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An innovative approach for developing and employing electronic libraries to support context-aware ubiquitous learning

Hui-Chun Chu and Gwo-Jen Hwang
Department of Information and Learning Technology, National University of Tainan, Tainan City, Taiwan, and
Judy C.R. Tseng
Department of Computer Science and Information Engineering, Chung-Hua University, Hsinchu, Taiwan

Abstract

Purpose – This paper aims to propose an innovative approach to assist teachers in using electronic libraries to develop learning activities for context-aware ubiquitous learning, in which the learning system can detect students' behaviors and guide them to learn in the real world with personalized support from the digital world.

Design/methodology/approach – An electronic library with context-awareness metadata for supporting learning activities conducted in real-world environments is presented. Furthermore, a systematic procedure for guiding teachers in employing the electronic library to develop learning activities is proposed based on an innovative approach.

Findings – From a practical application conducted on an elementary school, it is found that, with this innovative approach, electronic libraries not only have the potential in supporting traditional in-class or online learning activities, but also can assist teachers and digital content workers in developing high quality learning activities and related digital learning materials to support outdoor learning.

Research limitations/implications – The findings of this paper imply that, to promote the utilization rate of electronic libraries for more specified purposes, more features of the application domains need to be considered while designing the database schemas of the electronic libraries.

Practical implications – From the feedback of teachers and digital content workers, it is found electronic libraries have high potential for supporting outdoor learning activities for "Science" and "Social science" courses with proper database schema design and the provision of user guidance.

Originality/value – An electronic library for supporting context-aware ubiquitous-learning is presented and an innovative approach for guiding teachers to design learning activities is proposed.

Keywords Artificial intelligence, Learning, Knowledge engineering, Digital libraries

Paper type Research paper

1. Background and motivation

In the past decade, digital resources, including texts, videos, images and other types of data, have grown exponentially. This has encouraged the development of digital archives for various purposes. While many researchers have put their efforts into

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creating and digitizing resources, many others have focused on system development and maintenance of digital archives (Chu *et al.*, 2008; Sreekumar and Sunitha, 2005; Uzoka and Ijatuyi, 2005).

In the meantime, the popularity of computers and networks technologies has encouraged new attempts of using digital materials to support learning activities (Barrett and Lally, 1999). Recent advances in wireless communications and sensor technologies further lead the way of technology-enhanced learning into a new era, in which students can work with problems from the real world with support from the digital world. That is, students are placed in a series of designed lessons that combine both real-world and digital learning resources (Morikawa, 2003; Minami *et al.*, 2004). With the help of these new technologies, individual students are able to learn in a real situation with support or instructions from the computer system by using a mobile device to access the digital content via wireless communications. Such a new technology-enhanced learning model is called context-aware ubiquitous learning (u-learning), which not only supports learners with an alternative way to deal with problems in the real world, but also enables the learning system to more actively interact with the learners (Hwang *et al.*, 2008; Ogata and Yano, 2004; Yang *et al.*, 2008). This great innovation has changed the concept of applying digital contents and information technologies in instructions, not only in the teaching process itself but also in the methodology applied.

One of the major difficulties of digital technology-applied instructions is the lack of an easy-to-follow procedure for those inexperienced teachers to design subject contents such that suitable digital archives or technologies can be properly applied to the tutoring process (Chu *et al.*, 2008). Therefore, it has become an important but challenging issue to develop a systematic approach for restoring the content of electronic libraries and guiding the teachers to select and use proper materials for the design of context-aware u-learning activities.

To cope with these problems, in this paper, an electronic library for supporting context-aware u-learning is presented and an innovative approach for guiding teachers to systematically and efficiently design u-learning activities by selecting and using proper materials from the electronic library is proposed. Moreover, a context-aware ubiquitous learning environment has been implemented and a learning activity was conducted to demonstrate the effectiveness of the novel approach.

2. Literature review

An electronic library is not only a digitized collection with information management tools, it is also a series of activities that include collections, services, and people in support of the full life cycle of creation, dissemination, use, and preservation of data, information, and knowledge (Saeed, 2006). In recent years, owing to the popularity of computers and networks technologies, electronic library has become a main stream of library service.

Mourad *et al.* (2005) indicated that the availability of digital content has created opportunities for universities and publishers to improve the marketplace. Various powerful search engines enable users to search a world of information in few seconds; moreover, the popularity of Bulletin Board System (BBS) and web log systems has promoted professional communities by allowing people to post valuable articles. These web-based models for using and managing digital content have motivated educational applications on the internet.

There are several advantages of employing digital archives to keep materials, including safety, security, accessibility and reliability. In additions, digital archives can be more efficiently and effectively used with metadata that reflect the expertise and experiences of using the digital content (Saeed, 2006). Nowadays, electronic libraries have become a main stream of library service. Many studies have focused on the development of new information technologies to provide more efficient and effective library service (Uzoka and Ijatuyi, 2005). For example, Vandenburg (2008) developed a tool that allowed users to search for library materials with geographic subject headings using Google Maps as the primary interface for navigation.

Both online learners and traditional learners now have access to a universe of digital information on the Internet, especially those well-structured and managed contents in electronic libraries (Weaver, 2007); therefore, the development of electronic libraries to support learning design has become an important issue (Saeed, 2006; Chu *et al.*, 2008). Furthermore, the advance of wireless communications and sensor technologies has enabled new library service. For example, Kern (2004) employed radio frequency identification (RFID) techniques to develop a modern RFID library system, which provides borrowers with five self-check stations, 13 book return stations and 11 automatic check-out gates to enhance the efficiency of library book management system. Later, Yu (2007) demonstrated the use of RFID to replace barcodes and magnetic strips for security control and collections management in library. In the same year, Butters (2007) discussed the issue about how to maintain compatibility with RFID standards to maximize the data security and borrowers' privacy in electronic library systems. Moreover, Lin *et al.* (2009) demonstrated a RFID-based guiding system for a gallery, which allowed users to retrieve information using RFID readers and share the information with those who visited their blogs via mobile devices.

In the meanwhile, educators have attempted to benefit students by applying these new technologies to the development of context-aware u-learning activities, in which students are guided to work with problems from the real world and supports from the digital world. In this innovative learning environment, each student has a handheld device equipped with wireless communications and sensor facilities. With the help of the sensor technology, the learning system is able to detect the real-world learning status of the student and provide supports or guidance through the wireless communications accordingly. Several studies have been conducted to demonstrate how these new technologies support learning in the real world (Chen *et al.*, 2003, 2008; Chu *et al.*, 2010; Hwang *et al.*, 2008). For example, Hwang *et al.* (n.d.) presented an approach to determine personalized context-aware ubiquitous learning paths to maximize the learning efficacy for individual students via guiding individual students to observe real-world objects in a meaningful sequence. It can be seen that guiding the students to learn in the real world with support from the digital world has become an important and challenging issue.

Saeed (2006) indicated that, the growth in new technology-enhanced learning has raised new research issues for library services, implying that the development of new electronic library technologies to support new educational environments or activities is needed. The study of Deneen and Allert (2003) showed that students became familiar with using hand-held computers to access digital materials very soon, although the screen resolution of the hand-held devices was low at that time. Peters *et al.* (2003) further emphasized the potential of library-supported PDA-related content and service. They indicated that, owing to the popularity of PDA, each individual user would ultimately control the local collection, design and organization of that individual's information space. Recently, Hsu *et al.* (2006) proposed a knowledge-based mobile learning framework to integrate various types of museum-wide content, and support the visitors a ubiquitous, context-aware, personalized learning for museums. This framework has been successfully implemented in the Life Science Hall of the National Museum of Natural Science (NMNS). Those studies not only demonstrate the importance of providing new services of electronic libraries in education, but also show the necessity of developing a systematic learning activity-design procedure to effectively assist teachers in interpreting and organizing their personal knowledge while selecting and using digital materials from electronic libraries. In the following sections, a new approach for coping with these problems will be presented in detail.

3. Research method

Figure 1 shows the process of developing the context-aware u-learning environment with an electronic library. The target learning objects are labeled with an RFID tag and each student has a mobile device equipped with an RFID reader. As the amount of data in the electronic library is very large, a knowledge engineering approach is employed to assist the teacher in structuring the content of the electronic library, such that the proper materials can be selected and used in the learning activities. In the following subsections, the "butterflies and ecology" electronic library, the knowledge engineering approach to assist the teachers in structuring the digital materials for supporting authentic learning activities and the learning scenario are presented in detail.

3.1 Electronic library for "Butterflies and Ecology"

Figure 2 shows the structure of the "Butterfly and Ecology" electronic library. The database of this electronic library contains photos, video clips and text for describing

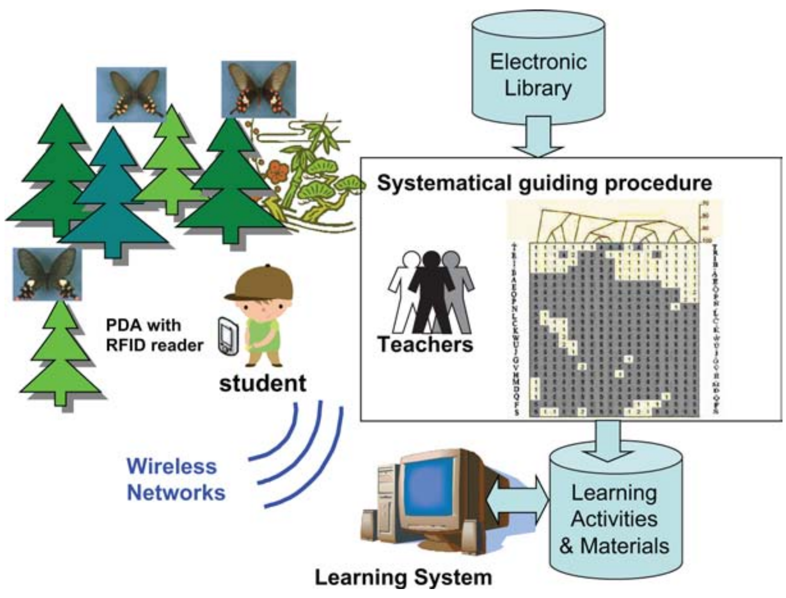

Figure 1.
Graphical representation of the innovative approach

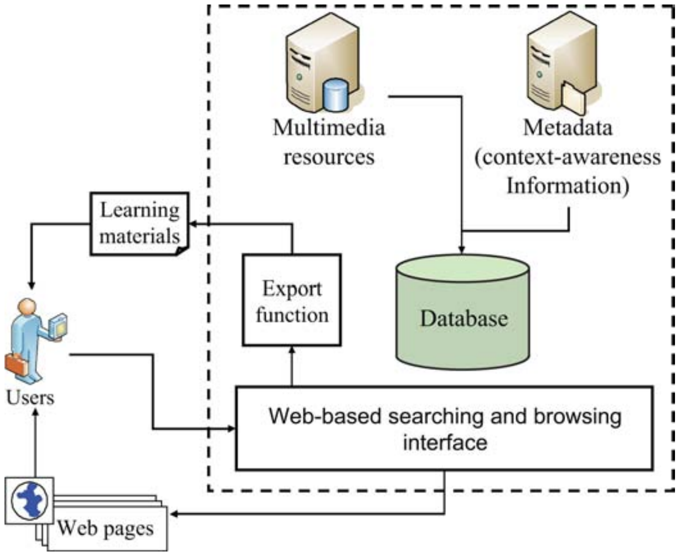

Figure 2.
Electronic library for supporting context-aware ubiquitous learning

the features and ecology of butterfly species and the related food plants. Moreover, to facilitate the concept of context-aware ubiquitous learning, the electronic library includes not only the metadata of ordinary digital content but also the context-awareness parameters, such as global positioning system (GPS) and radio frequency identification (RFID) positioning reference codes.

Figure 3 shows the user interface of the electronic library for butterflies and ecology. After logging in the electronic library, several basic functions are provided, including

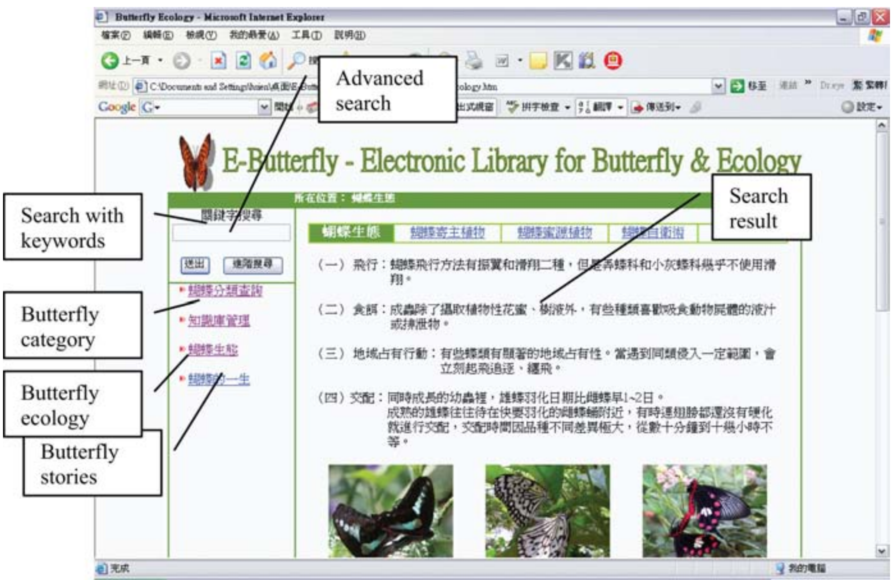

Figure 3.
Basic functions of the electronic library

"Search with keywords", "Advanced search", "Butterfly category", "Butterfly ecology" and "Butterfly stories". The search results can be web pages or learning materials (original photos, video clips and text files) so that the teachers can include them in the designed learning activities.

3.2 Repertory grid-based approach for developing learning activities

To effectively assist the teachers in interpreting and organizing their personal knowledge while selecting and using digital materials from electronic libraries, a systematic learning activity-design procedure is needed. Such a procedure for structuring the knowledge for special purposes or objectives is called knowledge engineering (Chu and Hwang, 2008). Among various knowledge engineering approaches, the repertory grid method that originates from the Personal construct theory proposed by Kelly (1955) has been recognized to be the most effective. Various studies have reported the effectiveness of using the repertory grid method in assisting the domain experts to better organize their knowledge and experiences (Boose and Gaines, 1989; Hwang *et al.*, 2006; Chu and Hwang, 2008).

A single repertory grid is represented as a matrix in which the columns have element labels and the rows have construct labels. Elements could be decisions to be made, objects to be classified, or concepts to be learned. Constructs are the features for describing the similarities or differences among the elements. Each construct consists of a trait and the opposite of the trait. A five-scale rating mechanism is usually used to represent the relationships between the elements and the constructs; i.e. each rating is an integer ranging from 1 to 5, where "1" represents that the element is very likely to have the trait; "2" represents that the element may have the trait; "3" represents "unknown", "no relevance" or "no significant tendency to both poles; "4" represents that the element may have the opposite characteristic of the trait; "5" represents that the element is very likely to have the opposite characteristic of the trait (Chu and Hwang, 2008). By means of the Repertory Grid, the learning activity development procedure is given in the following steps:

(1) Survey the authentic learning environment and decide on a set of target learning objects.
(2) Place the target learning objects on the top of the repertory grid.
(3) Determine a set of constructs that can be used to describe the relevance of the learning objects.
(4) Place the description of the construct and its opposite description on the left and right sides of the repertory, respectively.
(5) Rate each < learning object, construct > of the repertory grid.
(6) Analyze the relevance of each pair of learning objects and generate a relevance-analysis matrix.
(7) Generate the relevance-clustering tree from the matrix.
(8) Determine the learning sequence (or learning path) based on the relevance of the learning objects.
(9) Construct the learning materials by retrieving the relevant data from the electronic library.

Note that in this procedure, the repertory is used to represent the "relevance" of the learning objects (host plants of butterflies) rather than their "similarity". In most existing studies, researchers usually employ a repertory grid as a way to describe and compare the features of a set of elements (e.g. plants or butterflies); that is, the similarity analysis of the target elements is the main issue. However, in developing learning activities for guiding the students to observe an ecological environment, the relevance between each pair of learning objects is the main concern. To conduct a context-aware ubiquitous learning activity in a butterfly garden, the relevance among the host plants and the honey plants is considered. In the butterfly kingdom, the larva (caterpillar) of each species can only feed on specific species of plants, which are referred to as butterfly host plants. Honey plants are the plants that provide the nectar source for butterflies.

For example, the relevance of two butterfly host plants is high because both are food for some butterfly species. In raising host plants or honey plants, it is very important to take the ecological distribution and living habits of butterflies into consideration. Consequently, in the repertory grid for describing the ecology of butterflies, each rating is an integer ranging from 1 to 5, where "1" represents that the plant is very likely to be the food or nectar source of the butterfly species; "2" represents that the plant could be the food or nectar source of the butterfly species; "3" represents that the species of butterfly might take the plant as food or nectar source in some circumstances; "4" represents that the species of butterfly usually does not take the plant as food or nectar source; "5" represents that the plant is absolutely not the food origin or nectar source of the butterfly species.

Table I shows an illustrative example of describing the learning objects (host plants of butterflies) with a repertory grid, where E1, E2, … E12 represent "*Calamondin*", "*Tetradium glabrifolium Aristolochia kaempferi*", "*Aristolochia zollingeriana*", "*Aristolochia heterophylla*", "*Aristolochia cucurbitifolia Hayata*", "*Toddalia asiatica*", "*Zanthoxylum nitidum*", "*Crateva adansonii*", "*Severinia buxifolia*", "*Citrus limonia Osbeck*", "*Zanthoxylum ailanthoides*" and "Sieb. & Zucc.", respectively.

Once the repertory grid is constructed, a relevance-analysis formula is invoked to analyze the relevance among the elements (Shaw, 1980; Shaw and Gaines, 1989):

$$\mathrm{Relevance}(\mathrm{E_A}, \mathrm{E_B}) = 1 - \frac{\sum_{i=1}^{N} \left| RG(E_A, C_i) - RG(E_B, C_i) \right|}{K - 1} \times \frac{1}{N} \times 100\%,$$

where N is the number of learning objects and K is the maximum rating scale (in this case, $K = 5$), and RG $(\mathrm{E_A}, \mathrm{C_i})$ represents the rating for learning object $\mathrm{E_A}$ and construct $\mathrm{C_i}$. By applying the relevance-analysis formula, the relevance degrees between learning objects in Table I can be obtained, as shown in Table II.

The pairs of elements are then sorted, from larger to smaller, by the order of relevance degree; that is (E10, E11, 92.5) $>$ (E8, E11, 87.5) $=$ (E9, E10, 87.5) $=$ (E3, E6, 87.5) $=$ (E4, E5, 87.5) $>$ (E12, E7, 85) $=$ (E4, E6, 85) $>$ (E3, E11, 80) $>$ (E2, E12, 77.5) $=$ (E7, E8, 77.5) $>$ (E1, E2, 72.5). Note that in this sequence, all of the learning objects have been included. Consequently, those learning objects are then grouped based on the order of relevance degrees to form the relevance-clustering tree T, in the following iterations:

Table I.
Illustrative example of describing learning objects with a repertory grid

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	
Host plant of *Byasa polyeuctes termessus*	5	5	4	3	1	2	5	5	5	5	5	5	Not host plant of *Byasa polyeuctes termessus*
Host plant of *Byasa alcinous mansonensis*	5	5	2	2	1	3	5	5	5	5	5	5	Not host plant of *Byasa alcinous mansonensis*
Host plant of *Troides aeacus*	5	5	5	2	1	5	5	5	5	5	5	5	Not host plant of *Troides aeacus*
Host plant of *Pachliopta aristolochiae interpositus*	5	5	5	2	1	3	5	5	5	5	5	5	Not host plant of *Pachliopta aristolochiae interpositus*
Host plant of *Papilio hermosanus*	5	5	5	5	5	5	1	1	5	5	5	5	Not host plant of *Papilio hermosanus*
Host plant of *Papilio thaiwanus*	3	5	5	5	5	5	1	5	5	5	5	1	Not host plant of *Papilio thaiwanus*
Host plant of *Papilio polytes pasikrates*	2	5	5	5	5	5	2	2	5	1	1	2	Not host plant of *Papilio polytes pasikrates*
Host plant of *Papilio helenus fortunius*	1	1	5	5	5	5	2	5	5	5	5	2	Not host plant of *Papilio helenus fortunius*
Host plant of *Hebomoia glaucippe formosana*	2	5	5	5	5	5	5	5	1	2	5	5	Not host plant of *Hebomoia glaucippe formosana*
Host plant of *Papilio polyctor thrasymedes*	5	2	5	5	5	5	3	5	5	5	5	1	Not host plant of *Papilio polyctor thrasymedes*

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	–	*72.5*	60.0	42.5	30.0	52.5	70.0	67.5	75.0	82.5	75.0	75.0
E2	72.5	–	72.5	55.0	42.5	65.0	67.5	65.0	72.5	65.0	72.5	*77.5*
E3	60.0	72.5	–	82.5	70.0	*87.5*	50.0	72.5	*80.0*	72.5	80.0	55.0
E4	42.5	55.0	82.5	–	*87.5*	*85.0*	32.5	55.0	62.5	55.0	62.5	37.5
E5	30.0	42.5	70.0	87.5	–	77.5	20.0	42.5	50.0	42.5	50.0	25.0
E6	52.5	65.0	87.5	85.0	77.5	–	42.5	65.0	72.5	65.0	72.5	47.5
E7	70.0	67.5	50.0	32.5	20.0	42.5	–	*77,5*	50.0	57.5	65.0	*85.0*
E8	67.5	65.0	72.5	55.0	42.5	65.0	77.5	–	72.5	80.0	*87.5*	62.5
E9	75.0	72.5	80.0	62.5	50.0	72.5	50.0	72.5	–	*87.5*	80.0	55.0
E10	82.5	65.0	72.5	55.0	42.5	65.0	57.5	80.0	87.5	–	*92.5*	62.5
E11	75.0	72.5	80.0	62.5	50.0	72.5	65.0	87.5	80.0	92.5	–	70.0
E12	75.0	77.5	55.0	37.5	25.0	47.5	85.0	62.5	55.0	62.5	70.0	–

Table II. Consequence (%) of relevance analysis for learning objects

(1) Combine E10 and E11; T = {(E10, E11, 92.5)}.

(2) Combine (E10, E11) and E8; T = {((E10, E11, 92.5), E8, 87.5)}.

(3) Combine (E10, E11, E8) and E9, E3 and E6, and E4 and E5; T = {(((E10, E11, 92.5), E8, 87.5), E9, 87.5), (E3, E6, 87.5), (E4, E5, 87.5)}.

(4) Combine E12 and E7, and (E4, E5) and (E3, E6); T = {(((E10, E11, 92.5), E8, 87.5), E9, 87.5), ((E3, E6, 87.5), (E4, E5, 87.5), 85), (E12, E7, 85)}.

(5) Combine (E10, E11, E8, E9) and (E3, E6, E4, E5); T = {((((E10, E11, 92.5), E8, 87.5), E9, 87.5), ((E3, E6, 87.5), 80), (E4, E5, 87.5), 85), (E12, E7, 85)}.

(6) Combine (E12, E7) and E2; T = {((((E10, E11, 92.5), E8, 87.5), E9, 87.5), ((E3, E6, 87.5), 80), (E4, E5, 87.5), 85), ((E12, E7, 85), E2, 77.5)}.

(7) Combine (E12, E7, E2) and (E10, E11, E8, E9, E3, E6, E4, E5); T = {(((((E10, E11, 92.5), E8, 87.5), E9, 87.5), ((E3, E6, 87.5), 80), (E4, E5, 87.5), 85), ((E12, E7, 85), E2, 77.5), 77.5)}.

(8) Combine (E12, E7, E2, E10, E11, E8, E9, E3, E6, E4, E5) and E1; T = {((((((E10, E11, 92.5), E8, 87.5), E9, 87.5), E7, 77.5), ((E3, E6, 87.5), 80), (E4, E5, 87.5), 85), ((E12, E7, 85), E2, 77.5)), E1, 72.5}}.

From Tables I and II, a relevance-clustering tree (see Figure 4) is constructed, which depicts the relevance degrees between each pair of learning objects (host plants); moreover, the relationships between the learning objects and the related constructs (the butterfly species that take the host plants as food sources) are also depicted. With the assistance of the relevance-clustering tree, the teachers can more easily determine the schema of a learning activity by arranging the sequence for observing the host plants based on the relevance degrees between the plants, as shown in Figure 5.

In addition, from the relevance-clustering tree, the teachers are guided to retrieve detailed data from the electronic library for each host plant as well as the butterfly species that take the host plants as food sources. Figure 6 shows an illustrative example of retrieving the detailed data of the host plants from the electronic library. Figure 7 shows the interface of searching the data of butterfly species that take the host plants as food sources.

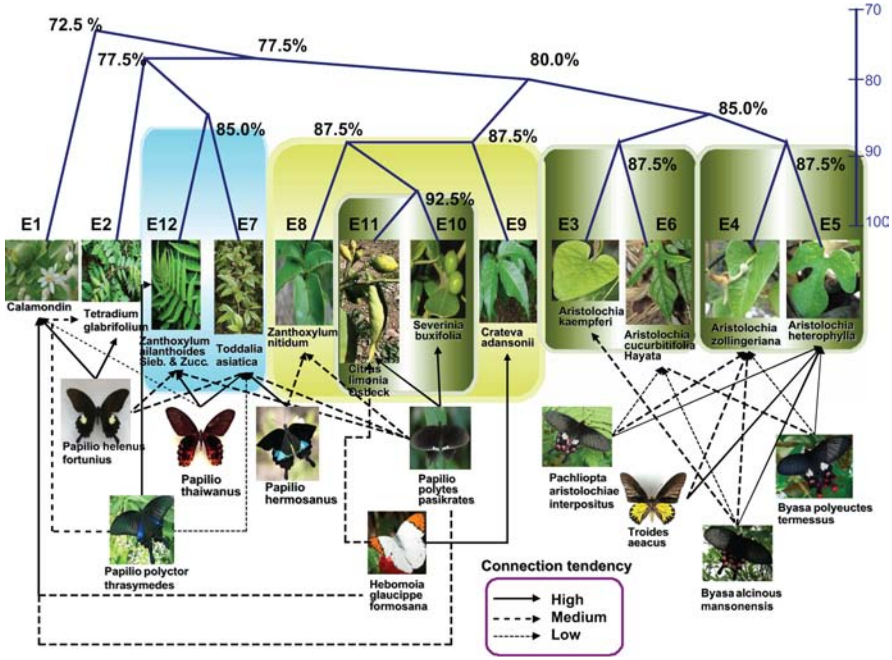

Figure 4.
Illustrative example of a relevance-clustering tree

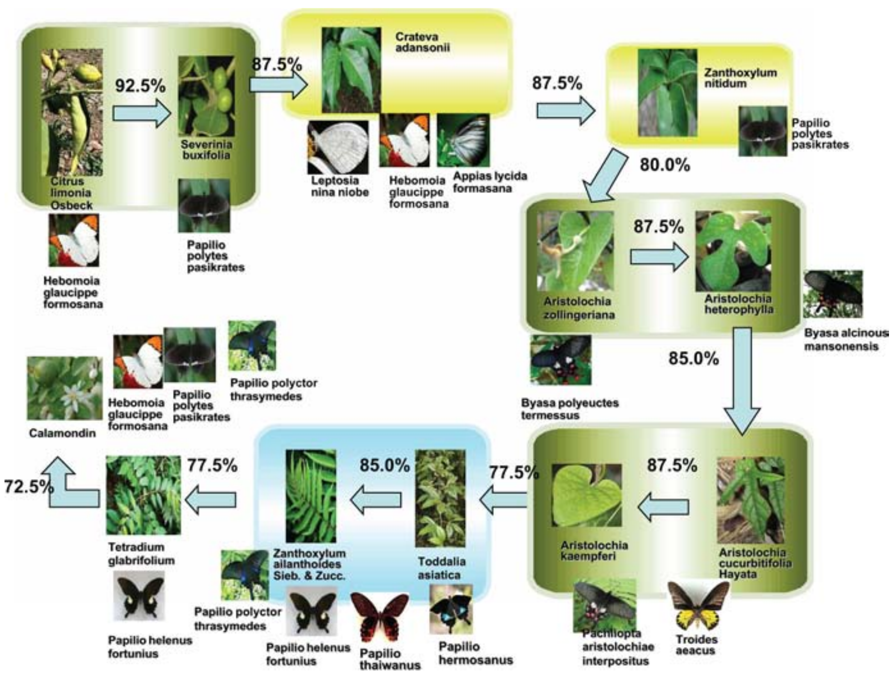

Figure 5.
Illustrative example of the schema of the learning activity designed by the teacher

3.3 Learning scenario

In this study, the authentic learning environment is an elementary school garden consisting of 18 ecological areas. Each area has an instructional sign to introduce the host plants and ecology of the butterflies in that area. Figure 8 shows the authentic learning environment, in which each host plant is labeled with an RFID tag and each student has a mobile device equipped with an RFID reader. In addition, wireless communication is provided, so that the mobile device can communicate with the learning system.

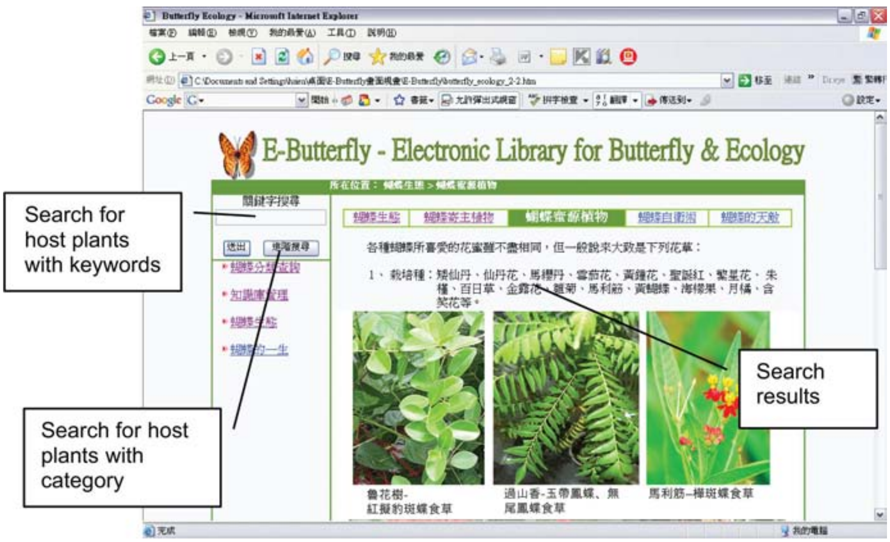

Figure 6.
Illustrative example of retrieving host plant data from the electronic library

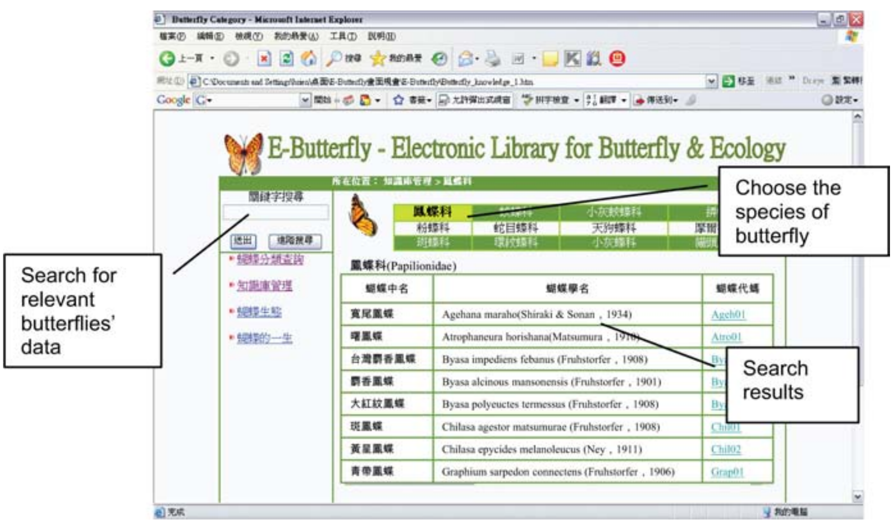

Figure 7.
Illustrative example of retrieving butterfly data from the electronic library

Figure 8.
The authentic learning environment

The students who participate in the learning activity are asked to observe the ecology of the butterflies. When the students move in the authentic learning environment, the learning system can detect the location of individual students by reading and analyzing the data from the nearest RFID tag; therefore, the learning system is able to actively provide personalized guidance or hints to individual students by interacting with them via the mobile device, as shown in Figure 9. Figure 10 shows the interface of

Figure 9.
A student is guided by the learning system to observe the ecology of butterflies

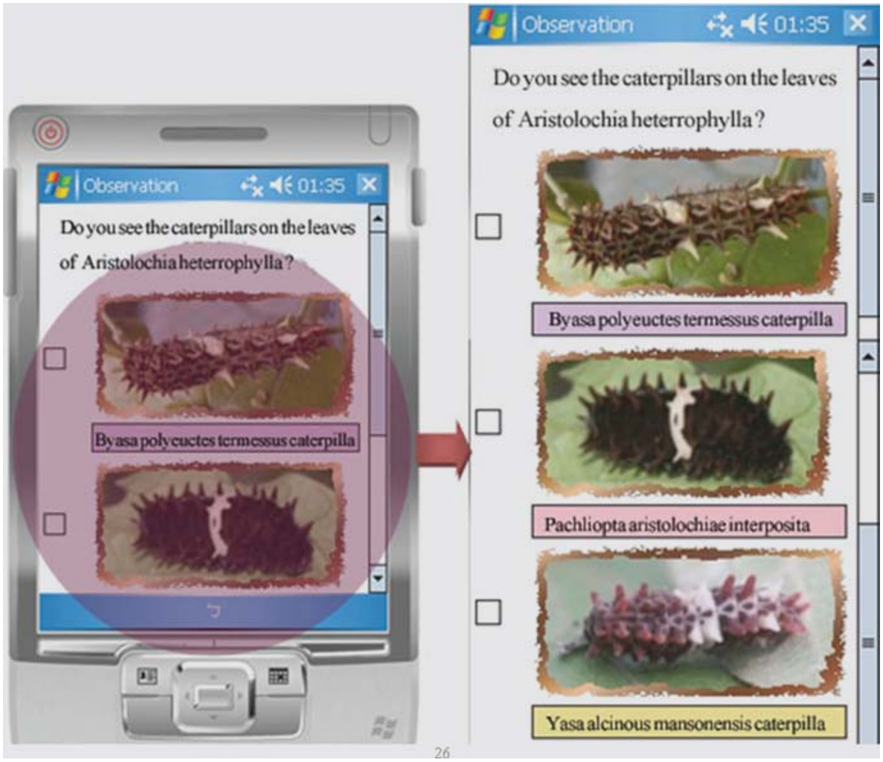

Figure 10. Interface of the mobile device for guiding the students to observe butterfly caterpillars

the mobile device for guiding the students to observe the butterfly caterpillars. Several versions of such learning materials and activities have been developed to meet the special ecological phenomena in different seasons.

4. Research findings

After experiencing the use of the electronic library and the learning activity development procedure, 35 elementary and high school teachers (learning activity designers) and 22 digital learning researchers (learning content workers) were invited to answer a questionnaire to evaluate the usefulness of the innovative approach. The questionnaire uses a five-point Likert-scale, where 1 represents "strongly disagree" and 5 represents "strongly agree." The statistical results are shown in Table III.

From Table III, it can be found that the teachers and the digital content workers are extremely positive about the innovative approach. All of the participants agree that the development of context-aware u-learning activities is difficult, and hence the provision of such a learning activity development procedure is necessary. More than 96 per cent of the participants indicate that the innovative approach is helpful to teachers in clarifying the relevance between the learning objects; 95 per cent of the participants believe that the innovative approach is useful to the teachers in planning authentic learning paths; 92 per cent of the participants feel that the approach makes it easier to develop context-aware u-learning activities.

Table III.
Statistical results for evaluating the "learning activity development procedure"

No.	Items	5	4	3	2	1	Mean
1	For most teachers, it is difficult to develop context-aware u-learning activities without guidance	23	36	0	0	0	4.39
2	The innovative approach can assist the teachers in clarifying the relevance between the learning objects (host plants)	37	20	2	0	0	4.59
3	The innovative approach can assist the teachers to efficiently plan the learning paths for conducting the context-aware u-learning activities	43	13	3	0	0	4.68
4	The innovative approach makes the development of learning activities in the authentic learning environment easier	26	28	5	0	0	4.36
5.	The innovative approach can assist the teachers to more efficiently and effectively utilize the contents of the electronic library	31	26	2	0	0	4.49
6	The innovative approach makes the authentic learning activities and the learning content easier to follow and understand	37	19	3	0	0	4.58
7	The innovative approach assists the teachers to design learning activities and content in a systematic way	33	21	5	0	0	4.47
8.	I am willing to use the innovative approach to develop learning activities or content in the future.	28	25	6	1	0	4.37
9.	I would recommend the innovative approach and tools to my colleagues	28	26	5	0	0	4.39

Furthermore, 98 per cent of the participants indicate that the innovative approach provides an efficient and effective way of utilizing the electronic library. This finding implies that, to promote the utilization rate of e-libraries for some specified purpose, the provision of a systematic guiding strategy is as important as the quantity and quality of the digital content. Finally, nearly 90 per cent of the participants would like to adopt the innovative approach and recommend it to their colleagues in the future. According to feedback to the open-ended question of the questionnaire, some teachers, however, hesitate to accept the innovative approach owing to their lack of computer knowledge and experience. One teacher indicated that "I think the approach is good; however, I am not sure whether I will be able to operate the computer tools and the electronic library system". From the responses, it can be seen that the development of a more user friendly interface is needed.

In addition to answering the questionnaire items, the participants were asked to select the courses that they feel are suitable for utilizing this approach. As shown in Figure 11, the number-one and number-two courses are "Science" and "Social science", respectively. For the number-three course, 17 teachers selected "Mathematics" while nine digital content workers selected "Arts". It can be seen that the viewpoints of the teachers and the digital content workers are quite different. When facing a learning environment with new technologies, the teachers consider the development of learning activities first, and hence well-structured and highly-logical courses (i.e. mathematics) seem to be preferable; on the contrary, digital content workers consider the development of learning content first, and hence they prefer courses with plenty of materials to be presented (i.e. arts).

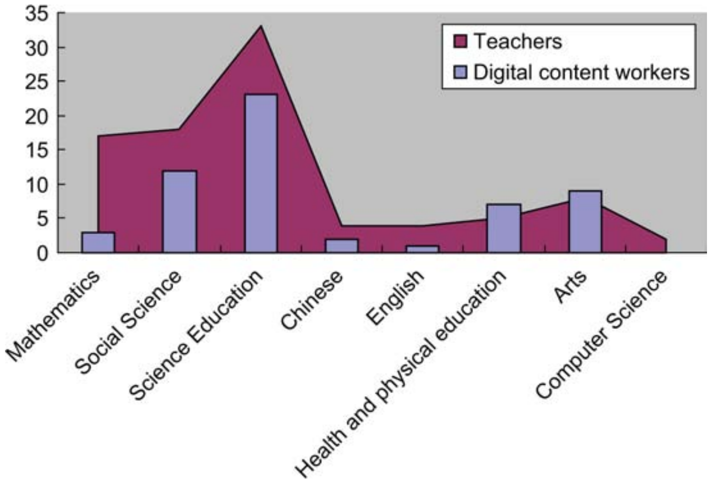

Figure 11.
Statistical results of suitable courses for applying the innovative approach

Furthermore, to have a better understanding of the students' learning effectiveness in the context-aware u-learning environment for butterfly ecology, five sixth grade students (R1, R2 ... R5) were chosen to participate in independent semi-structured interviews. The interview questions mainly explored the students' responses after experiencing the context-aware u-learning environment. When asked about the differences between the u-learning system environment and traditional training processes, it was found that five interviewed students shared a consistent point of view, that is, "interesting", "authentic" and "effective" were the benefits of the context-aware u-learning environment that they identified.

Take the "interesting" viewpoint for example; R1 stated that: "Unlike the traditional learning process guided by the teacher, the u-learning process is much more interesting, because the PDA will guide me to the target plants, and show me relevant information." As another example, R2 replied that: "Using the PDA to observe the plants and the butterfly ecology makes me have less pressure and more pleasure while learning." Similarly, R4 also asserted that: "It is interesting to compare the supplemental materials given by the learning system with the real things."

As to the "authentic" perspectives, all of the five students expressed positive perspectives for being able to observe the real objects with support from the digital world. For instance, R2, R4 and R5 responded that: "The PDA shows every detail of the plants and the related butterfly ecology that makes me feel like I have a personalized teacher, and I think I prefer to learn with this system."

For the "effective" viewpoint, all of the students agreed that the u-learning environment helps them better understand the details of the plants as well as the relationships between the plants and the butterflies. For example, R3 replied: "With the guidance from the learning system, I feel that the learning process is more systematic and more effective." Similarly, R5 replied: "The supplemental materials are really helpful. Now I know the relevance between different host plants and different species of butterflies."

5. Conclusions

In the past decades, various powerful search engines have been developed that enable users to search for information from digital archives on the internet. Such technologies for using and managing digital content have motivated educational applications on the Internet. Most current studies mainly focus on the issue of improving the efficiency of retrieving data from digital archives; nevertheless, one critical bottleneck of applying digital content to educational purposes is the lack of a systematic procedure for guiding the teachers to develop learning activities and the related subject materials.

As has been mentioned in the previous sections, the scenario of a context-aware u-learning is much more complex than those of other technology-enhanced learning models. This complexity is owing to the use of various new technologies in constructing the learning environment, such as sensor technology (e.g. RFID), wireless communication technology, mobile technology (e.g. PDA) and electronic library technology. Most teachers are unfamiliar with these technologies, not to mention how to apply them to the development of learning activities and related learning content.

In this paper, a "Butterfly and ecology" electronic library, which is designed to support context-aware u-learning activities, is presented. Moreover, an innovative approach based on the repertory grid method is proposed to assist teachers to develop context-aware u-learning activities with learning content retrieved from electronic libraries. A practical application has been conducted on an elementary school to evaluate the performance of the innovative approach. From the feedback of the students, it can be found that the developed learning activities as well as the subject content can motivate the students to learn. Moreover, from the statistical results of the questionnaire, it can be seen that the learning activity development procedure proposed in this paper is highly accepted by both teachers and digital content workers. These findings conform to the suggestions proposed by Peters *et al.* (2003), who pointed out the potential of library-supported PDA-related applications.

Currently, we are trying to apply the innovative approach to a variety of practical applications, such as the social science and natural science courses of several elementary schools, and the health and physical education courses of a university. In addition, it would be interesting to see whether students of different ages will reveal different attitudes when learning with these new technologies.

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About the authors

Hui-Chun Chu is currently an Assistant Researcher in the Department of Information and Learning Technology at National University of Tainan in Taiwan. Dr Chu received her PhD degree from that department in July, 2009. Her research interests include mobile and ubiquitous learning, information technology-applied instructions and knowledge engineering. She has published 48 papers, including 26 papers in such professional journals as *Computers & Education*, *Educational Technology & Society* and *The Electronic Library* among others.

Gwo-Jen Hwang is currently a Distinguished Professor in the Department of Information and Learning Technology, and Dean of the College of Science and Engineering at National University of Tainan in Taiwan. In 1991, Dr Hwang received his PhD degree in computer science and information engineering from National Chiao Tung University in Taiwan. His research interests include mobile and ubiquitous learning, computer-assisted testing, expert systems and knowledge engineering. Dr Hwang has published more than 300 academic papers, including 108 papers in such professional journals as *Computers & Education*, *Educational Technology & Society*, *British Journal of Educational Technology*, *Innovations in Education and Teaching International*, and *The Electronic Libraries* among others. Owing to the good reputation in academic research and innovative inventions of e-learning, in 2007, he received the annual Most Outstanding Researcher Award from the National Science Council in Taiwan. Gwo-Jen Hwang is the corresponding author and can be contacted at: gjhwang@academic@gmail.com

Judy C.R. Tseng is currently a Professor in the Department of Computer Science and Information Engineering at Chung-Hua University in Hsinchu, Taiwan. Her research interests include e-learning, knowledge management, data mining and database systems. She has published 87 papers, including 35 papers in such professional journals as *Computers & Education*, *International Journal of Innovative Computing*, *Information and Control* and *The Electronic Library* among others.