoL) may predict higher-order thinking efficacy (APS and CreT), which may in turn associate with academic self-efficacy regarding MASSL.

Although the abovementioned studies have revealed possible links among students' perceived learning practices, higher-order thinking efficacy and their academic self-efficacy, there is still a need for exploring the interaction of the above variables. First, previous studies did not include the aforementioned pivotal common dimensions of MASSL in their entirety. Second, an available study has attempted to measure a general model predicting self-efficacy (Chai et al., 2015), while their findings have overlooked the domain specific nature of learners' self-efficacy (e.g. Britner & Pajares, 2006; Capa Aydin & Uzuntiryaki, 2009; Lin & Tsai, 2013). It is worth clarifying clearly the connections among students' perceived learning practices, higher-order thinking efficacy and their academic self-efficacy in the field of science education supported by mobile technology. In this study, a structural equation model to understand the relationship was conducted that covered diverse dimensions of mobile-assisted seamless science learning. Such findings would provide better understanding of contemporary self-efficacy theories in science education context. As mentioned earlier, it is reasonable to hypothesise that the relationship between learning practices and academic self-efficacy of MASSL may be mediated by higher-order thinking efficacy.

Hypothesis 1. A higher level of learning practices may facilitate better higher-order thinking efficacy, which may in turn contribute to a higher degree of students' academic self-efficacy of MASSL.

Hypothesis 2. A lower level of learning practices may predict less favorable higher-order thinking efficacy, which may then lead to a lower degree of academic self-efficacy of MASSL.

Methods

Participants

The study participants ($N = 312$) were 158 female (50.6%) and 154 male (49.4%) primary school students from five public schools located in Southern China. The schools had equipped all primary school students with smartphones for over one year. The students' average age was 12.2 years and their ages ranged from 12–13 years. They were all in grade six. Regarding students' socio-economic backgrounds, we selected schools from urban, suburban, and rural school districts. Each district contains two schools. Then, we randomly selected one class in the school, so we had six classes in the study. The students know how to expertly handle the smartphones for science learning. Teachers who participated in the study were ready after a series of mobile teaching training projects to develop several learning activities supported by mobile technology. In each mobile learning activity, the students learned in teams to accomplish context-based and problem-based learning tasks. They should carry out the four kind of activities mentioned above that could train their learning practices and higher-order thinking efficacy through the mobile science learning curricula. At last, teachers distributed the survey to the participants without inducements or obligations, and participants filled out the scale voluntarily.

Instruments

To direct participants to their science learning assessment and to potentially improve the validity of scales, we added qualifiers, such as 'science learning' and specified 'netbook or notebook and smartphones' as the devices for each item. Chai et al. (2015) modified the items of SDL, CoL, CreT, APS, and ASE from the survey. The compiled survey was reviewed by five experts including three educational technology experts and two science experts to comment on the survey for face validity. The descriptions of the survey dimensions are shown in Table 1.

Learning practices for MASSL

Students' perceived learning practices for MASSL were assessed using multidimensional scales with 16 items (Chai et al., 2015; Chai et al., 2016), which includes three dimensions: authentic learning (AL), self-directed learning with technology (SDL) and collaborative learning with information and communication technology (CoL). Responses were made on a 5-point Likert-type scale (1: never, 5: always). The descriptions of the survey dimensions are shown in Table 1.

(1) Authentic learning items were modified from the survey by Chai et al. (2016). For example, 'I learn things about science that are related to what happen in daily life with our smartphones.'
(2) Self-directed learning with technology explores students' perceived willingness and confidence that they actively use smartphones to manage their own science learning. For example, 'I can keep record of my own learning pace for science by using the smartphones.'

Table 1. The CFA analysis of all scales.

Construct and Questionnaire Items	Factor loadings	*t*-value
Authentic Learning (AL)		
1. I learn things about science that are related to what happen in daily life with our smartphones.	0.72	0.20***
2. I attempt to work problems related to everyday life out by using the science knowledge supported by smartphones.	0.84	34.65***
3. I collect scientific information from everyday life using my smartphones (e.g. capture photos of seed germination etc.).	0.81	30.72***
4. I can apply what I have learned in the science class to daily life with the aid of my smartphones.	0.85	39.57***
5. I achieve comprehensive understanding of the real-life science problems with the help of my smartphones.	0.80	26.10***
Self-Directed Learning with technology (SDL)		
1. I can aware more information through my smartphones to deepen my understanding of science lessons.	0.70	16.39***
2. I can use the smartphone to gather and manage the information to learn science (e.g. watch science videos and take notes etc.).	0.75	22.39***
3. I can use applications on the smartphones to understand what I have learned in science subject.	0.70	18.20***
4. I can evaluate the effectiveness of my learning results with the aid of applications on the mobile devices.	0.75	24.93***
5. I can use the smartphones to keep record of my own learning pace for science.	0.80	29.35***
6. I can use the smartphones to help me learn beyond what I am expected to learn about science in school.	0.66	17.30***
Collaborative Learning with ICT (CoL)		
1. My peers and I are able to communicate via email and social networking applications in our smartphones to acquire scientific knowledge.	0.74	22.93***
2. I can express and share my opinions with my peers about science tasks through the smartphones.	0.84	35.21***
3. My peers and I are able to contribute to each other's work about science posted online through the smartphones.	0.85	37.58***
4. I feel confidence to discuss science content with my classmates online using my smartphones.	0.84	36.67***
5. I can comment on ideas made by my peers in science class to improve our work.	0.72	19.85***
Creative Thinking confidence (CreT)		
1. I am able to generate many new ideas about a science topic.	0.73	21.99***
2. I can create different solutions for a science problem.	0.84	33.52***
3. I can suggest new ways of doing science activities.	0.83	35.50***
4. I can evaluate the usefulness of the solutions for science problems.	0.84	34.37***
5. I can often propose ideas different from my classmates.	0.76	22.41***
Authentic Problem-Solving confidence (APS)		
1. I can examine possible reasons of real-world science problems.	0.80	32.49***
2. I can learn how to devise a solution when come across real-life science problems.	0.87	47.53***
3. I can understand many challenging real-life science problems (e.g. the essential conditions of seed germination issues).	0.74	25.40***
4. I can design plans to work out real-world science problems.	0.82	35.99***
5. I can apply what I learned to propose solutions to real-life science problems.	0.83	38.12***
Academic Self-Efficacy of MASSL (ASE)		
1. I can do well in completing science assignments with the aid of my smartphones.	0.76	21.38***
2. In science classes, I can achieve good scores supported by my smartphones.	0.84	31.69***
3. I am able to deepen my understanding of the most difficult science knowledge by using smartphones.	0.77	24.27***
4. I expect to do well in my science with the aid of smartphones.	0.80	22.46***
5. I can acquire science knowledge by using my smartphones.	0.82	31.68****

***$p < .001$.

(3) Collaborative learning with ICT measures students' perceptions of the extent to which students use mobile technology to achieve better understanding or new ideas through group collaboration, interaction, or discussion. For example, 'my peers and I are able

to communicate via email or social networking applications in our smartphones to acquire scientific knowledge.'

Higher-order thinking efficacy of MASSL

Students' higher-order thinking efficacy of MASSL was modelled after the original students' Perceptions of Twenty-First-Century Thinking Process Scale (Chai et al., 2015). Higher-order thinking efficacy includes two dimensions: creative thinking confidence (CreT) and authentic problem-solving confidence (APS). Every dimension has five items, which were rated on a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). The descriptions of the survey scales were as follows:

(1) Creative thinking confidence subscale examines students' perceptions of the extent to which students devise ideas or new solutions for science problems. For instance, 'I can create different solutions for a science problem.'
(2) Authentic problem-solving confidence subscale accesses students' perceived ability to solve science problems with real-world contexts in their science course. For instance, 'I can examine possible reasons for real-world science problems.'

Academic self-efficacy of MASSL (ASE)

Students' academic self-efficacy of MASSL was assessed using mobile technology (smartphones, etc.) to help students master science knowledge or form new ideas. The ASE scales was modelled after the self-efficacy questionnaire of the developed by Wong, Chai, Chen, and Chin (2013). The 5-item ASE anchored on a 5-point Likert scale at 5 (strongly agree) and 1(strongly disagree), which measured students' self-confidence in academic achievements in the subject of science learning supported by mobile technology. For example, 'I can do well in completing science assignments with the aid of my smartphones.'

Data analysis

SPSS 23.0 was used in our study to conduct descriptive statistics, correlation analyses, and reliability analyses. The results of the Kolmogorov-Smirnov test indicated that the data was not normally distributed, so the data was analysed by the maximum likelihood estimation with robust standard errors (MLR) following Muthén and Muthén (2012). The validation of each scale's structure was performed by confirmatory factor analysis (CFA) via Mplus 7.4 in this study. Model fit was assessed using multiple indicators: (a) Tucker-Lewis Index (TLI); (b) Comparative Fit Index (CFI); and (c) the standardised root mean square residuals (SRMR). Based on the recommendations of Marsh, Hau, and Wen (2004), a CFI of at least 0.90, a TLI of at least 0.90, and an SRMR < 0.08, together, would suggest a good fit between the hypothesised model and the data. Moreover, since this research also aimed to examine the relations among the perceived learning practices and associated self-efficacies of MASSL, a correlation analysis and mediating effect analysis with bootstrap method were conducted of learning practices, higher-order thinking efficacy, and academic self-efficacy of MASSL. As described previously, this study viewed the students' SDL, CoL, and AL as the predictors to explain those higher-order thinking efficacies (CreT and APS) and academic self-efficacy of MASSL (ASE).

Results

Validation of the instruments

To validate the questionnaires on the students' perceived learning practices and associated self-efficacies of MASSL, we first tested the factorial structure of each scale via CFA. The measurement model of learning practices for MASSL consisted of three latent factors (AL, SDL, and CoL) and 16 observed variables. For higher-order thinking efficacy of MASSL, the full measurement model was also tested for construct validity of two factors (CreT and APS), and each factor had 5 indexes. The measurement model of ASE had one factor with 5 items. The findings showed that all the scales exhibited acceptable fit indices (Table 2) with acceptable factor loadings.

CFA was performed by using the sample of 312 cases. In the process of performing CFA, the final version of MASSL was produced in the present study with a total of 31 items. Through the SEM analysis via Mplus 7.4, the results of the fit measures for the students' perceived learning practices and associated self-efficacies of MASSL (see Table 2) in the present study indicated a satisfactory fit and confirmed the structures (Jöreskog & Sörbom, 1993).

Students' scores on the scales of MASSL

The results of the descriptive statistics and correlation analyses of all study variables are shown in Table 3.

The correlations among students' perceived learning practices of MASSL

The correlations among students' learning practices, higher-order thinking efficacy thinking efficacy, and academic self-efficacy of MASSL were all positive and statistically significant at the $p < .001$ level (see Table 3). Coefficient alpha is reported along the diagonal. In this study, Coefficient alpha for each scale was larger than 0.88.

The relationships among students' perceived learning practices and associated self-efficacies of MASSL

This study conducted a structural equation model analysis to assess the contributions of learning practices (i.e. AL, CoL, and SDL), and thinking efficacy (i.e. CreT and APS) to academic self-efficacy of MASSL, respectively. Specifically, ASE can be predicted by AL

Table 2. Fit measures for the structural model of students' perceptions of mobile-assisted seamless science learning.

Fit index	Research model	Recommended value
χ^2	327.168	–
df	183	–
Chi-square per degree of freedom	1.72	<5
RMSEA	0.05	≦0.08
NFI	0.94	≧0.90
CFI	0.96	≧0.90
IFI	0.96	≧0.90
TLI	0.96	≧0.90
SRMR	0.04	<0.5

Table 3. Means, standard deviations, and correlations (Coefficient alpha).

	M	*SD*	1	2	3	4	5	6	7	8
1.AL	3.44	1.06	**(.90)**							
2.SDL	3.42	.96	.71***	**(.87)**						
3.CoL	3.15	1.16	.69***	.77***	**(.90)**					
4. LPM	3.31	.94	.89***	.90***	.87***	**(.96)**				
5.CreT	3.56	.98	.58***	.61***	.56***	.65***	**(.90)**			
6.APS	3.54	.99	.64***	.59***	.49***	.65***	.76***	**(.91)**		
7. HTE	3.56	.90	.66***	.65***	.57***	.70***	.93***	.92***	**(.95)**	
8.ASE	3.53	1.00	.69***	.69***	.63***	.75***	.67***	.70***	.72***	**(.90)**

AL, Authentic Learning; SDL, Self-Directed Learning with technology; CoL, Collaborative Learning with ICT; LPM, Learning Practices for MASSL; CreT, Creative Thinking confidence; APS, Authentic Problem-Solving confidence; HTE, Higher-order Thinking Efficacy of MASSL; ASE, Academic Self-Efficacy of MASSL. Off diagonals are the coefficient alpha value of the constructs.

***$p < .001$.

($\beta = 0.22$, $p < .05$), SDL($\beta = 0.34$, $p < .001$), and APS ($\beta = 0.38$, $p < .05$). These findings indicate that SDL, compared to APS, is a more pivotal predictor of ASE. However, when using AL, CoL, SDL, CreT, and APS together to predict ASE, only AL, SDL, and APS were revealed to be significant indicators to ASE. CoL and CreT did not show any significant mediating effects on higher-order thinking efficacy and ASE.

A two-step procedure was followed to test the mediation effect (see Tables 4 and 5). In step 1, direct effect was examined. The direct path coefficients from students' AL and SDL to ASE in the absence of mediator was significant (c1 = 0.40, $p < .001$; c2 = 0.45, $p < .001$). In step 2, the structural model with mediation variable APS was tested. The mediating effects were significant (a*b1 = 0.18, $p < .01$; a*b2 = 0.11, $p < .05$). With the mediator in the model, as expected, the coefficient for the direct relationship between students' AL and SDL on ASE dropped, but it remained statistically significant (c'1 = 0.22, $p < .05$; c'2 = 0.34, $p < .001$). Based on these results above, we constructed the mediation model portrayed in Figure 3, which may further indicate that higher-order thinking efficacy can function as a partial mediation variable in the effect of students' learning practices on academic self-efficacy of MASSL. Furthermore, the size of the mediating effect of students' APS was 0.18 and 0.11, which accounted for 43.99% and 24.56% of the total effects. Thus, students' perceived learning practices played positive roles in higher-order thinking efficacy, which in turn contributed to the enhancement of academic self-efficacy of MASSL.

Discussion and conclusion

In order to provide a measurement for educators to examine their MASSL activities or approaches for improving students' higher-order thinking efficacy and self-efficacy, a

Table 4. The Mediation effect of APS.

	Academic Self-Efficacy of MASSL	
Variables	M1a	M1b
AL	0.40***(0.11)	0.22*(0.11)
SDL	0.45* (0.11)	0.34*** (0.09)
APS		0.38*** (0.08)

AL, Authentic Learning; SDL, Self-Directed Learning with technology; APS, Authentic Problem-Solving confidence; ASE, Academic Self-Efficacy of MASSL.

*$p < .05$; ***$p < .001$

Table 5. Bootstrap analyses of the magnitude and statistical significance of indirect effects.

Rountie	a*b	95%CI	Mediate effect
AL-APS-ASE	0.18**	(0.06, 0.30)	43.99%
SDL-APS-ASE	0.11*	(0.01, 0.22)	24.56%

AL, Authentic Learning; SDL, Self-Directed Learning with technology; APS, Authentic Problem-Solving confidence; ASE, Academic Self-Efficacy of MASSL.
$*p < .05$; $**p < .01$.

MASSL questionnaire was developed in this study. According to the confirmatory factor analysis, three dimensions of the students' learning practices in MASSL (CoL, AL, and SDL) and two dimensions of the students' higher-order thinking efficacy (i.e. CreT and APS) were included. Furthermore, CFA performed by SEM was conducted, the fit measures for the model of the students' perceived learning practices and associated self-efficacies of MASSL showed highly acceptable fits.

A major finding of this study was that, compared to APS and AL, SDL was found to be a more significant contributor to ASE. More importantly, the finding confirmed that APS might be a partial mediator for the effects of learning practices on ASE. Students' confidence in authentic problem-solving could be considered an important mediator between their mobile learning practices and ASE. This result signifies that when increasing opportunities for cultivating students' self-efficacy, educators should encourage the students to engage in more authentic problem-solving in learning practices for MASSL. The results are, to some extent, in line with those of Chai et al. (2015), which demonstrated that students' perceived creative thinking and problem solving can account for more variance in their knowledge creation efficacy when compared to their perceptions about the learning processes (SDL, CoL). During the authentic problem-solving process, the students could experience more conflict or vital cognition, or epistemic science concept

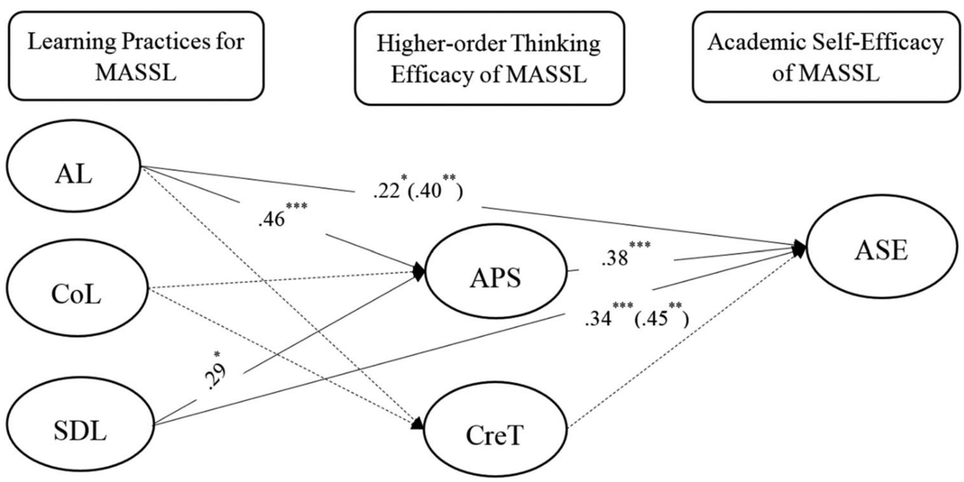

Figure 3. The structural equation model of students' perceived learning practices and associated self-efficacies of MASSL. $*p < .05$; $***p < .001$. The solid lines represent significant relationships while dotted lines represent insignificant relationships. The number in bracket express direct effect. AL, Authentic Learning; SDL, Self-Directed Learning with technology; CoL, Collaborative Learning with ICT; CreT, Creative Thinking confidence; APS, Authentic Problem-Solving confidence; ASE, Academic Self-Efficacy of MASSL.

change, which could stimulate self-reflection, control, motivation, and deep thinking about knowledge building (Carbonaro, Szafron, Cutumisu, & Schaeffer, 2010; Cheung & Lau, 2013; Gu et al., 2015). Besides, our study has confirmed that teachers could use various tools to consider self-directed learning and a stable authentic situation together in mobile science learning, which can take advantage of mobile technology (e.g. AR in this study) to link science concepts with the real world or everyday life for everyday applications (Lai & Hwang, 2015), as well as facilitate the learners' access to available information to manage their own science learning. Teachers could develop and implement scientific activities which suit the different characteristics of learning content to promote students' learning practices for MASSL, so as to help students solve their learning problems effectively and with creative thinking (Luo, Koszalka, Arnone, & Choi, 2018). Moreover, this finding is similar to previous findings (Chen, Hwang, & Tsai, 2014). According to their study, learners who were more self-directed in AL activities, as shown by a progressive prompt-based strategy, showed beneficial effects on their learning of natural science.

According to the derived path analysis of SEM, the students' conception of self-directed learning could play an important role in cultivating their creativity and complex problem-solving efficacies in mobile learning environments. The positive prediction of 'self-directed learning' on the higher-order thinking efficacy reveals that the more self-directed learning the students experienced in the science learning activity, the more opportunities of higher-order thinking efficacy they engaged in. This echoes the findings of several previous studies that engaging students in self-directed learning is likely to stimulate their higher-order thinking (Falloon & Khoo, 2014; Pilkington & Sanders, 2014; Sánchez & Olivares, 2011). Moreover, the positive prediction of 'AL' on 'APS' indicates the importance of providing the authenticity the students need (e.g. related to ones' daily life, situated in the real world) at the right time and in the right place, which could improve students' higher-order thinking in mobile-based learning environments (Hsu, Hwang, & Chang, 2013).

However, according to the SEM analysis result, CoL and CreT did not show any significant effects on ASE. Similar to Luo et al.'s (2018) study, this study further supports the idea that AL and SDL predicted ASE both directly and indirectly, while CreT and CoL may have an insignificant relationship with ASE. In some instances, greater communication and interactions occurred during the scientific learning process of primary school students via smartphones, which might have distracted them, instead of effective CoL. Since pupils are accustomed to learning under the guidance of their teachers, cooperating with each other through smartphones might increase their cognitive load. All of these factors may lead to the situation that CoL has no significant relationship with APS and ASE. Teachers should provide some support via mobile technology to help them reduce cognitive load by focusing on in-depth collaborations and communications in science learning practices (Chang et al., 2018; Harley et al., 2016). CreT has no significant effect on ASE, which may be due to the major efforts made to accomplish scientific learning problems or tasks in students' learning practices of MASSL. However, CreT comes from the discussions and in-depth exchanges with teachers and students, and is developed gradually in the process to verify scientific hypotheses in context (Tierney & Farmer, 2011). While the gap between the creative thinking visions is shrinking, students' perceptions of CreT still has no significant effect on ASE.

Overall, the provision of authentic learning and the students' perceived self-directed learning could be the most critical aspect of students' higher-order thinking efficacy in MASSL. Higher-order thinking efficacy can function as a partial mediation variable in the explanation of students' learning practices on academic self-efficacy of MASSL. With regular and effective authentic learning and self-directed learning activities, the students could foster their efficacy in complex problem-solving, which in turn explains academic self-efficacy of MASSL. The structural relationship of these findings identifies the benefits of considering both students' perceived learning practices and higher-order thinking efficacy when designing mobile science learning activities, so as to form a complete and systematic mobile science learning activity. It provides an available approach that teachers should not only pay attention to students' learning practices; they should also guide students' higher-order thinking processes at the same time. Such designs can also contribute much to students' higher-order thinking efficacy, which is a positive contributor to students' academic self-efficacy to facilitate science learning in mobile environment. For example, teachers could employ situational learning methods (such as outdoor teaching that incorporates AR technology with location-based and inquiry approaches) when planning scientific observation and experimental inquiry activities, and can supplement these activities with access to relevant resources via mobile devices, thus combining theory and practice. Employing these strategies, we can guide students to look critically at scientific problems and knowledge and push them to solve problems objectively and creatively.

The present findings may have potential contributions and implications for conducting proper mobile science learning activities for students to train their higher-order thinking efficacy and academic self-efficacy, the following aspects should be considered:

(1) The result of the mediation effect further strengthens our confidence that the learning practices for MASSL (SDL and AL) should be coupled with much attention to and direction of students' thinking efficacy (APS) to improve academic self-efficacy in the MASSL environment. Problem-based or issue-based pedagogical strategies are useful to promote learners' self-efficacy in mobile science learning. The result indicated that learning practices and higher-order thinking efficacy are both important for improving students' ASE of MASSL. In other words, teachers should pay attention to students' MASSL learning practices when designing problem-based science learning activities in the MASSL environment. Teachers could use various tools to lead SDL and AL and could develop scientific activities that suit the different characteristics of learning content to promote students' learning practices for MASSL. For instance, when planning around concepts that require or employ theoretical science knowledge, teachers could facilitate student-to-student interaction by using mobile technology to encourage SDL. Both in the process of scientific observation and through self-inquiry students could improve the quality of the cognitive process of scientific learning with their teachers' guidance (Hwang, Yang, Tsai, & Yang, 2009).

(2) This study aimed to gain an initial understanding of primary school students' preferences in MASSL environments. As mentioned above, higher-order thinking efficacy and academic self-efficacy was predicted by learning practices, implying that the most salient pedagogical strength of smartphones is that they facilitate scientific concepts and perpetual learning experiences that bridge the real-world environment and cyberspace (Pachler, 2010). When increasing opportunities for

developing primary school students' self-efficacy, educators should support all technical (i.e. multifunctional of mobile technology), content (i.e. access to authentic learning resource or information), and cognitive (i.e. SDL and CoL) aspects of scientific learning.

(3) The SEM analysis findings imply that developing primary school students' academic self-efficacy is difficult and quite complicated in MASSL environments. It is important for educators to pay great attention to facilitating higher-order thinking efficacy in mobile science learning practices. Through frequent higher-order thinking practices, students could have a greater chance of success in academic self-efficacy of a more in-depth level of thinking efficacy. Lin, Hu, Hu, and Liu (2016) revealed that the use of new technologies to create a deep interactive atmosphere can stimulate students to innovate and collaborate in the production of visual work in a timely manner, thus emphasising and improving student collaboration.

In conclusion, an initial exploration of students' learning practices, higher-order thinking efficacy, and academic self-efficacy in a mobile-assisted science learning environment was undertaken. However, there are some limitations and suggestions to consider in future studies. First, the SEM model in this study only consists of several learning aspects of environmental learning practices and several core efficacies. The involvement of more aspects of learning practices or variables of students' efficacies are encouraged for future explorations. A second limitation is that this study was conducted through a self-report survey. We suggest that future students discuss or examine the relationship between students' perceived science learning practices via the use of mobile devices as means of data collection (as in Zacharia, Lazaridou, & Avraamidou, 2016) and their self-efficacy regarding those practices through structural equation modelling. Future research could perhaps investigate the relationship between data from mobile phone applications and the type of efficacy they promote by examining students' perceptions of MASSL.

Acknowledgements

This study was funded by the Education Planning Project of Guangdong Province [grant number 2018GXJK025]. The authors express their gratitude to the anonymous reviewers and editors for their helpful comments about this paper.

Disclosure statement

The authors declare no conflict of interest. All procedures involving human participants were performed in accordance with the ethical standards of the institutional and national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Funding

This study was funded by The Major Project of National Social Science Fund of China [grant number 18ZDA334], Education Planning Project of Guangdong Province [grant number 2018GXJK025], and Guangdong province fund project for scientific and technological innovation and cultivation "Research on the Mode of Improving the Core Quality of Innovative Talents for the Guangdong-Hong Hong-Macao Greater Bay Area" [grant number pdjha0130].

ORCID

Xiao-Fan Lin http://orcid.org/0000-0002-4544-0849
Zhong-Mei Liang http://orcid.org/0000-0001-7969-0793
Chin-Chung Tsai http://orcid.org/0000-0001-7744-9971

References

Akcaoglu, M., & Koehler, M. J. (2014). Cognitive outcomes from the Game-Design and Learning (GDL) after-school program. *Computers & Education*, *75*, 72–81.

Areepattamannil, S., Freeman, J. G., & Klinger, D. A. (2011). Influence of motivation, self-beliefs, and instructional practices on science achievement of adolescents in Canada. *Social Psychology of Education*, *14*, 233–259.

Bandura, A. (1996). Multifaced impact of self-efficacy beliefs on academic functioning. *Child Development*, *67*, 1206–1222.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Barak, M., Ashkar, T., & Dori, Y. J. (2011). Learning science via animated movies: Its effect on students' thinking and motivation. *Computers & Education*, *56*, 839–846.

Bonsignore, E., Quinn, A. J., Druin, A., & Bederson, B. B. (2013). Sharing stories "in the Wild": A mobile storytelling case study using storykit. *Acm Transactions on Computer-Human Interaction*, *20*(3), 1–38.

Börner, D., Kalz, M., & Specht, M. (2014). Lead me gently: Facilitating knowledge gain through attention-aware ambient learning displays. *Computers & Education*, *78*, 10–19.

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching*, *43*, 485–499.

Burden, K., & Kearney, M. (2016). Future scenarios for mobile science learning. *Research in Science Education*, *46*(2), 287–308.

Capa Aydin, Y., & Uzuntiryaki, E. (2009). Development and psychometric evaluation of the high school chemistry self-efficacy scale. *Educational and Psychological Measurement*, *69*, 868–880.

Carbonaro, M., Cutumisu, M., Duff, H., Gillis, S., Onuczko, C., Siegel, J., & Waugh, K. (2008). Interactive story authoring: A viable form of creative expression for the classroom. *Computers & Education*, *51*(2), 687–707.

Carbonaro, M., Szafron, D., Cutumisu, M., & Schaeffer, J. (2010). Computer-game construction: A gender-neutral attractor to Computing science. *Computers & Education*, *55*(3), 1098–1111.

Chai, C. S., Deng, F., Tsai, P.-S., Koh, J. H. L., & Tsai, C.-C. (2015). Assessing multidimensional students' perceptions of twenty-first-century learning practices. *Asia Pacific Education Review*, *16*(3), 389–398.

Chai, C. S., Wong, L. H., & King, R. B. (2016). Surveying and modeling students' motivation and learning strategies for mobile-assisted seamless Chinese language learning. *Journal of Educational Technology & Society*, *19*(3), 170–180.

Chang, C. S., Chen, T. S., & Hsu, W. H. (2011). The study on integrating WebQuest with mobile learning for environmental education. *Computers & Education*, *57*(1), 1228–1239.

Chang, H.-Y., Hsu, Y.-S., Wu, H.-K., & Tsai, C.-C. (2018). Students' development of socio-scientific reasoning in a mobile augmented reality learning environment. *International Journal of Science Education*, *40*(12), 1410–1431.

Chen, C. H., Hwang, G. J., & Tsai, C. H. (2014). A progressive prompting approach to conducting context-aware learning activities for natural science courses. *Interacting with Computers*, *26*(4), 348–359.

Cheung, P. C., & Lau, S. (2013). A tale of two generations: Creativity growth and gender differences over a period of education and curriculum reforms. *Creativity Research Journal*, *25*(4), 463–471.

Chu, R. J., Chu, A. Z., Weng, C., Tsai, C. C., & Lin, C.-C. (2012). Transformation for adults in an Internet-based learning environment-is it necessary to be self-directed? *British Journal of Educational Technology*, *43*(2), 205–216.

Chu, H. C., Hwang, G. J., Tsai, C. C., & Tseng, J. C. R. (2010). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Computers & Education*, *55*(4), 1618–1627.

Crompton, H., Burke, D., Gregory, K. H., & Grabe, C. (2016). The use of mobile learning in science: A systematic review. *Journal of Science Education and Technology*, *25*(2), 149–160.

Delen, I., & Krajcik, J. (2015). What do students' Explanations look like when they use second-hand data? *International Journal of Science Education*, *37*(12), 1953–1973.

Dunlap, J. C. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Development*, *53*(1), 65–83.

Falloon, G., & Khoo, E. (2014). Exploring young students' talk in iPad-supported collaborative learning environments. *Computers & Education*, *77*, 13–28.

Farmer, J. L., Leonard, A. E., Spearman, M., Qian, M., & Rosenblith, S. (2016). Picturing a classroom community: Student drawings as a pedagogical tool to assess features of community in the classroom. *Action in Teacher Education*, *38*(4), 299–314.

Fu, Q.-K., & Hwang, G.-J. (2018). Trends in mobile technology-supported collaborative learning: A systematic review of journal publications from 2007 to 2016. *Computers & Education*, *119*, 129–143.

Gu, X., Chen, S., Zhu, W., & Lin, L. (2015). An intervention framework designed to develop the collaborative problem-solving skills of primary school students. *Educational Technology Research and Development*, *63*(1), 143–159.

Harley, J. M., Poitras, E. G., Jarrell, A., Duffy, M. C., & Lajoie, S. P. (2016). Comparing virtual and location-based augmented reality mobile learning: Emotions and learning outcomes. *Educational Technology Research and Development*, *64*(3), 359–388.

Howland, J. L., Jonassen, D. H., & Marra, R. M. (2012). *Meaningful learning with technology* (4th ed.). Boston, MA: Allyn & Bacon.

Hsi, S. (2007). Conceptualizing learning from the everyday activities of digital kids. *International Journal of Science Education*, *29*(12), 1509–1529.

Hsu, C. K., Hwang, G. J., & Chang, C. K. (2013). A personalized recommendation-based mobile learning approach to improving the reading performance of EFL students. *Computers & Education*, *63*, 327–336.

Hung, C. M., Hwang, G. J., & Huang, I. (2012). A project-based digital storytelling approach for improving students' learning motivation, problem-solving competence and learning achievement. *Educational Technology & Society*, *15*(4), 368–379.

Hwang, G. J., Tsai, C. C., Chu, H. C., Kinshuk, K., & Chen, C. Y. (2012). A context-aware ubiquitous learning approach to conducting scientific inquiry activities in a science park. *Australasian Journal of Educational Technology*, *28*(5), 931–947.

Hwang, G. J., Wu, P. H., & Ke, H. R. (2011). An interactive concept map approach to supporting mobile learning activities for natural science courses. *Computers & Education*, *57*(4), 2272–2280.

Hwang, G. J., Yang, T. C., Tsai, C. C., & Yang, S. J. H. (2009). A context-aware ubiquitous learning environment for conducting complex science experiments. *Computers & Education*, *53*(2), 402–413.

Jöreskog, K. G., & Sörbom, D. (1993). *LISREL 8: Structural equation modeling with the SIMPLIS command language*. Lincolnwood, IL: Scientific Software International.

Kim, P., Suh, E., & Song, D. (2015). Development of a design-based learning curriculum through design-based research for a technology-enabled science classroom. *Educational Technology Research and Development*, *63*(4), 575–602.

Kıran, D., & Sungur, S. (2011). Middle school students' science self-efficacy and its sources: Examination of gender difference. *Journal of Science Education and Technology*, *21*, 619–630.

Kuo, F. R., Chen, N. S., & Hwang, G. J. (2014). A creative thinking approach to enhancing the web-based problem solving performance of university students. *Computers & Education*, *72*, 220–230.

Kuo, F. R., Hwang, G. J., & Lee, C. C. (2012). A hybrid approach to promoting students' web-based problem-solving competence and learning attitude. *Computers & Education*, *58*(1), 351–364.

Kupermintz, H. (2002). Affective and conative factors as aptitude resources in high school science achievement. *Educational Assessment*, *8*, 123–137.

Lai, C. L., & Hwang, G. J. (2015). High school teachers' perspectives on applying different mobile learning strategies to science courses: The national mobile learning program in Taiwan. *International Journal of Mobile Learning and Organisation*, *9*(2), 124–145.
Lai, C.-L., Hwang, G.-J., & Tu, Y.-H. (2018). The effects of computer-supported self-regulation in science inquiry on learning outcomes, learning processes, and self-efficacy. *Educational Technology Research and Development*, *66*(4), 863–892.
Lau, S., & Roeser, R. W. (2002). Cognitive abilities and motivational processes in high school students' situational engagement and achievement in science. *Educational Assessment*, *8*, 139–162.
Lazakidou, G., & Retalis, S. (2010). Using computer supported collaborative learning strategies for helping students acquire self-regulated problem-solving skills in mathematics. *Computers & Education*, *54*(1), 3–13.
Lin, X.-F., Deng, C., Hu, Q., & Tsai, C. -C. (2019). Chinese undergraduate students' perceptions of mobile learning: Conceptions, learning profiles, and approaches. *Journal of Computer Assisted Learning*, *35*(3), 317–333.
Lin, X.-F., Hu, X., Hu, Q., & Liu, Z. (2016). A social network analysis of teaching and research collaboration in a teachers' virtual learning community. *British Journal of Educational Technology*, *47*(2), 302–319.
Lin, X.-F., Liang, J.-C., Tsai, C.-C., & Hu, Q. (2018). The moderating role of self-regulated learning in job characteristics and attitudes towards web-based continuing learning in the airlines workplace. *Australasian Journal of Educational Technology*, *34*(1), 102–115.
Lin, T. J., & Tsai, C. C. (2013). A multi-dimensional instrument for evaluating Taiwanese high school students' science learning self-efficacy in relation to their approaches to learning science. *International Journal of Science and Mathe-Matics Education*, *11*(6), 1275–1301.
Looi, C.-K., Sun, D., Kim, M. S., & Wen, Y. (2018). The impact of a professional development model for a mobilized science curriculum: A case study of teacher changes. *Research in Science & Technological Education*, *36*(1), 86–110.
Luo, H., Koszalka, T. A., Arnone, M. P., & Choi, I. (2018). Applying case-based method in designing self-directed online instruction: A formative research study. *Educational Technology Research and Development*, *66*(2), 515–544.
Manathunga, K., & Hernández-Leo, D. (2018). Authoring and enactment of mobile pyramid-based collaborative learning activities. *British Journal of Educational Technology*, *49*(2), 262–275.
Marsh, H. W., Hau, K. T., & Wen, Z. (2004). In search of golden rules: Comment on hypothesis-testing approaches to setting cutoff values for fit indexes and dangers in overgeneralizing Hu & Bentley's (1999) findings. *Structural Equation Modeling: A Multidisciplinary Journal*, *11*(3), 320–341.
Muthén, L. K., & Muthén, B. O. (2012). *Mplus user's guide* (7th ed.). Los Angeles, CA: Muthén & Muthén.
Osman, G., Duffy, T. M., Chang, J. Y., & Lee, J. (2011). Learning through collaboration: Student perspectives. *Asia Pacific Education Review*, *12*(4), 547–558.
Pachler, N. (2010). The socio-cultural ecological approach to mobile learning: An overview. In B. Bachmair (Ed.), *Medienbildung in neuen Kulturräumen* (pp. 153–167). Wiesbaden: VS Verlag für Sozialwissenschaften.
Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, *66*(4), 543–578.
Pantiwati, Y. (2013). Authentic assessment for improving cognitive skill, critical-creative thinking and meta-cognitive awareness. *Journal of Education and Practice*, *4*(14), 1–9.
Pilkington, C., & Sanders, I. (2014). An online collaborative document creation exercise in an ODL research project module. *Computers & Education*, *77*, 116–124.
Qian, M., & Clark, K. R. (2016). Game-based learning and 21st century skills: A review of recent research. *Computers in Human Behavior*, *63*, 50–58.
Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-century skills requires 21st-century teaching. *Phi Delta Kappan*, *94*(2), 8–13.
Sánchez, J., & Olivares, R. (2011). Problem solving and collaboration using mobile serious games. *Computers & Education*, *57*(3), 1943–1952.

Sharples, M., Taylor, J., & Vavoula, G. (2010). A theory of learning for the mobile age: Learning through conversation and exploration across contexts. In B. Bachmair (Ed.), *Medienbildung in neuen Kulturräumen: die deutschprachige und britische Diskussion* (pp. 87–99). Wiesbaden: VS Verlag für Sozialwissenschaften.

Song, Y. (2018). Improving primary students' collaborative problem solving competency in project-based science learning with productive failure instructional design in a seamless learning environment. *Educational Technology Research and Development*, *66*(4), 979–1008.

Sun, D., & Looi, C.-K. (2018). Boundary interaction: Towards developing a mobile technology-enabled science curriculum to integrate learning in the informal spaces. *British Journal of Educational Technology*, *49*(3), 505–515.

Sung, Y. T., Hou, H. T., Liu, C. K., & Chang, K. E. (2010). Mobile guide system using problem-solving strategy for museum learning: A sequential learning behavioral pattern analysis. *Journal of Computer Assisted Learning*, *26*(2), 106–115.

Sung, H. Y., Hwang, G. J., Liu, S. Y., & Chiu, I. H. (2014). A prompt-based annotation approach to conducting mobile learning activities for architecture design courses. *Computers & Education*, *76*, 80–90.

Teo, T., Tan, S. C., Lee, C. B., Chai, C. S., Koh, J. H. L., Chen, W. L., & Cheah, H. M. (2010). The self-directed learning with technology scale (SDLTS) for young students: An initial development and validation. *Computers & Education*, *55*(4), 1764–1771.

Tierney, P., & Farmer, S. M. (2011). Creative self-efficacy development and creative performance over time. *Journal of Applied Psychology*, *96*(2), 277–293.

Uzuntiryaki, E., & Capa Aydin, Y. (2009). Development and validation of chemistry self-efficacy scale for college student. *Research in Science Education*, *39*, 539–551.

Vinu, P. V., Sherimon, P. C., & Krishnan, R. (2011). Towards pervasive mobile learning–the vision of 21st century. *Procedia-Social and Behavioral Sciences*, *15*, 3067–3073.

Wang, S. L., & Lin, S. S. J. (2007). The application of social cognitive theory to web-based learning through NetPorts. *British Journal of Educational Technology*, *38*(4), 600–612.

Wells, G. (2006). Dialogue in the classroom. *The Journal of the Learning Sciences*, *15*(3), 379–428.

Wong, L. H., Chai, C. S., Chen, W., & Chin, C. K. (2013). Measuring singaporean students' motivation and strategies of bilingual learning. *The Asia-Pacific Education Researcher*, *22*(3), 263–272.

Wu, C. H., Hwang, G. J., Kuo, F. R., & Huang, I. (2013). A mindtool-based collaborative learning approach to enhancing students' innovative performance in management courses. *Australasian Journal of Educational Technology*, *29*(1), 128–142.

Wu, W.-H., Jim Wu, Y.-C., Chen, C.-Y., Kao, H.-Y., Lin, C.-H., & Huang, S.-H. (2012). Review of trends from mobile learning studies: A meta-analysis. *Computers & Education*, *59*(2), 817–827.

Zacharia, Z. C., Lazaridou, C., & Avraamidou, L. (2016). The use of mobile devices as means of data collection in supporting elementary school students' conceptual understanding about plants. *International Journal of Science Education*, *38*(4), 596–620.

Zeldin, A. L., & Pajares, F. (2000). Against the odds: Self-efficacy beliefs of women in mathematical, scientific, and technological careers. *American Educational Research Journal*, *37*, 215–246.