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Abstract

Modern digital libraries not only contain rich digital resources, they are also required to provide an environment which integrates collection provision, information services, and academic activities to support effective learning. This work chose the Digital Library of Nature and Culture established by the National Museum of Natural Science in Taiwan to investigate whether the design of the information architecture of a digital library influences learning performance and whether learners with different learning styles have different information usage behaviors and learning performance when they use the digital library to support e-learning. This work suggested that e-learning supported by a digital library resulted in excellent learning performance. Regarding the influence of information architecture on learning performance, this work found that the organization system was crucial to learning performance. Further, learners with different learning performance exhibit different behaviors when they use the information architecture of the digital library. Another finding was that the learning performance of global learners was better than that of sequential learners. Global learners and those learners with superior learning performance relied more heavily on the organization system, while sequential learners and those learners with inferior learning performance relied more heavily on the search system.

Keywords: Human-computer interface; Interactive learning environments; Teaching/learning strategies; Architectures for educational technology system

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Abstract

Modern digital libraries not only contain rich digital resources, they are also required to provide an environment which integrates collection provision, information services, and academic activities to support effective learning. This work chose the Digital Library of Nature and Culture established by the National Museum of Natural Science in Taiwan to investigate whether the design of the information architecture of a digital library influences learning performance and whether learners with different learning styles have different information usage behaviors and learning performance when they use the digital library to support e-learning. This work suggested that e-learning supported by a digital library resulted in excellent learning performance. Regarding the influence of information architecture on learning performance, this work found that the organization system was crucial to learning performance. Further, learners with different learning performance exhibit different behaviors when they use the information architecture of the digital library. Another finding was that the learning performance of global learners was better than that of sequential learners. Global learners and those learners with superior learning performance relied more heavily on the organization system, while sequential learners and those learners with inferior learning performance relied more heavily on the search system.

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1. Introduction

Present digital libraries not only digitize resources, they also offer integrated environments with collections, information services, and academic activities for preserving knowledge and effectively supporting learning. Lynch and Garcia-Molina (1995) regarded digital libraries as electronic information access systems that provide organizational, selective, and well-managed information. The information architecture of digital libraries is clearly superior to that of general Internet resources because digital libraries contain well-planned metadata and expert-confirmed digital archives. In terms of e-learning and instructions, digital libraries provide quality learning resources that effectively support e-learning and present tremendous potential for use in developing instructional applications (Fuchs *et al.*, 2004). Currently, there have been several examples of digital library-supported e-learning. For example, the website of National Science Digital Library (NSDL) (http://nsdl.org/) in the USA contains a series of science-related teaching materials for teachers utilizing through the Internet and for students proceeding autonomous learning. Moreover,

the Digital Library for Earth System Education (DLESE) (http://www.dlese.org/library/index.jsp) established by NSDL contains earth science materials compiled by a group of educators, students, and scientists aiming to improve the teaching and learning quality of earth science for learners in different levels, and offers high-quality educational resources and archives for instructors (Arko*et al.*, 2006). Additionally, the Chemical Education Digital Library (ChemEd DL) (http://www.chemeddl.org), a sub-project supported by National Science Foundation, collects the interactive resources between teaching and learning in chemistry with which learners could rapidly acquire the learning resources marked by the teachers through online searching and browsing. The British Library (http://www.bl.uk/) also provides e-learning websites with rich digital resource collections for students, teachers, and lifelong learners. The website presently contains thousands of digital resources, images, voices, and maps for use as teaching materials (Brindley, 2005). Additionally, the Taiwan Ministry of Education developed the Digital Education and E-learning - Integrating Digital Archives into Instructions (http://idatp.moe.edu.tw/index.aspx) to support the use of digital archives in the curricula of elementary and junior high schools, providing teachers with teaching resources, and enhancing the teaching quality for exquisite instruction. Apparently, digital library-supported e-learning has been gradually emphasized. However, e-learning is still in the stage of developing and providing supporting learning materials. The design of information architectures for digital libraries that support e-learning and models for effective learning have been neglected.

To explore how digital libraries effectively support e-learning and enhance learning performance, the interaction between learners and digital libraries during the learning process must be clearly understood. Digital libraries should present quality information organization and strong information retrieval systems for the convenience of learners when they search and browse digital collections to gain knowledge through reading and learning. Nevertheless, for any digital library, designing an information architecture that effectively supports learning is very challenging (Chen & Chen, 2010). Arms, Blanchi & Overly (1997) therefore proposed to organize digital libraries so as to confirm the users' demands and to design organization system, labeling system, navigation system, and search system with the concept of information architecture for learners searching and retrieving information. Dong and Agogino (2001) also argued that well-organized information can help learners create, integrate, and manipulate knowledge rather than simply accepting knowledge passively. Beiers (2000) considered the conformity of information architecture to learner demands and the provision of a user-friendly environment for learners concentrating on specific subjects to minimize obstacles to the use of information. Moreover, personal information management (PIM) refers to user activities related to acquiring, organizing, retrieving, and processing information in their personal information spaces (Indratmo & Vassileva, 2008). Studies of practical PIM for well-organized information systems provide insight into how information organization affects individual human life. This aspect also has positive impacts on the information architecture of digital libraries, particularly when designing appropriate organization systems for individual users.

As a result, the information architecture of digital libraries is a primary concern for learners, and the excellence and integrity of the information architecture should be considered when designing digital libraries so as to meet learner demands and to enable digital libraries to provide high-quality digital resources.

Based on the above research background and our literature review, this work found that studies of e-learning support in digital libraries are still insufficient; most focus on evaluating the usability of digital libraries rather on whether they effectively support learning. To fill the research gap, the first research dimension in this work examined the effectiveness and usage behavior of digital libraries for assisting learning from the perspective of the information architecture of digital libraries (*i.e.*, organization systems, navigation systems, and search systems). In addition to discussing the effects of the information architecture of digital libraries on learning performance, this study also investigated how the personal traits of learners affect learning performance. Keefe (1979) discussed the effects of learning styles on learning performance, including the interacting effects of cognition, emotion, and psychological behaviors in learning environments. Moreover, Felder and Silverman (1988) proposed that learning styles depend on how learners receive and deal with information and indicated that learning retardation was likely to appear when not offering learners with the preferred learning styles. In this case, the design of information architecture for digital library-supported e-learning should also provide suitable support and services to accommodate individual differences in learning styles. Therefore, from the perspective of information architecture in digital libraries, the second research dimension in this work was to compare information usage behaviors and learning performance in learners with different learning styles and learning proficiency levels in the context of e-learning with digital library support. Finally, the third research dimension in this work was to examine whether significant behavioral transfers occur in learners with different learning styles and learning proficiency levels in the context of e-learning with digital library support.

2. Literature Review

2.1 Digital library-supported e-learning

The rapid development of information and communication technologies as well as the demand for improvements in conventional instruction modes have gradually led to changes in teaching and learning methods. Libraries have a long history of use for assisting learning and have at least three roles in supporting learning (Marchionini & Maurer, 1995), including physically sharing rich and valuable resources, preserving and organizing antiques and thoughts culturally, and gathering people and thoughts socially and intellectually. Compared to conventional libraries, digital libraries provide users with more opportunities for information access and informal learning so that knowledge could be conveniently obtained by autonomous learning. Through digital libraries, learners do not acquire knowledge by instruction from teachers. Rather, they ubiquitously absorb new knowledge through the rich archives in digital libraries. This leads to an ambiguous boundary

between teaching and learning. Therefore, conventional libraries began providing virtual or digital support for e-learning and began providing learners with customized services and resources (Sharifabadi, 2006). To address these changes, Sharifabadi (2006) proposed that digital libraries should reconsider how to develop, manage, and deliver digital resources for effectively supporting e-learning. Kovel-Jarboe (2001) also claimed that digital libraries should develop e-learning environments and innovative methods for enhancing teaching and learning experiences.

Kuhlthau (1997) pointed out that the main advantage of learning supported by digital libraries is to provide a convenient learning environment where learners can identify relevant and useful resources, organize information, and solve problems by using the abundant resources in digital libraries. An effective digital library should also support knowledge construction by users and self-learning. Lee (2001) concluded that the benefits of digital library-supported e-learning include improving proficiency, increasing comprehensive education resources, and providing students and educators with easy access to digital library resources. Sumner and Marlino (2004) proposed that digital libraries can be considered cognitive tools for supporting learning and sense-making activities so that users can self-learn and self-construct knowledge with the support of rich digital resources in digital libraries. They also argued that digital libraries are component repositories that provide rich digital resources for educators and learners and they enable course designers to construct new teaching materials by reallocating the digital resources in digital libraries. The authors also suggested that digital libraries are knowledge networks that support users in constructing and sharing knowledge through interaction.

In recent years, the number of digital libraries has substantially increased, and the implementation of digital library-supported e-learning has been highlighted. Examples of digital library-supported e-learning include American Memory (http://memory.loc.gov/ammem/index.html) for teachers, which provides many value-added applications by transferring the digital archives for classroom-ready materials and teachers' professional development courses; DLESE Teaching Box (Arko*et al.*, 2006) offers classroom-ready materials that assist educators in applying the educational resources to classes; NSDL Strand Map Service (http://strandmaps.nsdl.org/), which supports users in comprehending the resources in digital libraries with interactive concept maps, helping them orientate the information search activities from the broad knowledge organization; Digital Water Education Library (DWEL) (Ziemba, Cornejo, & Beck, 2011) in the USA offers technological tools, which specifically support users in constructing knowledge and sharing knowledge, draw the knowledge related to water in the Earth system with ontology for the professional development of teachers, and possess rich and professional learning resources (Sumner & Marlino, 2004). Moreover, Goh*et al.* (2005) described GeogDL, a web-based application for accessing a digital library of geographical resources for Singapore students for a national examination in geography. Notably, GeogDL provides an active learning environment and a pragmatic approach to learning that recognizes the importance of examinations, especially those in the Singapore educational system. Chu *et al.* (2008) developed an e-library of butterflies and ecology with metadata to teach

elementary school students observation and classification skills in a mobile learning environment. Marshall *et al.* (2006) also developed the GetSmart system to support theoretically sound learning processes in a digital library environment by integrating course management, digital library, and concept mapping components of a constructivist, six-step information search processes. Chen and Chen (2010) demonstrated the superior learning performance and satisfaction of learners who performed problem-based learning supported by digital library resources compared to learners who performed problem-based learning supported by search engine resources.

The above studies and the overall literature confirm the high value of digital library-supported e-learning, and many domestic and international digital libraries have established websites for digital library-supported e-learning, in which the materials are designed for immediate application by teachers in their classes and for learners to implement self-learning through the well-organized learning websites. This study mostly focuses on how digital libraries provide digital resources for learning applications. The literature shows that few studies have evaluated learning performance when learners perform learning with the support of digital libraries. Therefore, this work focuses on evaluating learning performance in digital library-supported e-learning and observes how learners precede effective learning through the information architecture of digital libraries.

2.2 Applying information architecture to digital libraries

The term “information architecture (IA)” was coined by Wurman in 1975 to describe how data are organized into meaningful information (Dillon & Turnbull, 2005). Beiers (2009) claimed that information architecture is the art and science of organizing information for maximizing the accessibility and usefulness of information (Beiers, 2000). To assist users in finding and managing information effectively, information architectures can be divided into four dimensions: organization system, labeling system, navigation system, and search system, and is based primarily on constructivist learning theories with reference to information processing as a model of mental cognitive tasks (Dong &Agogino, 2001). Searching for data on the Internet has become very convenient in recent years, and search engines such as Google and Yahoo are widely used for information retrieval. Although users can receive abundant information from search engines, the information acquired by search engines generally lacks a strict information architecture (Dillon & Turnbull, 2010). Thus, users are easily becoming lost in hyperspace when seeking digital resources from the Internet (Chen & Chen, 2010). Similarly, digital libraries that lack good information architectures increase the mental effort required for searching and browsing digital resources. Thus, favorable information architecture designs are needed for digital libraries to provide convenient and easily used digital resources. Morville and Rosenfield (2007) argued that digital library websites require an effective information architecture to provide users with high quality and usable information. Therefore, information architectures benefit the website design and the information organization of digital libraries. In this case, Arms, Blanchi, and Overly (1997) also claimed that the organization of digital libraries should have a favorable information architecture because the

information architecture provides a valuable reference for guiding the design of digital libraries.

On the other hand, digital libraries must develop effective information architectures based on a long-term plan because digital libraries are the organism of information growth over time. The concepts and practices of information architecture provide a useful blueprint for establishing digital libraries (Surla, 2007). An optimal information architecture supports digital library services and ensures that the organized digital resources are user-oriented and user-centered and benefit users in searching and browsing digital resources (Parandjuk, 2010). The development of new multimedia formats also facilitates digital libraries in developing information architecture by providing optimal presentation and well-organized video and audio files (Dillon & Turnbull, 2010). Parandjuk (2010) also agreed that information architecture supports library services for accessing digital contents and that the information architecture of digital libraries can reduce browsing time and enhance information retrieval. Additionally, Dong and Agogino (2001) proposed several principles for applying information architecture to construct educational digital libraries. Their study argued that organization systems give students and educators opportunities to create, synthesize, manipulate, and debate digital collections rather than passively receiving information from the digital collections. Labeling systems precede information classifications with different educational purposes, such as information designed for different ages, instructional methods, and academic levels, in order to achieve the educational utilization. Navigation system proceeded collection navigation and assisted the users in adapting to learning resources and performing individual learning objectives. Finally, an effective search system is needed to enable searches based on personal interests, knowledge, comprehension, capabilities, and experiences of educators or students.

In summary, the quality of an information system mainly depends on the information architecture. Therefore, the information architecture of digital libraries should have a user-centered design, and the development of digital libraries with good information architecture should be regarded as a continuous process. However, to the best of our knowledge, the literature includes few studies of how the information architecture of digital libraries affects learning performance. Most studies of digital libraries have focused on evaluating usability rather on their effectiveness for providing learning support. Thus, this work aims to observe the effects of the information architecture of digital libraries on learning performance from the perspective of digital library-supported e-learning.

2.3 Effects of learning styles on information usage behavior and learning performance

The terms cognitive style and learning style are sometimes used interchangeably, but few studies claim that cognitive style can be considered a major component of learning style (Cassidy, 2004). Cassidy (2004) indicated that the cognitive style of an individual is a typical or habitual mode of problem solving, thinking, perceiving and remembering. In contrast, learning style refers to

how cognitive style is applied in a learning situation. Many studies agreed that learning style is a key factor in individual learning achievement (Abidin, Rezaee, Abdullah & Singh, 2011), learning behavior (Chen and Macredie, 2002), learning strategies (Liu & Reed, 1994), and organizing and processing information methods (Frias-Martinez, Chen, & Liu, 2007) during learning processes. Abidin*et al.* (2011) reported a significant relationship between overall academic achievement and learning styles. Chen and Macredie (2002) also argued that the cognitive styles of learners affect their reactions to the application interface of hypermedia learning systems in terms of user control, multiple tools and nonlinear interaction. Liu and Reed (1994) found that groups with different learning styles use different learning strategies to perform similar tasks in a hypermedia learning environment. Frias-Martinez, Chen and Liu (2007) confirmed that the cognitive styles of learners significantly affect their preferences for organizing and processing information.

Studies of the relations between cognitive style and information usage behavior of digital libraries have also attempted to improve the user interface and the mechanisms of digital libraries according to users' cognitive styles (Frias-Martinez, Chen & Liu, 2007; Frias-Martinez, Chen & Liu, 2008). Frias-Martinez, Chen and Liu (2007) reported that cognitive style is a relevant parameter for measuring how a user interacts with a digital library interface. Their study proposed a regression approach, which can automatically identify the cognitive styles of each user for personalized services, based on how a user interacts with a digital library interface. Analytical results revealed that using the proposed regression approach to predict the cognitive styles of users when providing personalized services effectively improves the satisfaction of users when they seek information in digital libraries. Moreover, Frias-Martinez, Chen and Liu (2008) further examined how the cognitive styles of users affect their behaviors and perceptions when they seek information in digital libraries. They classified users as field independence/field dependence and verbalizer/visualizer for investigation. Their study found that cognitive style is an influential factor in information seeking and that intermediate users and verbalizers not only have more positive perceptions compared to other users, they also complete the tasks more effectively. Thus, the interface design for digital libraries cannot neglect the demands and preference of users with various cognitive styles.

The learning styles proposed by Felder and Silverman (1988) analyzed learner perceptions and their information processing methods to understand their sensory preferences. According to learning preferences, Felder and Silverman (1988) proposed Index of Learning Styles (ILS) for identifying learners as four learning styles, namely active/reflective, sensitive/intuitive, visual/verbal, and sequential/global. Sensitive learners prefer facts, data and experimentation and are patient with details, but they dislike complications. Intuitive learners prefer principles and theories and are bored with details. Visual learners easily remember what they see in images, diagrams, timelines, films, demonstrations. In contrast, verbal learners easily remember what they have heard, read or said. Moreover, active learners learn most effectively when working in groups and when manipulating things while reflective learners work most effectively alone and learn when they can think and reflect about the information presented to them. Sequential learners prefer to follow a process of linear reasoning to resolve problems and can

work with material once they have partially or superficially understood it. Global learners make intuitive leaps when they interpret information and may find it hard to explain how they reached a solution. The rich digital resources in digital libraries present diverse information, and the different behaviors of learners with distinct learning styles during digital library-supported e-learning are worth exploring. Based on the Felder and Silverman concept of multi-dimensional learning styles, this work compares information usage behaviors in different information architectures of digital libraries and compares the learning performance of learners with various learning styles. The findings can be used to provide appropriate services when developing digital libraries for learners with distinct learning styles.

3. Research Methodology

3.1 Research architecture

According to the information architecture developed by Morville and Rosenfield (2007), the information architecture of digital libraries contains organization systems, navigation systems, search systems, and labeling systems. An organization system includes an organization scheme and organization structure. An organization scheme defines the shared characteristics of content items and affects the logical grouping of content items whereas an organization structure defines the types of relationships between content items and groups (Morville & Rosenfield, 2007). Organization schemes can generally be classified as exact schemes or ambiguous schemes. Exact organization schemes divide information into well-defined and mutually exclusive sections. Common exact schemes include alphabetical, chronological, and geographical organization schemes. Ambiguous organization schemes divide information into categories that defy exact definition. Because ambiguous organization schemes use ambiguous language and organization and are highly subjective, they are difficult to design and maintain. However, ambiguous organization schemes are often more important and useful than exact organization schemes (Morville & Rosenfield, 2007). Examples of ambiguous schemes are topic-based, task-based, audience-based, metaphor-based, and hybrid-based organization schemes. Moreover, commonly used organization structures include hierarchy model (a top-down approach) and database model (a bottom-up approach). The hierarchy model presents the relation of subordination, and the branches are exclusive so that the users could rapidly understand the content relationship through the hierarchical structure. The database model presents information based on relational database structure and is most suitable for collections of structured, homogeneous information within a broader web site (Morville & Rosenfield, 2007). The Digital Library of Nature & Culture used in this work contains topic-based, task-based, and audience-based organization schemes and applies a hierarchical organization structure to organize digital collections.

Navigation systems include global navigation systems that allow users to connect directly to important regions and functions, regardless of the hierarchy, local navigation system, providing the users with sub-website regions for rapid connection, and site map, reinforcing the information

hierarchy in digital libraries so that users can rapidly familiarize themselves with the content and directly access the website content. The Digital Library of Nature & Culture includes a global navigation system, local navigation system, and site map to help users avoid getting lost in the digital library web site. Moreover, the Digital Library of Nature & Culture search system enables full-text searches for all digital library contents and advanced search for setting the search conditions and acquiring more accurate results. Finally, according to Morville and Rosenfield (2007), the labeling systems effectively communicate information to learners to provide a clear understanding of the website content. A labeling system is also a medium that learners can use to find resources and is included in the entire digital library website, including situational connections, topics, options for navigation systems, and index terms. Thus, including labeling systems in the analysis of the effects on e-learning performance appears problematic and not very meaningful. This work therefore focuses on investigating how the information architecture of organization systems, search systems, and navigation systems in digital libraries affect e-learning performance.

Moreover, overall learning performance is assessed, and learning performance is differentiated among learners with different learning styles. Based on the Felder & Silverman Index of Learning Styles (ILS) (Felder & Silverman, 1988), this work classified learning styles as active/reflective, sensitive/intuitive, visual/verbal, and sequential/global to compare information usage behaviors in different information architectures of digital libraries and to compare the learning performance of learners with distinct learning styles. Figure 1 shows the research architecture of the study.

Insert Figure 1 about here

3.2 Experimental design

To explore the effects of the information architecture of digital libraries on learning performance during digital library-supported e-learning, this study performed an instructional experiment using the Digital Library of Nature & Culture established by the National Museum of Natural Science in Taiwan. Moreover, the earth science teachers in The Affiliated Senior High School of National Taiwan Normal University were invited to design the learning sheet related to climate change based on the website contents in the digital library to guide the learners in performing the major learning tasks. The learning sheets of pretest and posttest contain the same questions with 10 multiple-choice questions and 2 short answer questions. The evaluation outcomes of the learning sheet of pretest and posttest were regarded as the evaluation bases of prior knowledge and learning performance, respectively. Since the information architecture design of the Digital Library of Nature & Culture was complete and well-suited for supporting e-learning, the digital library conformed to the requirements of this work and was selected as the research tool. The Digital Library of Nature & Culture covers four topic-based projects, as animals, plants, geology, and anthropology containing 13 academies and 16 sub-projects. Figure 2 shows the Digital Library

of Nature & Culture website, which has two main parts, digital archival pages and e-learning pages. Digital archival pages in the Digital Library of Nature & Culture have widely varying digital content but do not have a well-organized instructional design. The e-learning pages have well-organized content based on reorganized digital archival pages that provide appropriate learning materials for some learning subjects so as to support online learning and instruction effectively. That is, compared with digital archival pages, the e-learning pages were ready-to-use learning materials that were easily incorporated in the library resources.

Insert Figure 2 about here

Based on the website content in the digital library, the learners were requested to solve the questions on the learning sheet. The Morae human-machine interactive analysis software was used to record the 70-min learning processes of learners who used the digital library to answer the questions on the learning sheet. Morae could record the entire learning processes of a learner, including the usage behaviors when operating the digital library website, the voice, facial expression, on-site answers, and questionnaire results. It also provides remote real-time monitoring and post-analysis of the test results.

3.3 Research instruments

To study how learning performance and information usage behaviors are affected by information architectures in digital libraries, Morae software was used to analyze the behaviors of learners during learning activities supported by digital libraries. The Morae software enabled measurement and observation of how learners use websites of digital libraries. Morae Recorder (TechSmith, Version 2.2) was used to record the screen actions that are analyzed in this work and detailed log files of the recordings were created with Morae Manager (TechSmith, Version 2.2) to enable in-depth analysis. The coding is processed by manpower and the marking function of Morae, and the information usage behaviors towards each click on the information architecture of the Digital Library of Nature & Culture are marked and summed. Three dimensions of information architectures were collected and coded: organization system, search system, and navigation system. For instance, the use of an organization system by a learner was recorded whenever the learner clicked on an organization system in the Digital Library of Nature & Culture during the learning processes.

This work also applied the Felder & Silverman Index of Learning Styles (ILS) (Felder & Silverman, 1988) to categorize the learning styles of learners into active/reflective, sensitive/intuitive, visual/verbal, and sequential/global in order to investigate the differences between the information usage behaviors towards the information architecture of digital libraries and the learning performance of learners with distinct learning styles. Felder and Spurlin's study (2005) indicated that the Cronbach's alpha values of all ILS dimensions for identifying learning

styles exceed the criterion value of 0.5. Tuckman (1999) argued that values greater than 0.5 are acceptable for attitude assessments such as the ILS. Thus, the ILS can be considered reliable.

3.4 Research participants and the experimental procedures

Twenty-seven students from The Affiliated Senior High School of National Taiwan Normal University were invited to be experimental subjects. To evaluate the learning performance, all invited learners were asked to assess their prior knowledge by answering the questions on the learning sheet before performing the learning activities. Moreover, to compare how the information architecture of the digital library affected information usage behaviors among learners with different learning styles during digital library-supported e-learning, the Felder & Silverman Index of Learning Styles (ILS) (Felder & Silverman, 1988) was used to classify learning styles. To ensure that the participants understood the archived contents and the functions provided by the Digital Library of Nature & Culture, the contents and the operating functions in the digital library were briefly introduced before performing the learning activities so that participants could quickly enter the learning condition. In the learning activities with digital library support, the learners were asked to answer the questions on the learning sheet. Morae was used to record the learning processes of all participants as they used the digital library to answer the questions on the learning sheet. After they completed the learning tasks on the learning sheet, the evaluation results were used as the posttest results and were compared with the pretest results to measure learning performance.

4. Experimental Analysis

4.1 Learning Performance Analysis

4.1.1 Comparison of the pretest and posttest results of the learners

To determine how the digital library affected performance of the assigned learning tasks included in the learning sheet, the pretest and the posttest results were compared by paired samples *t* test. Table 1 shows the comparison results. The pretest and posttest results significantly differed ($t=-9.32$, $p=.000<.05$) with the average score 4.22 for the pretest and 8.52 for the posttest. The improved posttest scores confirmed the improved learning performance achieved by using the digital library to support e-learning.

Insert Table 1 about here

4.1.2 Comparison of learning performance in learners with different learning styles

To confirm that the learning performance of learners with different learning styles did not result from differences in prior knowledge, the pretest results of the learners with distinct learning styles were analyzed by independent samples *t* test. The comparison results revealed no significant differences in the pretest results. That is, learners with distinct learning styles had equivalent prior

knowledge on the learning sheet of climate change. Next, the posttest results of the learners with the considered learning styles were analyzed by independent samples *t* test. Table 2 shows the results. The results shows the significant difference in the learning performance between sequential and global learners ($t=-2.67$, $p=.013<.05$), and global learners outperformed sequential learners. In contrast, the learning performance of the rest active/reflective, sensitive/intuitive, and visual/verbal learners did not significantly differ.

Insert Table 2 about here

4.2 Correlation analyses of information usage behavior of learners towards information architecture of digital library and learning performance

To perform correlation analyses of information usage behavior of learners towards information architecture of digital library and learning performance, this work considered three dimensions of information architecture: organization systems, search systems, and navigation systems. Any information usage behavior by a learner who used the digital library to solve the questions on the learning sheet in the 70-min learning processes was considered a unit of measurement. However, each learner showed different information usage behaviors on the same digital library while finishing the assigned learning tasks on the learning sheet. This work thus normalized the clicks by the learners when using the information architecture and analyzed the proportional use of the information architecture. Table 3 shows the descriptive statistics of the learners who used the information architecture of Digital Library of Nature & Culture for e-learning.

Insert Table 3 about here

4.2.1 Correlation of the posttest results and information usage behaviors in different information architectures of the digital library

This work performed the correlation analyses between the posttest results and the proportional use of the information architecture of the digital library website. In addition to providing general digital archives, the Digital Library of Nature & Culture website supports e-learning by providing well-organized e-learning pages based on predetermined learning topics. Therefore, this work performed the correlation analyses of the posttest results and the information usage behaviors towards the information architecture of the overall digital library, digital archival pages, and e-learning pages, respectively. Regarding the information architecture of the overall digital library, the results showed a significant positive correlation (0.491) between the posttest results and the proportional use of the organization system. This indicated that the learners who used organization system more frequently received higher posttest results. Regarding the information architecture of e-learning pages, the posttest results and the proportional use of the organization system showed a

significant positive correlation (0.661). That is, as the posttest scores increased, the proportional use of the organization system in the e-learning pages increased, but no significant correlation was identified in the information architecture of digital archival pages.

4.2.2 Correlation analyses of the posttest results and time spent using the information architecture of the digital archival and e-learning pages

To analyze the time spent using digital archival and e-learning pages when the Digital Library of Nature & Culture was used for learning activities, the time spent using digital archival and e-learning pages of the learners was calculated, and the correlations between learning performance and using time on digital archival and e-learning pages were analyzed. Pearson correlation analyses showed that the posttest results had a strong correlation (0.449) with time spent using e-learning pages, but not with time spent using digital archival pages. That is, the learners who spent the most time using e-learning pages had higher posttest results compared to those who spent the most time using digital archival pages.

4.3 Comparison of information architectures used for learners with different learning performance

To compare how learners with different performance use the information architecture of the digital library, this work followed the statistical procedure of using the upper and lower 27% of the posttest scores to identify extreme high-proficiency and low-proficiency groups under considering the degree of discrimination of high- and low-proficiency groups (Kelley, 1939). The proportion of using the information architecture of the digital library between high-proficiency and low-proficiency groups was analyzed based on the independent samples *t* test. Table 4 shows the results. The comparison results showed that the percentages of learners who used the information architecture of the digital library significantly differed between the two groups ($t=2.36$, $p=.031<.05$). Specifically, the use of the organization system was significantly higher in the high-proficiency group than in the low-proficiency group.

Insert Table 4 about here

Moreover, to differentiate the two groups in terms of time spent using digital archival and e-learning pages during digital library-supported e-learning, the using time of the digital library between high-proficiency and low-proficiency groups were analyzed based on the independent samples *t* test. Table 5 shows the results. The results presents significant differences in using time on e-learning pages between the two groups ($t=2.27$, $p=.037<.05$) and the high-proficiency group spent more time on e-learning pages than the low-proficiency group did. However, both the groups did not significantly differ in the time spent using digital archival pages.

Insert Table 5 about here

4.4 Lag sequential analyses

To analyze the behavioral transfer of the learning processes of learners who use the information architecture during digital library-supported e-learning, the information usage behaviors of the learners were encoded, according to the information architecture, for lag sequential analysis. To perform the lag sequential analysis, the number of samples in sequential analyses was calculated by frequency of the neighboring pairs of events. The Zero-order model proposed by Bakeman (1986) was used to calculate the Z score. The calculation is suitable for samples with a non-normal distribution when the probability of sequence is equal. A Z score above 1.96 indicated that the sequence presented remarkable coding transfer that the learners with obvious behavioral transfer in the information architecture could be observed, and a high Z score indicates a larger behavioral transfer compared to a low Z score. Figure 3 shows the lag sequential analyses of the behavioral processes of learners when using information architecture of digital library. Figure 3(a) shows the lag sequential analysis results for all learners in using the information architecture of the digital library. The results showed significant coding transfers for (Z >1.96) on S→S (30.62) and O→O (28.50), which indicated that the learners concentrated on the behavioral transfer between search system and organization system in the information architecture of digital library. That is, when using the digital library, the most frequently used system was the search system, followed by the organization system, and the behavioral process in search system → search system was slightly higher than it in organization system → organization system.

According to the previous analyses, sequential and global learners significantly differed in learning performance and global learners were superior to sequential learners. To differentiate behavioral processes in the information architecture, lag sequential analyses of sequential and global learners using the information architecture of digital library were performed. Figures 3(b-c) show the results. Figure 3(b) shows the significant coding transfer (Z >1.96) on S→S (24.83) and O→O (19.09) within the 15 sequential learners, and sequential learners showed higher behavior transfer when they used the search system compared to when they used the organization system. Figure 3(c) shows the remarkable coding transfer (Z >1.96) on S→S (18.05) and O→O (21.57) within the 12 global learners when using the information architecture. Notably, global learners presented higher behavioral transfer when using the organization system than they did when using the search system.

Moreover, previous analyses revealed significant behavioral differences between the high-proficiency and low-proficiency groups when using the information architecture of the digital library. To determine the behavioral sequence when using the information architecture of the digital library, lag sequential analyses of the behavioral processes were performed in the high-proficiency and low-proficiency groups. Figures 3(d) and 3(e) show the comparison results. Figure 3(d) shows

the significant coding transfer (Z >1.96) on S→S (11.60) and O→O (23.25) within the 9 learners in high-proficiency group, and the learners in high-proficiency group appeared higher behavioral transfer on using organization system than on using search system. Figure 3(e) shows the remarkable behavioral transfer (Z >1.96) on S→S (21.87) and O→O (13.15) in the nine learners in the low-proficiency group. Sequential learners exhibited higher behavioral transfer when using the search system than they did when using organization system.

Insert Figure 3 about here

5. Discussion

The experimental results revealed that learning performance was enhanced by using the digital library to support a specific learning task. Particularly, the research findings showed that learning performance increased with the frequency in using the organization systems in the digital library. Moreover, the experimental results revealed that use of the organization systems was higher in the high-proficiency group than in the low-proficiency group. Clearly, the organization system in the information architecture of the digital library is the major factor in learning performance. Chen and Chen (2010) claimed that digital libraries with well-organized information architectures facilitate better learning than open digital resources stored on the Internet. Their study also identified the importance of information architecture while reading or searching for information in digital libraries during problem-based learning activities. Dong and Agogino (2001) argued that organized information provides opportunities for learners and educators to create, synthesize, manipulate or debate content rather than merely passively receiving instructions; that is, information architectures can provide learners with a supportive environment so that they can concentrate on subject content rather than battling with the medium itself (Beiers, 2000). Particularly, in information architecture, organization systems mainly focus on organizing data into meaningful information to maximize user accessibility and usefulness based on the shared characteristics of content items, the logical grouping of contents items, and the relationships between content items and groups (Morville & Rosenfield, 2007). Therefore, compared with search systems and navigation systems, organization systems are more important for learning because well-designed organization systems can facilitate users in information seeking, information navigation, and information access.

Moreover, this work proved that, for improving learning performance, spending learning time on e-learning pages is more effective than spending learning time on digital archival pages and that the information architecture of digital archival pages is unsuitable for instructional support or for e-learning. When digital archival pages are organized for supporting e-learning, the efficacy of digital archives-supported e-learning is enhanced. In this case, the digital archival pages should be well-organized when planning digital library-supported e-learning so as to provide an environment conducive to learning. Many studies also show that learners with distinct learning styles present different learning performance (Zywno & Waalen, 2002; Chen & Sun, 2012). The research

outcomes show learning performance significantly differs between sequential and global learners and global learners outperform sequential learners. The literature shows that sequential learners tend to manipulate linear procedures for comprehension while global learners tend to manipulate unlinked sections or randomly comprehend information (Zywno & Waalen, 2002). Otter and Johnson (2000) pointed out that the confusion of information seekers mainly results from the difficulty in perceiving the entire information architecture. Additionally, learners often get lost in non-linear hyper-documentary spaces and web sites when following the page links during an information search and then have difficulty continuing the previous task objective (Katsanos, Tselios & Avouri, 2008). This work confirmed that the learning performance of global learners is better than that of sequential learners, as the latter are less adaptive to the linking sequence or the web page arrangement logic in the Digital Library of Nature & Culture. Klašnja-Milicevic*et al.* (2011) indicated that sequential learners tend to be logical and search for answers in steps whereas global learners rapidly solve complicated problems by using a general blueprint. Global learners therefore were unaffected by the linking sequence of web pages. This work inferred that this is the main reason why global learners outperform sequential learners.

Moreover, based on the Z scores in lag sequential analyses, the analytical results showed that the high-proficiency group and global learners tend to rely on organization systems while learners in low-proficiency group and sequential learners tend to rely on search systems. Kirsh (2000) mentioned that learners often spend excessive time on search tasks, which causes pressure during learning processes, and that learners are likely to perform more searches when resources are uncertain, which increases dissatisfaction. Gwizdka and Lopatovska (2009) indicated that the less use of search strategies, the less lostness in search, as learners believed in finding the required information within the page links without modifying the search strategies. Therefore, this work inferred that overdependence on search systems is the cause of the lower learning performance of sequential learners and learners in the low-proficiency group compared to the global learners and learners in the high-proficiency group.

Also, the user interface used in this study was not adjusted for different learning styles. To enhance the effectiveness of digital library-supported e-learning, building suitable e-learning environments for individual differences should be considered for digital libraries. Klašnja-Milicevic *et al.* (2011) argued that e-learning systems should automatically provide various learning interfaces for learners with different learning styles. Their research indicated that supporting learning with distinct learning interfaces based on learning styles can enhance learning performance. Moreover, the work also investigated learners' satisfaction to show that more than 70% learner agreed with the convenience of the system being able to guide them to get appropriate learning resources. Therefore, when the information architecture of digital libraries is adaptively adjusted and modified according to different learning styles, the benefits of digital library-supported e-learning are enhanced, and the differences in learning performance among learners with distinct learning styles might be reduced.

Finally, some study limitations merit consideration. First, this work did not compare control

and experimental groups in terms of the effects of information architecture of digital libraries on e-learning. The problem was the relative difficulty of seeking two digital libraries with the same digital archives but with different information architectures to confirm how information architectures affect learning performance. Second, the analysis was limited to senior high school students and to the Digital Library of Nature & Culture in National Museum of Natural Science of Taiwan. Therefore, the analytical results may not be applicable to other age groups and the other types of digital libraries.

6. Conclusions & Future Work

This work showed that using the digital library to support specific learning tasks improves learning performance and the organization system in the information architecture of the digital library is the major factor affecting learning performance. Importantly, the learning performance of learners is strongly correlated with the use of organization systems as well as the correlation coefficient reached as high as 0.491. Moreover, this work proved that, for improving learning performance, spending learning time on e-learning pages is more effective than spending learning time on digital archival pages. This work also found that the high-proficiency group used the organization system more frequently and spent more time on using e-learning pages of digital library than the low-proficiency group did during digital library-supported e-learning. When using the information architecture of the digital library, the learners' behavioral transfer focuses on organization system and search system, showing such information architecture is the major information usage behaviors in digital library-supported e-learning. Additionally, the analytical results show that the high-proficiency group and global learners present higher sequential transfer on organization system → organization system, but lower sequential transfer on search system → search system compared to the low-proficiency group and sequential learners.

Additional studies are warranted. First, this work mainly discusses how the information architecture of a digital library affects learning performance and does not confirm the correlations between the information architecture of digital libraries and cognitive load during digital library-supported e-learning. Conklin (1987) pointed out that ambiguous information architecture is the major factor affecting cognitive load and lostness. Katsanos, Tselios and Avouri (2008) also demonstrated the problem of usability in poorly designed information architecture, which worsens the interactive experiences between the users and web pages. Consequently, the effects of information architecture of digital library on cognitive load are worth exploring. Second, the three dimensions for the information architecture of digital libraries are used to analyze the effects on e-learning performance, and new information architecture models have been proposed recently. Ziemba, Cornejo and Beck (2011) mentioned numerous advantages of establishing websites based on knowledge ontology. For example, the resources can be presented with hierarchic correlations, which improve search efficiency. Moreover, knowledge ontology revealed flexible and expansible characteristics so that the information presentation styles and standards could be shared and reused. He and Peng (2010) also proved that use of DiLight, a digital library based on knowledge ontology,

is helpful for learners when searching for information in e-learning with digital library support. Therefore, further studies are needed to measure the effectiveness of knowledge ontology-based digital library-supported e-learning. Moreover, this work reveals that the organization system is the major factor affecting e-learning performance. Currently, many digital libraries provide diverse organization systems to aid users in acquiring resources and learning. Thus, the correlations between various organization systems and learning performance need improved understanding. Also, the work was constructed using a small sample of information usage behaviors of senior high school students. Therefore, future studies should extend the participant pool to a larger sample size to gather additional information usage behaviors in digital libraries. Finally, further studies are needed to compare how information architecture affects learning performance in different digital libraries and in different age groups.

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Captions of figures:

Figure 1. The research architecture of the study

Figure 2. The website of Digital Library of Nature & Culture

Figure 3. Sequential analyses of learners' behavioral processes in using the information architecture of digital library

Table 1. The paired samples *t* test results of the learning performance of all learners

	Number of Learners	Mean	SD	*t*	Degree of Freedom	Significance (two-tailed)
Pretest	27	4.22	1.81	-9.32*	26	.000
Posttest	27	8.52	1.99			

1

[1] * indicates p<.05

Table 2. The independent samples *t* test of the learning performance of the learners with distinct learning styles

	Learning Style	Number of Learners	Mean	SD	*t*	Significance (two-tailed)
Posttest	Sequential	15	7.70	1.97	-2.67*	.013
	Global	12	9.54	1.50		
	Active	20	8.50	1.78	-0.08	.936
	Reflective	7	8.57	2.64		
	Sensitive	16	8.25	1.83	-0.85	.406
	Intuitive	11	8.91	2.21		
	Visual	22	8.41	1.93	-0.60	.557
	Verbal	5	9.00	2.35		

[2]

[2] * indicates p<.05

Table 3. Descriptive statistics of coding learners using information architecture of the digital library

	Number of Learners	Minimum	Maximum	Mean	SD
Organization System	27	0.06	0.84	0.53	0.23
Search System	27	0.06	0.94	0.42	0.26
Navigation System	27	0.00	0.43	0.05	0.09

Table 4. The independent samples *t* test of high-proficiency and low-proficiency groups using the information architecture of the digital library

	Group	Number of Learners	Mean	SD	*t*	Significance (two-tailed)
Organization System	High-proficiency group	9	0.65	0.20	2.36*	.031
	Low-proficiency group	9	0.40	0.25		
Search System	High-proficiency group	9	0.32	0.21	-1.66	.117
	Low-proficiency group	9	0.52	0.29		
Navigation System	High-proficiency group	9	0.03	0.03	-1.05	.311
	Low-proficiency group	9	0.08	0.14		

[3]

[3] * indicates p<.05

Table 5. The independent samples *t* test of using time on digital archival and e-learning pages between high-proficiency and low-proficiency groups

	Group	Number of Learners	Mean	SD	*t*	Significance (two-tailed)
Using Time on Digital Archival Pages	High-proficiency group	9	.0944	0.09	-0.92	.374
	Low-proficiency group	9	.1867	0.29		
Using Time on E-learning Pages	High-proficiency group	9	.6178	0.15	2.27*	.037
	Low-proficiency group	9	.3989	0.25		

4

[4] * indicates p<.05

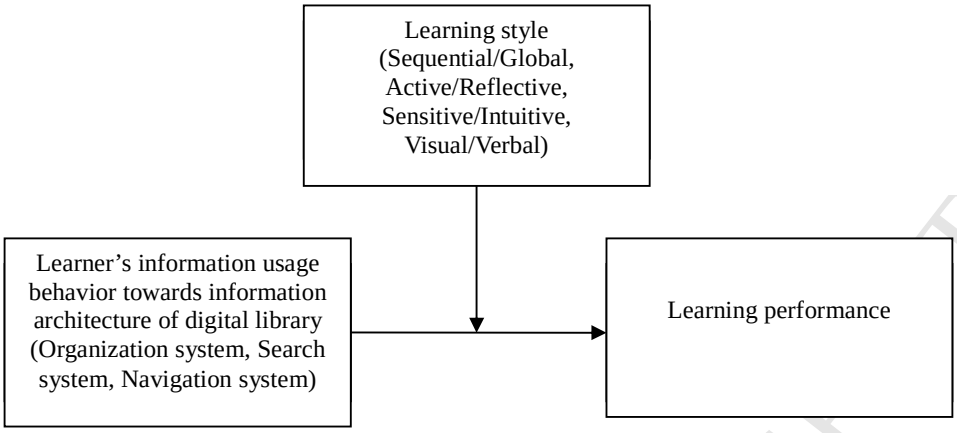
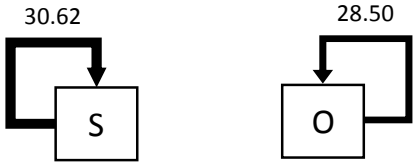
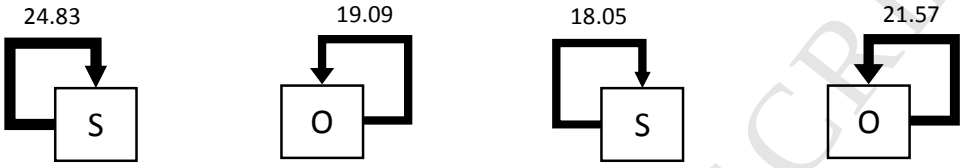


Figure 1. The research architecture of the study

Figure 2. The website of Digital Library of Nature & Culture

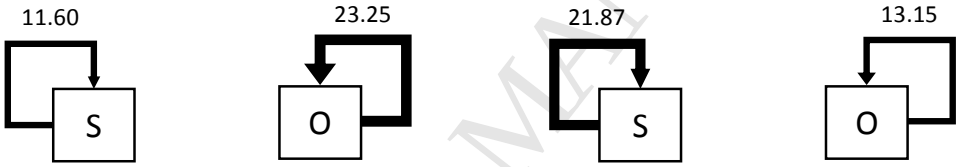


(a) Lag sequential analyses of all learners' behavioral processes



(b) Lag sequential analyses of sequential learners' behavioral processes

(c) Lag sequential analyses of global learners' behavioral processes



(d) Lag sequential analyses of behavioral processes of learners in high-proficiency group

(e) Lag sequential analyses of behavioral processes of learners in low-proficiency group

Figure 3. Lag sequential analyses of learners' behavioral processes in using the information architecture of digital library

HIGHLIGHTS

► Organization system in the digital library is the major factor affecting learning performance

► Learners with various learning performance showed different behavior when using digital library

► The learning performance of global learners was better than that of sequential learners

► Global learners and learners with good learning performance relied heavily on organization system

► Sequential learners and learners with poor learning performance relied heavily on search system