Game-Based Learning for Competency Abilities in Blended Museum Contexts for Diverse Learners*

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Museums offer a lifelong edutainment environment with flexible choices for the public and provide fruitful interdisciplinary learning resources to support competency-based education. However, the lack of proper scaffolding and supports in museums negatively affect learner learning. Further, the individual differences need to be considered to effectively support the diverse learners learning in museums. In this study, an innovative learning model to support competency education for lifelong learning in museums is proposed. A game-based learning service named CoboFun that offers various types of problem-solving activities was developed to facilitate learners’ interaction with exhibits and their peers in the museum. To examine the service design of CoboFun, learners’ perceptions were evaluated and the differences in their cognitive styles were examined (Field Independent (FI) and Field Dependent (FD)). The results showed that both FI and FD learners enjoyed learning with CoboFun but that flexible learning tools needed to be provided to satisfy the different needs for the learners with different cognitive styles.

Keywords: competency-based learning, museum learning, game-based learning, virtual and physical, lifelong learning

Competency refers to a high-level ability to integrate learned knowledge, experiences, and related skills to solve problems that require critical thinking, creativity, or social skills (Barth, Godemann, Rieckmann, & Stoltenberg, 2007). Recently, there has been world-wide attention on how competency-based learning can develop lifelong learners who can deal with complex issues and future challenges. In science education, many studies have reported the equal importance of cognitive competencies (knowledge and concepts: know-what), behavior competencies (inquiring abilities: know-how), and social skills (communication and collaborative work skills) (Assamoi & Christophe, 2015). These competencies are required in the science professions. Competency-based education highlights the importance of providing a flexible learning environment with cross-disciplinary learning resources that will encourage each student to develop their competency abilities during their active research and problem-solving processes (Valanne, Al Dhaferi, Kylmalahti, &

* Funding/Acknowledgements: This study is supported in part by the Ministry of Science and Technology of the Republic of China under contract number MOST 108-2511-H-178-001 and MOST 109-2511-H-178-001.


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While teachers are limited by what can be achieved in the classroom, science museums can provide both a lifelong edutainment environment with flexible choices for the public and fruitful interdisciplinary learning resources to support competency-based education. However, most students have inadequate inquiry skills and motivation to learn independently in museums (Gutwill & Allen, 2017). Besides, it is difficult for teachers and museum staff to support all students’ needs at the same time. Therefore, proper scaffolding and support is needed to effectively engage learners in museums.

To do this, various types of digital applications have been used in the design of museum services. These include ubiquitous learning applications (Chen, Zhang, Chen, & Fan, 2016), augmented reality (Efstathiou, Kyza, & Georgiou, 2018), and game-based learning services (Sintoris et al., 2010). Although digital technologies have the potential to improve learners’ motivation and learning experiences in museums, researchers have indicated that only properly designed applications can be of benefit in museum learning (Bowen et al., 2008). Falk and Storksdieck (2005) proposed a context model of learning and explained that museum learning is a dynamic process involving the interaction of various contexts. These include the personal (personal qualities), the physical (exhibits and environments), the sociocultural (social interactions and cultural influences), and the time factor. Each learner’s personal qualities, including prior experience and preferences, significantly affect his/her learning behaviors and experiences in museums (Falk & Dierking, 2018). The learners obtain knowledge from their in-depth observation and active inquiry in museums, and their learning is enhanced as they share ideas and communicate with others. The use of digital applications means that learning has shifted from the purely physical context to a blended virtual and physical context. In view of this, Hsu and Liang (2017) extended the context model of learning and proposed an online and on-site cyclical learning model to promote learner learning in museums: using digital applications to integrate the digital and physical spaces.

Previous research has indicated that neglecting the influence of museum contexts can isolate learners from the external environment and limit their interaction with museum exhibits and other learners (Hou et al., 2014). Further, limited interactions with museum contexts will have a negative effect on learners’ ability to construct knowledge related to exhibits and result in learners being reluctant to engage in learning and to re-visit museums. The studies highlighted the need to consider the influence of museum contexts when designing material to promote learners’ interactive learning experiences and encourage return visits. That is, learners’ interaction with museum exhibits and their peers, and the digital applications should all be considered when designing material. In addition, appropriate material and adequate support needs to be provided to meet diverse learners’ needs and the influence of their personal context on their museum learning (Falk & Dierking, 2018).

Due to the strong impact of learning with digital applications, there has been a focus on cognitive style in effectively supporting diverse learners (Hsu & Hwang, 2014). Cognitive style refers how a learner perceives, processes, and organizes information, such as Field Independent-Dependent (Witkin, Moore, Goodenough, & Cox, 1975). The Field Independent (FI) and Field Dependent (FD) represent different learning behaviors in thinking, remembering, and problem-solving (Chen, 2002). FI learners usually take a breadth-first path to processing their information, while FD learners prefer to take a depth-first path (Witkin et al., 1975). FI learners prefer to take a global approach to their learning by first developing an overall impression of the
subject; FD learners usually take an analytic approach and like details (Chen, 2010). FI learners rely more on internal references and are less influenced by external information, while FD learners rely more on external references and like being given guidance (Witkin et al., 1975). FI and FD learners have different interpersonal learning styles: FIs prefer to learn independently, while FDS like interacting with others (Witkin & Goodenough, 1976).

It is apparent that the different learning styles need to be considered in the design of teaching and support material, such as the interface, the design of system functions, and how content is presented. For example, FIs prefer to use hyperlinks to select what they are interested in learning, while FDS prefer to peruse the content in the recommended order (Chen, 2002). Despite the clear differences between FI and FD learners, there are limited studies relating to how cognitive style impacts museum learning, meaning that this area is still undefined. Given that museums open their doors to diverse learners from all over the world, it is important to identify the impact of different cognitive styles to better support learning in museums. It is also important to develop proper methodologies or tools to support learning when making the connection between the virtual and physical contexts in museums.

To meet these criteria, this study developed a game-based learning service named CoboFun that offers a flexible game-based learning environment. Incorporated in the design are various problem-solving tasks to engage learners in interacting with museum exhibits and their peers during their visits. The design includes learning supports such as hints and a map to aid museum learning. The aim of this study is to evaluate the advantages and disadvantages of CoboFun and whether it supports diverse learners’ acquisition of knowledge in museums. The results of the study can be used to improve the design of CoboFun and to address areas that do not meet the specifications. Therefore, this study attempts to answer the following three research questions:

1. Can CoboFun facilitate interactive museum learning experiences for FI and FD learners?
2. What are the differences in museum learning experiences between the learners with different cognitive styles: i.e., FI and FD?
3. Do FI and FD have different preferences for the system design?

**Service and Learning Activities Design**

**Learning Activities Design**

To support competency-based learning in museums, a learning activity named “Life origin, evaluation and extinction” was designed to introduce the exhibitions in the Life Science Hall in Taiwan’s National Museum of Nature Sciences (NMNS). The learning activity is designed to be a real-world adventure game consisting of eight learning tasks that develop cognitive and behavior competencies related to science education.

The cognitive competency refers to thematic knowledge relating to the exhibition of the origin, evolution, and extinction of life on earth. In this learning activity, each task represents a key concept to support the construction of the thematic knowledge—the learner will gain progressive understanding of the origin of the earth, the evolution of plants, and the other living creatures, and learn the possible reasons for extinction (natural or artificial selection).

The behavior competencies include inquiry and social skills. Each task includes a problem-solving puzzle to help the learners do the research: Each puzzle is designed to scaffold the expected research so that the learner can construct thematic knowledge related to the exhibits. Various puzzles are designed to facilitate different types of inquiry behaviors, such as observing, identifying, and comparing the differences among exhibits,
making deductions from the evidence, and manipulating the hands-on activities. The learners can build their inquiry skills during the problem-solving process, such as questioning, in-depth observation, hand-on activities (experiments), or critical thinking.

The learning tasks allow learners to interact with others: They can collaborate with others to solve the puzzles by brainstorming possible solutions, sharing collected information, and discussing the puzzles. Sharing their ideas with others helps learners revise their own solutions to the puzzles and helps them to identify and institute different actions to solve the puzzles. By doing so, the learners can practice their social skills during the gaming process.

**System Design**

A game-based learning service named CoboFun was developed to improve learner’s interactive experiences in the NMNS. To encourage learning in the museum, the service provides various real-world game quests designed to satisfy diverse learners’ preferences and to motivate them to actively interact with the physical contexts and their peers. Having fun while doing the inquiry and the sense of achievement in solving puzzles motivate the participants to continue learning in museums. Once the learners have downloaded and installed the app from the Google Play store or the App store (Taiwan only), they can select a game of their choice and start their explorations in the NMNS. Figure 1 display the system flow of CoboFun.

![Figure 1. The game-based learning service flow of CoboFun.](image)

To fulfil the learning activity of “Life origin, evaluation and extinction”, a quest named “Doctor D’s
Dinosaur Park” was designed. At the start of the game, the learner is given a story describing the requirements of the task and stories are shown before each task to explain its goal. The beacon technology was applied to locate the learners’ position and help in planning their path to each task (Figure 2). The learners can select a specific learning task on the map to start a learning task, and can decide their learning paths to complete all the learning tasks.

![Figure 2. The learners exploring in the NMNS with Exploration Map.](image)

Figure 3 gives an example of this quest’s learning task. The learners can find related information by using the clue function, and can integrate the information from exhibits and digital clues to solve the puzzle with others. The hint function is provided to support the learner in solving puzzles: It gives detailed descriptions of solutions when the learners are unable to solve the puzzles (after the learner has twice submitted wrong answers).
After the learner finishes a task, an illustrated explanation (learning summary) is provided to summarize the thematic knowledge of each task. As well as this, VR and AR technologies were developed to encourage immersion experiences for learners. The learners can collect VR objects (dinosaurs) after they have finished the learning tasks, and are able to view their dinosaur park with VR glass or take an AR photo after they have completed the quest (Figure 4).

Experiment Design

Participants

This study examined the design of CoboFun and how it can be used by learners with different cognitive styles in an interactive learning experience in the museum. The sample comprised 58 sixth-grade elementary school students (28 boys and 30 girls) who had experience in digital manipulation. The students were randomly selected to visit Taiwan’s NMNS and to use CoboFun to do inquiry on the exhibitions of the “Origin of Life”, “Age of Dinosaurs”, “Extinction”, and “Evolution of Mammals”.

Research Measures

In order to answer the three research questions, three measures were employed in this study. The learners’ cognitive style was examined by the Groups Embedded Figure Test (GEFT) (Cronbach α = 0.82), which is a standardized test to identify FI and FD learners, and was modified by Wu (1987).
The service design was evaluated by a questionnaire that consisted of 13 questions to examine the design of Cobofun. The user-interface interaction included usability and visual design of the interface to present contents were evaluated. The measure was rated on a five-point Likert scale with 1 = strongly disagree and 5 = strongly agree (Cronbach α = 0.70).

The interactive museum learning experiences were evaluated by a questionnaire that was adapted from the Contextual Model of Learning Fulfilment questionnaire assessing children’s interactive museum experience (Hsu, Liang, Chiou, & Tseng, 2018). The questionnaire included eight questions assessing children’s motivation and their interactive experiences with museum exhibitions and the other children. All questions were assessed using a five-point Likert scale with 1 = strongly disagree and 5 = strongly agree (Cronbach α = 0.76).

**Experimental Procedure**

The experiment started with a 10-minute presentation to introduce the learning workflow and system operation, followed by a 30-minute period during which the GEFT was applied to assess the learners’ cognitive styles. Based on the results, the participants were assigned to collaborative learning groups and heterogeneous grouping was used to minimize the influence of group effects (each group included both boys and girls and FI and FD learners). Each group included four or five members. The group leader was asked to arrange the work for each member, and all groups were asked to complete the quest, “Doctor D’s Dinosaur Park” within 90 minutes. After the participants had completed all the tasks, VR glasses were provided to review their collection of virtual rewards. Finally, 30 minutes were allocated for the learners to complete the questionnaires. The total duration of the learning activity was about 160 minutes.

**Data Analysis**

To evaluate the service design of Cobofun and learners’ interactive museum learning experiences, the data obtained from the questionnaires were analyzed by the Statistical Package for the Social Sciences (SPSS) for Windows (release 18.0). Descriptive analysis was used to examine learners’ museum experiences. An independent t-test was applied to compare the differences in FI and FD learning experiences. The significance level was $p = 0.05$ for each statistical analysis.

**Results**

**Interactive Museum Learning Experiences**

Table 1 gives the t-test results of FI and FD learners’ interactive museum learning experiences. The results show that both FI and FD learners believed that Cobofun facilitated their interactive learning experiences in museums, and that there is no significant difference between FI and FD learners. Further, the results show that most learners found that Cobofun made learning very interesting. The various types of problem-solving puzzles encouraged the learners to actively explore and interact with the museum exhibits and they interacted more with their peers during their visits. The playful learning experiences provided by Cobofun were motivating for both learning and for re-visit intention. Therefore, the answer to first research question is that Cobofun can facilitate the learner’s interactive museum learning experiences. For the second research question, there is no significant difference in museum learning experiences between FI and FD learners.
Table 1

The T-Test Results of FI and FD Learners’ Interactive Museum Learning Experiences

<table>
<thead>
<tr>
<th>Item</th>
<th>Cognitive style</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learning with CoboFun is very interesting and enjoyable.</td>
<td>FI</td>
<td>26</td>
<td>3.81</td>
<td>1.059</td>
<td>0.222</td>
<td>0.825</td>
</tr>
<tr>
<td>2. Compared to traditional museum visits, learning with CoboFun</td>
<td>FI</td>
<td>26</td>
<td>3.69</td>
<td>1.011</td>
<td>0.836</td>
<td>0.407</td>
</tr>
<tr>
<td>3. CoboFun can support me in exploring and learning</td>
<td>FI</td>
<td>26</td>
<td>3.65</td>
<td>0.936</td>
<td>0.252</td>
<td>0.803</td>
</tr>
<tr>
<td>4. CoboFun can encourage me to actively explore and observe</td>
<td>FI</td>
<td>26</td>
<td>3.62</td>
<td>0.941</td>
<td>0.351</td>
<td>0.727</td>
</tr>
<tr>
<td>5. CoboFun can encourage me to interact and communicate</td>
<td>FI</td>
<td>26</td>
<td>3.69</td>
<td>0.928</td>
<td>0.018</td>
<td>0.986</td>
</tr>
<tr>
<td>6. I read the description and observe the exhibits carefully</td>
<td>FI</td>
<td>26</td>
<td>3.12</td>
<td>1.107</td>
<td>-0.696</td>
<td>0.490</td>
</tr>
<tr>
<td>7. I will recommend that my friends experience CoboFun.</td>
<td>FI</td>
<td>26</td>
<td>4.19</td>
<td>0.849</td>
<td>1.927</td>
<td>0.059</td>
</tr>
<tr>
<td>8. I will visit the museum again and experience the new</td>
<td>FD</td>
<td>32</td>
<td>3.62</td>
<td>1.388</td>
<td>-0.224</td>
<td>0.823</td>
</tr>
</tbody>
</table>

Perceptions of Service Design

Table 2 shows FI and FD learners’ evaluation of the service design. It shows that while many learners were satisfied with CoboFun, the t-tests show that the FI learners’ preferences are different from those of the FD learners. The FI learners show noticeable preferences for icons with text labels (t (56) = 1.93, p = 0.059) and landmarks (t (55) = 1.91, p = 0.061) in the interface design compared to FD learners. There is also a significant difference between FD and FI learners in their preferences for the corrective feedback (t (56) = 2.55, p = 0.014). Therefore, in answer to the third research question, the learners with different cognitive styles prefer different design systems.

Table 2

The T-Test Results of FI and FD Learners’ Perceptions About Service Design

<table>
<thead>
<tr>
<th>Item</th>
<th>Cognitive style</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The system manipulation is easy to use.</td>
<td>FI</td>
<td>26</td>
<td>3.85</td>
<td>0.834</td>
<td>-0.510</td>
<td>0.612</td>
</tr>
<tr>
<td>2. It is easy to identify the functions of each graphic icon.</td>
<td>FI</td>
<td>26</td>
<td>4.19</td>
<td>0.849</td>
<td>1.927</td>
<td>0.059</td>
</tr>
<tr>
<td>3. It would be easier if text labels could be used to clarify the</td>
<td>FI</td>
<td>26</td>
<td>3.72</td>
<td>0.991</td>
<td>1.248</td>
<td>0.217</td>
</tr>
<tr>
<td>4. The design of the task icon means that the process of unsolved</td>
<td>FI</td>
<td>26</td>
<td>3.62</td>
<td>1.388</td>
<td>-0.224</td>
<td>0.823</td>
</tr>
<tr>
<td>5. It is easier for me if the tasks are shown with sequential</td>
<td>FI</td>
<td>26</td>
<td>3.73</td>
<td>1.079</td>
<td>-0.075</td>
<td>0.941</td>
</tr>
<tr>
<td>6. The map is effective in helping me explore and solve puzzles in</td>
<td>FI</td>
<td>26</td>
<td>3.75</td>
<td>0.846</td>
<td>1.910</td>
<td>0.061</td>
</tr>
<tr>
<td>7. I would like the addition of landmarks or photos to be added to</td>
<td>FD</td>
<td>32</td>
<td>3.91</td>
<td>0.893</td>
<td>1.910</td>
<td>0.061</td>
</tr>
</tbody>
</table>
8. It is very inconvenient that the hint function is only available after two incorrect answers.

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>2.96</th>
<th>0.958</th>
<th>0.892</th>
<th>0.236</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>2.66</td>
<td>0.971</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. I am satisfied with the interface design of CoboFun.

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>3.58</th>
<th>1.301</th>
<th>-0.161</th>
<th>0.873</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>3.63</td>
<td>0.976</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. The location of each icon is well-designed making accidental manipulations unlikely.

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>3.31</th>
<th>1.192</th>
<th>0.313</th>
<th>0.756</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>3.22</td>
<td>0.975</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. I understand clearly how to play CoboFun so that it is unnecessary to use the tutorials for beginners.

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>3.12</th>
<th>0.816</th>
<th>1.426</th>
<th>0.160</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>2.78</td>
<td>0.941</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. I would like immediate feedback in the form of hints to help me to solve the puzzles.

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>4.23</th>
<th>0.863</th>
<th>2.545</th>
<th>0.014*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>3.59</td>
<td>1.012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. The system manipulation is complex and difficult to learn (reverse question).

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>26</th>
<th>3.12</th>
<th>1.033</th>
<th>0.557</th>
<th>0.580</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>32</td>
<td>2.97</td>
<td>0.967</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *p < 0.05.

**Discussion**

In this study, a game-based learning service named CoboFun was developed to engage learners with different cognitive styles in a blend of physical and digital space in a museum. A flexible learning environment with various types of learning supports and problem-solving tasks was provided to encourage diverse learners to interact with museum exhibits and with their peers. The learners’ perceptions were assessed to understand the needs of the learners with different cognitive styles. The results show that FI and FD learners have different preferences for service design. Although the t-test results did not reach a significant level, FI learners show noticeable preferences on “marks”, such as icon labels or map landmarks. These results are similar to previous studies that found FI learners prefer navigational structures such as indexes or searches to identify specific contents (Alhajri & Ahmed, 2016). Nisiforou and Laghos’s eye-movement (EM) study to understand FI and FD learners’ learning preferences on user-interface interactions (2016) found that FI learners have more oriented and organized EM activity in detecting specific features. In contrast, the FD learners usually use more saccades and fixations to read all the content and find specific features. The different EMs shown by FI and FD learners explain that FI learners use navigational tools because they improve their efficiency in detecting specific content. FD learners prefer to use well-structured tools because these support their learning in detailed saccades for all contents.

The results also show the different need of a corrective feedback design for FI and FD learners. The FI learners described their need for immediate, detailed corrective feedback in solving the puzzles, while the FD learners found that the minimum feedback provided by CoboFun was adequate as they just needed to know whether the answer was right or wrong. It could be that because FI learners prefer to learn alone, they need elaborative feedback to support their independence. FD learners, preferring to interact with others, can ask for help and do not need too much feedback (Chen, 2002). The results imply that the social interactions in groups are helpful to minimize the negative effects of unmatched designs for FD learners. Hence, the unmatched service design has less influence on the FD learners’ perceptions than on FI learners.

Although the FI learners are less satisfied with the service design of CoboFun than FD learners, they judged their performance to be better than the FD learners did. The differences in self-judgment on learning performances may reflect that the FD learners described their worse performances compared to those without social supports. Despite the different preferences for learning support design, both FI and FD learners agree that CoboFun creates an interactive learning experience in museums. The results show that CoboFun helps learners...
to actively engage in the museum by means of problem-solving puzzles. However, there is a need to provide flexible learning supports to meet the needs of diverse learners in their museum learning.

Conclusions

The study develops a game-based learning service to promote interactive learning experiences in a museum. Various problem-solving puzzles are provided to scaffold the expected research behaviors in order to build competency. Further, different learning supports are provided for different approaches to learning in museums. Regarding the first research question, CoboFun can facilitate an interactive museum learning experiences for diverse learners. Regarding the second research question, both FI and FD learners are satisfied with CoboFun, and there are no significant differences between FI and FD learners. Regarding the third research question, learners with different cognitive styles have different preferences and service design needs. The FIs need to help to efficiently locate specific information and they want elaborative corrective feedback to support their independent learning. The unmatched service design may influence FI learners’ perceptions better than the FD learners without the alternative social supports.

The results of this study provide practical evidence to understand the learning differences between diverse learners. However, there are some limitations. First, this study only evaluated learning perceptions. Future studies should examine the actual learning achievements. Furthermore, an analysis of learning behaviors is necessary to better support diverse learners in museums. In addition to the effect of cognitive style, factors such as prior knowledge and age can be evaluated to design better services and match diverse learners’ needs in museum learning.

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