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DEVELOPMENT ARTICLE

Informal learning in science museum: development and evaluation of a mobile exhibit label system with iBeacon technology

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Abstract Informal science learning has drawn the attention of researchers, educators and museum administrators for a long time. However, the problem of how to better support visitors to be more engaged while visiting exhibits and improve informal science learning performance is still missing. Context-aware technologies have the advantages of fostering learning interest and providing real time feedback. Previous studies have examined the effectiveness of 5E Learning Cycle in science learning. To address the problem, this study aims to develop a mobile label assisted system using the 5E Learning Cycle approach based on iBeacon technology in a science museum. A total of 43 college students participated in this study. Participants from different majors were assigned to two groups in an effort to make the groups relatively equivalent in terms of student majors. One group was the experimental group (mobile label assisted visiting mode, n = 21), and the other one was the control group (traditional visiting mode, n = 22). From the results of learning performance, stay-time, behavioral pattern analysis, and interviews, it was found that the mobile label assisted system can effectively guide visitors to interact with exhibits, conduct thoughtful learning, and prolong the visiting stay-time. Visitors are willing to visit the science museum with it. This was one of the very few studies focusing on the application of iBeacon to design mobile label system in a science museum. It turned out that iBeacon technology has huge potential applications for the future science museum.

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Introduction

Informal science learning means science learning activities which take place outside the formal classroom and they are learner-motivated, personalized, contextually relevant, nonlinear, and open-ended (Falk and Dierking 2000; Gerber et al. 2001; National Research Council 2009; Patrick 2010). Science museums have significant contributions to informal science learning with the interactive exhibits (Wellington 1990). With the advance of wireless communication and mobile technologies, numerous studies concerning mobile and ubiquitous learning in museum settings have been conducted in the past 15 years (Chiou et al. 2010; Hwang and Tsai 2011; Hwang et al. 2012). Researchers found that students' achievement in science and mathematics was somewhat higher for those students who visited science museums frequently during the school year or summer (National Research Council 2009). Some studies claimed that interactive exhibits could enhance informal learning when they were well designed to follow the visitors' laws of cognitive development (Feher and Rice 1985; Hofstein and Rosenfeld 1996; Tuckey 1992).

Several instructional models were proposed to help informal science instructional design, including Heiss et al.'s Learning Cycle (1950), the Science Three Phases Learning Cycle proposed by Curriculum Improvement Study (SCIS) (Thier and Karplus 1967), and the 5E Instructional Model proposed by Biological Sciences Curriculum Study (BSCS) (Bybee 2002, 2015; Bybee et al. 2006). Among the above mentioned instructional models, BSCS 5E model is a widely accepted one. BSCS 5E Instructional Model, or the 5E Learning Cycle consists of five phases. These include engagement, exploration, explanation, elaboration, and evaluation.

Studies have confirmed that 5E Learning Cycle can be applied to a variety of subjects and grade levels (Akar 2005; Balci et al. 2006; Campbell 2006; Wilder and Shuttleworth 2005). For example, Liu et al. (2009) designed plants related learning activities with 5E Learning Cycle for fourth-grade students and found out that the learning activities can enhance students' scientific knowledge and understanding levels. Students also had positive perceptions to the learning activities. Akar (2005) compared the effectiveness of the tenth-grade chemistry instruction based on 5E Learning Cycle over traditionally designed instruction. The results indicated that instruction based on 5E Learning Cycle caused a significantly better acquisition of scientific conceptions and produced significantly higher positive attitudes toward chemistry than the traditionally designed chemistry instruction.

A label is an important part of the exhibit in a science museum. As mentioned by Loomis (1987), the label is a kind of important interpretive material to help the general visitor understand exhibit objects. It can be all types of media, including print, audio, and graphics (Screven 1992). Badly designed exhibit labels are "instruments for torture on helpless visitors" (Bitgood 1991). Meanwhile, well-written exhibit labels will increase visitors' use of labels, encourage reading, and foster engagement, comprehension, and meaning making. Screven (1992) proposed that exhibit labels design frameworks should focus on the following components: content (text and message), structure (legibility, size, typeface, and color), presentation format (interactivity, sound, graphics, and video), and context (the physical and environmental context, noise, lighting, for example). The observational research, however, found that visitors did not use the labels effectively in an exhibition. Even the most diligent visitors do not read everything (Serrell 2015, p. 3). Sparacino (2002) also stated that most people did not spend sufficient time to read or digest the informative content of the exhibit labels.

There are two possible reasons why exhibit labels are lacking effectiveness. On one hand, the main function of current labels is a display or delivering of information. The informal educational function is not included in the labels design framework. The self-organization and free choice in traditional label reading do not necessarily lead to research-question-driven learning processes (Vartiainen and Enkenberg 2013) which is the cause of ineffective informal learning. On the other hand, textual labels used for decades are fixed both in terms of format and content. In today's science museum, visitors expect more intuitive multisensory experiences with digital technologies (Parry and Sawyer 2005).

Therefore, to solve the aforementioned problems, there are two ways to go. From the theoretical perspective, additional instructional models of exhibit labels design should be adopted. Studies suggested 5E Learning Cycle might be an effective complement of existing frameworks (Bybee 2015). From the practical perspective, exhibit labels should become digital. With the advanced Human–Computer Interactive (HCI) technology, wireless technology, and mobile technology, digital labels could be context-aware, which means the system can deliver right learning content at the right time and the right place to the right person (Chen and Huang 2012; Wang and Wu 2011).They broadcast the latest interpretations of the exhibits. The content could change over time or in response to certain environments (Parry and Ortiz-Williams 2007). Digital labels could also work as the bridge between the fruitful digital resources on the Internet and artifacts. Relevant content presented in the digital label is the key to comprehending the story/knowledge behind the artifacts. Researchers have explored the possibilities of using digital technologies in the museum. For instance, Parry and Ortiz-Williams (2007) built, demonstrated, and evaluated an editable, wireless digital label system in three UK museums and received positive feedback from both visitors and curators. Serrell (2015, p. 205) also indicated that digital devices with audio, multimedia, apps, interactive games, videos, and links to the Internet serve as important secondary sources of information.

Among the mentioned technologies, a great number of context-aware technology and products could be used for digital labels system, such as Global Position System (GPS), Radio Frequency Identification (RFID), Near Field Communication (NFC), etc. (Shen et al. 2014). Chen and Huang (2012) proposed a context-aware ubiquitous learning system (CAULS) based on RFID, wireless network, embedded handheld device, and database technologies to detect and examine real-world learning behaviors of students in the museum. The results showed that this approach can enhance students' learning outcome and learning intention. However, GPS, RFID, and NFC have limitations in indoor settings, the GPS signal weakens or distorts as it travels through the building, RFID and NFC only works within the distance of several centimeters. iBeacon is a new alternative power-based indoor positioning system based on Bluetooth low energy (BLE) technology which was introduced by Apple in 2013. It has the advantages of being low-powered and low-cost compared with the other indoor positioning systems (Newman 2014; Ng 2015). iBeacon is specialized in the detection of proximity and it can be deployed in museums, stores, and stadiums for information broadcasting purposes.

In summary, context-aware technologies have the advantages of fostering learning interest and providing real-time feedback (Chen and Huang 2012; Parry and Ortiz-Williams 2007; Wang and Wu 2011). Previous studies have examined the effectiveness of 5E Learning Cycle in science learning (Akar 2005; Balci et al. 2006; Campbell 2006; Liu et al.

2009; Wilder and Shuttleworth 2005). This study is designed to develop a mobile label assisted system based on iBeacon technology in science museum which aims to better engage the visitors while visiting exhibits and facilitate informal science learning through using 5E Learning Cycle approach. The following research questions are addressed:

1. Can the participants accomplish better learning performance by using the mobile label assisted system compared to the use of the traditional visiting mode with static labels?
2. Would participants stay more time on visiting exhibits by using the mobile label assisted system compared to the use of the traditional visiting mode with static labels?
3. What are the difference in behavior patterns between participants using the mobile label assisted system and the traditional visiting mode?
4. What are the participants' perceptions and attitudes toward the mobile label assisted system?

System design

A mobile label assisted system running on iOS has been developed to assist the visitors to interact with the exhibit and learn science knowledge. As shown in Fig. 1, the system was designed based on 5E Learning Cycle. Let us first introduce the main task for teachers or students to do in each phase of 5E Learning Cycle.

Engagement (*E*1) The teacher accesses the students' prior knowledge. The teacher designs short activities to promote curiosity and help them connect the past and present learning experiences.
Exploration (*E*2) The teacher provides the students with a series of activities within concepts, processes, and skills. Students complete the activities with their prior knowledge to generate new ideas, explore possibilities, and conduct a preliminary investigation.
Explanation (*E*3) The explanation phase provides opportunities for students to demonstrate their conceptual understanding, process skills, or behaviors. Teachers may directly introduce or explain a concept, process, or skill in this phase to foster students' deeper understanding as well.
Elaboration (*E*4) Through the challenge experiences given by teachers, the students develop deeper and broader understanding, more information, and adequate skills. Students conduct additional activities with the new learned concepts and skills.
Evaluation (*E*5) Teachers evaluate students' progress or students' self-access their understanding and abilities based on the educational objectives.

The developed system has the following five system functions.

Push notification, a notification will be pushed to the Bluetooth enabled mobile devices by the iBeacon base stations installed on the exhibits when the visitors are approaching them within five meters. The learning activity page in iOS app will be opened when the visitor clicks on the notification message.
World menu, all learning activities related to a specific exhibit label are listed under the "World" menu.
The nearby menu, all learning activities could be participate nearby the specific exhibit label are listed under the "Nearby" menu.

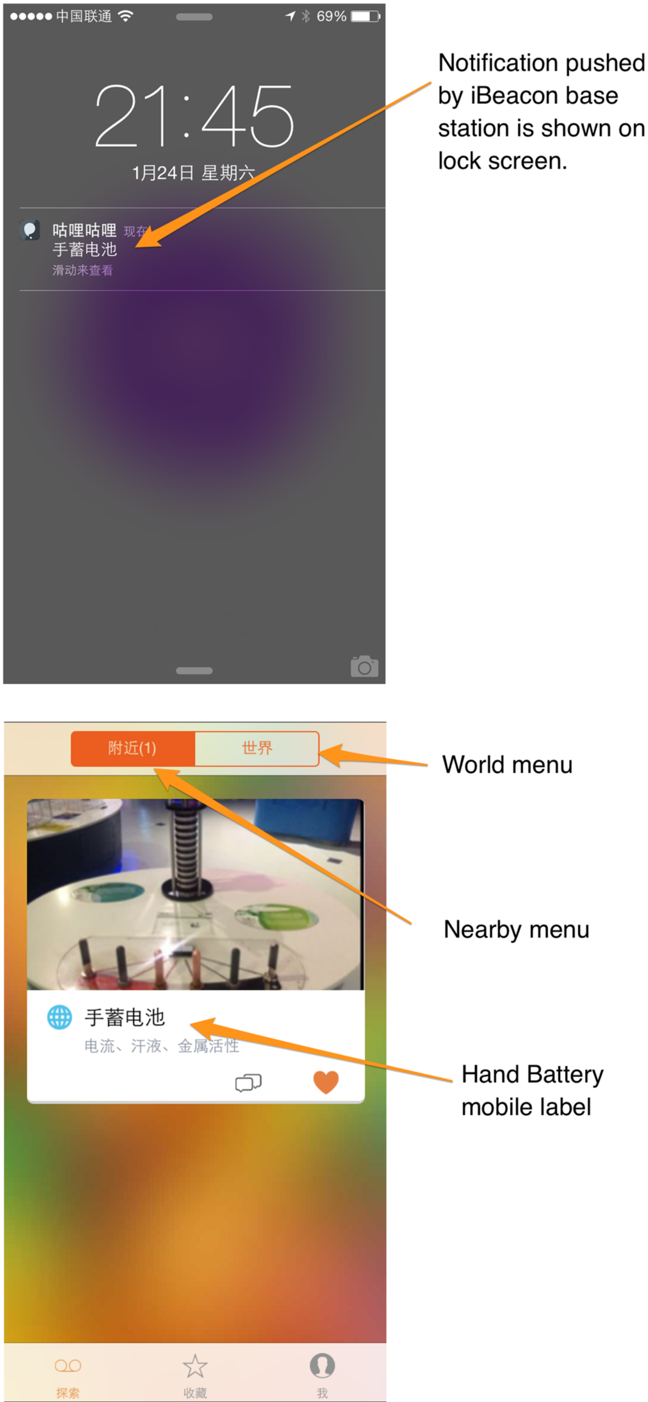

Fig. 1 Push notification and nearby menu

Under the Comments section, visitors can leave their comments regarding their participation and learning activities in this section.
Favorite section, visitors can save some learning activities as their favorites for further reference.

The learning activities were designed in multimedia format (text, animation, audio and video) according to the 5E Learning Cycle. "Hand Battery" exhibit was selected as an example to illustrate how this mobile label system works, guiding visitors to explore the exhibit. "Hand Battery" is one of the classic exhibits in China Science and Technology Museum (CSTM) and it has great interactivity. As shown in Fig. 7, 8, and 9, the exhibit consists of one theory explaining label, one operation label, one ammeter, and a set of touchable metal rods.

(1) *Engagement* ($E1$) A story about a lady with sets of dentures made of gold and stainless steel is presented in both text and audio format. The lady has a headache since then and goes to see a doctor. It turns out that the gold tooth and steel tooth acts as two terminals of a battery. The said headache of the lady was caused by the electrical current running through. This introductory story engages visitors to find the scientific explanation of the reason why she has a headache (as shown in Fig. 2).
(2) *Exploration* ($E2$) An animation is shown as guidance to visitors. They can try holding two different metal rods and observe the movement of the ammeter needle (as shown in Fig. 3).

Fig. 2 E1: the introductory story of "Hand Battery"

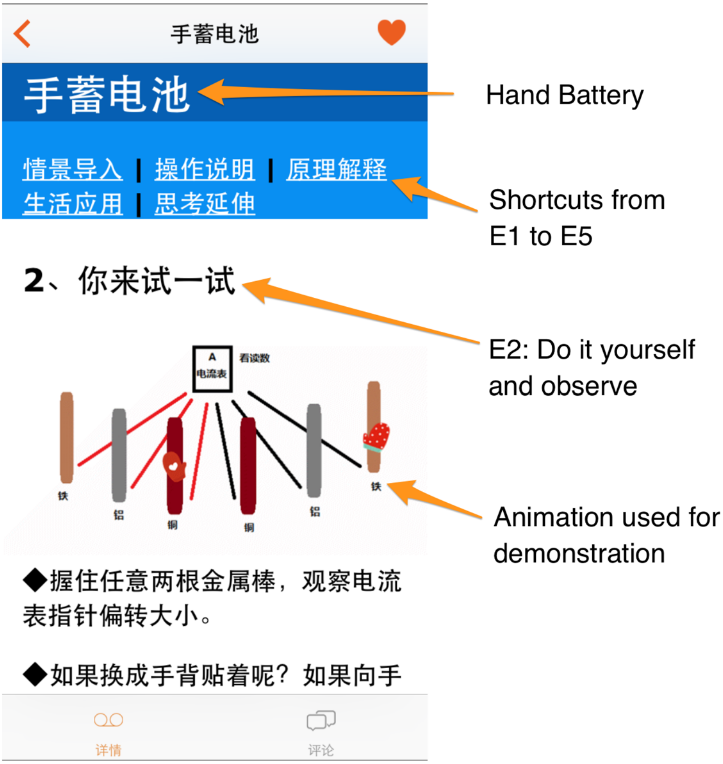

Fig. 3 E2: the guidance animation of "Hand Battery"

(3) *Explanation* (*E*3) A detailed explanation of the Biology, Chemistry, and Physics principles behind this exhibit is presented. Visitors can listen to the audio as well as read the text (as displayed in Fig. 4).

(4) *Elaboration* (*E*4) A short expository essay of how batteries are made and the necessity of recycling old batteries is shown (as seen in Fig. 5).

(5) *Evaluation* (*E*5) In this "Going Further" section, evaluation can be done through answering questions about which metal produces the highest/lowest current reading. Visitors can also self-access their understanding and abilities through an apple battery making task (as shown in Fig. 6).

The mobile label assisted system was installed on iPod touch 5 as mobile exhibit label client. iPod touch 5 had 4-inch retina display with 1136 $\times$ 640 screen resolution. The whole setup is shown in Fig. 7.

Method

Participants

The participants of this study were 48 college students. Data of five students, however, were discarded due to video damage caused by a technical issue. Among the 43 students,

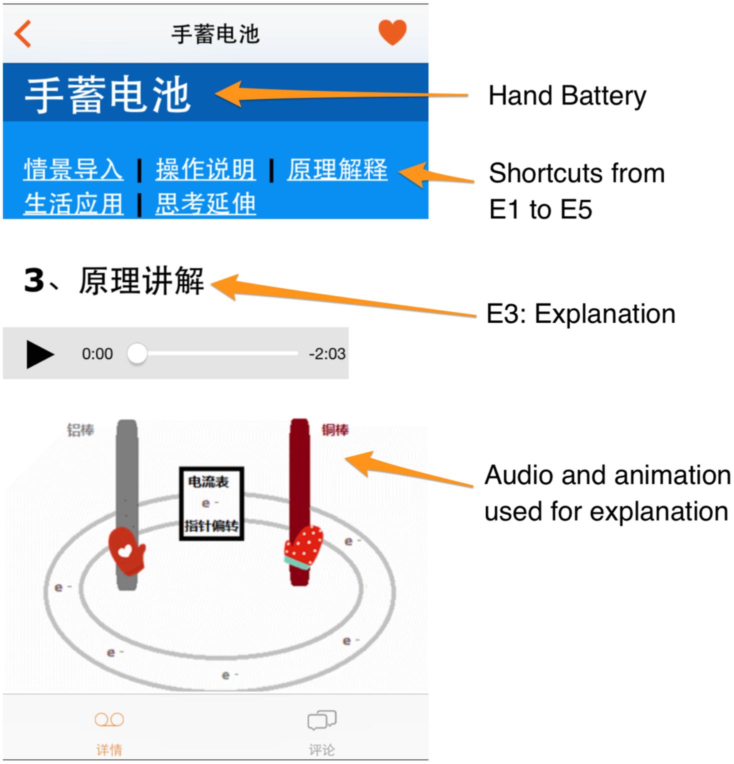

Fig. 4 E3: explanation of scientific principles of "Hand Battery"

there were 29 (67%) female and 14 (33%) male. Their majors included Education, Language Arts, Finance, Philosophy, Journalism, Computer Science, Geography, and Engineering. Participants from every major were assigned to two different groups in an effort to make the groups relatively equivalent in terms of student majors. One group was the experimental group (mobile label assisted visiting mode) with 21 participants, and the other one was the control group (traditional visiting mode) with 22 participants. They were recruited by online advertisement and paid for participation in this research.

Research design

A quasi-experimental design was used in this study. The independent variables were the two modes of visiting: traditional visiting mode and mobile label assisted visiting mode. The dependent variables were learning performance, the stay-time on exhibit, visiting behavioral patterns, and visitors' attitude regarding the use and acceptance of the mobile label system. The experimental group visited the exhibit with mobile devices which could receive the push notifications and learning materials. The control group visited the exhibit in a traditional way, and all information was presented by the static exhibit labels next to the exhibit.

Fig. 5 E4: an expository expansion essay of "Hand Battery"

Research tools

Assessing learning performance

All participants were asked to finish a learning performance test after visiting the "Hand Battery" exhibit. It was set to compare whether there was a difference in learning performance after exploring the exhibit between the two different labeling approaches. The test had five multiple choice questions related to the exhibit, and it was validated by one domain expert. The test–retest reliability was 0.82. The five questions are as follows.

Q1. Which statement about ammeter needle's movement is correct?

(A) It shows that the ammeter was broken.
(B) It shows that the activities of metal were different.
(C) It shows that there was electric current going through the ammeter.
(D) It shows that the electric current was different.

Q2. What will happen to the electric current intensity if you touch the metal rods with wet palms?

(A) The electric current intensity will decrease.
(B) The electric current intensity will increase.

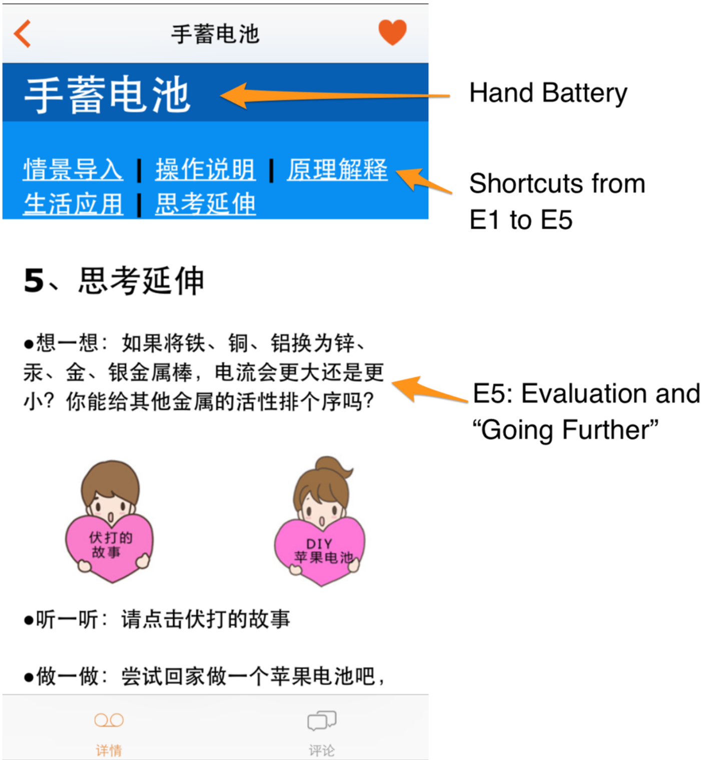

Fig. 6 E5: self-accessing through answering questions and making an apple battery

Fig. 7 Visiting with mobile label assisted system

(C) The electric current intensity will not change.
(D) None of the above.

Q3. Which metal activity series is correct?

(A) Al > Fe > Cu
(B) Fe > Al > Cu
(C) Cu > Fe > Al
(D) Al > Cu > Fe

Q4. The electric current was caused by the chemical reaction between metal rods and ________.

(A) Thumbs
(B) Fingers
(C) Palms
(D) Sweat

Q5. Who invented the "Prime Cell"?

(A) Thomas Edison
(B) Alessandro Volta
(C) James Maxwell
(D) Luigi Galvani

Interview questions

The interview was designed to collect the visitors' perception and attitude toward the two different visiting modes. The interview questions were adopted from the Sung et al. (2010) study about mobile guide application at the museum, for example, "do you like visiting with mobile label assisted system?", "does the technology and learning content improve your visiting experience?". Participants of the experimental group answered all seven questions after the visiting session. Participants of the control group answered six out of seven questions because one question was technology related.

Index of learning styles questionnaire

The aim of filling this questionnaire was to let participants to avoid rehearsing knowledge of the exhibit. It had 44 items and the test–retest reliability for all four scales varied between 0.7 and 0.9. This questionnaire had convergent construct validity according to Felder and Spurlin (2005).

Instruments

To observe the visitors' interactive behavior with the exhibit, iPod touch was used as a video camera in this study. Video data were used for a participants' stay-time and behavioral pattern analysis.

Procedure

The experiment was conducted in China Science and Technology Museum. "Hand Battery" exhibit was selected from three different exhibits as the learning topic (the other two exhibits are "Tesla's Egg of Columbus" and "Gear Walls"). One participant was guided by an experimenter to conduct the experiment at each time. They had to sign the consent form at the beginning. Then, the experimental group explored exhibit with the help of mobile devices (as shown in Fig. 8). A push notification of learning activities showed up when they approached the exhibit. They were asked to follow the instruction shown on a mobile label. The control group, however, investigated exhibit in the traditional way with the help of static labels (as shown in Fig. 9). Behaviors of both groups were recorded by a video camera which included interaction with the exhibit, interaction with the mobile label, interaction with the static label, interaction with the experimenter, and other behaviors. All participants were asked to finish the Index of Learning Styles Questionnaire (Felder and Spurlin 2005) after exploring the exhibit. Finally, all participants were asked to finish the multiple choices learning performance test and answer the interview questions.

Data coding and analysis

Quantitative and qualitative data was collected. The quantitative data included participants' learning performance and stay-time. Learning performance was analyzed with independent sample *t* test using test scores to find out whether there was a difference between the two groups. For each test question, there was 1 point for a correct answer. The highest score for all five questions was five points. To examine the difference of spending time on visiting exhibit between the two groups, stay-time was measured by the length of video recording from the beginning to the end of visiting (with or without mobile devices). This data (in seconds) was analyzed with independent sample *t* test as well.

The qualitative data contained participants' behavioral patterns, perceptions, and attitudes toward mobile label assisted system. Quantity content analysis (QCA) and lag

Fig. 8 Mobile label assisted visiting

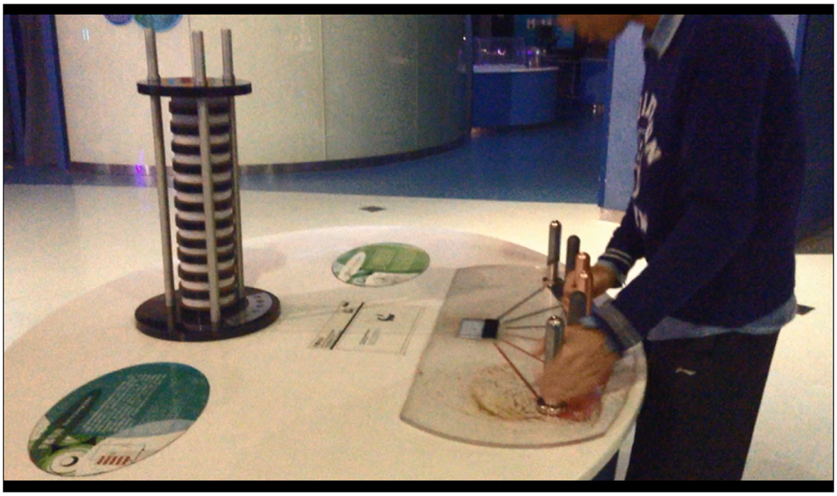

Fig. 9 Traditional visiting

sequential analysis (LSA) were used for analyzing the behavioral pattern data (Rourke and Anderson 2004). LSA was usually used for examining whether the sequential relationships between each participant's behaviors reached statistical significance or not, which can demonstrate the particular characteristics of the behavioral patterns between the two groups (Bakeman and Gottman 1997; Lin et al. 2014). They have been utilized this approach in studies that examine students' online discussion behavior (Hou et al. 2009; Hou and Wu 2011; Serce et al. 2011) and mobile learning behaviors (Chang et al. 2014). This study adopted the coding scheme within the human–computer–context interaction (HCCI) framework proposed by Sung et al. (2010) and Chang et al. (2014). All behaviors were divided into four dimensions: human–exhibits interaction (observe/operate exhibit/label), human–device interaction (explore different sections of the mobile label), human–human interaction (communicate with experimenters), and other behaviors (walk/move, etc.). Every 5 s of video were encoded as one behavior. The 5 s time interval was widely accepted and used in the previous studies (Chang et al. 2014; Hou and Wu 2011). Two trained graduate student coders from the school of educational technology coded all 43 videos. The inter-coder kappa coefficients reliability was 0.85 which indicated high consistency. The applied coding scheme was given in Table 1. Moreover, the perception and attitude toward mobile label assisted system reflected visitors' technology acceptance through qualitative content analysis of the interview transcripts.

Results

Analysis of visitors' learning performance

The independent samples *t* test showed that there is a significant difference between high-score groups (upper 27%, M = 5.00, SD = 0.00, n = 12) and low-score groups (lower 27%, M = 2.58, SD = 0.79, n = 12); t (22) = 10.56, p = 0.000, Cohen's d = 4.33. The result indicated that the learning performance test had a good discriminating ability.

Table 1 Coding scheme for visiting behaviors

	Visiting behaviors (for more than 5 s)	
A1	Observe/operate exhibit	Human–exhibits interaction
A2	Observe operation exhibit label (static label 1)	
A3	Observe theory-explaining label (static label 2)	
B1	Explore engagement section of mobile label	Human–device interaction
B2	Explore exploration section of mobile label	
B3	Explore explanation section of mobile label	
B4	Explore elaboration section of mobile label	
B5	Explore evaluation section of mobile label	
C1	Communicate with experimenters	Human–human interaction
D1	Walk/move	Other behaviors
D2	Adjust devices settings (put on/take off earphones, adjust volume, and pointless clicking)	

Therefore, an independent-samples *t* test was conducted to compare post-test score in mobile label assisted and traditional visiting modes. As shown in Table 2, there was no significant difference in the scores for the mobile label assisted group (M = 4.00, SD = 0.95, n = 21) and the traditional group (M = 3.86, SD = 1.13, n = 22); t (41) = 0.43, p = 0.670. The answer to research question 1 is NO: "Can the participants accomplish better learning performance by using the mobile label assisted system compared to the use of the traditional visiting mode with static labels?"

Analysis of visitors' stay-time

Results of independent-samples *t* test indicated that the stay-time (in seconds) of the mobile label assisted group (M = 426.71, SD = 246.93, n = 21) was significantly longer than the traditional visiting group (M = 144.55, SD = 93.88, n = 22); t (41) = 5.00, p = 0.000, Cohen's d = 1.51. The answer to the research question 2 is YES: "Would participants stay more time on visiting exhibits by using the mobile label assisted system compared to the use of the traditional visiting mode with static labels?" (Table 3).

Analysis of visitors' behavioral patterns

Lag sequence analysis (LSA) was used to analyze the behavioral patterns of the two visiting modes. First, we transformed the encoded raw data tables into frequency tables of behavioral sequences. Thereafter the two frequency tables were transformed into adjusting

Table 2 Results of *t* test and descriptive statistics for learning performance by visiting modes

	Visiting modes						95% CI for mean difference	t	df
	Mobile label assisted			Traditional					
	M	SD	n	M	SD	n			
Post-test score	4.00	0.95	21	3.86	1.13	22	−0.51 to 0.78	0.43	41

Table 3 Results of *t* test and descriptive statistics for stay-time (in seconds) by visiting modes

	Visiting modes						95% CI for mean difference	t	df
	Mobile label assisted			Traditional					
	M	SD	n	M	SD	n			
Stay-time	426.71	246.93	21	144.55	93.88	22	168.13–396.21	5.00***	41

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

residual Z-scores tables (as shown in Tables 4 and 5). Columns represented the previous behavior and the rows represented the following behavior. The adjusted residual Z-score greater than 1.96 meant the behavioral sequence reached the level of significance ($p < 0.05$) (e.g., 5.82 in Table 4 meant A2 happened right after C1 and this behavioral sequence was significant; 1.20 in Table 4 meant A2 happened right after D1 and this behavioral sequence was not significant). The significance of behavioral sequences meant the frequency of certain sequences is statistically higher than the frequency of other sequences. QCA found out 2337 different behavioral sequences, including 591 from the traditional visiting mode and 1746 from the mobile label assisted mode. LSA revealed that there were six significant behavioral sequences for the traditional visiting mode and 20 significant behavioral sequences for the mobile label assisted mode.

Figure 10 indicates six behavioral sequences A3 ↔ D1, C1 ➔ A2, A1 ➔ A1, A2 ➔ A2, and A3 ➔ A3 from the traditional visiting mode achieved the level of significance. The bi-directional status of A3 ↔ D1 indicates that visitors have to walk or move (D1) to observe the theory explaining label (A3). The behavioral sequences C1 ➔ A2 shows that visitors observe the operation exhibit label (A2) after seeking help from the experimenter (C1). A1 ➔ A1, A2 ➔ A2, and A3 ➔ A3 indicate that visitors focus on the exhibit, the operation exhibit label, and the theory explaining label.

Figure 11 indicates 20 behavioral sequences A1 ↔ B2, A2 ↔ C1, A3 ↔ D1, C1 ➔ D1, C1 ↔ D2, A1 ➔ A1, A2 ➔ A2, A3 ➔ A3, B1 ➔ B1, B2 ➔ B2, B3 ➔ B3, B4 ➔ B4, B5 ➔ B5, C1 ➔ C1, D1 ➔ D1, and D2 ➔ D2 from the mobile label assisted mode achieved the level of significance. The bi-directional behavioral sequences A3 ↔ D1 for mobile label assisted visiting mode reach significance as well as for traditional visiting mode. The significance of A2 ↔ C1 shows that visitors need help from the experimenter about traditional labels, even if they have mobile label assisted system in their hands. Furthermore, the most obvious new behavioral sequences were A1 ↔ B2, and it indicates that there is a bi-directional interaction between the exploration section of mobile label (B2) that led to the observation or operation of exhibits (A1). As a result of the implementation of mobile label assisted system, there are hardware related behavioral sequences (C1 ↔ D2) which represent visitors seeking help from the experimenter (C1) to

Table 4 Adjusted residuals Z score of traditional visiting mode

Z	A1	A2	A3	C1	D1
A1	**15.26***	−1.79	−13.92	None	−3.32
A2	−0.20	**4.66***	−1.65	None	0.13
A3	−13.54	−1.38	**13.00***	None	**3.56***
C1	−1.16	**5.82***	−0.59	None	−0.40
D1	−4.43	1.20	**4.38***	None	0.21

* $p < 0.05$

Table 5 Adjusted residuals Z score of mobile label assisted visiting mode

Z	A1	A2	A3	B1	B2	B3	B4	B5	C1	D1	D2
A1	**31.77***	0.75	−1.12	−5.90	**2.11***	−4.22	−8.90	−9.79	−3.30	−0.03	−3.42
A2	−0.79	**13.88***	−0.10	−0.58	−0.37	0.89	−0.83	−0.96	**2.55***	−0.10	−0.45
A3	−1.21	−0.11	**32.20***	−0.88	−0.57	−1.11	−1.27	−1.47	−0.55	**6.32***	0.85
B1	−5.89	−0.59	−0.84	**33.59***	1.11	−4.90	−5.82	−7.93	−1.79	−0.84	−0.87
B2	**5.32***	−0.38	−0.53	−2.64	**15.43***	−0.91	−4.05	−4.23	−0.15	−0.53	−2.38
B3	−5.31	−0.73	−1.03	−5.38	−3.76	**32.56***	−5.60	−9.25	−2.62	−1.03	−1.85
B4	−9.05	−0.82	−1.17	−6.40	−3.37	−8.16	**34.96***	−8.84	0.53	−1.17	−3.44
B5	−9.43	−0.94	−1.33	−7.36	−4.60	−9.20	−10.69	**37.42***	−3.27	−0.36	−3.85
C1	−3.06	**2.50***	−0.52	−0.94	1.00	−3.35	0.69	−3.48	**13.71***	**3.54***	**2.55***
D1	1.35	−0.09	**7.52***	−0.74	−0.48	−0.94	−1.07	−1.24	1.79	**7.52***	−0.59
D2	−5.05	−0.46	−0.65	1.14	0.44	−2.22	−4.30	−4.34	**4.01***	−0.65	**20.72***

* $p < 0.05$

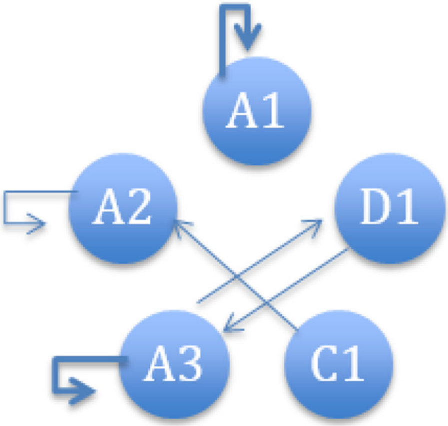

Fig. 10 Significant behavior patterns from the traditional visiting group A1: Observe/operate exhibit, A2: Observe operation exhibit label (static label 1), A3: Observe theory-explaining label (static label 2), C1: Communicate with experimenters, D1: Walk/move

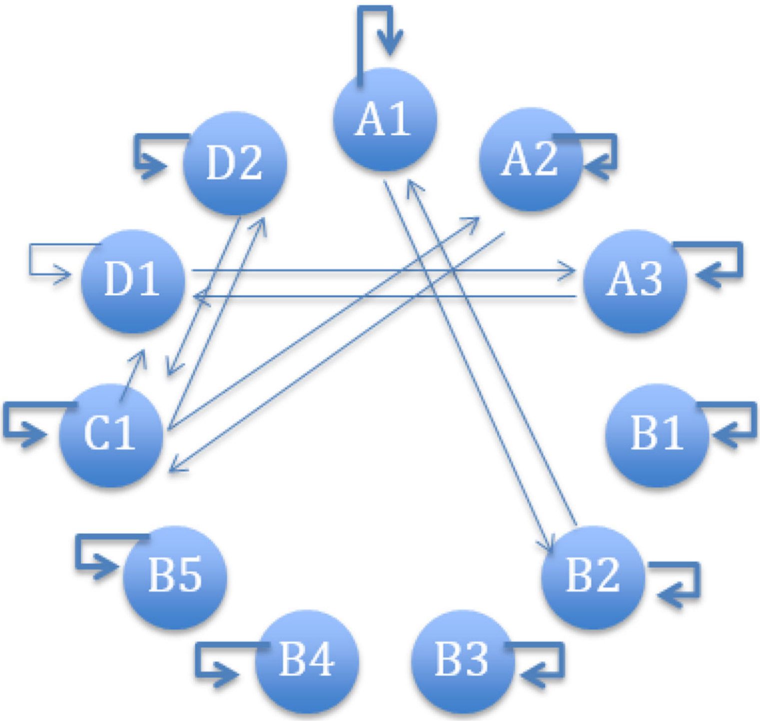

Fig. 11 Significant behavior pattern from the mobile label assisted group A1: Observe/operate exhibit, A2: Observe operation exhibit label (static label 1), A3: Observe theory-explaining label (static label 2), B1: Explore engagement section of mobile label, B2: Explore exploration section of mobile label, B3: Explore explanation section of mobile label, B4: Explore elaboration section of mobile label, B5: Explore evaluation section of mobile label, C1: Communicate with experimenters, D1: Walk/move, D2: Adjust devices settings (put on/take off earphones, adjust volume, and pointless clicking)

set up their devices (D2). The visitors also need to move to ask for help from the experimenter (C1 ➔ D1). The behavioral sequences A1 ➔ A1, A2 ➔ A2, A3 ➔ A3, B1 ➔ B1, B2 ➔ B2, B3 ➔ B3, B4 ➔ B4, B5 ➔ B5, C1 ➔ C1, D1 ➔ D1, and D2 ➔ D2 demonstrate that visitors concentrate on each task no matter what kind of task it is.

From the comparison of behavioral patterns of these two visiting modes, the answer to research question 3 "What are the difference in behavioral patterns between participants using the mobile label assisted system and the traditional visiting mode?" is that the mobile label assisted visiting group showed bi-directional interaction between mobile label and observation or operation of exhibits (A1 ↔ B2). The traditional visiting group, however, did not have this kind of interactive behaviors. There was label-operation behavioral pattern in the mobile label assisted visiting group but not in the traditional visiting group.

Analysis of the interviews

The results of the interviews (as shown in Table 6) found that 19 out of 21 participants in the experimental group would like to use the mobile label assisted systems to visit the science museum in the future. They claimed that the implementation of push notification with iBeacon technology brings good visiting experience. Meanwhile, 19 out of 22 participants in the control group stated that they were willing to try the mobile label assisted system after experimenters gave them a demonstration. The mostly positive perceptions and attitudes towards the mobile label assisted system answered the research question 4 "What are the participants' perceptions and attitudes toward the mobile label assisted system?".

A total of five participants from both groups, however, were reluctant to use this kind of mobile label assisted system to visit science museums. They argued that there were two reasons: first, mobile devices hindered the interaction with exhibits; second, pushed

Table 6 Answers to interview questions

Interview questions	Mobile label assisted n = 21		Traditional n = 22	
	Positive	Negative	Positive	Negative
1. Have you ever been to CSTM?	2 (10%)	19 (90%)	1 (5%)	21 (95%)
2. Does the visiting method used today make you familiar with the exhibit?	17 (81%)	4 (19%)	19 (86%)	3 (14%)
3-1. Do you like visiting with mobile label assisted system? (Mobile label assisted group only)	19 (90%)	2 (10%)	N/A	N/A
3-2. Are you willing to try visiting with mobile label assisted system in the future? (Traditional group only)	N/A	N/A	19 (86%)	3 (14%)
4. Does the technology and learning content improve your visiting experience?	21 (100%)	0	N/A	N/A
5. Will you recall the knowledge learned today in the future?	21 (100%)	0	22 (100%)	0
6. Are you willing to visit CSTM in the future?	19 (90%)	2 (10%)	20 (91%)	2 (9%)
7. Other suggestions	N/A	N/A	N/A	N/A

information might make visitors passively accept the learning content. We will discuss this issue further and make some suggestions for improvement in the discussion section.

Discussion and conclusion

In this study, a mobile label assisted system with iBeacon technology was developed and a learning activity instructed by 5E Learning Cycle was conducted. Visitors' learning performance, stay-time, behavioral patterns, and attitude towards use and acceptance was evaluated and analyzed. The existing context-aware technologies, such as GPS, RFID, and NFC all have disadvantages. For example, GPS is not suitable for indoor positioning; RFID and NFC both can only cover a very short range (Ng 2015). iBeacon has a much flexible coverage range from within a few centimeters to an approximate range of 70 meters. It has a low power consumption quality, and inexpensive in initial setup and maintenance cost. Some business solutions have confirmed iBeacon can be implemented in shopping malls and stadiums (Newman 2014). However, this is one of the very few studies focusing on the application of iBeacon technology for informal learning in a science museum. Although the learning performance of the mobile label assisted group was better than the learning performance of the traditional visiting group, the difference between two group didn't reach significance. The Biology, Chemistry, and Physics concepts behind "Hand Battery" are quite fundamental. Participants had learned the related knowledge in high school. This is one of the possible reasons for the result. Another possible reason is that the static explanatory label of the exhibit, although the lack of interactivity, has provided enough information for participants to get a good grade in the learning performance test.

Serrell (2015) had concerns about the visitors' stay-time or focusing time of exhibits. The present study found that with the help of mobile label system and 5E Leaning Cycle, visitors spent much more time studying exhibits, compared to those who visited in a traditional way. This compared to the audio-guide devices or wearable devices implement in museums (Sparacino 2002), the mobile label system in this study not only deliver text, audio, and video messages but provide interactive learning activities which can engage visitors during exploring exhibits. This result is consistent with the report that guided tour in the museum would increase visitors' focusing time effectively (Chang et al. 2014).

Caulton (1998) emphasized that the development of interactive displays has changed the relationship between visitors and exhibits. Visitors expect to have hands-on experience of the objects and be actively involved with the exhibits. The present study used QCA and LSA to visualize visitor's behavioral pattern while they interact with the exhibits. Some significant behavioral patterns were commonly found in both two visiting groups like patterns A3 ↔ D1 and C1 ➔ A2. However, the only significant interactive behavioral sequence A1 ↔ B2, was only found in the mobile label assisted visiting group. It indicates that there is bi-directional interaction between the exploration section of the mobile label (B2) and observation or operation of exhibits (A1) which means visitors would interact with the exhibit by learning how to operate them. Therefore, the mobile label assisted system can effectively guide visitors interact with the exhibit and conduct thoughtful learning. The behavioral patterns of the traditional visiting group, nevertheless, showed no significant behavioral sequences among A1–A3 which suggested the traditional static label did not play a role in guiding the interaction with the exhibits.

The significance of A1 ➔ A1, A2 ➔ A2, A3 ➔ A3 from the traditional visiting group and A1 ➔ A1, A2 ➔ A2, A3 ➔ A3, B1 ➔ B1, B2 ➔ B2, B3 ➔ B3, B4 ➔ B4, B5 ➔ B5, C1 ➔ C1, D1 ➔ D1, D2 ➔ D2 from the mobile label assisted visiting group revealed that visitors keep focusing on each learning tasks instead of navigating from one task to another. They would like to follow the instruction and finish learning activities one by one.

Although participants in the experimental group were told to ignore the existing static labels, the traditional labels related to behaviors A2 and A3 were found in the mobile label assisted visiting group. It means a visitor cannot neglect static labels because they are parts of exhibits (Serrell 2015). If the museums would like to adopt the mobile label assisted system and keep the traditional labels at the same time, they should make these two labels a bit different to avoid duplicate contents. For example, the static labels should be brief, simple, and direct. Visitors can acquire all the information at a glance. The mobile label assisted system should come with some well-designed learning activities to those visitors who would like to spend more time on it.

Meanwhile, the behavioral sequence A3 (observe the theory explaining label) ↔ D1 (walk/move) suggested that this label was inappropriately placed because visitors have to walk or move to see it. Behavioral sequence C1 ↔ D2 from the experimental group represents that visitors seek help from experimenter (C1) to set up their devices (D2). It reminds us that a help or Q n' A section should be added to the mobile label system to make it more user-friendly.

To address the concerns mentioned by some visitors in the interview, we would like to suggest that the science museum should choose the device with the right screen size. Some mobile device, such as Apple iPad or Samsung Galaxy Tabs, has an over 7.0-inch screen. It might hinder the interaction between visitors and exhibits, also, because the visitors have to hold it in their hands all the time. Mobile phone with a smaller screen, which can be put into a pocket while operating the exhibits, is more suitable for the scenario in a science museum. In addition, iBeacon technology has huge potential applications for the future science museum. Not only can it be used as context-aware mobile label system, but also as an extension part of the exhibit. For instance, visitors with iBeacon enabled mobile devices or apps can get push notifications when they approach the exhibit. They can interact with the exhibit and get the results showed on the main screen. The museum administrators can also collect interactive data through iBeacon to evaluate the effectiveness of layouts and display settings for exhibits to improve learning activities designed for informal learning in a science museum.

The science museums play several roles nowadays, such as improving the public perception of science, contributing to a positive evaluation of science, and supporting formal education. Delivering scientific concepts, is only one of the above-mentioned roles. With the help of the mobile label system and instructional design introduced in this study, visitors would like to spend more time on exhibit. Most of them also had more positive perceptions and attitudes towards the exhibits and science museum.

Researchers claimed that lots of museums have started using mobile devices as guide-tour or learning tools as well as traditional labels (Parry and Ortiz-Williams 2007; Parry and Sawyer 2005). The present study is an initial efficacy study with limited participant group. However, we hope it can inspire researchers, educators, and curators to explore informal science learning with emerging technologies and instructional theories. For the researchers, not only the effectiveness of new technologies but also some variables such as social interaction and motivation should be considered in future studies. More exhibits should be examined to reveal the regular behavior pattern of mobile label assisted visiting. For the educators, the proper learning strategies or support provided during learning process should be adopted. Let us take the 5E Learning Cycle in the present study as an example, teacher's evaluation or feedback mechanism should be added in Evaluation (E5) in the future design. How museums are embracing the digital age is a question to be answered. According to the results of the present study, the development, deployment, and management of multiple versions of mobile label/learning systems for visitors with different backgrounds, or an adaptive mobile label system could be put on the agenda.

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