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RESEARCH ARTICLE

A long-term experiment to investigate the relationships between high school students' perceptions of mobile learning and peer interaction and higher-order thinking tendencies

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Abstract In this study, a one-year program was conducted to investigate the relationships between students' perceptions of mobile learning and their tendencies of peer interaction and higher-order thinking in issue-based mobile learning activities. To achieve the research objective, a survey consisting of eight scales, namely, usability, continuity, adaptive content, collaboration, communication, problem-solving, critical thinking and creativity, was developed. A total of 658 students from 38 high schools in Taiwan filled in the questionnaire after experiencing issue-based mobile learning activities. From the exploratory and confirmatory factor analyses, it was found that the questionnaire had high reliability and validity. The structural equation model further revealed that the provision of adaptive content in the mobile learning had positive impacts on the students' tendency to interact with peers (i.e., collaboration and communication), which further affected their tendency to engage in higher-order thinking (i.e., problem-solving, critical thinking, and

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creativity). The findings of this study provide a good reference for researchers and school teachers who intend to promote mobile learning in school settings.

Keywords Mobile learning · Higher-order thinking skills · Structural equation model · Continuity · Adaptive content

Introduction

Following the advancements in information technology, the educational mode has shifted from teacher-centered to student-centered learning (Al-Samarraie et al. 2013). In a student-centered learning environment, learning is regarded as a knowledge constructing process whereby students are able to acquire, reorganize, and apply knowledge to analyze and solve problems (González-Marcos et al. 2016). With the rapid advancement and popularity of mobile technology, researchers have further indicated the potential of mobile devices in enabling students to link what they have learned to real-world contents; that is, using mobile technology to support learning could be an effective learning mode for facilitating student-centered learning (Chang et al. 2011). Researchers have called the learning mode that employs mobile technology to facilitate or support learning "mobile learning" (m-learning).

Mobile learning refers to a learning context in which learners utilize their individual portable devices to access a mobile network to conduct their learning, whether in or out of the classroom (Song 2014). This approach provides more opportunities and flexibility for learners to engage in self-directed and collaborative learning (Swallow 2015). Due to the potential of mobile learning, the issue of cultivating students' cognitive abilities has been recognized by researchers (Kong and Song 2014; Lai and Wu 2012). For instance, Mouza and Barrett-Greenly (2015) incorporated mobile devices into the school settings of several low-income underserved schools, and found that the approach empowered the students' academic performance. Several studies have further signified the positive impacts of incorporating mobile technologies into school curriculums on students' higher-order thinking performances, such as their problem-solving, critical thinking and creativity (Kim et al. 2015; Kong and Song 2014). For example, (Toh et al. 2013) indicated that the merits of using handheld devices and wireless networks for accessing required information could facilitate students' problem-solving and critical thinking performances. The studies of (Boyce et al. 2014) and (Kim et al. 2014) also revealed that using mobile technology to access supplementary materials in the field not only enabled students to apply what they had learned to problems in real-world contexts, but also fostered their higher-order thinking skills such as critical thinking and creativity.

As a consequence, several countries, such as Singapore, Thailand and Taiwan, have put a great deal of effort into implementing mobile learning in school settings to improve students' higher-order thinking (Looi et al. 2014; Ozdamli and Uzunboylu 2014). For instance, in Taiwan, a nation-wide mobile learning promotion program aimed at improving the higher order thinking of high school students was initiated in 2013. It encouraged students to learn by utilizing their personal devices, and was aimed specifically at learning in mainstream education settings. However, few studies have examined how students perceive the impacts of mobile learning environments on their higher-order thinking, such as problem-solving, critical thinking, and creativity. In order to avoid pedagogical pitfalls and to develop mobile learning activities for effectively engaging students in higher-order thinking activities, educators and teachers need to understand students' perceptions of the learning activities or environments in which they are situated (Zhu 2013). Therefore, the purpose of this study was to investigate the relationship between the perceptions of mobile learning and the tendency of the students who participated in a long-term mobile learning program to engage in higher order thinking.

Literature review

Interaction and higher order thinking competences

Due to the trend of globalization, several competences are regarded as key elements in empowering people's technology literacy and competitiveness (Kong et al. 2014; Bellanca and Brandt 2010). In the educational field, the Partnership for 21st Century Skills (2009) first proposed that learning and innovation skills have been recognized as the skills that students must prepare for the increasingly complex life and working environments they will face. They also classified the skills of communication, collaboration, critical thinking, problem solving, and creativity as being essential to prepare students for their future.

On the other hand, several governmental organizations have successively pointed out the need to incorporate higher order thinking competences training into classrooms (The Ministry of Education in Singapore 2010; The U.S. Department of Education 2012). In Taiwan, several strategies and indicators for fostering and evaluating students' interaction and higher order thinking have been proposed, including collaboration (Chuang et al. 2012), communication (Lan et al. 2012), problem-solving (Hwang et al. 2014), critical thinking (Yang et al. 2014), and creativity (Chuang et al. 2012; Chen and Chiu 2016). In summary, cultivating students' interaction and higher order thinking competences is regarded as an important issue and a critical educational policy in many countries (Kong et al. 2014; Washor et al. 2013). Moreover, it is urgent for schools to develop teaching plans to help students develop these competences (Looi et al. 2011).

Collaboration is an important strategy that engages students in interacting with their peers to share their perspectives and ideas for achieving learning goals or completing learning tasks (Osman et al. 2011; Morrison et al. 2009). Communication refers to the ability that "articulates thoughts and ideas effectively by using oral, written and nonverbal communication skills in a variety of forms and contexts" (Frazier and Reynolds 2012, p. 10). Problem solving refers to the abilities of identifying problems, collecting and analyzing relevant information, proposing possible solutions, and choosing the most effective solution for dealing with the problem (Wang and Chiew 2010; Wiley 1998). Critical thinking refers to a cognitive strategy that students use to judge their methods and beliefs in a reflective way (Kozma and Voogt 2003; OECD 2008). Creativity refers to the ability of developing innovative ideas or products via elaborating, refining, analyzing and evaluating existing ones (Jarvis et al. 2013; Yang and Cheng 2010). It has been regarded as one of the most important skills that students need to acquire (Zeng et al. 2011).

Research of mobile learning for fostering interaction and higher order thinking competences

The potential of incorporating mobile technology into school settings for cultivating students' 21st century core competences has also been recognized (Chang et al. 2011). For instance, Guerrero, Ochoa, Pino, and Collazos (2006) have reported the need to incorporate collaborative tasks into mobile learning activities, and have argued that mobile computing should fulfill the goal of engaging students in effective communication and collaboration. Kong (2014) also noted that the integration of mobile learning with well-developed pedagogical designs benefits the students' development of their information literacy competency as well as their critical thinking skills. Moreover, Lai and Hwang (2014) also revealed the positive correlation of engagement in mobile learning to students' problem-solving, critical thinking and creativity.

Several researchers have also reported that employing effective learning strategies or tools in mobile learning activities could be an empowering approach for cultivating those competences (Kim et al. 2014; Wong et al. 2015). For instance, Tsai, Tsai and Hwang (2012) developed a context-aware ubiquitous learning environment survey (CULES) for investigating the factors that might affect students' acceptance and learning outcomes of mobile technology-enhanced learning. The findings signified that the provision of real-context information, timely guidance, and collaboration mechanisms is important for engaging students in higher level cognitive processes. Other studies have also reported the potential of mobile and wireless communication technologies in fostering students' interaction and higher order thinking competences (Song 2014; Zydney and Warner 2016). For example, the merits of wireless communication and personalized devices have facilitated students' discussion and collaboration in learning activities (Toh et al. 2013); the provision of relevant learning materials in the field via mobile devices can encourage students to use their learning knowledge in real contexts, and can also sharpen their higher-order thinking skills (Boyce et al. 2014; Looi and Wong 2014). Moreover, some studies have investigated students' improvement, such as in their critical thinking, collaboration and problem solving as a result of mobile learning (Vogel et al. 2014; Wang and Wu 2008), and have proved that integrating seamless mobile technology into students' learning activities may enhance their higher order thinking. According to previous research, it was concluded that proper learning devices and platforms, ubiquitous learning environments, and adaptive learning content were the basic elements of students' mobile learning activities (Hwang et al. 2008; Al-Samarraie et al. 2013).

In Taiwan, a nation-wide mobile learning promotion program funded by the government has been conducted. The aim of the program is to engage students in higher order thinking activities via using mobile technology in school settings. As indicated by several researchers, the use of new technologies is likely to make learning different from conventional technology-enhanced learning (e.g., using projectors and PowerPoint), and thus teachers or educators need to rethink the structure and the procedure of learning activities and take students preferences into account (Kamarainen et al. 2013; Ruchter et al. 2010). Therefore, exploring students' mobile technology preferences and their relation to their higher order thinking tendency in mobile learning has gained importance. In this study, the questionnaire of 4C1P awareness (i.e., "collaboration," "communication," "critical thinking," "creativity" and "problem-solving") was adopted to explore students' awareness of interaction and higher order thinking. This study also probed whether the students' mobile learning preferences, such as "ease of use", "continuity", and "adaptive content", could affect their 4C1P awareness. This study first explored the component of the students' 4C1P awareness in mobile learning, and then explored the structural relationship of their 4C1P awareness and mobile learning preferences. Accordingly, the factors affecting students' higher order thinking and peer interaction tendencies were discussed and provided to school teachers or educators as a reference (Tsai 2005) for modifying their mobile learning activities and learning systems.

Research framework

In this study, an exploration of students' mobile learning preferences and their awareness of peer interaction and higher-order thinking was conducted. To ensure that all of the participants had the same mobile learning experience, the teachers were guided to develop mobile learning activities based on a recommended learning mode. In this learning mode, the students utilized the same type of tablet computers (i.e., HTC Flyers) donated by an enterprise to collaboratively search for information on the Internet; moreover, they needed to select and summarize the searched information based on a series of questions related to an issue specified by the teachers.

Furthermore, this study developed the framework of higher-order thinking tendency in issue-based mobile learning activities based on the characteristics of the activities and with reference to previous studies (Kong et al. 2014). Three aspects were cataloged as the important elements in this framework, namely technology preferences, interaction with learners, and higher order thinking tendency, as shown in Fig. 1. The "technology preference" aspect refers to the characteristics of technologies in mobile learning, which can be regarded as the fundamental aspect relating to the "interaction with learners" aspect (Hwang et al. 2008; Lee and Kim 2015). The "interaction with learners" aspect refers to the interactions between students in dealing with learning tasks (Jones et al. 2013), while the "higher order thinking tendency" aspect refers to students' higher-order thinking tendencies or awareness after experiencing the issue-based mobile learning activities (Liu et al. 2010). According to the studies reported by Kong et al. (2014) and Tsai et al. (2012), the "technology preference" and "interaction with learners" aspects could be the predictors of the "higher order thinking tendency" aspect.

In particular, the "technology preference" aspect refers to students' mobile adoption and learning behaviors in inquiry (Vogel et al. 2014). Some studies have signified that the provision of a user-friendly interface on devices is important for engaging students in higher-level cognitive processes (Hwang et al. 2008). Moreover, the merits of wireless communication and personalized devices have facilitated students' continuous engagement in learning activities (Toh et al. 2013). Finally, the provision of adaptive learning materials that meet students' needs can encourage students to use their learning knowledge in real contexts, and sharpens their higher-order thinking skills (Looi and Wong 2014; Kim et al. 2014).

In addition, when dealing with issue-based tasks in teams, the interaction between team members is an important element of learning; therefore, "collaboration" and

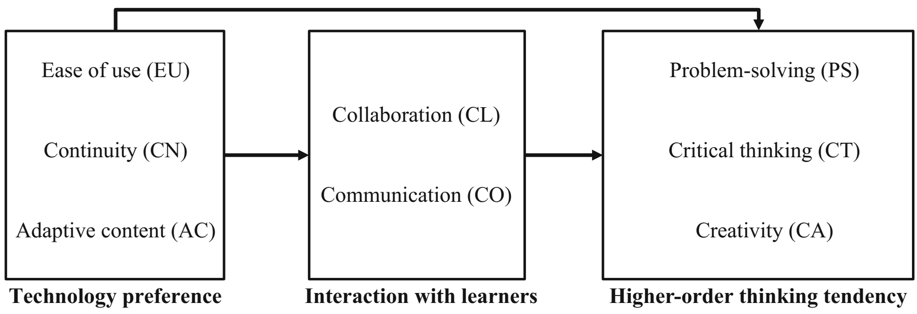

Fig. 1 The framework of higher-order thinking tendency in issue-based mobile learning activities

"communication" need to be taken into account (Frazier and Reynolds 2012; Osman et al. 2011; Morrison et al. 2009).

The context of mobile learning achieves the goal of providing opportunities to develop higher-order thinking skills. Anderson and Krathwohl (2001) asserted that the higher-order thinking skills include analysis, evaluation, and creativity. Analysis refers to the problem-solving abilities of identifying problems, exploring relationships, and collecting and analyzing relevant information for dealing with problems (Lazakidou and Retalis 2010); evaluation refers to critical thinking, a strategy that students employ to judge their methods and beliefs in a reflective way (Kozma and Voogt 2003), while creativity refers to the ability of developing innovative ideas or products via elaborating, refining, analyzing and evaluating existing ones (Yang et al. 2014; Yang and Cheng 2010). It is regarded as one of the most important skills a student needs to acquire (Zeng et al. 2011).

In order to examine the students' higher-order thinking tendency in mobile learning, in this study, the issue-based mobile learning activities which were conducted and the framework and questionnaire were developed by previous researchers (Kong et al. 2014; Tsai et al. 2012). According to the literature review, these three aspects (technology preference, interaction with learners, and higher-order thinking tendency) were suitable for explaining the relationship of mobile learning and higher-order thinking from students' perspectives.

Method

Participants

In this study, a long-term mobile learning program supported by the Ministry of Education in Taiwan was conducted (http://mlearning.ntust.edu.tw/). A total of 38 schools voluntarily participated in the program from August 2014 to July 2015. In order to help the high school teachers develop quality mobile learning activities, a series of training courses was provided, and a consultant team made up of 40 experienced scholars from several universities in Taiwan was formed to assist individual schools. In addition, nine training courses (about 70 h) were provided to help the school teachers develop mobile learning activities in school settings based on the mobile learning model and strategies provided by the consultant team. During the academic year, an advisor from the consultant team was invited to visit a school 4–6 times to give comments on the mobile learning activities the teachers had designed. Several demonstrated examples were also provided to the teachers to ensure that quality issue-based mobile learning activities were conducted in those schools to engage students in higher-order thinking. In each learning activity, a series of learning tasks related to a specific issue was raised by the teacher. The students learned in teams. Each team of students needed to search for information on the Internet, collect data in the field, discuss with team members, and summarize their findings to complete the learning tasks, as shown in Fig. 2.

The participants were the students from ten randomly selected schools. They were aged from 16 to 18 (from K10 to K12). After experiencing one year of mobile learning activities, a total of 809 students voluntarily responded to a survey with open-ended questions via an online survey system. A total of 658 effective responses were included in this study, including responses from 318 males and 340 females. The ratio of the students who voluntarily responded compared to the total student population in the selected schools was

Fig. 2 Learning scenarios of the issue-based mobile learning activities

34%, while the ratio of the effective responses compared to the students who voluntarily responded was 81%. In addition, the distribution of students in northern, central and southern Taiwan was 25, 35, and 40%, respectively.

Instruments

To meet the purpose of this study, the questionnaires of Mobile Learning Preferences and awareness of Collaboration, Communication, Critical thinking, Problem-solving and Creativity were adopted to measure the students' perceptions after the mobile learning program. All of the items in the questionnaires were presented using a five-point Likert scale, ranging from "1—strongly disagree" to "5—strongly agree".

The Mobile Learning Preference (MLP) questionnaire was revised from the measure developed by Tsai et al. (2012) for investigating learners' preferences in mobile learning environments. It consists of three dimensions: ease of use (3 items), continuity (3 items), and adaptive content (3 items), which have been identified as important elements affecting students' mobile learning performance (Hwang et al. 2012). Ease of use (EU) refers to students' perceptions of the ease with which they can use the mobile learning system (e.g., "When navigating m-learning environments, I prefer that they have well-suited mobile devices"). Continuity (CN) refers to students' preference for learning continuously when situated in the mobile learning environment (e.g., "When navigating m-learning environments, I prefer that they can provide the function of recording what I have learned"). Adaptive content (AC) refers to students' perceived importance of whether the information provided by the mobile learning system meets their requirements (e.g., "When navigating m-learning environments, I prefer that they can provide information which I need, e.g. documents, images, voice, etc.").

The 4C1P Awareness questionnaire (4C1PA) consists of five dimensions, that is, collaboration, communication, complex problem solving, critical thinking, and creativity with 5, 6, 4, 4, and 3 items, respectively. The Collaboration (CL) dimension was developed by

Jeng and Tang (2004); for example, "I try to provide useful and sufficient information when I conduct collaborative learning." The Communication (CO) dimension was revised from the Communicative Adaptability Scale (Duran 1992) for investigating students' conceptions of communicating with others (e.g., I am verbally and nonverbally supportive of other people). The Problem-Solving (PS) dimension was a modified version of the problem-solving questionnaire developed by Pan (2001); for example, "When facing problems, I believe I have the ability to solve them." The Critical thinking (CT) dimension was modified from the measure developed by Schraw and Dennison (1994); for example, "I consider several alternatives to a problem before I answer." The Creativity (CA) dimension was proposed by Lin and Wang (1994) for measuring the creative tendency of students (e.g., "I like to observe something I haven't seen before and understand it in detail").

Data analysis

This study involved three phases of the data analysis procedure, including exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modeling (SEM).

The finalization of the questionnaires was conducted through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The EFA was conducted to clarify the structure of each aspect (interaction with technologies, interaction with learners, and higher-order thinking tendency), and the CFA was used to examine the construct validity of the questionnaires and clarify the consequent structures. The participants ($n = 658$) were randomly split into two subsets, where half ($n = 329$, including 147 males and 182 females) were used for the EFA and the other half ($n = 329$, including 171 males and 158 females) for the CFA.

In the EFA, the items with factor loadings of less than 0.50 and with many cross loadings were omitted (Bentler 1990; Walker and Fraser 2005). The validity and reliability of the questionnaire were further evaluated accordingly. The scales of each aspect were clarified by employing IBM Statistical Product and Service Solutions (SPSS) version 20. The CFA employed Linear Structure RELationships (LISREL) to confirm the validity of the scales in the questionnaires (Jöreskog and Sörbom 1993).

Finally, the structure relationships existing between the three aspects were explored through a structural equation modeling (SEM) analysis, which offers a flexible and powerful means of examining the relationships among constructs (Kelloway 1998). In this study, LISREL version 8.80 was used to conduct SEM analysis.

Results

Validity and reliability of the students' higher-order thinking tendency in issue-based mobile learning activities

To validate the questionnaires on the students' higher-order thinking tendency in mobile learning, three principal component analyses with varimax rotation were performed to clarify the structure of all aspects. Table 1 shows the results of the EFA analysis of the students' interaction with technologies. The total variance explained was 77.94%, and the overall KMO value was greater than 0.50 (Field 2000), indicating that the factor analysis

Table 1 Rotated factor loadings, Cronbach's alpha values, factor means, and standard deviations for the three dimensions of interaction with technologies

		Factor loading
Dimension 1: ease of use (EU), α = 0.85, mean = 3.16, SD = 0.85		
E U1	When navigating m-learning environments, I prefer that they have good wireless communication	0.81
E U2	When navigating m-learning environments, I prefer that it takes only a short time to learn how to operate mobile devices	0.88
E U3	When navigating m-learning environments, I prefer that they have well-suited mobile devices.	0.71
Dimension 2: continuity (CN), α = 0.90, mean = 3.39, SD = 0.78		
C N1	When navigating m-learning environments, I prefer that they can provide the functions of recording what I have learned	0.83
C N2	When navigating m-learning environments, I prefer that they can provide the tools to continue with my learning	0.86
C N3	When navigating m-learning environments, I prefer that they can record the learning path that I have already been on	0.83
Dimension 3: Adaptive content (AC), α = 0.81, mean = 3.49, SD = 0.71		
A C1	When navigating m-learning environments, I prefer that they can provide information which I need, e.g. documents, images, voice, etc	0.81
A C2	When navigating m-learning environments, I prefer that they can provide a correct way to learn what I need to know	0.90
A C3	When navigating m-learning environments, I prefer that they can discuss a learning topic through various perspectives	0.74

Note Overall alpha: 0.90; total variance explained: 77.94%; KMO statistics: 0.88

was favorable for explaining the students' perception of interaction with technologies in the issue-based mobile learning activities. The students' responses regarding their interaction with technologies were grouped into three dimensions with a total of 9 items. Each dimension consisted of 3 items. The Cronbach's alpha coefficients for the three dimensions were 0.85, 0.90, and 0.81, and the overall Cronbach's alpha was 0.90. This suggests that these dimensions have high reliability for assessing students' perceptions of technologies in mobile learning.

On the other hand, the EFA result of the students' responses regarding interaction with learners is shown in Table 2. The total variance explained was 67.12% and the overall KMO value was 0.90, indicating that those factors were favorable for explaining the students' perceptions of interaction with learners in issue-based mobile learning activities. The students' responses regarding interaction with learners were grouped into two dimensions: collaboration and communication. The dimension of "collaboration" consisted of 5 items and "communication" consisted of 6 items. The Cronbach's alpha coefficients for the two factors were 0.87, 0.90, and the overall alpha was 0.89. This suggests that these factors have high reliability for assessing students' perceptions of interaction with learners.

Lastly, EFA analysis was also employed to examine the students' higher-order thinking tendency in issue-based mobile learning activities. The overall KMO value was 0.85, and the total variance explained was 69.62%. This result suggested that the students' responses

Table 2 Rotated factor loadings, Cronbach's alpha values, factor means, and standard deviations for the two factors of interaction with learners

		Factor loading
Dimension 1: collaboration (CL), α = 0.87, mean = 3.68, SD = 0.67		
CL1	I believe our team can cooperate successfully when I conduct collaborative learning	0.72
CL2	I try to provide useful and sufficient information when I conduct collaborative learning	0.74
CL3	I have good communication with my team members when I conduct collaborative learning	0.85
CL4	I can finish my work efficiently when I conduct collaborative learning	0.82
CL5	Work is split based on our abilities when I conduct collaborative learning	0.83
Dimension 2: communication (CO), α = 0.90, mean = 3.82, SD = 0.63		
CO1	I try to make the other person feel good	0.86
CO2	I try to make the other person feel important	0.80
CO3	I try to be warm when communicating with others	0.82
CO4	While I'm talking I think about how the other person feels	0.80
CO5	I am verbally and nonverbally supportive of other people	0.77
CO6	I disclose at the same level that others disclose to me	0.73

Note Overall alpha: 0.89; total variance explained: 67.12%; KMO statistics: 0.90

Table 3 Rotated factor loadings, Cronbach's alpha values, factor means, and standard deviations for the three factors of tendency of higher-order thinking

		Factor loading
Dimension 1: Problem-solving (PS), α = 0.85, mean = 3.73, SD = 0.62		
PS1	When facing problems, I believe I have the ability to solve them	0.81
PS2	I believe I can put effort into solving problems	0.81
PS3	I can solve problems that I have met before	0.76
PS4	I am willing to face problems and make an effort to solve them	0.79
Dimension 2: Critical thinking (CT), α = 0.84, mean = 3.62, SD = 0.63		
CT1	I ask myself periodically if I am meeting my goals	0.83
CT2	I consider several alternatives to a problem before I answer	0.77
CT3	I find myself pausing regularly to check my comprehension	0.85
CT4	I ask myself questions about how well I am doing once I finish a task	0.68
Dimension 3: Creativity (CA), α = 0.80, mean = 3.94, SD = 0.70		
CA1	I like to observe something I haven't seen before and understand it in detail	0.81
CA2	I like to try something new	0.84
CA3	I like to do something by myself	0.83

Note Overall alpha: 0.86; total variance explained: 69.62%; KMO statistics: 0.85

related to their higher-order thinking tendency were favorable for explaining their perceptions of the learning activities. The students' responses were grouped into three dimensions with a total of 11 items, as shown in Table 3. The Cronbach's alpha coefficients for the three factors were 0.85, 0.84, and 0.80, and the overall alpha was 0.86. This suggests that these factors have high reliability for assessing students' higher-order thinking tendency in issue-based mobile learning activities.

On the other hand, the confirmatory factor analysis (CFA) further confirmed the construct validity and the structure of the students' tendency of higher-order thinking in issue-based mobile learning activities. The CFA factor loadings and the t-values of all the items for each scale are presented in Table 4. The fitness of the items for each scale of the questionnaire (X^2 per degree of freedom = 1.85, RMSEA = 0.05, GFI = 0.87, NFI = 0.95, CFI = 0.98) indicated a sufficient fit and also confirmed the questionnaire structure. Moreover, the examination of the composite reliability and the convergent and

Table 4 The confirmatory factor analysis for the students' tendency of higher-order thinking in issue-based mobile learning activities

Scales	Item	Mean	SD	Factor loading	T-value
Ease of use (EU)	EU1	3.23	1.00	0.81	16.13***
	EU2	2.94	1.05	0.69	13.16***
	EU3	3.37	0.92	0.73	14.19***
Continuity (CN)	CN1	3.47	0.86	0.86	19.30***
	CN2	3.44	0.84	0.93	21.60****
	CN3	3.43	0.87	0.86	19.27***
Adaptive content (AC)	AC1	3.42	0.90	0.80	16.43***
	AC2	3.51	0.88	0.86	18.44***
	AC3	3.54	0.77	0.69	13.61***
Collaboration (CL)	CL1	3.76	0.87	0.68	13.06***
	CL2	3.84	0.79	0.74	14.64***
	CL3	3.68	0.86	0.73	14.45***
	CL4	3.76	0.82	0.78	15.89***
	CL5	3.57	0.94	0.66	12.57***
Communication (CO)	CO1	3.86	0.78	0.83	17.91***
	CO2	3.71	0.80	0.70	14.12***
	CO3	3.82	0.74	0.82	17.48***
	CO4	3.90	0.79	0.77	16.08***
	CO5	3.83	0.77	0.74	15.16***
	CO6	3.82	0.79	0.70	14.07***
Problem-solving (PS)	PS1	3.75	0.80	0.86	18.81***
	PS2	3.71	0.80	0.87	19.17***
	PS3	3.74	0.75	0.75	15.30***
	PS4	3.80	0.80	0.71	14.25***
Critical thinking (CT)	CT1	3.66	0.81	0.77	15.27***
	CT2	3.65	0.79	0.72	14.03***
	CT3	3.50	0.77	0.75	14.70***
	CT4	3.60	0.80	0.66	12.37***
Creativity (CA)	CA1	4.00	0.83	0.71	13.55***
	CA2	4.11	0.83	0.85	17.08***
	CA3	4.00	0.87	0.77	15.21***

Notes $N = 329$, $X^2 = 751.53$ ($p < 0.001$), *Degree of freedom* 406, X^2 *per degree of freedom* 1.85, *RMSEA* 0.05, *GFI* 0.87, *NFI* 0.95, *CFI* 0.9

*** $p < 0.001$

discriminant validities were also employed. Composite reliability (CR) of each scale was greater than 0.7, indicating an acceptable value for a reliable construct (Fornell and Larcker 1981). The average variance extracted (AVE) ranged from 0.52 to 0.78, which exceed the value of 0.5, indicating that the model was acceptable.

The structural equation model of the students' higher-order thinking tendency in issue-based mobile learning activities

According to previous research (Hwang et al. 2008; Kong et al. 2014), the aspect of "interaction with technologies" (EU, CN, and AC) was utilized as the exogenous variable to explain the aspect of "interaction with learners" and "higher-order thinking tendency." Furthermore, "interaction with learners" (CL and CO) was regarded as the predictor variable to explain the "higher-order thinking tendency" (PS, CT, and CA). The results of the fit measures for the students' higher-order thinking tendency in the issue-based mobile learning activities model are shown as Table 5, indicating a good satisfactory fit and confirming the structures (Jöreskog and Sörbom 1993). Since the GFI indices (0.87 for CFA, and 0.86 for the structural equation model) approached the recommended value (0.9), this study meets the requirements defined by researchers (Browne and Cudeck 1993).

The structural equation model of the students' higher-order thinking tendency in the issue-based mobile learning activities, the summary of the maximum-likelihood parameter estimates and the significance of the t-values are presented in Fig. 3. The statistically significant relationships are shown with solid lines, and, for a cleaner display, other non-significant relationships are concealed. Furthermore, the level of significance of the t-value was 3.29 ($p < 0.001$) (Jöreskog and Sörbom 1993).

According to the structural equation model, CA (Creativity) had a strong relationship with CO (communication) and CL (collaboration) in the aspect of interaction with learners. This indicates that, when students engage in the creative process, regular communication and collaboration with their peers is important. The students' critical thinking process (CT) was also related to communication and collaboration in the aspect of interaction with learners. Similar to the creativity aspect, the interaction with their peers and frequent discussion with their group members may engage students in evaluation and judgments.

In addition, the students' problem-solving (PS) was strongly related to their collaboration. In other words, the engagement of collaboration in mobile learning activities plays an important role when students analyze problems. Compared with the tendency of critical thinking and creativity, the communication aspect did not relate to the students' problem-solving process, which implies that these students regarded that the opportunity to

Table 5 Fit measures for the structural model of the students' higher-order thinking tendency in issue-based mobile learning activities

Fit index	Research model	Recommended value
X^2	837.62	–
Degree of freedom	410	–
X^2 per degree of freedom	2.04	<5
RMSEA	0.06	≦0.08
GFI	0.86	≧0.90
NFI	0.94	≧0.90
CFI	0.97	≧0.90

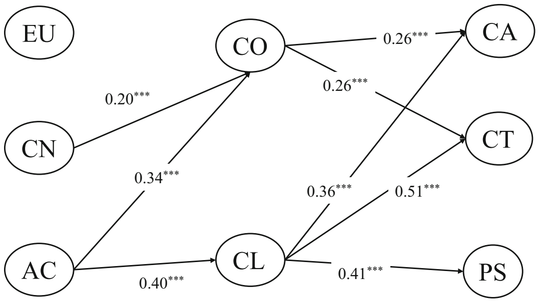

Fig. 3 Structural model of the relationships to the students' higher-order thinking tendency in mobile learning. N = 329. Significant t-value, $p < 0.001$. *EU* ease of use, *CN* Continuity, *AC* adaptive content, *CO* communication, *CL* collaboration, *CA* creativity, *CT* critical thinking, *PS* problem-solving

communicate with their peers was not the essential element when they engaged in examining problems, exploring relationships, or solving tasks.

Regarding the interaction with learners (communication and collaboration), CO (communication) was highly related to AC (adaptive content) and CN (continuity), indicating that the quality of the wireless connection and the provision of learning content that meets the students' needs should be considered in the communicating process. Moreover, CL (collaboration) was highly related to AC (adaptive content), which also indicated that, in order to assist the students in collaborative mobile learning, the provision of multiple and relevant learning material is essential.

In sum, with regard to helping students engage at the analyzing level in issue-based mobile learning activities, it would be better to take into account the process of collaboration and the provision of information based on students' needs. Moreover, for employing critical thinking and creativity in students' learning, the consideration of group discussion and collaboration in mobile learning is essential, while a continuous mobile learning environment that provides students with information based on their requirements should also be included.

Finally, it is interesting to note that the ease of use (EU) dimension of the interaction with technologies was not related to any dimension of the interaction with learners or their higher-order thinking tendency. This indicates that these students thought the interface of their mobile learning approach may not influence their higher-order thinking tendency in mobile learning.

Discussion and conclusions

In recent years, the investigation of improving students' interaction and higher-order thinking skills has been increasingly discussed (Yang and Wu 2012; Zydney and Warner 2016). Some researchers have implemented experimental designs to explore the effects of mobile technology on students' specific skills (Vogel et al. 2014), but have rarely paid attention to students' actual views on mobile technology and the technology support for the interaction and higher-order thinking skills. Since mobile technology has been recognized as an important technology in learning (Chang et al. 2010), it is urgent that students' views on the effectiveness of mobile learning for cultivating their interaction and higher-order thinking skills be understood. In this study, a long-term mobile learning program was conducted. Moreover, several instruments were developed and used to explore the relationships between the students' technology uses (ease of use, continuity, and adaptive content), peer interaction (communication and collaboration) and their higher-order thinking skills tendency (problem-solving, critical thinking, and creativity).

According to the structural equation model, the positive predictive link from "Adaptive content" to "Collaboration" and "Communication" indicated the importance of providing proper content to students (e.g., text, voice data, and image data) in mobile learning. Moreover, students' engagement in communication and collaboration are important mediators between their technology preferences and higher-order thinking tendency (e.g., problem-solving, critical thinking, and creativity). This result signifies that, in order to stimulate students to reach the higher-order thinking level, it is important to encourage them to engage in more communication and collaboration in mobile learning activities, and hence experience more discussion with group members, which could in turn allow them to engage in self-reflection and in-depth knowledge exploration (Carbonaro et al. 2010; Cheung and Lau 2013; Morrison et al. 2009). Moreover, when taking adaptive learning content into account, those learning supports not only assisted the students to acquire available information, but also led them to explore task related information, and to solve their learning problems effectively and collaboratively. This finding is consistent with the results reported by Gan and Balakrishnan (2014) who found that real-time accessible learning sources and quality wireless communications are important criteria for developing mobile learning environments.

Nevertheless, the technical preference of "ease of use" did not play any positive role in any aspect, implying that those students might think an appropriate interface is a common and basic element of a mobile learning environment (Hwang et al. 2008). Therefore, they considered that the provision of a good learning interface in mobile activities is not an important element.

Unlike most mobile learning studies which aimed at the lead-in of sensing technologies or the provision of learning guidance mechanisms for individuals (e.g., Chu 2014; Hwang et al. 2014), this study explored the students' perceptions of using mobile technologies in school settings and the impacts of mobile learning on their higher order thinking. Moreover, some qualitative data based on the students' open-ended feedback were also analyzed. Accordingly, several findings are derived as follows:

(1) The enabling of seamless learning: a stable wireless connection in the mobile learning environment for students to have continuous learning should be considered when developing the environment for learning (Hsiao et al. 2010). For example, one student with experience of an in-class issue-based discussion stated that, "It is helpful that I can access the network and search for the information I want. Without the tablet, I might forget the question that I want to find out." Another student who participated in an in-field activity of a geography course indicated that, "I can learn by employing some Apps at any real location, and I can compare the real objects with the information in the textbook; it made me enjoy the geography courses more than before." These findings confirm what has been indicated by Sharples (2015), namely that well-constructed mobile wireless technology could guide students to experience seamless and effective learning.

(2) The enabling of peer interactions: the design of collaborative tasks to facilitate peer interactions through mobile technologies is necessary, as indicated by several researchers (Nova et al. 2005; Spikol and Otero 2012). For example, a student who studied in a mobile learning context for a chemistry course stated that, "It was fun that I could work together with my classmates and we could share our own thinking about the chemistry concept." Another student also shared the same feeling, saying

that, "I was afraid to answer questions before. The use of mobile devices changed my thinking. Now I find that answering questions in front of lots of classmates is not so embarrassing after reading the answers and opinions they shared through their devices." Several students also indicated that they were more willing to share information with peers and to participate in brainstorming after using mobile technologies to learn.

(3) Encouragement of higher-order thinking: One student stated that, "When I was taking the civics course, our teacher asked us to search for the issue on the Internet; it surprised me that I can discuss some social issues in our life rather than just memorizing the knowledge in the text book." Another student said, "The issue of national identity raised by our teacher really reflected the phenomenon in Taiwan; we found different kinds of opinions on the Internet and then we thought and developed our personal opinion critically and seriously." Several students also shared similar opinions. It was found that mobile learning can provide students with opportunities to apply what they have learned to their daily-life contexts (Pérez-Sanagustín et al. 2012). Moreover, through frequent collaboration and communication, the students' performance could be more satisfactory and they could attain a more in-depth level of thinking (Hwang et al. 2014).

On the other hand, some limitations and suggestions are provided for consideration in future studies. First, this current model only involves several technical, interaction aspects and several complex learning skills. It is encouraged that more variables of students' competences be considered in future explorations. Second, it is also suggested that the relationship between students' mobile learning and their learning outcomes in those environments be the subject of future discussion.

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