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Online knowledge-structure-based adaptive science learning: Integrates adaptive dynamic assessment into adaptive learning

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Abstract: This paper aims to report the Adaptive E-learning for Science Project (AESP) in Taiwan. The AESP aims to develop an adaptive science learning system, introduce it to primary science teachers and examine the effectiveness of using this adaptive science learning system. The adaptive learning system is knowledge-structure-based and integrates adaptive dynamic assessment into adaptive learning. Besides, to construct the diagnostic items and learning materials, a group of expert primary science teachers and science educators also participated. With a knowledge-structure-based approach, we analyzed and constructed the conceptual (or skill) nodes and conceptual (or skill) network (i.e., knowledge structure) based on the Taiwanese Science Curriculum Guidelines for grade 1-6 firstly. The conceptual (or skill) network reveals the hierarchical relationships among the conceptual nodes. Then, according to the conceptual (or skill) nodes, diagnostic items for adaptive dynamic assessment and instructional materials (videos) for adaptive learning were designed. After developing the system, the adaptive science learning system was introduced to primary science teachers and conducted preliminary studies to evaluate the effects of using this online adaptive learning system in different science learning contexts (e.g., ICT-based lecture and flipped classroom). The major findings derived from two preliminary studies are discussed.

Keywords: adaptive learning, knowledge-structure-based, science learning

1. Introduction

Conventional instruction relies on the way that teachers convey and transfer knowledge completely to their students (Ewing, 2011; Myers, Monypenny & Trevathan, 2012). Considering students' diverse backgrounds in the conventional instruction, teachers have been encouraged to incorporate students' learning needs with their instructional arrangements (Bergmann & Sams, 2012). In a recent decade, science education proposes the significance of inquiry-based and hands-on learning activities to the cultivation of scientific literacy. However, insufficient qualified teachers in teaching primary science and science class time constitute fundamental challenges of primary science teaching and learning in Taiwan. There is a need to offer a viable alternative to conventionally instructional approach, and provide more personalized learning and remediation for fulfilling students' individual differences in the current status of science instruction.

Adaptive e-learning could be viewed as a promising way to address these challenges, as well as would be helpful to Taiwanese students' science achievement and motivation toward science learning. Adaptive learning is an approach to create a personalized learning experience for students that use a "data-driven", and in some cases, nonlinear approach to instruction and remediation (Education Growth Advisors, 2014). Many studies have proposed the benefits of using adaptive e-learning technology (Kerns, 2013; Hicks, 2015) such as providing real-time response for students to accelerate their learning progression and engaging students in learning by technology tools. Students can work on their own time at different pathways and paces, as well as teachers can get data with insights into student needs and free up time for one-on-one instruction. Although many systems have been created to support adaptive e-learning, but an adaptive e-learning system designed based on Taiwanese students' need and curriculum standards is still not available.

This study proposed an adaptive e-learning project for science in Taiwan (sponsored by Ministry of Education, MOE). The goals of Adaptive E-learning for Science Project (AESP) aim to develop an adaptive E-learning system for science, namely Adaptive Science E-Learning System (AELS). Incorporating the perspective of knowledge structure with adaptive testing, the development of AELS adopts multiple components and mechanism together to carry out science instruction tailored to the needs of the individual students. In addition to the introduction of the developed AELS, this study revealed some preliminary findings form pilot studies to demonstrate the effectiveness of applying adaptive e-learning system (AELS) in primary school students' science learning.

2. Methodology

2.1. Adaptive Science E-Learning System (AELS)

AELS consisting of multiple components together enables science instruction tailored to the needs of the individual students. These components as shown in Fig 1, according to literature are: the content model, the learner model, the instruction model (interface model) and the adaptive engine. The content model contains the concepts that a student should master. In educational research, the concepts are usually described as learning objectives. The learner model contains information about the individual student, such as demographic data, and information about the knowledge of a specific topic. The instruction model monitors the learner model in relation to the content model in order to ascertain the student's mastery of concepts. As such, the instruction model determines how close a student is to the target competence level after carrying out a learning activity. The adaptive engine is an algorithm that integrates information from the preceding models in order to select appropriate learning content to present to the student.

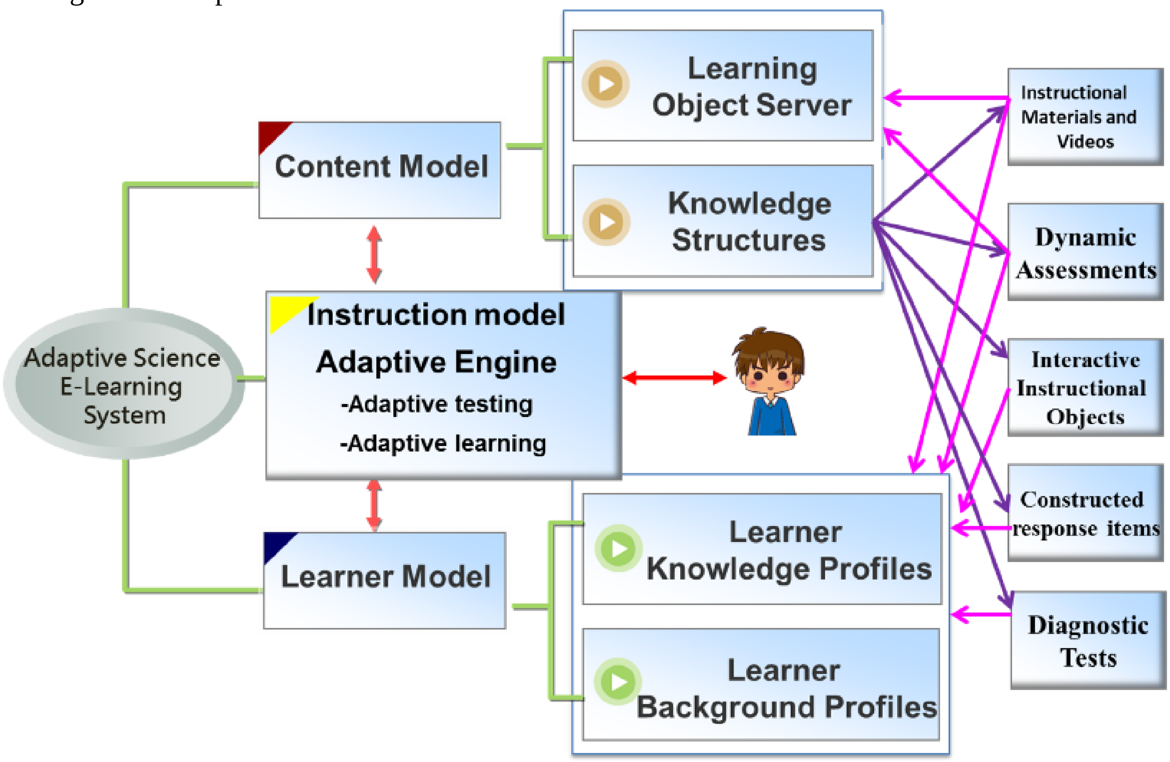


Figure 1. The Framework of Adaptive Science E-Learning System

2.2. *Knowledge Structure Maps*

The construction of knowledge structure maps is the core of adaptive e-learning system for science instruction and learning. Knowledge structure maps are constituted of conceptual (or skill) nodes and networks, as shown in Figures 2 and 3. Nodes were identified based on the Taiwanese Science Curriculum Guidelines for grade 1-6, which represent the science competences required for successful learning in a specific grade. The conceptual (or skill) network reveals the hierarchical relationships among the conceptual nodes and conceptual learning sequence. There are two layers of nodes and networks in knowledge structure maps. First layer of nodes and networks (Figure 2) represent the conceptual network of grade competence indicators of Taiwanese grade 1-6 curriculum guidelines. For example, the grade competence indicator nodes (e.g., 110-2a, 110-2b) within the knowledge structure map of the sub-theme, “earth environment.” The code “110” refers to “earth environment”; “2” refers to “3rd or 4th grade”; “b” refers to “number.” The second layer of nodes and networks (Figure 3) represents the conceptual network of sub-concepts and sub-skills which are subdivided from each grade competence indicator node in the first layer. The second layer of knowledge structure can provide learning information at a micro level.

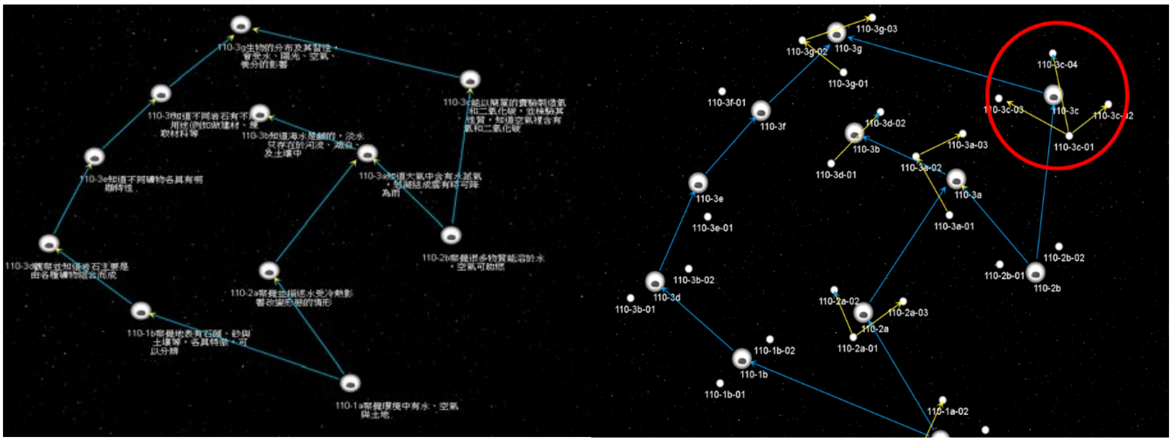
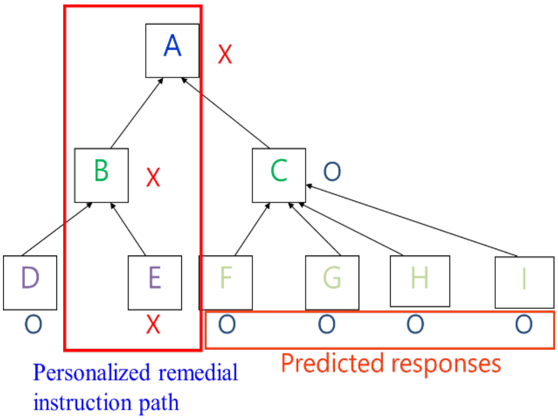


Figure 2. First layer of knowledge structure maps Figure 3. Second layer of knowledge structure maps

2.3. *Adaptive Diagnostic Test*

The adaptive testing algorithm is based on the knowledge structure. As shown in Figures 4, if the subject gets a top skill such as item A incorrect, then the low-level item will test to detect where is student’s problem, If high-level node such as item C is correct then it is inferred that he or she also understands its prerequisites (items F, G, H, I). This algorithm can predict students’ profiles using fewer items than in original paper-and-pencil based tests.



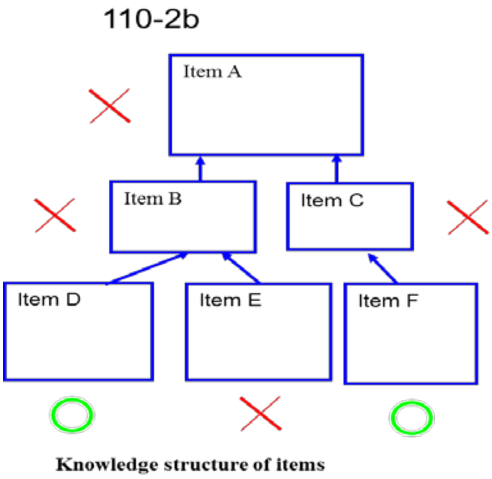
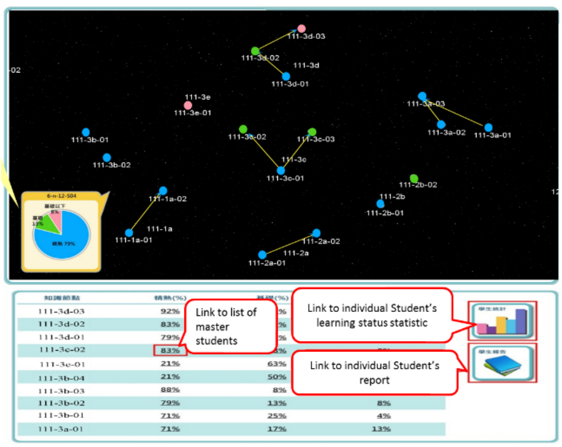


Figure 4. Adaptive testing algorithm

Figure 5. Personalized remedial instruction path based on experts' knowledge structure for student B

2.4. Learning profiles

According to adaptive diagnosis report (learning profile), different learning paths and resources are suggested for each student to advance his/her optimal learning. Three learning profiles regarding specific competence indicator learning (Figure 6), single grade learning and longitudinal learning (Figure 7) are provided for individual student, teacher, and school.



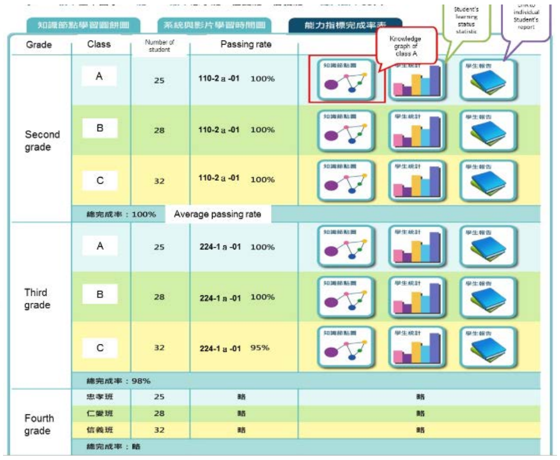


Figure 6. Specific competence indicator learning

Figure 7. Longitudinal learning profile

3. Data collection and analysis

A total of 136 primary school students with 4th-6th grades were recruited from six partner schools attending in AESP in Taiwan. The students were assigned to different instruction modes of ICT-based instruction, flipped classroom and longitudinal adaptive review learning conducted respectively in three pilot studies. A quasi-experimental design was conducted in ICT-based instruction and flipped classroom instruction, and one-group pretest-posttest design was employed in the instruction mode of longitudinal adaptive review learning.

Based on the knowledge structure, instructional materials and diagnostic items were developed on a single concept or skill node in the second layer of knowledge structure map. Each node in the second layer of knowledge structure map contains an instructional video and four items at least. In order to get fine-grained diagnostic information, each item was developed to assess knowledge on a single concept or skill node in the second layer of knowledge structure. The students' of diagnostic test performance was employed to validate the effectiveness of adopting adaptive science e-learning system in primary school students' science learning through different instructional modes conducted in this study.

4. Results

In the pilot study of utilizing ICT-based instruction mode, the t-test results of Table 1 reveal that the students in experimental and control groups did not have significant difference in the pre-test performance (67.62 versus 74.48). Further examination of post-test performance reveals that the students in experimental group significantly outperformed the students in control group (88.43 versus 77.33, $p<0.05$) through the ICT-based instruction mode.

Table 1: Pilot study 1: ICT-based instruction mode

	Experimental group(n=21)	Contorl group(n=21)	
	Mean./S.D.	Mean/S.D.	t-value
Pre-test	67.62/18.60	74.48/14.93	1.32(n.s.)
Post-test	88.43/17.03	77.33/17.97	-2.05*

*p<0.05

As shown in Table 2, in the pilot study of employing flipped classroom mode, there is no significant difference of students' pre-test performance between experimental and control groups (75.32 versus 71.36). The t-test result of post-test performance reveals a significant difference between experimental and control groups (92.60 versus 79.36, $t<0.001$), which indicates that students could have better learning performance through flipped classroom mode than conventional instruction.

Table 2: Pilot study 2: Flipped classroom mode

	Experimental group(n=21)	Contorl group(n=21)	
	Mean./S.D.	Mean/S.D.	t-value
Pre-test	75.32/14.84	71.36/19.12	-1.22(n.s.)
Post-test	92.60/9.08	79.36/11.16	-5.62***

***p<0.001

In the pilot study of adapting longitudinal adaptive review learning mode, the method of paired-t test was employed to examine the difference between pre- and post- test performance within the same group of students. As shown in Table 3, significant results of paired-t test reveal that the students may have better performance of learning science through the implementation of longitudinal adaptive review learning mode.

Table 3: Pilot study 3: Longitudinal adaptive review learning mode

	Pre-test Mean./S.D.	Post-test Mean/S.D.	t-value
6th graders (N=52)	65.94/14.60	75.83/11.23	--8.73***

***p<0.001

5. Conclusion and Discussion

This study introduced the development and properties of Adaptive Science E-Learning System (AELS). Some initial positive results provide some evidence that the adaptive e-learning system could be incorporated with various instructional modes to promote students' performance of learning science. AESP's future work will focus on revising and expanding knowledge structure maps and instructional materials and videos to 9th grade science learning, improving system interface and functions and co-working with more partner schools to find out better practices.

Acknowledgements

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