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Development of an Adaptive Learning System with Multiple Perspectives based on Students' Learning Styles and Cognitive Styles

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ABSTRACT

In this study, an adaptive learning system is developed by taking multiple dimensions of personalized features into account. A personalized presentation module is proposed for developing adaptive learning systems based on the field dependent/independent cognitive style model and the eight dimensions of Felder-Silverman's learning style. An experiment has been conducted to evaluate the performance of the proposed approach in a computer science course. Fifty-four participants were randomly assigned to an experimental group which learned with an adaptive learning system developed based on the personalized presentation module, and a control group which learned with the conventional learning system without personalized presentation. The experimental results showed that the experimental group students revealed significantly better learning achievements than the control group students, implying that the proposed approach is able to assist the students in improving their learning performance.

Keywords

Adaptive learning, Personalization, Learning style, Cognitive style

Introduction

The rapid advancement of computer and network technologies has attracted researchers to develop tools and strategies for conducting computer-assisted learning activities (Hwang, Wu, & Chen, 2012; Tsai, 2004). With these new technologies, learning content becomes rich and diverse owing to the use of hypermedia and multimedia presentations. Researchers have indicated that hypermedia systems are suitable for providing personalized learning supports or guidance by identifying the personal characteristics of students and adapting the presentation styles or learning paths accordingly (Tseng, Chu, Hwang, & Tsai, 2008). In the past decade, various personalization techniques have been proposed for developing adaptive hypermedia learning systems, and have demonstrated the benefit of such an approach (Mampadi, Chen, Ghinea, & Chen, 2011; Nielsen, Heffernan, Lin, & Yu, 2010; Wells & McCrory, 2011). For example, Papanikolaou, Grigoriadou, Magoulas and Kornilakis (2002) developed an adaptive learning system by taking students' knowledge levels as the main factor for adapting the learning content; moreover, Tseng, Su, Hwang, Hwang, Tsai and Tsai (2008) developed an adaptive learning system based on an object-oriented framewok that composes personalized learning content by considering individuals' knowledge level and the difficulty level of the learning objects.

Although the knowledge level of the students and the difficulty level of the learning content are good factors for adapting presentation layouts and selecting appropriate learning content for individuals, researchers have indicated the importance of taking personal preferences and learning habits into account (Hsu, Hwang, & Chang, 2010; Tseng, Chu, Hwang, & Tsai, 2008). Among those personal characteristics, learning styles which represent the way individuals perceive and process information have been recognized as being an important factor related to the presentation of learning materials (Papanikolaou, Grigoriadou, Magoulas, & Kornilakis, 2002). On the other hand, cognitive styles have been recognized as being an essential characteristic of individuals' cognitive process. In the past decade, researchers have tried to develop adaptive learning systems based on either learning styles or cognitive styles; nevertheless, seldom have both of them been taken into consideration, not to mention the other personalized factors (Hsieh, Jang, Hwang, & Chen, 2011; Hwang, Tsai, Tsai, & Tseng, 2008; Mampadi, Chen, Ghinea, & Chen, 2011).

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Researchers have indicated the importance of taking multiple personalization factors into account in order to deliver effective learning systems to individual students (Lee, Cheng, Rai, & Depickere, 2005; Hwang, Yin, Wang, Tseng, & Hwang, 2008). To cope with this problem, in this study, an adaptive learning system is developed by taking students' preferences and characteristics, including learning styles and cognitive styles, into consideration. Moreover, an experiment has been conducted to show the effectiveness of the proposed approach.

Literature review

Learning styles and cognitive styles

Learning styles have been recognized as being an important factor for better understanding the model of learning and the learning dispositions/preferences of students (Filippidis & Tsoukalas, 2009). Keefe (1987) defined an individual's learning style as a consistent way of functioning that reflects the underlying causes of learning behaviors. Keefe (1991) pointed out that learning style is a student characteristic indicating how a student learns and likes to learn. He also stated that learning style could be an instructional strategy informing the cognition, context and content of learning. Reiff (1992) indicated that learning styles are likely to influence how students learn, how instructors teach, and how they interact. Coffield, Moseley, Hall and Ecclestone (2004) further suggested that teachers and course designers pay attention to students' learning styles and design teaching and learning interventions accordingly.

There have been several learning style theories proposed by researchers, such as those proposed by Honey and Mumford (1992), Keefe (1979), Kolb (1984) and Felder and Silverman (1988). Several previous studies have demonstrated the use of learning styles as one of the parameters for providing personalized learning guidance or contents (Graf, Lin, & Kinshuk, 2007; Papanikolaou, Mabbott, Bull, & Grigoriadou, 2006; Tseng, Chu, Hwang, & Tsai, 2008). Among various learning styles, the Felder–Silverman Learning Style Model (FSLSM) developed by Felder and Soloman (1997) have been recognized by many researchers as being a highly suitable model for developing adaptive learning systems (Huang, Lin, & Huang, 2012; Akbulut & Cardk, 2012). Carver, Howard and Lane (1999) indicated that FSLSM could be the most appropriate measurement for developing hypermedia courseware by taking into personal factors into account. Kuljis and Lui (2005) further compared several learning style models, and suggested that FSLSM is the most appropriate model with respect to the application in e-learning systems. Consequently, this study adopted FSLSM as one of the factors for developing the adaptive learning system.
On the other hand, cognitive style has been recognized as being a significant factor influencing students' information seeking and processing (Frias-Martinez, Chen, & Liu, 2008). It has also been identified as an important factor impacting the effectiveness of user interfaces and the navigation strategies of learning systems (Mampadi, Chen, Ghinea, & Chen, 2011). Several studies have shown the effectiveness of considering cognitive styles in designing user interfaces for information seeking (Frias-Martinez, Chen, & Liu, 2008) and developing adaptive learning systems for providing personalized learning guidance (Evans, & Waring, 2011; Lo, Chan, & Yeh, 2012). Among various proposed cognitive styles, the field dependent (FD) and field independent (FI) styles proposed by Witkin, Moore, Goodenough and Cox (1977) are the most frequently adopted. Several studies have reported the usefulness of FI/FD cognitive styles in determining the suitability of learning supports or learning system designs (Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009; Lin, Hwang, & Kuo, 2009). For example, Weller, Repman and Rooze (1995) indicated that FI/FD cognitive style is very suitable for personalized learning design since it reveals how well a learner is able to restructure information based on the use of salient cues and field arrangement. Ford and Chen (2000) further indicated that the FD/FI cognitive style is highly related to hypermedia navigation and is very suitable for evaluating the usability of websites to students. Therefore, in this study, FI/FD cognitive style is adopted as another factor for developing the adaptive learning system.

Scholars have proposed different aspects to address the relationships between learning styles and cognitive styles. For example, some scholars have indicated that learning styles are applied cognitive styles (Keefe, 1979; Jonassen & Grabowski, 1993; Papanikolaou, Mabbott, Bull, & Grigoriadou, 2006); some have further concluded that learning styles could be viewed as a subset of cognitive styles, and could be classified as activity-centered cognitive styles (Huang, Lin, & Huang, 2011). However, the common definition of cognitive style refers to the individual differences in preferred ways of organizing and processing information and experience (Chen & Macredie, 2002; Triantafillou, Pomportsis, & Demetriadis, 2003), while learning style is defined as a consistent way of functioning that reflects the underlying causes of learning behaviors (Keefe, 1987). Moreover, cognitive styles deal with a cognitive activity (i.e., thinking, perceiving, remembering), while learning styles are indicators of how learners perceive, interact with and respond to learning environments, including cognitive, affective and psychological behaviors (Triantafillou, Pomportsis, & Demetriadis, 2003).

To deal with the relationship between cognitive and learning styles, researchers have indicated that cognitive styles could be classified as cognition centered, personality centered, or activity centered; moreover, learning style can be perceived as the activity-centered cognitive style (Sternberg & Grigorenko, 1997). From this aspect, learning styles are viewed as a subset of cognitive styles (Riding & Rayner, 1998; Sternberg & Grigorenko, 1997). Accordingly, this study employs cognitive styles in dealing with the adaption of the learning environment, such as the navigation modes, whereas learning styles are used to deal with the presentation modes of multi-source materials that are composed of figures, videos and texts.

Accordingly, in this study, learning styles are used to provide personalized learning materials and presentation layouts (Liegle & Janicki, 2006), while cognitive styles are used to develop personalized user interfaces and navigation strategies (Chen, Fan, & Maredie, 2004; Chen & Macredie, 2002; Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009).

Cognitive load and multimedia learning

To understand, accommodate and align the interaction between learners' cognitive system and the given learning environment, the cognitive load theory (CLT) has become an acknowledged and broadly applied theory for instruction and learning (Van Merriënboer & Sweller, 2005; Schnotz & Kürschner, 2007). Cognitive load theory is a framework of instructional design principles based on the characteristics and relations between the structures that constitute human cognitive architecture, particularly working memory and long-term memory (Wong, Leahy, Marcus, & Sweller, 2012). For a multimedia instructional design, CLT responses the limited working memory for holding visual (such as figures) and verbal (such as text) information as well as the number of operations it can perform on the information (Van Gerven & Pascal, 2003).

Cognitive load is defined as a multidimensional construct representing the load that a particular task imposes on the performer (Paas & van Merrienboer, 1994). It can be assessed by measuring mental load, mental effort (Sweller, van Merriënboer, & Paas 1998; Paas, Tuovinen, Tabbers, & Gerven, 2003). Mental effort is related to the strategies used in the learning activities, whereas mental load refers to the interactions between the learning tasks, subject characteristics and subject materials, which are highly related to the complexity of the learning content that the students need to face (Hwang & Chang, 2011). To respond to the reality that most digital learning materials are developed with multimedia, Mayer (2001) proposed a cognitive theory of multimedia learning (CLML), which assumes that human process pictorial and verbal materials via different sense channels (i.e., sight and hearing). Consequently, cognitive overloading could occur when learners receive redundant information, poorly structured information, or large amount of information in a sense channel.

On the other hand, Paas, Tuovinen, Merriënboer and Darabi (2005) addressed that learners' motivation had a significant relation with cognitive load, especially on mental effort. They suggested that motivation could be identified as a dimension that determines learning success, especially in complex e-learning environments (Paas, Tuovinen, Merriënboer and Darabi, 2005). The relationship between cognitive load and motivation is also stated by Moos (2009).

Adaptive learning systems

An adaptive learning system aims to provide a personalized learning resource for students, especially learning content and user-preferred interfaces for processing their learning (Aroyo et al., 2006). Brusilovsky (2001) has indicated that two adaptation approaches can be used in developing web-based adaptive learning systems, that is, "adaptive presentation" which presents personalized content for individual students, and "adaptive navigation support" which guides individuals to find the learning content by suggesting personalized learning paths. Other researchers have further indicated the importance of providing personalized user interfaces to meet the learning habits of students (Mampadi, Chen, Ghinea, & Chen, 2011).

In the past decade, various adaptive learning systems have been developed based on different parameters that represent the characteristics or preferences of students as well as the attributes of learning content (Wang & Wu, 2011). For example, Karampiperis and Sampson (2005) proposed an adaptive resource selection scheme by generating all of the candidate learning paths that matched the learning objectives and then selecting the most fitting one based on the suitability of the learning resources for individual students. Hwang, Kuo, Yin and Chuang (2010) further developed an adaptive learning system to guide individuals to learn in a real-world environment by generating the personalized learning paths based on the learning status of each student and the relationships between the authentic learning targets. It can be seen that the provision of personalization or adaptation modules, including personalized learning materials, navigation paths or user interfaces, has been recognized as an important issue for developing effective learning systems (Chiou, Tseng, Hwang, & Heller, 2010; van Seters, Ossevoort, Tramper, & Goedhart, 2012).

Several studies have been conducted to develop adaptive learning systems based on learning styles or cognitive styles. For example, Tseng, Chu, Hwang and Tsai (2008) proposed an adaptive learning system for elementary school mathematics courses by considering students' learning styles and the difficulty of the learning content. Mampadi, Chen, Ghinea and Chen (2011) developed a web-based learning environment by providing different user interfaces based on students' cognitive styles. Furthermore, Hsieh, Jang, Hwang and Chen (2011) developed an adaptive mobile learning system that guided individual students to learn in a butterfly ecology garden based on students' learning styles. However, few studies have considered multiple learning criteria, including learning styles, cognitive styles, and knowledge levels, for developing adaptive learning systems.

Research questions

In this study, an adaptive learning system is developed based by taking both cognitive styles and learning styles into account. It is expected that the proposed approach can benefit students in improving their learning achievement, reducing their cognitive load and promoting their learning motivation. Accordingly, the following research questions are investigated:
1. Does the adaptive learning system developed based on both cognitive styles and learning styles benefit students more than the conventional learning style-based system in terms of learning achievements?
2. Can the learning system developed based on both cognitive styles and learning styles decrease students’ cognitive load in comparisons with the conventional learning style-based system?
3. Does the learning system developed based on both cognitive styles and learning styles benefit students more than conventional learning style-based system in terms of learning motivations?

Adaptive learning system with multi-dimensional personalization criteria

In this section, an adaptive learning system, AMDPC (Adaptation with Multi-Dimensional Personalization Criteria) is presented. AMDPC consists of four modules: the Learning content-Generating Module (LCGM), the Adaptive Presentation Module (APM), the Adaptive Content Module (ACM) and the Learning Module (LM).

Learning content-generating module

Figure 1 presents the concept of the learning content-generating module, which is used to extract contents from raw materials and generate chunks of information for composing personalized learning materials based on the presentation layout. Each subject unit contains a set of components, such as the ID of the unit, texts, photos, etc. The components of a subject unit are classified into the following six categories:
- *Concept unit*: containing the title, concept ID, abstract and representative icon of the course unit.
- Text components: the text content of the course unit.
- Example component: the illustrative examples related to the course content.
- Figure component: the pictures, photos and figures related to the course unit.
- Fundamental component: Fundamental components contain the primary contents of a course, including the title of each learning unit or concept, and the corresponding texts, figures, examples and exercises.

- Supplementary component: Supplementary components contain supplementary materials that are helpful to students in extending the learning scope or realizing the concepts to be learned.

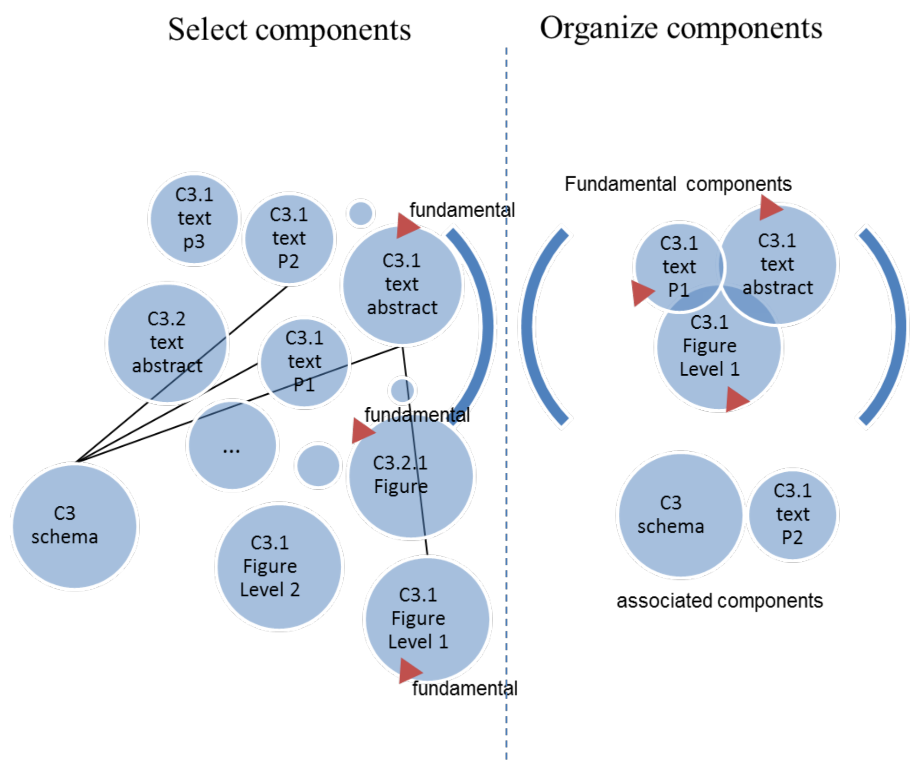

Figure 1. The learning content-generating module

After selecting the appropriate components (learning materials), LCGM organizes the selected components based on individual students' learning styles and cognitive styles. The organized learning content is then presented to individual students based on the presentation layout framework. Figure 2 shows this framework, which consists of the following areas:

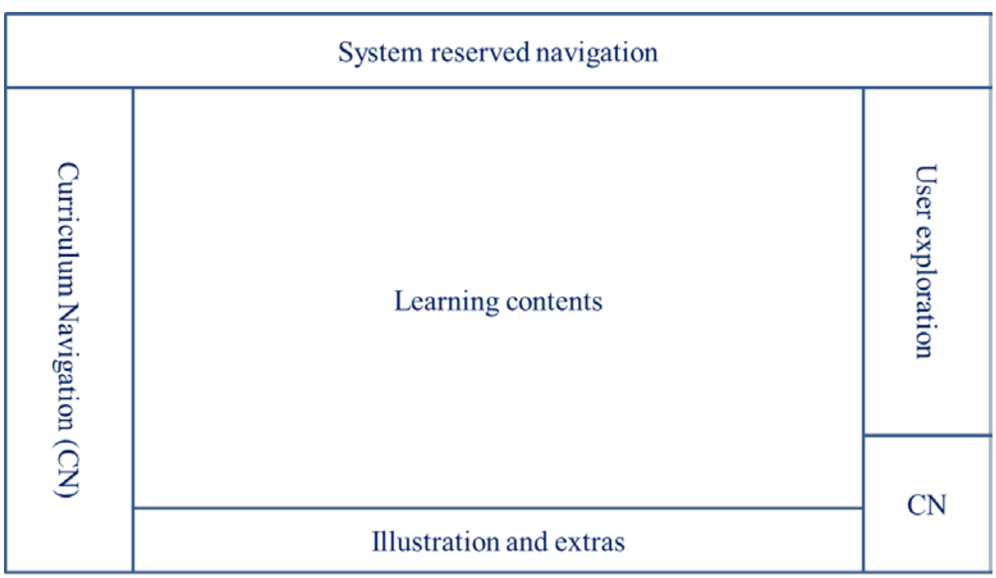

Figure 2. The presentation layout framework of AMDPC

- The system reservation area. This area is reserved for the learning system to display the status or announcements about courses, students or the system.
- The curriculum navigation area. This area contains the information about the relationships between the course units, the outline of individual courses, and the suggested learning sequence of the course units.
- The learning content area. This area is located in the center of the screen for presenting the learning materials organized by LCGM.
- The supplementary material area. This area is used to present supplementary learning materials to individual students based on their personalized learning needs.
- The user exploration area. In this area, three icons linked to three different versions of learning content are presented to enable flexible student control during the learning process.
- The guided navigation area. This area is allocated at the bottom-right corner of the screen. It is used to provide style-matching learning guidance or navigation functions for students with different learning styles or cognitive styles. For example, for the FD students, "next stage" and "previous stage" buttons are provided to guide the students to learn the course materials in an appropriate sequence.

Adaptive presentation module

The adaptive presentation module consists of two parts: The layout strategy based on student cognitive styles and the instructional strategy based on their learning styles.

The layout strategy focuses on adjusting the presentation layout for individual students based on their cognitive styles. In order to measure students' cognitive styles, the Group Embedded Figures Test (GEFT), proposed by Witkin (1971), was employed in this study. According to the score gauge of the GEFT, students are determined as having an FI style if their test score is in the top 50% (in this study, 16); otherwise, if the test score is less than 16, students are categorized as having an FD style of learning. The FD students prefer structured information, promotion and authority navigation; on the other hand, the FI students like to organize information by themselves. From the perspective of the course lesson navigation, the user interface for the FD students is designed to show less information at the same time to avoid distracting them, which is called “Simpler interface” in this study; on the contrary, the interface for the FI students presents more information to help them make a comprehensive survey of the learning content, which is called “more complex interface,” as shown in Table 1.

Table 1. User interface design principle for FI/FD students.

Field-Dependent (FD)	**Field-Independent (FI)**
Simpler interface	More complex interface
Less information presented at the same time	More information presented at the same time
Providing only frequently used functions and links to the information related to the current learning content	Providing links to show the full functions of the system and the schema of the entire learning content

Adaptive content module

The ACM is related to content adjustment for students of different learning styles. The Index of Learning Style questionnaire (ILS), proposed by Felder and Soloman (1997), was embedded in the learning system for measuring the learning styles of the students. There are four dimensions of learning style (LS) in the Felder-Silverman learning style model:

1. Active/Reflective dimension. *Active students* are active, motivated, prefer trial-and-error, and enjoy discussion rather than learning independently. We use the term “learning by doing” to describe how active students learn. *Reflective students* perceive a sense of pleasure when learning by themselves by thinking deeply. The term “learning by thinking” could describe Reflective students.

2. Sensing/Intuitive dimension. *Sensing students* like to learn from facts and dislike surprises; moreover, they are good at memorizing facts and like to solve problems by well-established methods. They are patient with details, good at doing hands-on (laboratory) work. They tend to be practical and careful. They do not like courses that have no apparent connection to the real world. On the contrary, *Intuitive students* like innovative things and

dislike doing the same thing repetitively. They prefer discovering possibilities and relationships and tend to be better at grasping new concepts.

3. Visual/Verbal dimension. *Visual students* remember best what they see, as in pictures, diagrams, flow charts, time lines, films, and demonstrations. *Verbal students* prefer text description and get more out of written and spoken explanations.

4. Sequential/Global dimension. *Sequential students* tend to gain understanding in linear steps, with each step following logically from the previous one, and tend to follow logical stepwise paths when finding solutions. *Global students* tend to solve problems quickly once they have grasped the big picture, and tend to learn in large jumps without seeing connections.

The rating of each dimension ranges from -11 to +11. Based on individual students' ratings in each dimension, the learning system adapts the instructional strategy to meet their needs. The instructional strategies of the proposed system are given in Table 3. The content adjusting principle was designed based on the characteristics of each Felder-Silverman learning style dimension; for example, visual-style learners tend to learn better from visualized materials, such as pictures, diagrams and films, while text-style learners prefer text materials (Felder & Silverman, 1988).

Table 3. Content adjusting principles of ACM

Learning Style	Content adjusting principles	Component selecting rules
Active	Provide examples to further explain the learning content. Provide illustrative examples to link the knowledge to real life or to show the process of solving problems.	Text: fundamental Figure: fundamental Example: fundamental+supplementary
Reflective	Remind students to review what they have learned. Encourage students to think of possible questions or applications. Encourage students to write short summaries or notes based on what they have learned in their own words.	Text: fundamental Figure: fundamental Example: fundamental
Sensing	Provide specific examples of concepts and procedures, and find out how the concepts can be applied to practical applications.	Text: fundamental Figure: fundamental+supplementary Example: fundamental+supplementary
Intuitive	Provide interpretations or theories related to the course content. Remind the students by providing illustrative examples to address some easy-to-confuse concepts.	Text: fundamental+supplementary Figure: fundamental Example: fundamental+supplementary
Visual	Provide the students with more visual materials, such as diagrams, sketches, schematics, photographs, or flow charts.	Text: fundamental Figure: fundamental+supplementary Example: fundamental+supplementary
Text	Provide students with more text materials.	Text: fundamental+supplementary Figure: fundamental Example: fundamental
Sequential	Present the learning materials in a logical order.	Text: fundamental+supplementary Figure: fundamental Example: fundamental Scope: a concept or learning step
Global	Enable students to browse through the entire chapter to get an overview before learning.	Text: fundamental with an abstract Figure: fundamental+supplementary Example: fundamental+supplementary Scope: a chapter

Learning module

The LM provides students with the learning content and user interface generated based on their cognitive styles and learning styles. Figure 3 shows a learning module for an FI student with [ACT/REF: -4], [SEN/INF: 2], [VIS/VRB: -9] and [SEQ/GLO: 4]), while Figure 4 is a learning module for another FI student with [ACT/REF: -8], [SEN/INF: 6], [VIS/VRB: -11] and [SEQ/GLO: 8].

Figure 3. Illustrative example of a learning module (1)

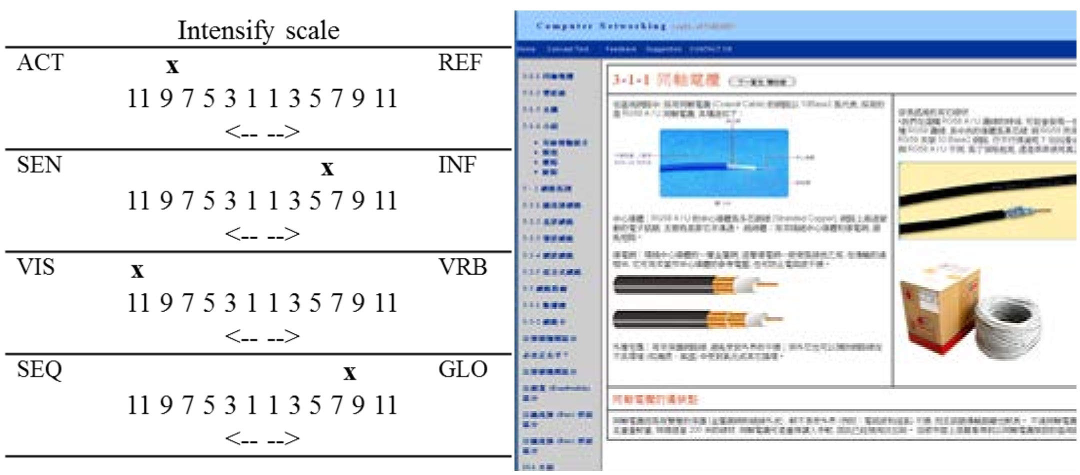

Figure 4. Illustrative example of a learning module (2)

Figure 5 shows another illustrative example to show the similarities and differences between the learning modules generated for FD students with verbal and visual learning styles. It can be seen that the learning content has been adjusted to meet the students' learning styles. Moreover, the user interface in Figure 5 (for FD students) is much simpler than that in Figures 3 and 4 (for FI students), showing part of the adjustments made for the students with different cognitive styles. The user interface for FI students (Figure 3) included the course schema in the left panel and a navigation button on the top of the screen, while that for the FD students only had the title of current course unit. From literature, most FD students were likely to be affected by contexts. Although the difference between Figure 3 and Figure 5 was not significant, the impact of additional cognitive load could be avoided for FD students via considering those interface details in designing each part of the learning system.

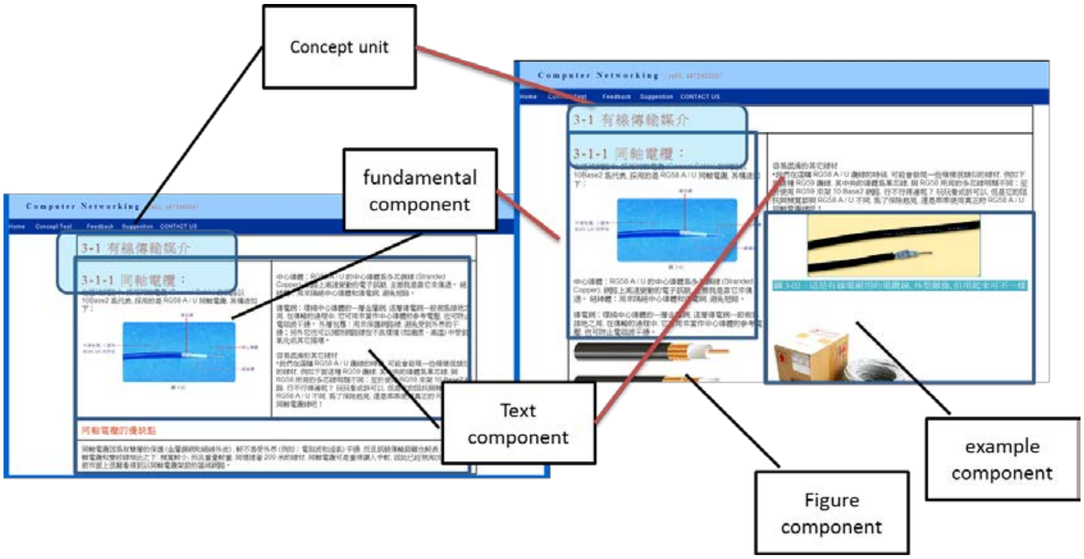

Figure 5. Learning modules for FD students with verbal and visual learning styles

Experiment and evaluation

To evaluate the performance of the proposed approach, an experiment was conducted on the learning activity of the "Computer Networks" course of a college in central Taiwan. In the following, the details of the experiment are stated.

Participants

The participants were fifty-four students, including thirty-two undergraduate students and twenty-two graduate students from a computer science department. The participants were randomly divided into a control group (n = 27) and an experimental group (n = 27).

Learning activity design

Figure 6 shows the procedure of the experiment. In the first stage (two weeks), the students were instructed in the basic knowledge of computer networks. After receiving this fundamental knowledge, the students were asked to take a pre-test, which aimed to evaluate their basic knowledge before participating in the learning activity.

In the second stage, the students in the experimental group were arranged to learn with the AMDPC system; that is, they were provided with an adaptive interface and learning content by taking both their cognitive styles and learning styles into account. On the other hand, the students in the control group learned with a conventional adaptive e-learning approach; that is, they were provided with only adaptive learning content which took their learning styles into account, as most relevant studies (e.g., Filippidis & Tsoukalas (2009), Hwang, Sung, Hung and Huang (2012), and Tseng, Chu, Hwang and Tsai (2008)) have done. This stage took 120 minutes. After conducting the learning activity, the students took a post-test and answered a post-questionnaire.

Instruments

To evaluate the effectiveness of the proposed approach, a pre-test, a post-test, and the measures of cognitive load and learning motivation were employed in the experiment.

The pre-test aimed to confirm that the two groups of students had the equivalent basic knowledge required for taking this particular subject unit. It was composed of 15 true-or-false items and 15 multiple-choice items with a full score of 100. The post-test consisted of 10 true-or-false items and 23 multiple-choice items with a full score of 100. It focused on evaluating the students' knowledge about network ontology, device and know-how based on the given scenario. Both the pre-test and post-test were designed by the teacher who taught the Computer Networking course to the two groups of students. Moreover, the test items were mainly in the knowledge and understanding levels of the taxonomy of Bloom's educational objectives (1956). The tests were evaluated by two science educators for expert validity.

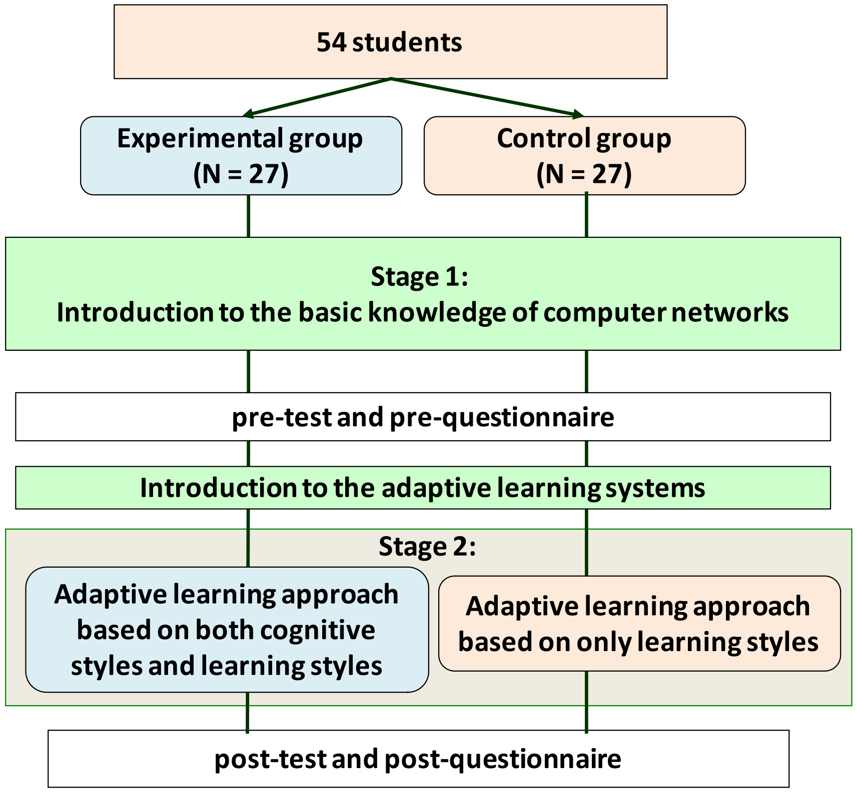

Figure 6. Procedure of the experiment

The cognitive load measure used in this study was proposed by Sweller, van Merriënboer and Paas (1998). It consisted of two dimensions, that is, mental load and mental effort. Each dimension contained two items. The Cronbach's alpha values of the two dimensions were 0.72 and 0.71, respectively.

Furthermore, the Motivated Strategies for Learning Questionnaire (MSLQ) with a five-point Likert rating scheme was used to evaluate the learning motivation of the students. The questionnaire was revised from the measure proposed by Pintrich, Smith, Garcia and Mckeachie (1991). It consists of 29 items covering six dimensions, that is, intrinsic goal orientation, extrinsic goal orientation, task value, control beliefs for learning, self-efficacy and test anxiety. The Cronbach's alpha values of the six dimensions are 0.67, 0.73, 0.67, 0.72, 0.73 and 0.74, respectively.

Results

Learning achievement

An independent t-test was used to analyze the pre-test, as shown in Table 4. The result implying that these two groups did not significantly differ prior to the experiment. That is, the two groups of students had statistically equivalent abilities before taking the subject unit.

Table 4. Descriptive data and t-test result of the pre-test scores.

	N	Mean	S.D.	*t*
Experimental group	27	74.38	10.89	-0.82
Control Group	27	77.34	9.47	

Table 5 shows the ANCOVA result of the post-test using the pre-test as a covariate. It was found that the students in the experimental group had significantly better achievements than those in the control group with F = 5.35 and $p < .05$, indicating that learning with the proposed adaptive learning approach significantly benefited the students in comparison with the conventional learning style-based adaptive learning approach.

Table 5. Descriptive data and ANCOVA of the post-test scores

	N	Mean	S.D.	Adjusted Mean	Std.Error.	*F value*
Experimental group	27	84.85	7.32	84.88	4.76	5.35*
Control group	27	80.33	7.22	80.30	4.76	

$^{*}p<.05$

Cognitive load

Cognitive load refers to the demand on working memory when engaging in learning activities, such as comprehending, problem solving, and reasoning. Table 6 shows the t-test result of the cognitive load ratings of the two groups. There is no significant difference between the two groups in terms of mental effort, while the experimental group showed significantly lower mental load than the control group with t = 1.46 and $p < .05$.

Table 6. The t-test of the cognitive load levels of the control group and experimental group. post-test result

		N	Mean	S.D.	t
Mental load	Experimental group	27	4.07	1.07	1.46*
	Control group	27	4.59	1.50	
Mental effort	Experimental group	27	5.56	1.78	-0.84
	Control group	27	5.14	1.77	

$^{*}p < .05$

Learning motivation

An independent t-test was conducted to evaluate the learning motivation pre-questionnaire, and no significant difference was found for the six dimensions, as shown in Table 7.

Table 7. Independent t-test on the pre-questionnaire of the experimental group and the control group students

	Experimental Group (Mean, S.D.)	Control Group (Mean, S.D.)	*t*
Intrinsic Goal Orientation	4.02/0.50	3.91/0.40	-0.82
Extrinsic Goal Orientation	3.84/0.49	3.77/0.0.54	0.91
Task Value	4.13/0.43	4.01/0.42	-1.08
Control Beliefs for Learning	3.54/0.48	3.52/0.53	0.59
Self-efficacy	3.30/0.59	3.59/0.64	0.59
Test Anxiety	3.14/0.64	2.86/0.64	-1.02

The ANCOVA was then used to analyze the pre-questionnaire ratings of the two groups by using the pre-questionnaire result as a covariate, as shown in Table 8. A significant difference was found between the two groups in terms of the "Control Beliefs" dimension with F = 5.52 and $p < .05$. The dimension is related to the students' beliefs that making more effort to learn and practicing more would lead to better results. Therefore, this finding reveals that the proposed learning approach is able to engage the students in the learning process with beliefs of obtaining good learning achievements.

Table 8. ANCOVA results of the learning motivation ratings of the two groups

Variable		N	Mean	S.D.	Adjusted Mean	Std.Error.	*F value*
Intrinsic Goal Orientation	Experimental group	27	4.12	0.45	4.05	0.20	0.04
	Control group	27	4.08	0.52	4.02	0.28	
Extrinsic Goal Orientation	Experimental group	27	3.84	0.51	3.80	0.37	0.10
	Control group	27	3.88	0.40	3.82	0.30	
Task Value	Experimental group	27	4.29	0.51	4.22	0.26	0.73
	Control group	27	4.16	0.41	4.10	0.16	
Control Beliefs for Learning	Experimental group	27	3.79	0.60	3.74	0.37	5.22*
	Control group	27	3.62	0.74	3.52	0.55	
Self-efficacy	Experimental group	27	3.49	0.72	3.32	0.52	2.22
	Control group	27	3.41	0.70	3.24	0.50	
Test Anxiety	Experimental group	27	3.19	0.57	3.02	0.33	0.40
	Control group	27	3.20	0.66	3.06	0.45	

$^{*}p < .05$

Discussion and conclusions

Adaptive learning has been identified as being an important and challenging issue of computers in education. In the past decades, various methods and systems have been proposed to provide students with a better learning environment by taking personal factors into account. Learning styles have been one of the widely adopted factors in previous studies as a reference for adapting learning content or organizing the content. In most studies, only one or two dimensions of a learning style model are considered while developing the adaptive learning systems. Moreover, in most systems, only a fixed type of user interface is provided. In this paper, we propose an adaptive learning system developed by using both learning styles and cognitive styles to adapt the user interface and learning content for individual students; moreover, the full dimensions of a learning style model have been taken into account. The experimental results showed that the proposed system could improve the learning achievements of the students. Moreover, it was found that the students' mental load was significantly decreased and their belief of learning gains was increased.

As mental load refers to the interactions between the learning tasks, learning content, and the characteristics of the content (e.g., difficulty level), it is highly related to the difficulty level of the content presented to the students and the students' prior knowledge for comprehending the content (Verhoeven, Schnotz, & Paas, 2009). In this study, the learning content provided to both group of students was identical although the presentation style might be adapted based on their learning styles and the interface was adapted based on their cognitive styles. On the other hand, mental effort is related to the learning strategies used in the learning activities (Verhoeven, Schnotz, & Paas, 2009). Therefore, based on the Cognitive Load Theory, it was expected that the two groups had similar mental loads and different mental efforts. However, the experimental result was opposite to the expectation, which challenges some of the main assumptions of the Cognitive Load Theory with regard to learning styles and is worth further studying.

In terms of control beliefs, which refer to learners' beliefs of being able to understand the learning content and have good learning achievement, the generated learning materials were adapted to meet individual students' characters of processing information; that is, the presentation style of the learning content was more suitable to the students' information processing styles. Therefore, it is reasonable that the students in the experimental group showed higher control beliefs than those in the control group.

From the experimental results, it can be seen that the proposed approach is promising. The developed system can be applied to other applications by replacing the learning components with new ones. To develop new adaptive learning applications, teachers or researchers only need to transform the new learning materials into individual types of learning components and store them in the database of the learning system.

On the other hand, there are some limitations of this study. First, the sample size of the experiment was not large; therefore, the findings could not be inferred to general cases. In addition, the present study mainly focused on the use of learning styles and cognitive styles in providing a personalized user interface and learning content, while some other factors, such as the knowledge levels of the students, the difficulty levels of the learning materials and compensation type of adaption, were not considered. Another limitation of this study is that the experimental group received more treatment than the control group owing to the use of different adaptive learning approaches. In the near future, we plan to apply the proposed approach to other applications with larger sample sizes and analyze the size effect as well; in the meantime, we also plan to expand the learning system by taking more parameters into consideration with more precise experiment design to control possible factors that might affect students' learning performance. Furthermore, it is expected that the learning portfolios of students can be analyzed and more constructive suggestions can be given to teachers and researchers accordingly.

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