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An Adaptive e-Learning System for Enhancing Learning Performance: Based on Dynamic Scaffolding Theory

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ABSTRACT

Adaptive learning for individual learners has recently become popular in education. This study aims to fill the void in the existing literature by building an adaptive e-learning system with self-assessment rubrics based on the dynamic scaffolding theory in response to different student needs. Meanwhile, the purpose of this study is to explore the effectiveness of using adaptive e-learning with dynamic scaffoldings and rubrics in fostering students' learning outcomes. An experimental design was conducted to evaluate learning effectiveness and learning satisfaction in the Excel (spreadsheet) of the course for using the developed adaptive e-learning system. Sixty undergraduate students from a technology university in central Taiwan participated in this experimental study and executed a pretest and a posttest. Research results revealed that the developed adaptive e-learning system can effectively support students with personalized learning materials and successfully helps students acquired knowledge and develop cognitive abilities. The results recommend that teachers could employ rubrics as a self-assessment tool for supporting students with dynamic scaffoldings to conduct a learner-centered e-learning environment. Additionally, the lack of generalizability is clearly a limitation of the present data due to a few participants. Finally, future research direction of this study was also discussed.

Keywords: adaptive learning, e-learning, dynamic scaffoldings, rubric

INTRODUCTION

Individual differences among students have significant effects on their learning outcomes (Rukanuddin, Hafiz, & Asfia, 2016). Previous studies examined these effects and indicated that providing the same learning materials and delivering the same instructional conditions to all students may lead to a reduction in learning performance without considering their different background characteristics, prior knowledge, experiences, and learning aptitudes (Smith-Jentsch et al., 1996; Ford & Chen, 2000). For ensuring effective learning for all students, adapting teaching strategies and content to meet individual student needs has long been regarded as a central and persistent issue in education.

Many researchers have conducted studies adapting instruction procedures to individual student variables. Until the 1990s, when the field of adaptive learning systems arose (Mödritscher, 2008); and radical development in the field was observed in the last decade (Popescu, 2010). In contrast to the difficulties of individual difference diagnosis in traditional classroom settings, adaptation to student differences are easier in e-learning environments because the development of educational technology has provided a powerful tool for conducting and implementing sophisticated instructional systems from diagnosing a student's specific learning needs during the learning process. Therefore, more and more e-learning systems were developed to accommodate a certain level of adaptability to suit individual student needs better. Stoyanov and Kirschner (2004) proposed the concept of an adaptive e-learning system "that personalizes and adapts e-learning content, pedagogical models, and interactions between participants in the environment to meet the individual needs and preferences of users if and when they arise" (p. 41).

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Contribution of this paper to the literature

- This study provides a theoretical framework for building an adaptive learning system.
- The developed system in this study employs Rubrics as a self-assessment tool assisting a better understanding of students' cognitive abilities.
- The study makes a significant contribution to the literature with empirically examine the learning effectiveness and satisfaction towards the adaptive e-learning system.

Over the past decade, various adaptive e-learning systems have become popular in education because of modern advances in information communication technology that allow for the delivery of individually tailored instruction to mass audiences simultaneously (De Bra et al., 2004; Park & Lee, 2004; Wang & Liao, 2011). Meanwhile, there are numerous studies focusing on the issues of adaptive e-learning systems. Researchers began to integrate various pedagogical theories/approaches in adaptive e-leaning systems such as scaffolding theory, learner-centered theory, and assessment methods for learners. Although previous studies have developed adaptive e-learning systems with scaffolding theory to facilitate student learning (Brusilovsky et al., 1996; Shi et al., 2002; Murray, 2003; Azevedo, Johnson, Chauncey, & Burkett, 2010; Molenaar, van Boxtel, & Sleegers, 2011), study related to developing rigorous student self-assessment to underpin adaptive e-learning systems remain limited. In fact, most adaptive e-learning systems assess/diagnosis individual student differences during the initial learning period and provide tailored learning instruction; and the scaffoldings/supports are not adjusted in accordance with concerning students' learning progress (Molenaar, Roda, van Boxtel, & Sleegers, 2012). In this regard, conducting an adaptive e-learning system that is dynamic and adapts specific instructional procedures and strategies for specific student characteristics has received considerable attention in pedagogical research. This study aims to fill a void in the existing literature by building an adaptive e-learning system with self-assessment rubrics based on dynamic scaffolding theory in response to different student needs.

The core objectives of the current study, scheduled to run for one semester, were to investigate the outcomes of using adaptive e-learning with dynamic scaffoldings upon learning Excel (a spreadsheet). Based on the research purposes, the research questions addressed in this study are as follows: 1) What are the effects of the adaptive e-learning system with dynamic scaffoldings on students' learning? And 2) What extent students satisfy adaptive e-learning systems with dynamic scaffoldings?

In the following sections, the theoretical framework of the study and related theories are introduced, followed by the research methodology. The results of the study are reported next. Finally, the discussion and conclusions are reported.

LITERATURE REVIEW

E-Learning System

Electronic learning (e-learning) integrates related ICT applications in the teaching and learning process. E-learning has a dramatic change on the modes of teaching and learning and provides a great way to remove drawbacks that are inherent in traditional classroom learning, especially its lack of flexibility in time and space (Rosenlund & Damark-Bembenek, 1999). There are numerous and different definitions for e-learning in the literature. Rosenberg (2001) proposed a broad definition of e-learning as "the use of Internet technologies to deliver a variety of solutions that enhance knowledge and performance" (p.28). Rosenberg also addressed three essential characteristics of all e-learning environment: 1) e-learning is networked, making it capable of instant updating, storage/retrieval, distribution and sharing of instruction or information; 2) it must be accessible to learners via a computer; and 3) it goes beyond the traditional paradigms of training.

In comparison with traditional classroom education that centers on instructors who have control over class content and learning process, e-learning systems offer a learner-centered, self-paced learning environment that enables learners to access learning resources at any time and from any place via web technologies. A learner-centered instruction means that learners take the initiative and responsibilities to determine their learning needs at their own schedule and pace (Zhang, 2004).

No doubt, implementing e-learning strategy has become a common practice for delivering training and education in corporations and educational institutions. However, most e-learning courses still follow a traditional homogenous model, i.e. a "one size fits all" approach that delivers the same static learning materials to all learners, although they have different prior knowledge, experience, cognitive abilities, and learning goals (Stewart et. al., 2005; Dominic & Francis, 2015). Supporting this, Chiu (2008) indicated that identifying learner requirements dynamically is an important and missing part for most conventional e-learning systems. Additionally, Premlatha, Dharani, and Geetha (2016) pointed out that numerous existing e-learning systems have problems with offering

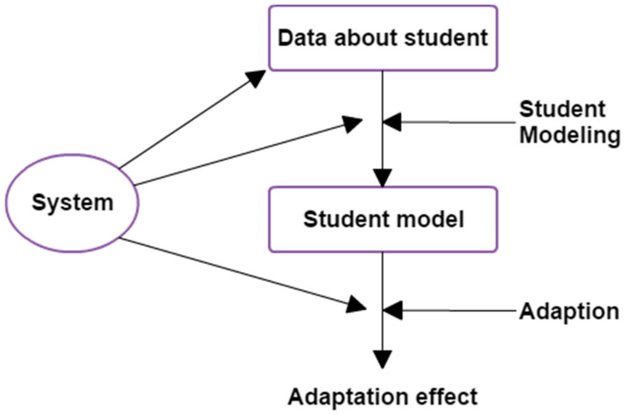

Figure 1. The architecture of an adaptive e-learning system. Adapted from "From adaptive hypermedia to the adaptive web", by P. Brusilovsky and M. T. Maybury, 2002, *Communications of the ACM*, *45*(5), p. 32.

reusable, personalized, and learner-centric content. This weakness of the existing e-learning systems become obvious, particularly when implemented in educational environments where the student characteristic is varied. Ignoring this weakness leads to an unchanging static profile construction, which may, in turn, keep students from achieving their own learning goals. Thus, the concept of adaptation has become a major issue in e-learning.

Adaptive E-Learning System

In consideration of the weakness of conventional e-learning, a number of online learning systems try to bring individualization into the learning process by providing learner-centered instruction, but the adaptive learning system is viewed as one of the most popular models (Surjono, 2011). An adaptive learning system can tailor its reaction to various circumstances. To be specific, this system in education aims to develop and implement a solution framework for individualized instruction in accordance with real-time individual differences (Brusilovsky, 2001; De Bra et. al., 2004). In other words, an adaptive learning system focuses on delivering learning contents in a customized and adaptive manner.

Adaptive e-learning, a variant of e-learning, endeavors to satisfy the demand of individualization in learning. Adaptive e-learning systems refers to a set of information techniques oriented to offer all students appropriate learning materials in response to their requirements and characteristics (Brusilovsky, 2001). In the same line, the adaptive e-learning system, according to Stoyanov and Kirschner (2004), is "an interactive system that personalizes and adapts e-learning content, pedagogical models, and interactions between participants in the environment to meet the individual needs and preferences of users if and when they arise." In summary, the adaptive e-learning system aims to give the best support to students on their learning path with the final goal of maximizing their learning performance.

As a developing new teaching method, the field of adaptive e-learning has received much attention since 1990 (Mödritscher, 2008), and recent research statistics demonstrated that there is a significant growth of applying adaptive e-learning for delivering various courses in the last decade (Popescu, 2010). A growing interest in building adaptive e-learning systems has led to the development of a wide range of adaptive processes and models. For example, Brusilovsky and Maybury (2002) proposed the architecture of an e-learning adaptive system (see **Figure 1**). The system intervenes at three stages during the process of adaptation and controls the process of collecting data about the student, the process of building up the student model, and during the adaptation process. Brusilovsky and Maybury also indicated that this system collects data for the user model from various sources that can include implicitly observing student interaction and explicitly requesting direct input from the student.

Compared with e-learning, adaptive e-learning systems are more personalized and stress the adaptation of learning content and the presentation of that content (Froschl, 2005). Thus, the implementation of adaptive e-learning systems asks for appropriately assessing individual difference of all students. In other words, these systems are capable of measuring learner difference and account for this while creating the learning path. Continuous assessments (i.e. collecting data) for student modeling incorporated into adaptive learning systems during the learning process helps deliver suitable learning instruction to each student.

Scaffolding and Dynamic Scaffolding

The concept of scaffolding refers to providing additional support or scaffolding by a "master" teacher (e.g. a teacher, an expert, or a more capable peer) in a learning setting for assisting students' cognitive development

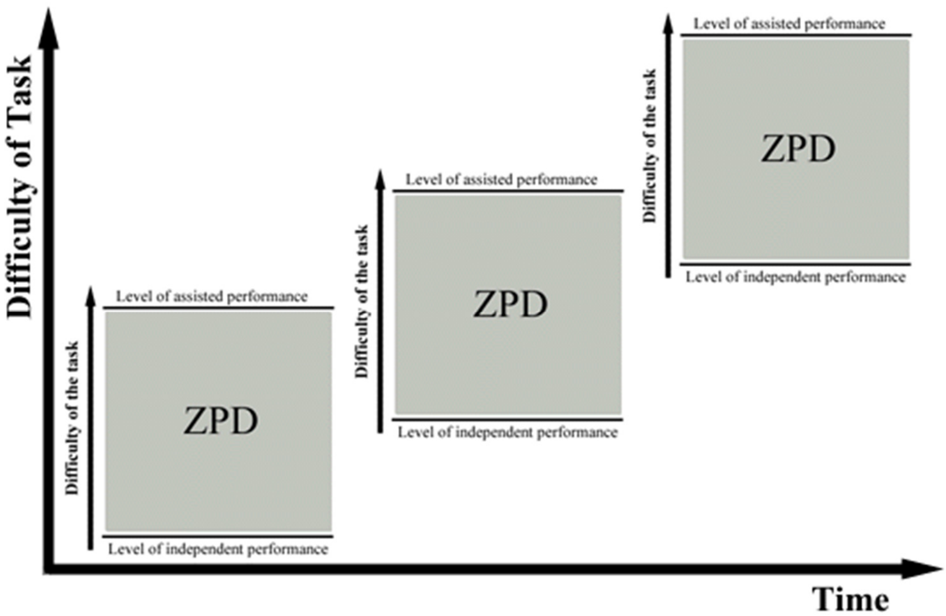

Figure 2. Changes in a learner's ZPD over time. Reprinted from: "Scaffolding emergent writing in the zone of proximal development," by E. Bodrova and D. J. Leong, 1998, *Literacy, Teaching and Learning*, *3*(2), p. 3.

(Wood, Bruner, and Ross, 1976). The supports that teachers use to assist students engage in a learning process are called "scaffolding". Scaffolding activities will take many forms, depending on the needs of the students such as models, cues, prompts, hints, partial solutions, think-aloud modeling, and direct instruction (Hartman, 2002). These scaffolds help the learner eventually solve a problem, carry out a task, master a concept, or achieve a goal (Wood, et al., 1976; Vygotsky, 1978). As students become capable of independent activity, scaffoldings/supports will be gradually removed.

Scaffolding is widely considered an essential component of effective instruction; therefore, the scaffolding strategy has been wildly employed to include several tools such as multimedia and hypermedia software to provide learners with supports (Kim & Hannafin, 2011). Most studies applying scaffolding theory provided static scaffolds in their learning contexts without considering students' changes during the learning process. However, learning styles may be influenced by students' experiences, so they are not unchanged traits that can be measured through explicit questionnaires once and ignored until the end of the implementation.

Scaffolding can be either static or dynamic, static scaffolding is constant over time and the same for all students; whereas, dynamic scaffolding continually assesses the students' ability after selecting one scaffold. Then an appropriate scaffold is provided to students according to the assessment. In other words, static scaffolding does not adjust to individual students' progress in the learning process, but dynamic scaffolding does. According to Vygotsky's Zone of Proximal Development (ZPD), learners develop new skills/knowledge at a high level of mastery (Vygotsky, 1978), both their actual level and potential level increase. That is to say, with mastery the entire zone moves along the developmental course. **Figure 2** shows the ZPD itself is not static but progresses as students attain a higher level (Leong & Bodrova, 1995), because learner development involves a sequence of constantly changing zones. Since the zone is dynamic and never static, dynamic scaffolds are required for learners for analyzing learner behavior after an appropriate scaffold being selected.

RESEARCH METHODS

The Experimental Design

A pretest-posttest designed experiment with two equivalent groups was conducted in this study. The independent variables were the different learning modes; the experimental group took part in an adaptive e-learning system with dynamic scaffoldings and rubrics, while the control group participated in a traditional e-learning system. The total duration of the experiment was one semester. The dependent variables were the learning effectiveness and learning satisfaction consisting of learner interface, learning content, and personalization.

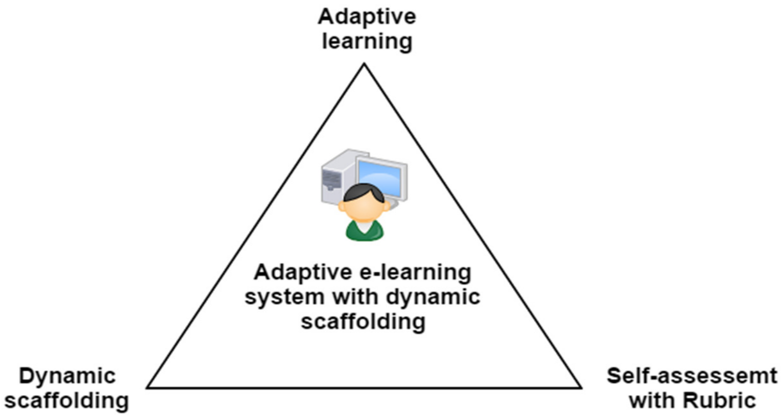

Figure 3. The theoretical foundation for adaptive e-learning system with dynamic scaffolding

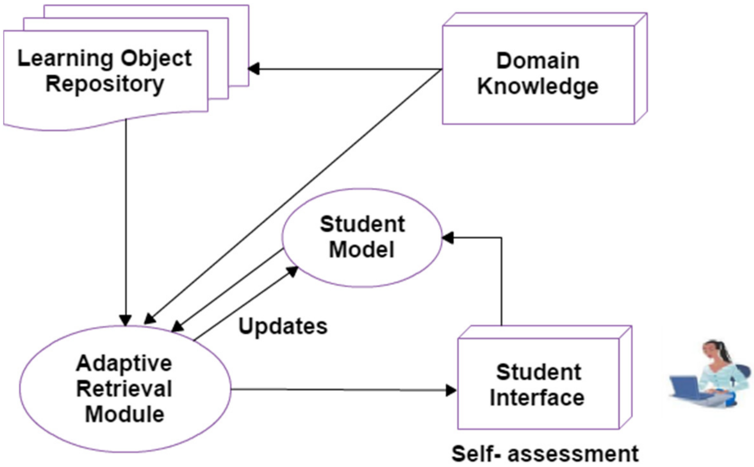

Figure 4. The architecture of an adaptive e-learning system

Participants

A total of 60 undergraduate students with an average age of 21 from a technology university in central Taiwan volunteered to participate in this experimental study. Each student was randomly assigned using SPSS software to either the experimental or the control group, each of which had 30 students. Students in each group were independent of those in the other, meaning that no students in either group could influence students in the other group and no group could influence the other group in this experiment.

To avoid the Hawthorne effect and the John Henry effect, students in both groups were not informed of the experiment. Both groups were taught by the same instructor who used the same curriculum materials for learning Excel.

System Description

This study developed an adaptive e-learning system with dynamic scaffolding for learning Excel by integrating online rubrics to assess students' capabilities and then provide suitable learning materials to them. The theoretical underpinning of the developed system includes dynamic scaffolding, adaptive learning, and self-assessment with rubrics (**Figure 3**).

In detail, based on Roy and Roy's (2011) study, this adaptive e-learning system presents an architecture consisting of five major components: domain knowledge, student model, learning object repository, adaptive retrieval module, and student interface (**Figure 4**). The lines in **Figure 4** represent a logical connection among the linked models.

Compared with e-learning, adaptive e-learning systems are more personalized and stress the adaptation of learning content and the presentation of this content (Froschl, 2005). Thus, the implementation of adaptive e-learning systems asks for appropriately assessing individual differences for all students. In other words, these systems are capable of measuring learner difference and account for this while creating the learning path. Continuous assessments (i.e. collecting students' data) incorporated into adaptive learning systems during the learning process helps deliver suitable learning instruction to each student. These five components in the developed system are described as follows.

1) Domain knowledge: Storing learning content that is to be taught in specific academic courses.
2) Student model: Storing information and data about students. This component determines the student's skill/competence level.
3) Learning object repository: Storage of learning objects. It allows students to retrieve learning materials based on their own objectives.
4) Adaptive retrieval module: The adaption technique allows students select suitable required materials in accordance with their own learning goal and individual learning capabilities.
5) Student interface: Providing learning materials and information. In addition, a self-assessment test using rubrics is conducted during the learning process.

According to Andrade (2008), rubrics can be a powerful self-assessment tool. Under the right conditions, student self-assessment can offer accurate, useful information to improve learning. In this study, the developed system uses feedback from students' self-assessments to guide revision.

Research Hypotheses

The potential payoffs of designing, developing, and employing good e-learning solutions are great and include improved effectiveness and satisfaction of the learning experience. Therefore, this study addressed the following research hypotheses.

H1. There is a significant difference in individual learning outcomes between students who receive dynamic scaffoldings and who do not receive dynamic scaffoldings.

H2. There is a significant difference in learning satisfaction towards the e-learning system between students who receive dynamic scaffoldings and who do not receive dynamic scaffoldings.

H2a. There is a significant difference towards learning interface of the e-learning system between students learning with dynamic scaffoldings and students learning without dynamic scaffoldings.

H2b. There is a significant difference towards learning content of the e-learning system between students learning with dynamic scaffoldings and students learning without dynamic scaffoldings.

H2c. There is a significant difference towards personalization of the e-learning system between students learning with dynamic scaffoldings and students learning without dynamic scaffoldings.

Experimental Procedure

All participants first joined a 30-min training session to become familiar with both systems (adaptive e-learning system and traditional e-learning system). Following that, both experimental and control groups underwent a pretest that was distributed at the beginning of the course, which enabled us to determine that there was no statistically significant difference between two groups concerning their pre-existing Excel knowledge. **Figure 5** shows the experimental procedure used in this study.

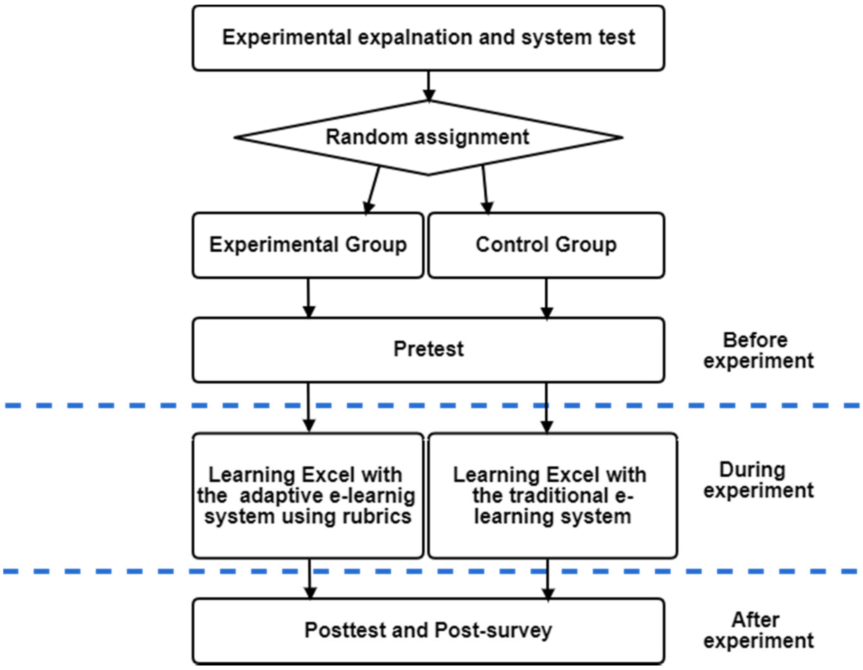

Figure 5. The experimental procedure of this study

Figure 6. A snapshot of the adaptive e-learning system

Participants in both groups received the same content except for using a different e-learning system. Students in the experimental group use an adaptive learning system with dynamic scaffolding and rubrics (**Figure 6**), whereas students in control group adopt a traditional e-learning system without dynamic scaffolding and rubrics. The experiment lasted for one semester.

Measuring Instruments

Learning effectiveness and satisfaction were used broadly to assess learning performance in previous studies (Hung et al., 2009). Learning effectiveness is to understand whether learners obtain domain knowledge and understand major issues of courses. Moreover, the most common way to measure learning effectiveness is

Table 1. Comparison between experimental and control group in pretest scores

Group	N	Mean	SD	*t*-statistics	*p*-value
Experimental group	30	77.1	17.899	0.148	.883
Control group	30	76.6	4.553		

Table 2. Comparison between experimental and control group in posttest scores

	N	Mean	SD	*t*-statistics	*p*-value
Experimental group	30	89.0	10.73	2.882	.006 **
Control group	30	77.3	19.48		

Note: ** p < .01

quantitatively with pre and posttests. In addition, satisfaction was adopted to evaluate learning performance in numerous educational studies. Therefore, this study measured students' learning performance at two different levels: learning effectiveness and learning satisfaction. Further, there were three aspects for learning satisfaction: learner interface, learning content, and personalization.

A pretest and a posttest were conducted to evaluate learning effectiveness. The pretest was designed to evaluate the students' pre-existing knowledge of Excel course content, while the posttest was designed to evaluate students' Excel skills. Both the tests were developed by two experienced teachers.

The learning satisfaction measuring instrument, consisting of a total of 12 items, was adopted from Wang (2003). It consisted of three constructs, including learner interface (4-items), learning content (4-items), and personalization (4-items). All items were measured by a five-point Likert scale in which 1 represented strongly disagree, 3 was the neutral point, and 5 represented strongly agree.

In this study, we attempted to use valid and reliable measures. First, items were adopted from previously validated instruments. Second, content validity was established through both academics during the phase of questionnaire development. Third, the reliability of the measures were reassessed with the current sample.

DATA ANALYSIS AND RESULTS

This study collected quantitative data to answer the research questions including 1) pretest/posttest scores of the experimental group and the control group, and 2) a learning satisfaction survey towards the use of e-learning systems.

Analysis of Learning Effectiveness

Quantitative data were collected from pre and posttests for students in the experimental group and in the control group.

Research collected data were analyzed with independent *t*-test using the SPSS version 20 to assess whether the means of two groups are statistically different from each other. **Table 1** shows there are no significant difference between the mean pretests of two groups (t=0.148, p=.883 > .05), so it is assumed that participants in both groups had equivalent prior knowledge.

The mean score of the experimental group is also compared with that of the control group in the mean score of the posttest. The mean is found to be 89.0 for the experimental group and 77.3 for the control group. The independent-sample *t*-test procedure was adopted to examine differences of learning outcomes between two groups. **Table 2** shows the *t*-test results revealed that a significant difference was found between the experimental and the control groups (t=2.882, p= *.006* < .01) and indicated that the research hypothesis H1 was supported. From *t*-test analytical results of **Table 2**, it was found that participants in the experimental group perform better learning than the control group. In other words, the adaptive e-learning system with dynamic scaffolding strategy proposed by this study was verified to be able to successfully help students enhance student learning outcomes. **Figure 7** presents an overview of the pretest and posttest scores of participants in deferent groups. The experimental group demonstrated significant higher learning effectiveness gains than the control group.

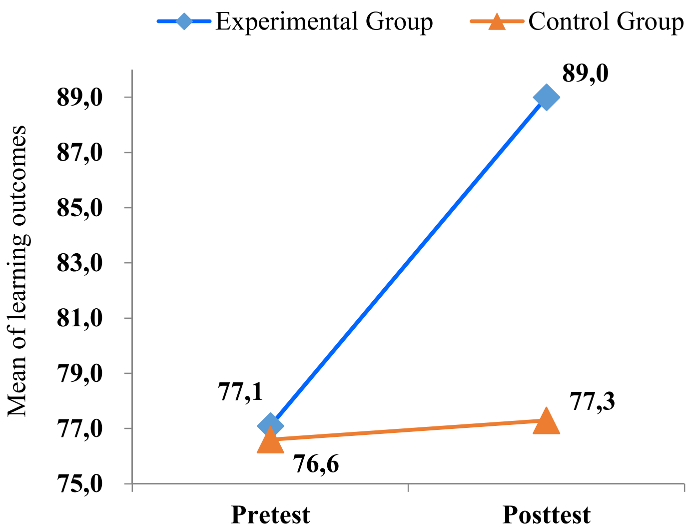

Figure 7. Differences in pretest and posttest of learning outcomes

Table 3. Reliability coefficients for all constructs of learning satisfaction

Constructs	Item description	Cronbach's α
Learning satisfaction		.951
Learner interface	The e-learning system is easy to use	.852
	The e-learning system is user-friendly	
	The operation of the e-learning system is stable	
	The e-learning system makes it easy for you to find the content you need	
Learning content	The e-learning system provides up-to-date content	.884
	The e-learning system provides content that exactly fits your needs	
	The e-learning system provides sufficient content	
	The e-learning system provides useful content	
Personalization	The e-learning system enables you to learn the content you need	.915
	The e-learning system enables you to choose what you want to learn	
	The e-learning system enables you to control your learning progress	
	The e-learning system records your learning progress and performance	

Table 4. Descriptive statistics and *t*-test for all constructs of learning satisfaction

Constructs	Experimental group		Control group		*t*-statistics	*p*-value
	Mean	SD	Mean	SD		
Overall satisfaction	4.20	0.44	3.91	0.62	2.036	.047*
Learner interface	4.15	0.48	3.96	0.63	1.229	.224
Learning content	4.21	0.55	3.99	0.60	1.506	.137
Personalization	4.24	0.58	3.79	0.79	2.468	.016*

Note: * $p < .05$

Analysis of Learning Satisfaction

Cronbach's *α* (Cronbach, 1951) was used as a test for the internal consistency reliability of each scale. Cronbach's *α* ≥ .70 are judged to be high in internal consistency (Nunnally, 1978). In this study, **Table 3** shows the reliability coefficients of learner interface, learning content, and personalization were ranging from .852 to .915, which exceeds the recommended cut-off level of 0.70. Furthermore, the Cronbach's *α* test suggested good reliability for overall learning satisfaction questionnaire (Cronbach's *α*=.951); thereby, implying an adequate level of internal consistency.

Table 4 presents the descriptive statistics and independent *t*-tests for all constructs of learning satisfaction questionnaire. It was found that students in the experimental group have higher overall satisfaction and personalization towards the used e-learning system than the control group, which means H2 and H2c can be considered to have empirical support from the data at hand. However, there is no significant difference between two groups towards learner interface and learning content of the used e-learning system, which means H2a and H2b are not supported.

DISCUSSION AND CONCLUSIONS

E-learning systems are considered adaptive when they can dynamically change in response to individual student differences. Major challenges faced by researchers and instructors are to optimally integrate learning theories and instruction strategies with system functions and to empirically examine the effects and value of these systems in real-world environments (Park & Lee, 2004). To enhance learning effectiveness for all students, this study developed an e-learning system based on an integrated theoretical framework that consists of adaptive instruction strategy, dynamic scaffolding theory, and self-assessment mechanism. The developed adaptive e-learning system can take the dynamic student ability into account and deliver suitable learning materials to all students.

The experimental results revealed that there is a significant difference in student learning effectiveness and learning satisfaction between the experimental and control groups. When comparing learning effectiveness, the experimental group's score was significantly higher than the control group's scores. With the capabilities adapting to the needs of individual students, the adaptive e-learning system with dynamic scaffolding and rubric was confirmed to successfully foster students' learning effectiveness. From the students' perceived learning satisfaction, this developed adaptive e-learning system enabled students to learn the content they need, to choose what they want to learn, to control their learning progress, and to record their learning progress and performance. In summary, the developed adaptive e-learning system in our study can effectively support students with personalized learning materials and to successfully help students acquire knowledge and develop cognitive abilities.

The research results are consistent with previous studies. For instance, Mampadi et al. (2011) developed dynamic scaffoldings tailored to students' cognitive style in an adaptive hypermedia learning system and examined the effect compared with an ordinary hypermedia learning system that does not exhibit any adaptation. The findings indicated students who used the adaptive hypermedia learning system obtained better learning outcomes for learning eXtensible Markup Language (XML) than those with an ordinary hypermedia learning system that did not support any adaptation. Likewise, Molenaar et al. (2012) measured the effects of dynamic scaffolding supported by an attention management system on middle school students' learning in small groups with the experimental method. Their findings indicated that the dyads with dynamic scaffolding were more positive about their teachers and collaborators than students without dynamic scaffolding.

The results of this study can be of the reference for system developers, programmers, platform operators, teachers, and relevant personnel in education in the hope to conduct a successful adaptive e-learning environment. Particularly, the results suggest that teachers can employ rubrics as a self-assessment tool to support students with dynamic scaffoldings to conduct a learner-centered e-learning environment.

This study, like much of the empirical research, has limitations that should be addressed. First, the lack of generalizability is clearly a limitation of the present data due to a few participants. The findings for this study cannot be generalized across a large population because participants in this study were selected from the same university. This study still retains considerable space for growth. Future research could consider the other individual learner variables and provide dynamic scaffoldings for them.

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