Wu, H. M., Kuo, B. C., & Wang, S. C. (2017). Computerized Dynamic Adaptive Tests with Immediately Individualized Feedback for Primary School Mathematics Learning. *Educational Technology & Society, 20* (1), 61–72.

Computerized Dynamic Adaptive Tests with Immediately Individualized Feedback for Primary School Mathematics Learning

Huey-Min Wu[1], Bor-Chen Kuo[2*] and Su-Chen Wang[3]

[1]Research Center for Testing and Assessment, National Academy for Educational Research, New Taipei City, Taiwan // [2]Graduate Institute of Educational Information and Measurement, National Taichung University of Education, Taichung, Taiwan // [3]Taiping District Sin-Guang Elementary School, Taichung, Taiwan // whm@mail.naer.edu.tw // kbc@mail.ntcu.edu.tw // mandy2539@gmail.com

[*]Corresponding author

(Submitted September 18, 2015; Revised December 2, 2015; Accepted January 22, 2016)

ABSTRACT

In this study, a computerized dynamic assessment test with both immediately individualized feedback and adaptively property was applied to Mathematics learning in primary school. For evaluating the effectiveness of the computerized dynamic adaptive test, the performances of three types of remedial instructions were compared by a pre-test/post-test nonequivalent group design. These remedial instructions are the adaptive dynamic assessment with individualized instruction, the individualized instruction without adaptive dynamic assessment, and the traditional classroom remedial instruction. One hundred and eighteen 5th grade elementary school students from six classes participated in the study and were assigned to three remedial instruction programs on a random basis. The results demonstrated that the computerized dynamic adaptive test with individualized prompts outperformed the other two instruction methods.

Keywords

Computerized adaptive test, Dynamic assessment, Graduated prompts, Knowledge structure, Mathematics

Introduction

With the use of computer and communication technology, researchers have developed various assessment systems in improving students' learning achievement. The characteristic of learning or testing systems is to provide meaningful and personalized feedback that can accommodate a diversity of student personalization (Chen, 2009; Chen, 2011; Hwang, Panjaburee, Triampo, & Shih, 2013; Kao, Lin, & Chu, 2012; Luft, Gomes, Priori, & Takase, 2013; Moridis & Economides, 2012; Panjaburee, Hwang, Triampo & Shih, 2010). However, many computerized-based tests place greater emphasis on feedback on the final product of assessment tasks rather than the process of the learning. Moreover, all examinees received the same items and were required to complete all the items within the assessment procedure. These test systems do not capitalize on advantage of combining technology with testing, a computerized adaptive test (CAT). CATs offer examinees customized items suited to their aptitudes and cognitive status and shorten the length of the test (van der Linden & Pashley, 2010). Adaptive tests can provide equal measurement precision for most test-takers (Yen, Ho, Chen, Chou, & Chen, 2010; Yen, Ho, Liao, & Chen, 2012).

Wu, Kuo, and Yang (2012) have developed a knowledge structure-based computerized adaptive test for diagnosing students' learning profiles. In the research of Wu et al. (2012), an adaptive test algorithm that can utilize fewer items than the original paper-based tests was proposed. The knowledge structure-based computerized adaptive test provides feedback regarding how well students performed on specific skills immediately after testing with fewer items (Wu et al., 2012); however, it is not sensitive to the process of students' learning. Meaningful feedbacks that can facilitate learning effectiveness are timely feedback and process-oriented feedback (Gabelica, Van Den Bossche, Segers, & Gijselaers, 2012; Harks, Rakoczy, Hattie, Besser, & Klieme, 2014; Hattie &Timperley, 2007; Parr & Timperley, 2010; Wang, 2011).

Dynamic assessment is an interactive assessment that can provide students with both timely and process-oriented feedback (Campione & Brown, 1990; Haywood & Lidz, 2007). Dynamic assessment is grounded in Vygotsky's (1978) sociocultural theory, especially the Zone of Proximal Development (ZPD) concept, which describes how a student can go from his actual development level to his potential development level through continuous communication and consultation in the course of interactions with teachers, peers, or parents (Poehner, 2008). The ZPD relates to the gap between what the child can learn without help and what he or she can learn with adult guidance or in collaboration with more capable peers.

Dynamic assessment embeds intervention within the assessment procedure. Typically there is a pre-test (to diagnose the characteristics of the student), an intervention (to provide appropriate feedback based on the student's characteristics and to help him or her learn), and then a post-test (to examine whether the student has learned the new concept after the intervention) (Haywood & Lidz, 2007). Despite the potential benefits of dynamic assessments, the need for experienced administrators and the amount of time involved have limited their use in applied educational settings (Frisby & Braden, 1992). Some researchers have reported the effectiveness of web-based dynamic assessments in enhancing students' academic performance (Chen et al., 2010; Wang, 2010; Wang, 2011). Computerized dynamic assessments can be applied to the majority of students and would greatly improve the feasibility of using dynamic assessments in the classroom.

Based on the application of Vygotsky's theory, Campione and Brown (1987) have developed the graduated prompt procedure to implement dynamic assessments. In the graduated prompt procedure, predetermined prompts that range from general to specific are given to provide students with gradual assistance until they solve the problem. In the beginning, students are provided general prompts. If students still cannot solve the problem after the first prompt, clearer and more specific prompts will be presented. The number of prompts required to solve the problem is taken as an indication of the students' ZPD.

In the graduated prompt procedure, a student is given the same prompt (a general prompt) when he or she makes a mistake for the first time, regardless of which answer he or she chose. When the student makes a mistake for the second time, the student receive the same second level prompt (a specific prompt), regardless of which answer he or she chose. When the student makes a mistake for the third time, the teacher steps in and provides direct guidance (Campione & Broen, 1987). The graduated prompt procedure could promote precision in the estimation of individual learning ability and help teachers understand individual learning flexibility and modifiability (Hsu, 2008; Jitendra & Kameenui, 1993; Wang, 2011); however, little research has been done on the efficacy of the prompts in relation to students' personal needs.

Computerized dynamic assessment can provide immediate feedback and is sensitive to progress. Providing feedback related to the process of problem solving could benefit students' learning (Adesina, Stone, Batmaz, & Jones, 2014; Wang, 2010; 2011). A computerized adaptive test can offer customized items and reduce the length of the test and the time needed to take it. Adaptive dynamic assessments can benefit students' learning in calculus (Ting & Kuo, 2015). Some preliminary studies on computerized dynamic adaptive test system had been introduced in the conference by Cheng, Wu, Kuo and Li (2013).The comprehensive results on evaluating the effectiveness of computerized dynamic adaptive test system in primary school Mathematics learning is presented in this study. The advantages of computerized dynamic assessment and adaptive tests are applied into a computerized dynamic adaptive assessment. The graduated prompt procedure that meets the students' personal needs is integrated into the computerized dynamic adaptive assessment and will be referred to as "individual instruction prompts" in this paper.

Aim of the study

This study aimed to explore the effect of using the knowledge structure-based dynamic adaptive assessment as a remedial instruction program in comparison with a didactic teaching approach remedial instruction program in primary school mathematics. The research questions to be addressed in this study are as follows:

- How effective are the three remedial instruction programs at improving primary school mathematics?
- How effective is the computerized dynamic adaptive assessment compared with a didactic teaching approach?
- How efficient is the developed computerized dynamic assessment system for primary school mathematics?

Domain experts' knowledge structure

In a task analysis, the cognitive skills required for successful learning and performance in a specific domain are usually defined by experts (Kalyuga, Rikers, & Paas, 2012). In this study, the "addition and subtraction of fractions with different denominators" unit of mathematics utilized in Taiwanese elementary schools is adopted by four practicing teachers and two domain experts (hereinafter referred to as "the experts") to construct a knowledge structure. By analyzing teaching materials and objectives, the important cognitive skills of this unit were defined by the experts. After many discussions, the experts portrayed the sequence of the skills' development and the relationships between these cognitive skills in a tree diagram. There were a total of eighteen cognitive skills for the "addition and subtraction of fractions with different denominators" unit. Figure 1 is an example of part of the experts' knowledge structure, and it demonstrates that the upper-level cognitive skills, such as "apply addition and subtraction of fractions with different denominators," are advanced cognitive skills, while low-level cognitive skills, such as “calculate addition of improper fractions with different denominators,” are basic-level cognitive skills. “S” refers to the symbol of the cognitive skill. In this study, tests were developed based on the experts’ knowledge structure. Generally, an item was developed to assess knowledge on a single cognitive skill.

An adaptive test algorithm based on the knowledge structures suggested in the research of Wu et al. (2012) was used in this study. For example, S10 is forwardly linked to S11, which means that S10 must be mastered before S11 can be attempted; that is, S10 is a prerequisite to S11. If the student gets S11 correct, then it is inferred that he or she also knows its prerequisite (S10). This algorithm in computerized adaptive diagnostic tests can predict students’ learning profiles by utilizing fewer items than those used in original paper-based tests (Wu et al., 2012).

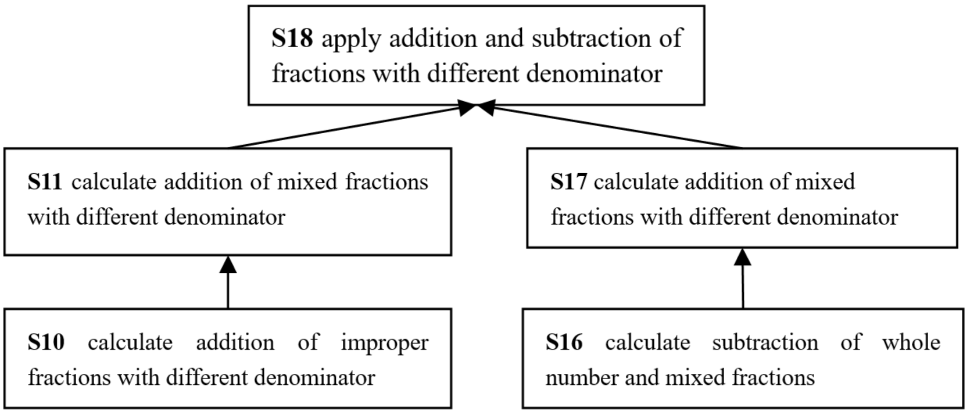

Figure 1. Part of the domain experts’ knowledge structure

Computerized dynamic adaptive test

A computerized dynamic adaptive test system has been developed with PHP and MySQL on APACHE web servers. It consists of five modules: the Item Bank Management Module, Account Management Module, Test Management Module, Test Result Searching Module, and Dynamic Assessment Module. The Item Bank Management Module includes items and the knowledge structure of specific unit updates, modification, and management. The Account Management Module provides creation, modification, and management of user accounts. The Test Management Module sets the approach of test administration. Figure 2 represents the interface for an item’s administration. The Test Result Searching Module provides the group results (shown in Figure 3) and the individual results (shown in Figure 4) to the instructor and the student, respectively.

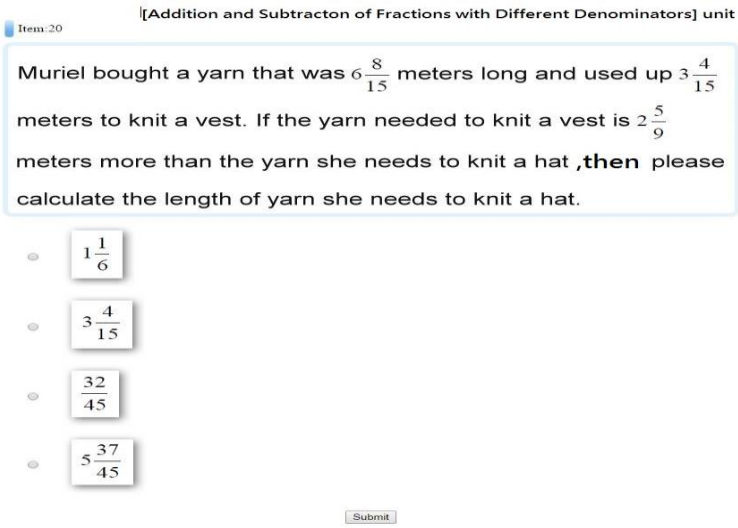

Figure 2. The test administration interface

The Dynamic Assessment Module sets the algorithm of dynamic adaptive assessment based on the knowledge structure, as shown in Figure 5. First, the upper-level item with the most links is administered to a student. The status of the response is checked by the system. If the student answers the item correctly, then it is inferred that the student also knows its prerequisites concepts. The item's related prerequisite concepts will not be administered to the student and will be assumed to be answered correctly. The system checks whether or not there are any non-response items and, based on the results, either goes back to the first step or concludes the test. If the student answers an item incorrectly, based on the distracter option the student chose, the system will present the individualized instruction prompts with different levels to the student, as shown in Figure 6. A detailed description of the instruction prompts is given in the next section. If there are no more prompts, the process for solving this question will be provided to the student. Finally, the system checks whether or not there are any other non-response items and, based on the results, either goes back to the first step or concludes the test.

The Group Profile Happy City Happy Elementary School Grade 5 Class

Unit【addition and subtraction of fractions with different denominators】

Skill List	Passing Rate	
	Test1 (%)	Test2 (%)
【S1】Find equivalent fractions using expansion	97.6	100
【S2】Find equivalent fractions using reduction	88.1	96.6
【S3】Solve problems involving integers and fractions	59.5	83.3
【S4】Solve problems involving improper fractions and mixed fractions	81.0	88.1
【S5】Understand why fractions with different denominators are rewritten using common denominators the	97.6	92.9
【S6】Compare two fractions with different denominators by finding common	90.5	100
【S7】Solve problems involving adding proper fractions with different single-digit denominators	92.9	100
【S8】Solve problems involving adding proper fractions with different denominators by multiplying denominators with a single-digit number	59.5	88.1
【S9】Solve problems involving adding fractions with different denominators that require carrying	85.7	92.9

Figure 3. The profile for groups interface

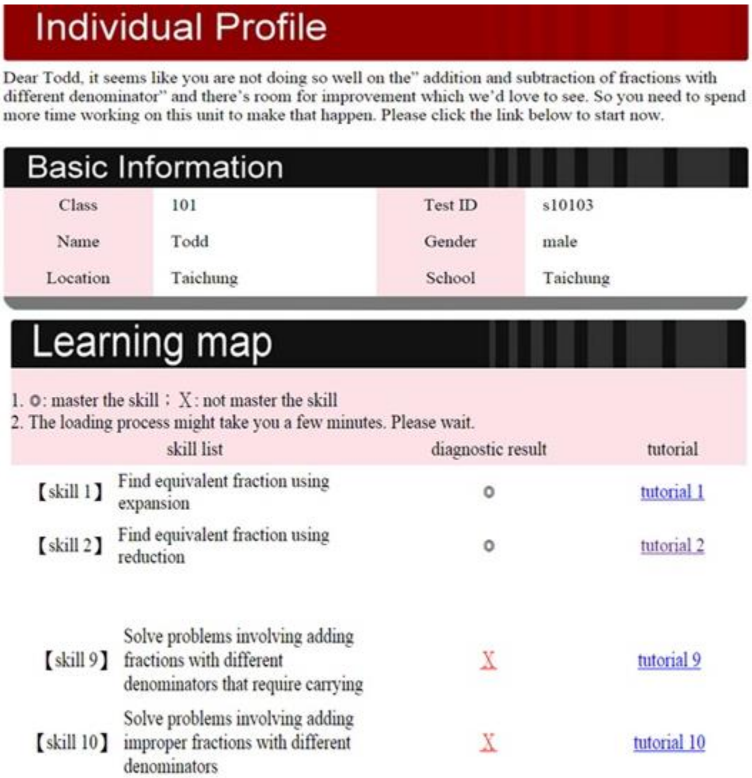

Figure 4. The profile for individual student's interface

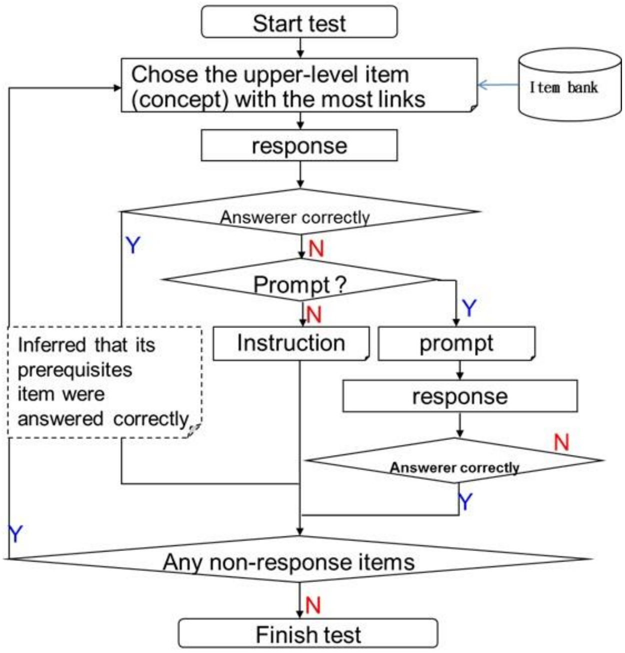

Figure 5. The algorithm of the computerized dynamic adaptive assessment

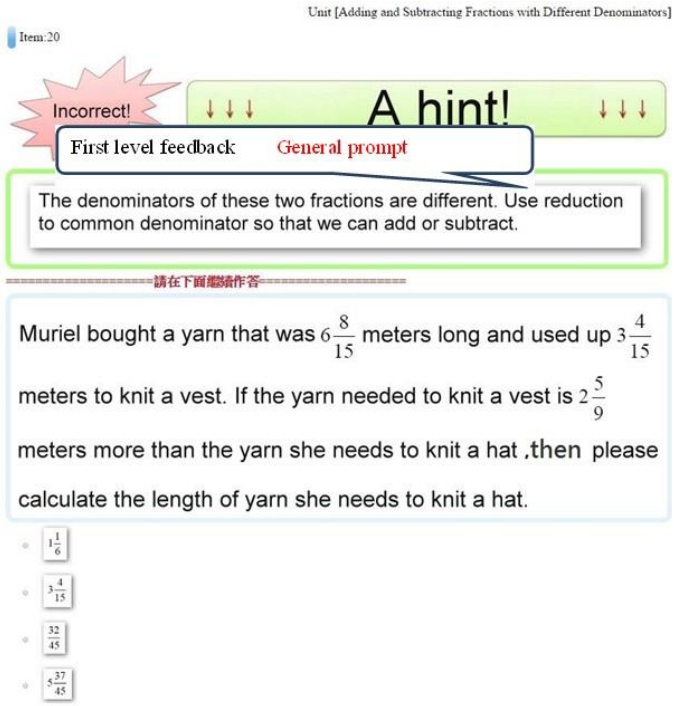

Figure 6. The general prompt interface

Instruction prompts

The experts designed the dynamic assessment test which consisted of 20 items, based on the experts' knowledge structure shown in Figure1 and the distracter options, based on the misconceptions, for the purpose of providing different instruction prompts for students who have different misconceptions related to the "addition and subtraction of fractions with different denominators" unit. When the student responded incorrectly to an item, he or she would be able to receive instruction prompts with different levels based on the number of times the student responded incorrectly for that item, thereby learning based on the nature of his or her misconceptions. In other words, each individual student would receive a different set of instruction prompts according to his or her needs.

Taking item 1 in Table 1 as an example, the skill related to item 1 is "find equivalent fraction using expansion" and two misconceptions were embedded into the three distracter options. Based on the misconceptions that the student may have, individualized instruction prompts with different levels are provided by the system. Table 2 is an example of varied instruction prompts with different levels for item 1. When the student responds to item 1 incorrectly for the first time, a first level instruction prompt (general prompt) is given based on which distracter option was chosen. When the mistake is made for the second time, a second level instruction prompt (key word, specific prompt) is given based on the distracter option chosen. When the mistake is made for the third time, the third level instruction prompt, direct instruction is provided to the student.

Table 1. An example of developing an item according to skills and misconceptions

Item 1	4/5 = ( )/40, what is the number in ( )?
Option	Related to skill or misconceptions
(1) 8	M1: when seeking an equivalent fraction, multiply the denominator and the numerator by different numbers
(2) 10	M1: when seeking an equivalent fraction, multiply the denominator and the numerator by different numbers
(3) 32	S1: find equivalent fraction using expansion
(4) 39	M3: falsely believe that adding a number to both the numerator and the denominator can result in an equivalent fraction

Note. S1 and M1 are the symbols of cognitive skill and misconception, respectively.

Table 2. Options-based instruction prompts of Item 1

Prompt	Option			
	(1) 8	(2) 10	(3) 32	(4) 39
Without instruction prompt			Great! Respond correctly	
First level prompt general prompt	Incorrectly! Your answer is $40 \div 5 = 8$ What is expansion?	Incorrectly! Your answer is $40 \div 4 = 10$ What is expansion?		Incorrectly! Your answer is $40 - 1 = 39$ What is expansion?
Second level prompt keywords, concrete prompt	Incorrectly! The numerator is $5 \times 8 = 40$ How to expand the denominator?	Incorrectly! The numerator is $5 \times 8 = 40$ How to expand the denominator?		Incorrectly! Expansion of a fraction is not the numerator minus the denominator. How to expand the denominator?
Third level prompt direct instruction	The expansion refers to multiplying the numerator and denominator of a fraction by the same (bigger than 1) integer, which results in a fraction that is equivalent to the original fraction. Multiplying the numerator and denominator of $\frac{4}{5}$ by 8, that is, $\frac{4}{5} = \frac{4 \times 8}{5 \times 8} = \frac{32}{40}$, the number in ( ) is 32.			

Summative assessment

Based on the experts' knowledge structure, two summative assessments with alternate-form items were developed by the experts. The summative assessment, which consisted of 20 items, was used as the pre-test and post-test to evaluate the academic performance of students. The pre-test presents students' understanding in the "addition and subtraction of fractions with different denominators" unit before the remedial instruction conducted in this study. The post-test demonstrates students' understanding after receiving remedial instruction. Students were required to record the problem solving process in both their pre-test and post-test. The average difficulty index and the average discriminate index were 0.78 and 0.51, respectively. The Cronbach's Alpha of the summative assessment was 0.93, indicating a high degree of internal reliability. The content validity for the summative assessment was reviewed by four domain experts (two professors and two elementary school mathematics teachers) with significant experiences in mathematics education. Items in the summative assessment did not show up in the dynamic assessment adaptive system.

Participants

One hundred and eighteen students (59 males and 59 females) from the fifth grade of a Taiwanese elementary school were selected to participate in this study. Using each class as a unit, students from the six classes were randomly assigned to three groups: a dynamic individualized assessment and individualized instruction group (DIA_II), an individualized instruction group (nDIA_II), and an instruction group (nDIA_nII). There were 42 students (18 males and 24 females) in the DIA_II group, 37 students (21 males and 16 females) in the nDIA_II group, and 39 students (20 males and 19 females) in the nDIA_nII group.

Experiment design

The pre-test/post-test nonequivalent group design was adopted in this study. Three remedial instruction programs were designed: the dynamic individualized assessment and individualized instruction group (DIA_II), the individualized instruction group (nDIA_II), and the instruction group (nDIA_nII). In the DIA_II group, the expert knowledge structure-based dynamic adaptive assessment was administered and students received the individualized instruction prompts based on the items and distracter options from the system. In the nDIA_II group, according to the pre-test results, the individualized remedial instruction based on the expert knowledge structure was provided by the system. In the nDIA_nII group, the group remedial instruction based on the classroom report of the pre-test was performed by the teachers.

The difference in experimental treatment between the three groups is shown in Table 3. Both the DIA_II and nDIA_II groups received computerized individualized instruction based on the expert knowledge structure. The students in the DIA_II group received prompts according to the options they chose and the students in the nDIA_II group received direct instructions. In the nDIA_nII group, cognitive skills were taught by the teachers in sequence, based on the group report of the pre-test. Since cognitive skills with a lower correct response rate indicated relative weaknesses for a specific group, these cognitive skills were targeted as a priority for remedial instruction. The pedagogy for the nDIA_nII group was more like a traditional remedial teaching program (i.e., didactic teaching) commonly used in Taiwan.

Table 3. Research design of the three groups

	DIA_II	nDIA_II	nDIA_nII
Individualized prompt	○		
Individualized instruction	○	○	

Experiment procedure

The experiment procedure is shown in Figure 7.

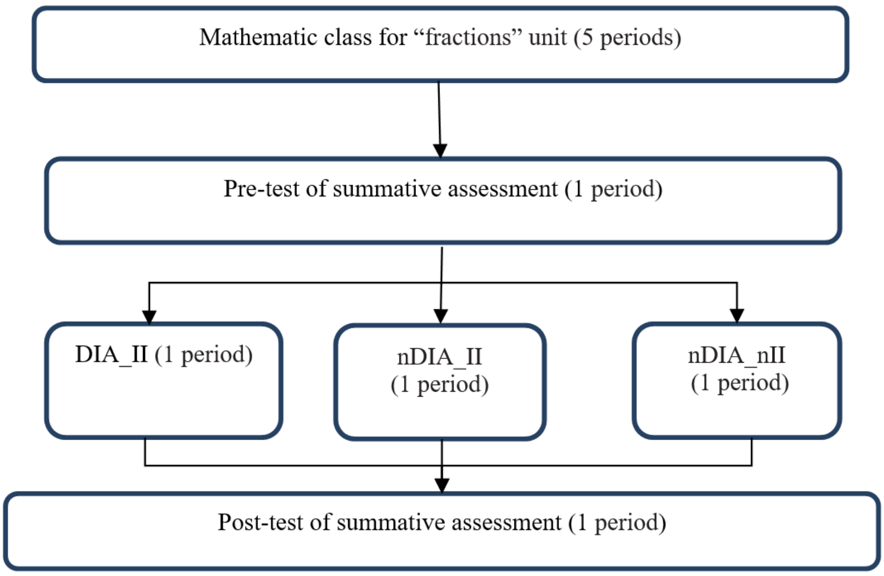

Figure 7. Research procedure

First, all students received five periods of mathematics instruction for an "addition and subtraction of fractions with different denominators" unit. One period is 40 minutes. The curriculum used for the three groups was the same. After mathematics instruction, all students took the pre-test of the summative assessment. The function of this pre-test was to understand the learning conditions of the students prior to the remedial instruction. The six classes were randomly assigned to three groups and students took part in one of the three remedial instruction programs. Finally, to understand the effectiveness of the remedial instruction programs, all students took the post-test of the summative assessment. The control factors were grade five students, instruction time, pre-test time, experiment time, post-test time, and instruction material.

Data collection and analysis

The data collected in this research included the pre-test scores of the summative assessment and the post-test scores of the summative assessment. The utilization of test items and accuracy rate were computed as criteria to evaluate the efficiency of the knowledge structure-based dynamic adaptive assessment system. While the students completed the adaptive portion of the test, the system continued to administer the rest of the 20 items in order to compute the accuracy rate. The utilization of test items is determined by the average number of items administered to the examinees in the knowledge structure-based dynamic adaptive assessment system. The mathematics formula of accuracy rate is (the total number of items-the items which inferred answered correctly but failed) / the total number of items.

The study used PASW statistics 18 (SPSS, Inc.) to conduct data analysis. To explore the performance of the three remedial instruction programs (DIA_II, nDIA _II, and nDIA_nII) in improving learning, a paired-samples t-test was conducted to compare the scores in pre-test and post-test conditions. In addition, analysis of covariance (ANCOVA) was used to detect significant differences between the three remedial instruction programs. In ANCOVA, the pre-test scores were taken as the covariate, the post-test scores were taken as the dependent variable, and the three remedial instruction programs were taken as the fixed factor. The Least Significant Difference (LSD) method was used to perform post hoc analysis. The criterion for the level of statistical significance was set at 0.05.

Effectiveness of the three remedial instruction programs

In order to investigate whether students showed an improvement after participating in the remedial instruction programs, a paired sample *t*-test was carried out, as shown in Table 4. The difference in mean scores between pre-test and post-test was 12.14 for the dynamic individualized assessment and individualized instruction group (DIA_II). The difference in mean scores between pre-test and post-test was 8.51 for the individualized instruction group (nDIA_II). The difference in mean scores between pre-test and post-test was 7.95 for the instruction group (nDIA_nII). As Table 4 shows, the average score of the post-test was significantly higher than the average pre-test score ($p = .000 < .05$) for all three groups, which demonstrates that the students showed an improvement after the remedial instruction programs.

Table 4. Results of difference in scores between pre-test and post-test for three groups

Group	Pre-test score		Post-test score		*t*-values
	Mean	*SD*	Mean	*SD*	
DIA_II ($n = 42$)	80.12	15.87	92.26	11.59	9.43*
nDIA _II ($n = 37$)	81.22	13.61	89.73	10.67	6.42*
nDIA_nII ($n = 39$)	81.67	13.39	89.62	10.91	6.33*

Note. $^*p < .001$.

Effectiveness of the computerized dynamic adaptive assessment

ANCOVA was conducted to investigate the differences in learning effectiveness of the different remedial instruction programs. Homogeneity of variance was conducted first; the result of Levene's test showed the requirement of homogeneity of variance was not violated ($F(2,115) = 1.11$; $p = .332$). In addition, the assumption for homogeneity of regression coefficients was also conducted ($F(2,115) = 0.058$; $p = .944$). That is, the homogeneity for regression coefficients within the three groups is confirmed.

The results of ANCOVA are shown in Table 5, which reveals the effect of different remedial instruction programs on post-test scores after adjusting for the effect of the pre-test scores. According to Table 5, there were significant differences in post-test scores between the three types of remedial instruction programs. The results of the LSD test, which showed that the difference between the dynamic individualized assessment and individualized instruction group (DIA_II) and the individualized instruction group (nDIA_II), was 3.23 ($p < .05$), which is statistically significant. The difference between the dynamic individualized assessment and individualized instruction group (DIA_II) and the instruction group (nDIA_nII) was 3.64 ($p < .05$), which is also statistically significant. However, the difference (0.40) between the nDIA_II group and the nDIA_nII group was not significant (0.40) ($p > .05$).

The results indicated that the DIA_II group outperformed the nDIA_II group and nDIA_nII group. The knowledge structure-based dynamic adaptive assessment which provides dynamic individualized assessment and individualized instruction could effectively benefit mathematics students. Wang (2011) pointed out that graduated prompts in the assessment in comparison to direct assessment (web-based assessment and paper-pencil assessment) can help junior high school students learn mathematics. In this study, compared to direct instruction (nDIA_II and nDIA_nII), the graduated prompts based on options could not only provide individualized instruction to meet the students' needs but could also assist elementary school students in learning mathematics.

The instruction based on the expert knowledge structure was provided to both groups (nDIA_II and nDIA_nII). The students in the nDIA_II group were taught by computers, based on an individualized profile, and the students in the nDIA_nII group were taught by teachers using a group profile. There were no significant differences between the nDIA_II group and the nDIA_nII group, which demonstrates that the results from technological assistance were as good as those from teachers delivering remedial instruction. The primary advantage of technological assistance was that it reduced human resources costs.

Table 5. Results of ANCOVA on the learning effectiveness of the three remedial instructions

Variable	Level	Mean[a] (*SE*)	*F* values	Post hoc[b]
Pre-test			250.137*	
DTRIP	DIA_II	92.81	4.154*	DIA_II > nDIA _II*
	nDIA _II	89.58		DIA_II > nDIA _nII*
	nDIA_nII	89.17		

Note. *$p < .05$. DTRIP: Different Types of Remedial Instruction Programs. [a] = Covariates appearing in the model are evaluated at the following value: 80.97. [b] = Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

The pre-test and post-test passing rate on cognitive skills

A deeper discussion on the dynamic individualized assessment and individualized instruction group via passing rates on cognitive skills is provided in this section. The pre-test and post-test were developed based on the expert knowledge structure consisting of eighteen cognitive skills. The passing rate on cognitive skills is the rate of questions answered correctly. For example, if question 1 measures skill 1, the passing rate on cognitive skill 1 is 97.62 % (the percentage of students who answered question 1 correctly). In this study, skills were measured by one question, except cognitive skill 11 and cognitive skill 18, which were measured by two questions each. The passing rate on cognitive skills is shown in Table 6. Since the pre-test was used to diagnose whether a student is equipped with the cognitive skills for the "addition and subtraction of fractions with different denominators" unit and provided feedback to the remedial instruction programs, the easier questions were developed by the teachers. Therefore, the passing rate is rather high for most cognitive skills except for cognitive skill 18. As a result, the improvement that can be demonstrated is relatively low for some cognitive skills such as skill 2, skill 11, and skill 14.

Table 6 demonstrates that student performance for cognitive skills 5 and 17 showed a decline after the dynamic individualized assessment and individualized instruction. The reason for this may be that cognitive skill 5 is measured by a concept problem where no calculation step is required and the choices were changed for the post-test, so the students may have been too careless. Cognitive skill 17 is measured by an item without a wording context, 3 -2(7/15) = ( ). A few students mistook the problem on subtraction as a problem on addition, which resulted in an error. More notably is the highest improvement rate on cognitive skill 18 (32.14%), which is the most upper-level cognitive skill in the expert knowledge structure. In other words, cognitive skill 18 is the hardest cognitive skill in the expert knowledge structure. This means that the dynamic individualized assessment and individualized instruction program can help students to improve their academic performance, especially when learning harder cognitive skills.

Table 6. The passing rate on cognitive skills

Skill	Pre-test	Post-test	Improvement	Skill	Pre-test	Post-test	Improvement
S1	97.62	100	2.38	S10	83.33	97.62	14.29
S2	88.10	97.62	9.52	S11	92.86	97.62	4.76
S3	59.92	83.33	23.81	S12	78.57	92.86	14.29
S4	80.95	88.10	7.15	S13	80.95	83.33	2.38
S5	97.62	92.86	-4.76	S14	80.95	100	19.05
S6	90.48	100	9.52	S15	85.71	97.62	11.91
S7	92.86	100	7.14	S16	64.29	83.33	19.04
S8	59.52	88.10	28.58	S17	97.62	95.21	-2.38
S9	85.71	92.86	7.15	S18	46.43	78.57	32.14

The efficiency of the computerized dynamic adaptive assessment

Two criteria, the utilization of test items and accuracy rate, were used to evaluate the efficiency of the knowledge structure-based dynamic assessment system. This test consisted of 20 items. The average utilization of test items was 3.92. In other words, the system could reduce approximately 16 test items on average. The number of inferred answered correctly but failed items average was 2.17; therefore, the accuracy rate was 89.2 % ((20-2.17)/20).

The experts designed the dynamic assessment test which consisted of 20 items, based on the experts' knowledge structure (as described in Figure1) and the distracter options, based on the misconceptions, for the purpose of providing different instruction prompts for students who have different misconceptions related to the "addition and subtraction of fractions with different denominators" unit. When the student responded incorrectly to an item, he or she would be able to receive instruction prompts with different levels based on the number of times the student responded incorrectly for that item, thereby learning based on the nature of his or her misconceptions. In other words, each individual student would receive a different set of instruction prompts according to his or her needs.

This result was acceptable according to the research results of Wu et al. (2012). The knowledge structure-based dynamic adaptive assessment provided individualized prompts, which implied instruction, so the learning of a student was based on the nature of his or her misconceptions. Based on the knowledge structures adaptive test algorithms, if the student responds to an item correctly, it is inferred that he or she also knows its prerequisites; therefore, the average utilization of test items was low in this research. The knowledge structure was defined by the experts in this research, and a differently constructed knowledge structure approach could be attempted to increase the accuracy rate (Wu et al., 2012).

Conclusion

Dynamic assessment is sensitive enough to provide information about an individual's ability, change processes, and the mediation strategies responsible for cognitive modifiability. However, dynamic assessment takes more time and requires more skill than static testing. A computerized adaptive test can increase the efficiency of the testing process by offering customized items. Nevertheless, a computerized adaptive test is not sensitive to progress within a test. The computerized dynamic adaptive assessment system which combines the advantages of both dynamic assessment and computerized adaptive tests was developed in this study. The selling point of the computerized dynamic adaptive assessment system is that it provides both tailored assessment and individualized prompting. Three remedial instruction programs – the dynamic individualized assessment and individualized instruction, individualized instruction, and didactic teaching – can improve elementary school students' performance in mathematics.

The students with tailored assessment and individualized prompting score significantly higher in primary school Mathematics than those with individualized instruction and with didactic teaching, respectively. The computerized dynamic adaptive assessment system can help students learning effectively. Although this study has offered valuable insights into dynamic assessment and pedagogical implications, its design is not without flaws. The first limitation concerns the knowledge structure defined by the experts. The risk of constructing incorrect links between cognitive skills will lead to a decrease in the accuracy rate of this study. The second limitation is rooted in guessing correctly. Further research could incorporate a constructed response item into the knowledge structure-based dynamic adaptive assessment system. Finally, the generalization of the results to other content with different populations may be limited.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology in Taiwan (Grant No. MOST 103-2511-S-656-003-MY2 and102-2511-S-142 -008 -MY3) for partly supporting this study.

References

Adesina, A., Stone, R., Batmaz, F., & Jones, I. (2014). Touch arithmetic: A Process-based computer-aided assessment approach for capture of problem solving steps in the context of elementary mathematics. *Computers & Education*, *78*, 333-343.

Campione, J. C., & Brown, A. L. (1987). Linking dynamic assessment with school achievement. In C. S. Lidz (Ed.), *Dynamic assessment* (pp. 82-115). New York, NY: Guilford Press.

Campione, J. C., & Brown, A. L. (1990). Guided learning and transfer: Implications for approaches to assessment. In N. Frederiksen, R. Glaser, A. Lesgold, & M. G. Shafto (Eds.), *Diagnostic monitoring of skill and knowledge acquisition* (pp. 141-172). Hillsdale., NJ: Erlbaum.

Chen, C.-M. (2009). Ontology-based concept map for planning a personalised learning path. *British Journal of Educational Technology*, *40*, 1028–1058. doi:10.1111/j.1467-8535.2008.00892.x

Chen, L. H. (2011). Enhancement of student learning performance using personalized diagnosis and remedial learning system. *Computers & Education*, *56*(1), 289-299.

Chen, C. P., Tai, D. W. S., Lee, C. Y. Zhang, R. C. (2010). Constructing the graduated prompting assessment learning system for computer-aided manufacturing cutting technique. *World Transactions on Engineering and Technology Education*, *8*(2), 175-181.

Cheng, C. Y., Wu, H. M., Kuo, B. C., & Li, C. T. (2013, July). *A Knowledge structure based computerized adaptive dynamic assessment.* Paper presented at the 2013 International Meeting of the Psychometric Society, Amhem, The Netherlands.

Frisby, C. L., & Braden, J. P. (1992). Feuerstein’s dynamic assessment approach: A Semantic, logical and empirical critique. *Journal of Special Education*, *26*, 281-301.

Gabelica, C., Van Den Bossche, P., Segers, M., & Gijselaers, W. (2012). Feedback, a powerful lever in teams: A Review. *Educational Research Review*, *7*(2), 123-144. doi:10.1016/j.edurev.2011.11.003

Harks, B., Rakoczy, K., Hattie, J., Besser, M., & Klieme, E. (2014). The Effects of feedback on achievement, interest and self-evaluation: The Role of feedback’s perceived usefulness. *Educational Psychology*, *34*(3), 269-290. doi:10.1080/01443410.2013.785384

Hattie, J., & Timperley, H. (2007). The Power of feedback. *Review of Educational Research*, *77*, 81-112.

Haywood, C. H., & Lidz, C. S. (2007). *Dynamic assessment in practice: Clinical and educational applications.* New York, NY: Cambridge University Press.

Hsu, C. H. (2008). 不同策略教學及鷹架中介設計對個體數學文字題解題學習潛能開展效益影響之動態評量研究 [The Effects of strategy instruction and scaffolding mediation in dynamic assessment for facilitating first graders’ learning potential on mathematical problem solving]. *Bulletin of Educational Psychology*, *39*(4), 513-532.

Hwang, G.-J., Panjaburee, P., Triampo, W., & Shih, B.-Y. (2013). A Group decision approach to developing concept–effect models for diagnosing student learning problems in mathematics. *British Journal of Educational Technology*, *44*, 453-468. doi:10.1111/j.1467-8535.2012.01319.x

Jitendra, A. K., & Kameenui, E. J. (1993). An Exploratory study of dynamic assessment involving two instructional strategies on experts and novices’ performance in solving part-whole mathematical word problems. *Assessment for Effective Intervention*, *18*(4), 305-325. doi:10.1177/073724779301800404

Kalyuga, S., Rikers, R., & Paas, F. (2012). Educational implications of expertise reversal effects in learning and performance of complex cognitive and sensorimotor skills. *Educational Psychology Review*, *24*(2), 313-337.

Kao, Y. T., Lin, Y. S., & Chu, C. P. (2012). A Multi-factor fuzzy inference and concept map approach for developing diagnostic and adaptive remedial learning systems. *Procedia-Social and Behavioral Sciences*, *64*, 65-74.

Luft, C. D. B., Gomes, J. S., Priori, D., & Takase, E. (2013). Using online cognitive tasks to predict mathematics low school achievement. *Computers & Education*, *67*, 219-228.

Moridis, C. N., & Economides, A. A. (2012). Applause as an achievement-based reward during a computerized self-assessment test. *British Journal of Educational Technology*, *43*(3), 489-504.

Panjaburee, P., Hwang, G. J., Triampo, W., & Shih, B. Y. (2010). A Multi-expert approach for developing testing and diagnostic systems based on the concept-effect model. *Computers & Education*, *55*(2), 527-540.

Parr, M. J., & Timperley, H. S. (2010). Feedback to writing, assessment for teaching and learning and student progress. *Assessment Writing*, *15*, 68–85.

Poehner, M. E. (2008). *Dynamic assessment: A Vygotskian approach to understanding and promoting second language development*. Berlin, Germany: Springer Publishing.

Ting, M. Y., & Kuo, B. C. (2015). A Knowledge-structure-based adaptive dynamic assessment system for calculus learning. *Journal of Computer Assisted Learning.* doi:10.1111/jcal.12119

van der Linden, W. J., & Pashley, P. J. (2010). Item selection and ability estimation adaptive testing. In W. J. van der Linden & C. A. W. Glas (Eds.), *Elements of adaptive testing* (pp. 3-30). New York, NY: Springer.

Vygotsky, L. S. (1978). *Mind and society: The Development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wang, T. H. (2010). Web-based dynamic assessment: Taking assessment as teaching and learning strategy for improving students' e-Learning effectiveness. *Computers & Education*, *54*, 1157-1166.

Wang, T. H. (2011). Implementation of eeb-based dynamic assessment in facilitating junior high school students to learn mathematicss. *Computers & Education*, *56*, 1062-1071.

Wu, H. M., Kuo, B. C., & Yang, J. M. (2012). Evaluating knowledge structure based adaptive testing algorithms and system development. *Journal of Educational Technology & Society*, *15*(2), 73-88.

Yen, Y. C., Ho, R. G., Chen, L. J., Chou, K. Y., & Chen, Y. L. (2010). Development and evaluation of a confidence-weighting computerized adaptive testing. *Journal of Educational Technology & Society, 13*(3), 163-176.

Yen, Y. C., Ho, R. G., Liao, W. W., & Chen, L. J. (2012). Reducing the impact of inappropriate items on reviewable computerized adaptive testing. *Journal of Educational Technology & Society*, *15*(2), 231-243.