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Using Web-based Practice to Enhance Mathematics Learning and Achievement

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Abstract

This article describes 1) the special features and accessibility of an innovative web-based practice instrument (WebMA) designed with randomized short-answer, matching and multiple choice items incorporated with automatically adapted feedback for middle school students; and 2) an exploratory study that compares the effects and contributions of web-based practice on students' learning processes with that of traditional paper-and-pencil practice. With multiple practices and immediate adapted feedback, the web-based group performed significantly better than the paper-and-pencil group on both fraction and decimal operations at the end of the study. On an average, female students gained a higher score on the post-test. However, females were distracted by the web features more than males. Students enthusiastically expressed their desires of having more of this dynamic and interactive practice by the end of the study.

Keywords: Web-based practice, adapted feedback, randomization, achievement, and mathematics.

Integrating web-based practice in the contexts of learning and assessment is one of the primary goals of the Congressional Web-based Education Commission in the twenty first century ("Web-based Education Commission," 2001). Recently with the use of JavaScipts and Perl, web-based practice has become a powerful and innovative assessment tool. It serves as a central part of the virtual teaching and learning efforts (Bennett, 2001) and as an interactive and informative resource of information ("NCTM," 2000). Web-based assessment via distance learning, within classrooms, or in computer labs enables teachers to monitor student progress, to allow students to self-assess and self-regulate, and to become self-directed learners (Kinzer, Cammack, & Cammack, 2004; Morgan & O'Reilly, 2001). Furthermore, according to Allen (2001), Linn (2002) and Chung and Baker (2003), web-based assessment introduces students to exciting ways of learning and introduces teachers to powerful tools of assessing student

progress. With these considerations in mind, the authors of this study collaborated with a group of mathematics educators, mathematicians and computer scientists to design a web-based practice tool – WebMA – for use at the middle school level to discover its potential effects on improving students' mathematics learning and achievement. The unique feature that made the WebMA obtain the pioneer position in comparison with other web-based practices was its randomization and automatically adapted feedback. With the WebMA, students not only had multiple practices in different problem settings but also received immediate instructional feedback, especially for their incorrect responses.

Background

Web-based Assessment Enhancing Mathematics Learning and Achievement

According to Hart and Walker (1993) and Wong (2001), students' attitudes toward learning a subject vary based on characteristics of classroom instruction, such as types of assessment, topics, and material delivery tools. Steele and Arth (1998) also indicated that the flexibility in accepting students' ways of solving problems can increase students' participation, reduce anxiety, and increase positive attitudes toward learning. Indeed, web-based practice can create different learning and assessment contexts, and produce flexible approaches to instruction and evaluation (Middleton & Spanias, 1999; Beevers, McGuire, Sterling, & Wild, 1995). These flexible approaches allow students to receive timely information regarding their improvement and adjustment. With this unique feature, web-based assessment carries a virtual instructional mission that traditional paper-and-pencil assessment can never accomplish (Carter, 2004). Several studies have shown that students who used web-based learning and practice find mathematics more enjoyable. They like the freedom provided by computers to do experiments, spend long hours at a computer to complete a task, and enjoy testing out new ideas on a computer (Galbraith & Haines, 1998; Chi, Lewis, Reiman, & Glaser, 1989; Reif, 1987).

Web-based Assessment As an Authentic Assessment Tool

Building on the recent recommendations of new principles for assessment by the NCTM 2000, web-based assessments are heading in the direction of "[engaging] students in learning and requiring thinking skills" (McMillan, 2001, p. 14), allowing students to have independent practice and self-evaluation, and helping students to form self-motivation and self-efficacy in mathematics learning and problem-solving (Morgan & O'Reilly, 2001). According to Bennett, web-based assessment has the potential to meet the authentic assessment goals (Bennett, 2001). Recently with the use of Java Applets, JavaScript and Perl, these authentic assessment tools not only become more interactive and more robust, but also ultimately serve the three following objectives:

- "Improvement of instruction and learning,
- Evaluation of student achievement and progress, and

- o Feedback for the students, providing information to aid them in seeing inappropriate strategies, thinking, or habits" (Kulm, 1994, p. 4).

Sanchis (2001) and Mavrikis and Maciocia (2003) illustrated that immediate feedback is the most important issue and the strongest asset in web-based practice. The immediate scores and feedback guide student's learning and prepare them not only for the exams but also for independent learning and regulations (Sangwin, 2002). Lin and Hsieh (2001) indicated that web-based assessment has caught the attention of instructional designers, particularly because of its flexibility. This flexibility allows students to play an important role in their own learning, to emphasize learning activities that are student-centered, to integrate classroom learning with multiple practice and real life applications (Mavrikis & Maciocia, 2003; Jonassen, 2000), and to deliver timely and adapted feedback (Salpeter, 2003). With the above features, web-based assessment can be considered as a mind tool to "drive and shape" student learning, achievement, interests, habits and motivation (Morgan & O'Reilly, 2001, p. 185).

However, web-based instruction and assessment has some limitations. For example, students must have reliable access to computers and the Internet connection without time restrictions. Some technical problems such as slow modem speed, slow bandwidth, or network jam may need to be allowed for the use of the web-based tool. Research by Russell and Haney (1997) and Russell (1999) have shown that assessment presented via a computer underestimated students' mathematics achievement regardless of their level of computer familiarity. However, the assessment tool used in Russell and Haney's research was delivered through a network based system with very little or almost no flexible level, and was simply a paper-and-pencil assessment that was transcribed to computer and without feedback. That was very different in comparison with the recent dynamic and interactive web-based assessment with the aid of Java Applets, JavaScript and Perl (Sanchis, 2001). Moreover, to meet the current demands of the technological era, web-based practice has continued to develop, and has improved its unique features and characteristics step-by-step. Therefore, this study was designed to explore (1) accessibility issues of the WebMA instrument at the middle school level, (2) the extent that web-based practice affects students' mathematics learning and achievement, and (3) the differences on students' achievement between web-based and paper-and pencil practice.

Description of Research Instruments

Web-based Instrument

JavaScript, Perl and HTML (Hypertext markup language) played a major role in the WebMA instrument. JavaScripts were written to generate randomized items, to derive adapted feedback, and to record times taking and time length. Perl scripts were embedded to map the responses with the coded answers, to provide scores, and to automatically collect students' responses and store them as HTML files as well as record students' grades to Excel grade sheets.

Web-based Features

The web-based practice tasks were generated with randomized items so that numbers, words and answer choices were varied each time a student repeated each question or a whole task. Students were able to check their scores instantly as well as choose to view correct answers or receive feedback for each item during the homework or for an entire homework assignment when students finished their practices. Feedback to students was adapted to the nature of incorrect responses, providing targeted help or examples for specific errors (see examples on Figures 2a and 2b). In brief, the WebMA tool designed for this study provides (a) a method of randomly generating items and randomly generating entire tasks using a web-based format that allows students to have multiple practice opportunities, (b) a method of automatic grading and adapted feedback that provides students with detailed instruction and guidance, and (c) a method of automatic data collection. In addition, the WebMA recorded the time taken by a student to finish each task, and the number of times a student repeated each practice set.

Descriptions of Pre- and Post-tests, Practice Tasks and Survey

Test items and practice homework were derived from existing problems appearing as exercises in the students' textbook, along with some exercises from the Connected Mathematics (Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998) series. The pre-test and post-test were designed to assess students' level of fraction computation and computation in context. The pre- and post-tests contained eight multiple-choice and two short-answer questions similar to the homework items. These tests and homework items were carefully examined by the former program director of the American Association for the Advancement of Science (AAAS). The web-implemented versions were carefully tested at a middle school with 315 participants prior to the study with the observation of six in-service teachers. Homework was selected and designed in ways that allowed students to have opportunities to practice fraction and decimal operations, including addition, subtraction, multiplication, division, simplification, and converting simple and mixed number fractions of the same and different denominators in different settings. Mathematical and computational skills were combined and applied in the context of word problems. A variety of mathematical procedures was included to accommodate different features and mastery skills. Each homework set contained a detailed review with mathematical concepts and procedures which can be considered as instructional materials, worked examples, and 15 short answer questions and matching items. Figure 1 shows selected items from the pre- and post-tests; Figure 2a and 2b provide a sample adapted feedback and a sample solution for homework items. A survey set was designed by the researchers with fifteen rating questions that were adapted from the Instrument for Assessing Educator Progress in Technology Integration (IITTL) (2002) and one essay question to probe students' evaluations, perceptions and opinions regarding the web-based practice, scoring, and feedback features (see Table 3).

Methodology

Participants

This study took place in two different middle schools in Southeast Texas. Since the information gathered from the state report card on the diversity, end-of-course exams, and school classification and ranking were similar, they were combined for this study. There were 95 students from six math classes participating in the study. There were 50 seventh and 45 eighth graders; 41 were females and 54 were males. The racial composition was 12 percent African American, 25 percent Hispanic, and 63 percent White. Nine of the students (seven from one school and two from the other) were classified as at-risk by their schools, based on state guidelines. All students, except one, were proficient English speakers. Students from the six math classes were randomly assigned to one of two treatment groups within each class. Half of the students in each class participated in Web-based Assisted Learning and Practice (WALA) and spent their in-class practice time in the school computer lab. The other half remained in the classroom and did paper-and-pencil practice – Traditional Assisted Learning and Practice (TALA) with their mathematics teacher during the homework practice time. These practice sessions lasted about 30 minutes each day, three times a week. The study was conducted in three weeks.

Procedures

Prior to the study, all students took a mathematics pre-test. The questions on the pre-test were the same for all students in both groups. The WALA group took the pre-test via computer while the TALA group used paper-and-pencil. During the entire study, the WALA students did their practice homework in the computer lab under the supervision of the first author. They had the option to check if they got the correct or incorrect answer for each question. They also received adapted feedback for each answer, and the total score when they finished each assignment. With the random feature, students were allowed to practice as many times as they wished. These students were also informed that the highest score would be recorded. Each time a student repeated the homework task, the homework item was slightly different.

The TALA students practiced the same homework sets as the WALA but on printed worksheets. There were two additional alternative versions of each printed worksheet available. TALA students were encouraged (but not required) to complete these alternative exercises for extra practice. These students were also informed that if they took more than one version of each homework, then the higher or highest score would be recorded. If students had questions, they could get help from their teachers. The students' homework papers and additional versions were collected, graded by the researcher, and returned to students by their teachers. The feedback provided for TALA homework papers were similar to the feedback for the WALA. Additionally, each TALA student also received a detailed solution sheet attached to each returned homework set.

At the end of the study, students in both WALA and TALA took a mathematics post-test. Again, the post-test questions were the same for all students in both groups. Students in the WALA continued to take the post-test on computers while the TALA on paper-and-pencil. Students in the WALA were also asked to complete the survey regarding their evaluations and perceptions of the web-based practice.

Figure 1. Sample items from the pre- and post-tests

Sample 1:

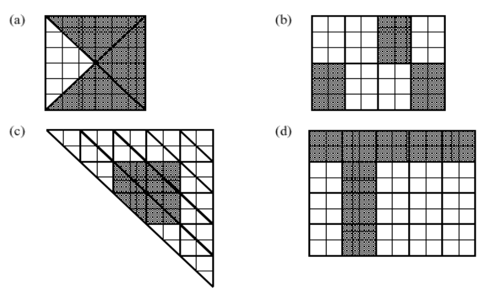
Select an equivalent expression to: $1\frac{3}{4} + 2\frac{1}{2}$

☐ $(1 + 2) \times (\frac{3}{4} + \frac{1}{2})$ ☐ $1 \times 0.75 + 2 \times 0.50$ ☐ $(1 \times \frac{3}{4}) + (2\frac{1}{2})$ ☐ $\frac{7}{4} + \frac{5}{2}$

Check

Sample 2:

What fraction of each shape is shaded?



(a)

(b)

(c)

(d)

Check

Sample 3:

$\frac{9}{10}$ of all men in the U.S. own at least one car, and $\frac{2}{3}$ of all men in the U.S. own *more than one* car.

(a) What fraction of men in the U.S. do **not** own a car?

Check

(b) What fraction of men in the U.S. own **only one** car?

Check

Sample 4:

Calculate the answers to the following questions. Give your answer (i) as decimal and (ii) as fractions

(a) $0.7 + 0.6$ (i) Check (ii) Check

(b) $8.21 - 0.31$ (i) Check (ii) Check

Sample 5:

Rachel caught 5 of the 20 softballs that were thrown to her. Represent the percentage of the softballs that Rachel caught as a decimal:

Check

Click to grade

Figure 2a. *Sample Adapted Feedback*

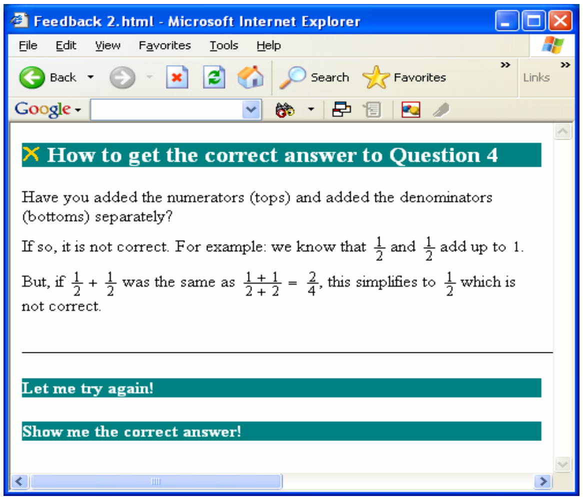
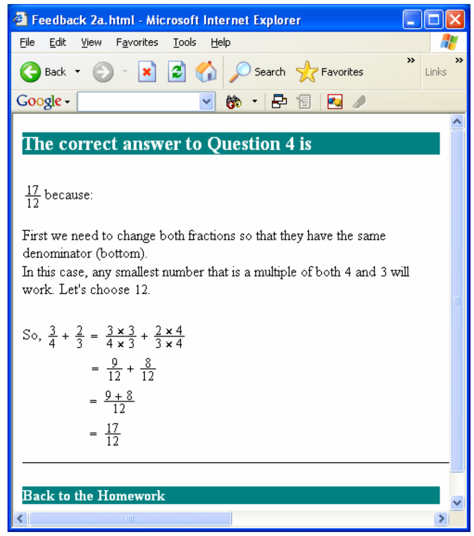


Figure 2b. *Sample Solution*



Findings

Descriptive analysis, analysis of variance (ANOVA), and pair-wise and independent sample t-tests were used to analyze the effects of the practice methods. Reliability analyses of inter- and intra-consistencies were conducted on pre- and post-tests for each treatment group to measure the proportion of variability in the measurements that is attributable to variation in students' performances. The reliability coefficients of pre- and post-tests from both groups were all higher than 77%. Analysis of ANCOVA shows that the intra-test consistency coefficient, the Cronbach's alpha (α), of combined pre-test, homework, and post-test is 0.83 and 0.66 for TALA and WALA respectively, and of pre- and post-tests is 0.93 and 0.71 for TALA and WALA respectively. According to George and Mallery (2001), α greater than 0.8 considered as high consistency level, but α from 0.60 to 0.69 is somewhat questionable. One possible explanation of the lower reliabilities for WALA tasks is that students had opportunities to practice homework sets more than once and their answers could change from one set to another. Therefore, it is possible that homework scores are the main factor that affected the reliability of WALA mathematics tasks. For the TALA, since the feedback came the following day while the new topic had already been introduced, the feedback probably did not influence or change students' ways of solving problems. Therefore, TALA students' scores on homework and tests were rather uniform and attained higher levels of reliabilities than WALA's.

The descriptive analysis of the homework practices shows 78% of WALA students retook each homework assignment the second time and 45% the third time. In contrast, even though students in the TALA group were provided with two alternative versions of each homework set, few students (14%) took advantage of the second extra practice sets, and none ever tried the third set. Table 1 shows the WALA and TALA practice times on each homework set.

Table 1.

WALA and TALA Practice Times

	Fraction Operations Homework Set			Converting Decimals to Fractions Homework Set		
	Number of Students in			Number of Students in		
	1st Practice	2nd Practice	3rd Practice	1st Practice	2nd Practice	3rd Practice
WALA	49	32	9	49	45	34
TALA	46	8	0	46	5	0

The descriptive data and the results of the pair-wise t-test analysis show there was no significant difference on the pre-test scores ($p = 0.2$) between the TALA and WALA groups prior to the study. But, there was a significant difference of post-test results between the TALA and WALA, $p<0.01$ (WALA mean of 70.08 and TALA mean of 53.23). The effect size, estimated by Cohen's d, of the difference in post-test scores between the two groups was $d = 0.83$ indicating that the post-test score of the average student in the WALA group exceeded the post-test score of 80% of the TALA group. These data indicate that starting from the same level, the WALA group significantly outperformed the TALA group in mathematics achievement by the end of the study. Within the WALA group, female students dramatically gained an average of 29 points on the post-test in comparison with the pre-test (see Table 2).

Table 2.

Means of Pre- and Post-tests for TALA and WALA Groups

	TALA			WALA			Significant Differences (p-value)
	Male	Female	Whole group	Male	Female	Whole group	
Number of Students	25	21	46	29	20	49	
Pre-test Mean Score	38.75	44.12	43.73	46.90	41.45	44.57	0.20
Post-test Mean Score	51.45	57.65	53.23	71.51	70.00	70.08	0.01

The survey results and informal follow-up conversations with selected students indicate that students did not confront any problems of slow connection or task downloading. Many students from the WALA group expressed their excitement by the end of the experiment that: "The computer math makes me smarter"; " The computer math gives more clues, more information and more practice"; "Computer math is more fun to learn"; "Computer math makes me understand fractions better"; "Doing math on computer is cool." Only one male student said he disliked computer practice because it did not allow him to write down his explanations. He also added his parent did not want him to spend too much time on the Internet. From the survey results, 94% (46 out of 49 students) preferred web-based over paper-and-pencil practice (see items E1, E10 and E15 on Table 3).

Table 3.

WALA Survey Questionnaire and the Results

#	Question/Rate	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Missing Data
E1	I like to do math on the computer.	38	9	1	1	0	0
E2	Computer-based math tasks are clear and easy to read.	32	13	3	0	0	1
E3	Computer-based homework is more interesting than paper-pencil homework.	27	17	3	1	1	0
E4	I like to receive immediate scores on my homework and tests from the computer.	42	4	2	1	0	0
E5	Immediate scores help me to be aware of my performance.	20	25	4	0	0	0
E6	I like the help and suggestions on homework from the computer.	9	26	12	1	0	1
E7	Computer feedback helps me to recognize my mistakes instantly.	13	29	6	1	0	0
E8	Computer immediate feedback is useful for mathematics problem solving.	11	29	6	1	0	2
E9	Computer-based homework gives me more chance to practice.	32	14	3	0	0	0
E10	I enjoyed practicing homework on computer more than on paper-and-pencil.	38	8	0	2	1	0
E11	The lesson review on the computer-based homework helps me to review mathematics concepts.	20	22	6	0	0	0
E12	Computer-based tests help me to be less anxious in waiting for my scores.	42	5	2	0	0	1
E13	I have less anxiety in taking computer-based quizzes than paper-and-pencil quizzes.	38	8	3	0	0	0
E14	Computer-based math tests with immediate scoring help me evaluate my own understanding and performance.	20	17	11	0	0	0
E15	I like computer-based math tests more than paper-and-pencil tests.	39	8	2	0	0	0
E16	Do you want to have more of the computer-based homework and tests? Why or why not?						

* Part of these questions were adapted from the Instrument for Assessing Educator Progress in Technology Integration (2002) from the University of North Texas

Besides the above statistical analyses, the study also revealed some issues regarding the use of Internet in learning and practice. First, there were five students, four males and one female, who attempted to use the web calculator for their homework practices even though students were advised not to use any calculator for the practice. These students were asked to quit their current work and restart with a new version of homework. Second, there were seven female students, who checked and sent e-mail during the practice time even though the computer lab had the policy of no email checking during the class session. One of these seven females also logged in the Yahoo

chat room having a conversation with her friend. Once being interrupted by the lab coordinator, this female student logged out of the chat room but became upset and did not continue with the practice for the rest of that class period. Third, one male student asked for permission to use headphones to listen to classical music on the web while doing homework. This student provided the lab coordinator with the reason that he had that kind of habit every time he sat in front of the computer.

Discussion

The mathematics achievement of students who participated in the web-based approach was significantly higher than that of their classmates who received the same items using paper-and-pencil. Female students in the web-based group had an impressive improvement by the end of the study. According to Mavrikis and Maciocia (2003), one explanation for the higher achievement by the web-based group was the availability of immediate and adapted feedback on homework items. Students taking the web-based practice were able to instantly determine whether their answers were correct or incorrect. On the practice homework, the feedback and immediate result checking allowed students to recognize their mistakes and re-attempt the problems if their answers were incorrect. This feature ultimately helped students adjust their computational technique and revise incorrect procedures during the practice process (Mavrikis & Maciocia, 2003; Wong, 2001; Sanchis, 2001). The students appreciated the opportunity to retake items and make corrections. For the TALA group, the feedback was not received until the following day. By that time, the students had already begun working on new material and were not highly interested in specific feedback. Those factors would contribute to the lower performance of TALA in comparison to WALA students, especially toward the end of the three-week period.

The randomized items with contexts changing on each assignment provided the opportunity for enriching practices. Students taking the web-based practice were able to take and retake each homework task as many times as they wished. Every time they retook each homework task, the wording or numbers used in the items as well as the required computational procedures were slightly different, but the mathematical content and concepts remained the same. Therefore, these students experienced a greater number of different items on the same mathematical procedures in various contexts. On the other hand, the TALA students perceived the alternative homework sets as additional work and were not motivated to complete them.

The exposure to new and different learning tools provided a break from classroom routine. For the TALA group, even though being told that homework and tests taken from this experimental study would be counted toward their in-class grade, students were probably not highly motivated to work in the classroom with the printed worksheets. On the other hand, the WALA group was taken to the computer lab and tried a new method of practice. Working on the web-based practice was considered an exciting experience according to some students because they had never had an opportunity to do mathematics using computers. Besides sitting at the computer and working with the keyboard in doing mathematics, students in the WALA group were highly stimulated by the new features such as the help, instruction, check buttons, and immediate score on the assignment (Allen, 2001; Nguyen, 2002). Furthermore, with

the web-based setup, students could approach each assignment as many times as they liked, until they were satisfied with their performance or felt confident in their understanding. Learning how to operate the computer keyboard to input the answer in the provided box and learning how to get help and feedback and access the final score were considered exciting by the students. This excitement was expressed by the number of times that students checked the help button and accessed the final score.

In summary, students in the web-based group were provided with a new experience with computers to complete mathematics assignments, with help and feedback provided, and the opportunity of more practice for better scores. Those factors would ultimately affect the WALA results of having higher scores on the post-test by exposing them to more practice in comparison with their counterpart.

The WALA students enjoyed working with the web-based tasks and desired to have more of this kind of interactive practice. The survey results indicated that the immediate feedback was the most attractive feature of the web-based delivery instrument (see item E4 on Table 3). These results confirm the results from the research conducted by Sanchis (2001) and Mavrikis and Maciocia (2003). Students also considered the instant score and adapted feedback as the most important factor in mathematics learning and assessment. This finding reinforces the findings from previous research that students highly desire confirmation of their understanding and knowing their performance (Bransford, Brown, & Cocking, 1999; Flavell, 1976). It is not surprising to teachers that students need to recognize their mistakes as early as possible, so that they have an opportunity to correct and adjust their understanding before they start to forget how they made those mistakes. The immediate response in this study not only let students know whether their answer was correct or incorrect but also provided students with adapted feedback and guidance, encouraging students to examine their own mistakes and adjust their procedures. According to Steele and Arth (1998), these activities appeared to be the key factors in enhancing students' levels of confidence and self-regulation, and reducing their anxieties about doing mathematics.

Along with the immediate feedback and automated scoring, randomized item generation encouraged low achieving students to practice more to improve their scores. Feedback also supported students who highly desired a perfect performance, giving them an opportunity to reach the maximum scores. Finally, students who lacked confidence in their understanding received immediate confirmation and feedback about the mathematical concepts and procedures. These features resulted in better understanding, more experience, better retention, and higher self-regulation (Sanchis, 2001). Even though some critics indicate the benefits of drill-and-practice are only short-term memory (see, e.g., Carpenter & Lehrer, 1999), long-term retention can be gradually built if students are interested in their practice and experience it with different items in various contexts. Students' evaluation of the web-based practice suggests that they were willing to spend more time on the computer to obtain better mathematical knowledge and gain better understanding.

Implications

The results of this exploratory study indicate web-based practice can offer a unique opportunity to improve students' learning and practices when embedded into a

cohesive curriculum. Since this study took place in two different middle schools but with a limited amount of mathematical content and was carried out over a short time period, it is recommended that more web-based practice on different mathematical contents should be developed for different grade levels and implemented for use throughout the entire school year or throughout the summer break to help students reinforce and maintain their mathematical skills. The measurement of the mathematical achievement along with the practice should be the result of long-term studies across diverse populations. An implementation of an automatic diagnostic system that can perform detailed analysis of students' responses is also suggested to enrich the feedback to teachers and educators. Additionally, the web-based practice instrument should be set up with an additional feature that does not allow students to browse another website during the time they are currently on the task. There should be a pop-up window to remind students to get back to the task if they attempt to open any other websites. These features would minimize the distraction of email or chat or any other Internet browsing.

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