Original article

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A web-based curriculum-based measurement system for class-wide ongoing assessment

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Abstract

Internet technology has offered opportunities to develop ongoing assessment systems for classroom-based evaluation – on a daily basis. In this study, the researcher developed a web-based, curriculum-based measurement system with dynamic features which could generate different types of mathematics probes, track students' progress and provide diagnosed information as well as instructional suggestions for teachers. This paper explores the effects of the system on students' mathematical achievements. A total of 134 third-grade students (9- to 10-year-olds) in four classes participated. The teachers in all groups used the web-based curriculum-based measurement system with different types of curriculum-based measurement probes and growth modeling. The results indicated that the use of class-wide dynamic-growth modeling combined with mixed-type probes enabled the students to perform better than those using single-type probes. This outcome was not seen with the linear-growth modeling groups. The positive findings suggested that applying class-wide dynamic-growth modeling as well as the assessment of integrated mathematics competency in the instructional processes facilitated students' mathematics learning. Therefore, the web-based, curriculum-based measurement system was not only an assessment system, but also a tool for teachers to integrate instructional strategies based on curriculum-based measurement.

Keywords

class-wide assessment, curriculum-based measurement, Internet, mathematics, web-based technology.

Introduction

Over the past 15 years, information and communication technologies (ICTs) have been developed to make it more feasible for teachers to assess student progress more frequently (Woodward & Cuban 2001; He & Tymms 2005). The most promising benefit of using technology-based assessment systems is the timely and precise information provided for each student's performance in specific content areas (He & Tymms 2005). A variety of technology-based assessment systems in mathematics have been developed for specific purposes, including computer-based diagnosis systems (Monson & Judd 2001; He & Tymms 2005), computer-based dynamic assessment systems (Gerber *et al*. 1994), intelligent tutoring systems (Anderson *et al*. 1985; Aleven & Koedinger 2002), computer-based assessments (Nguyen *et al*. 2006), formative assessments (Buchana 2000) and computerized adaptive tests (Legg & Buhr 1992). However, many systems are designed primarily to access an individual's mastery of single mathematical concepts. Thus, the accessed information is unrelated to a specific mathematics curriculum and is therefore unable to identify the ability of a student to master the various levels of the learning objectives. As a result, these systems are generally not useful for

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goal-setting and intervention planning by classroom teachers (Shinn 1998). Moreover, most of the systems are developed for higher and supplemental educational organizations (Conole & Warburton 2005). Limited attention was paid to primary education (He & Tymms 2005). Besides, researchers have called for instructional decision-making procedures based on an ongoing assessment process, which has better capacity to inform, foster and document treatment efficacy (e.g. Reschly 1988; Fuchs & Fuchs 1997). The ongoing assessment for monitoring students' performance levels with formal testing is crucial for teachers evaluating whole classrooms (Fuchs & Fuchs 2002). Thus, through the rapid development of hardware and software, the ongoing assessment systems that track student progress for classroom-based evaluation on a daily basis have become possible.

The curriculum-based measurement (CBM) is a data-based, problem-solving model for indexing students' academic competence and progress through ongoing assessment (Deno 1985; Green & Shinn 1990). The effectiveness of CBM in monitoring the learning progress has been well-researched both in special education (e.g. Fuchs *et al*. 1984) and general education (e.g. Fuchs *et al*. 1994). Longitudinal CBM studies have indicated that incorporating CBM feedbacks into instructional planning enables general educators to provide more effective instructional programs and thus promotes students' achievements in reading (Jones & Krous 1988; Wesson 1991), mathematics (Fuchs *et al*. 1991; Stecker & Fuchs 2000) and spelling and written expression (Espin *et al*. 2005).

The use of computers to help teachers implement CBM not only to save substantial time in collecting data, but also to analyse ongoing assessment information in an effective way. A computerized system, the Monitoring Basic Skills Progress (MBSP), was proposed by Fuchs *et al*. (1992; 1998) that collected and managed students' CBM mathematics data. One of the most challenging tasks in CBM mathematics research by using MBSP was the content validity and technical adequacy (Thurber *et al*. 2002). Helwig *et al*. (2002) indicated that research on implementing CBM mathematics has been overwhelmingly focused on basic skills. Although knowledge of computation is essential in mathematics, the National Council of Teachers of Mathematics's principle and Standards for School Mathematics emphasize a student's ability on math-related concepts to think and reason mathematically (NCTM 2000). Further, the single problem-type CBM probes in MBSP may decrease correlations between CBM and the general measures of mathematics (Helwig *et al*. 2002).

Consequently, there is a need to expand the stand-alone computerized CBM programs with web technology and new features. The current study developed the web-based CBM system for primary school teachers to conduct ongoing assessment of students' integrated mathematics competencies.

Web-based, curriculum-based measurement system (ECBM)

ECBM was developed with web-based technology. It can access various relational database systems through the active server page programming languages, e.g. VBSCRIPT, ACTIVEX and JAVA. ECBM provided teachers to manage multiple CBM tasks such as selecting test stimuli from students' curriculum, administrating and scoring tests, analysing assessment information, monitoring progress and maintaining records on instructional strategies. The main components of ECBM are as follows:

Mathematics CBM item bank

The item bank of the ECBM includes all questions on two versions of mathematics textbooks in Taiwan. The item bank was built according to the three following processes. First, every math question in the textbooks was categorized into one of three problem types: concept, computation or application. The examples of problem types were as following:

- 1580 − 437 = (   ) (computation problem)
- Identify place value with ones and tens. 28 = (   ) tens and (   ) ones. (concept problem)
- From the following triangles, please mark the right-angled triangles. (concept problem)
- Mary used her pocket money to buy a CD for 250 dollars and a book for 119 dollars. How much does she spend? (application problem)

Second, the information on each question was recorded into the item bank database including unit, learning objective, instructional activity, question, image and the textbook page number. Third, the mathematics concept-skill codes were used to analyse every math question. The concept-skill analysis provides teachers with qualitative information about the curricular concepts that have and have not been mastered. The mathematics concept-skill codes were expanded from the previous study (Fuchs *et al*. 1989), which includes 188 concepts in nine mathematical domains (e.g. whole number computation, fractions, addition and subtraction with decimals and relationships among numbers). Another key feature of ECBM was using the multi-skill codes to measure students' concepts in each math question. For example, determining how many centimetres longer the blue line is than the red one requires a student to understand three concepts: the length measurement, subtraction of tenths-decimal numbers with one-step regrouping and decimal number comparisons.

Test-related database

The proposed system includes teachers' information and instructional strategies database, a students' database, a CBM probes database and an item bank database. ECBM provided each teacher with their own privilege to dynamically generate CBM probes through module selection. ECBM randomly selected a specific number of math questions from the item bank to generate a single or mixed-type math CBM probe. The single type of math CBM probes consisted of only one type of mathematics problem on a CBM test sheet. The computation math CBM probe includes 10 math computation problem questions. There are 10 concept questions on a concept math CBM probe. The application math CBM probe includes six questions, while the mixed type included five concepts, three computations and two application questions on a CBM test sheet.

The algorithms of the ECBM selecting modules for generating CBM tests were as follows:

Step 1: Teachers set four parameters in the ECBM system: version of textbook, semester, grade level and problem type.
Step 2: According to the CBM probe types (computation, concept, application) and parameters, ECBM automatically and randomly selected non-repeated units. Then, the ECBM system randomly selected one objective of the selected unit from a specific item bank.
Step 3: ECBM randomly selected a non-repeated question from every selected objective from step 2.

Thus, every CBM probe was an alternative form that sampled 10 non-repeated questions and thus reflected 10 different learning objectives in each semester's curriculum. Using these standard selecting modules of ECBM, students were assessed each week with an alternative CBM test that sampled from the grade level's problem types in the proportion constituting the curriculum in each semester. In this manner, teachers can use ECBM system to conduct CBM tests dynamically.

In addition to its dynamic features, the ECBM provides teachers with the ability to administer CBM probes (add, delete and print), maintain students' basic information and record CBM test scores. As all of the questions in the item bank were fill-in-the-blanks or free-text-entry questions, teachers administered CBM tests by printing the system-selecting items on paper sheets for children to answer. After CBM tests have been implemented and scored, students' scores can be recorded into ECBM system.

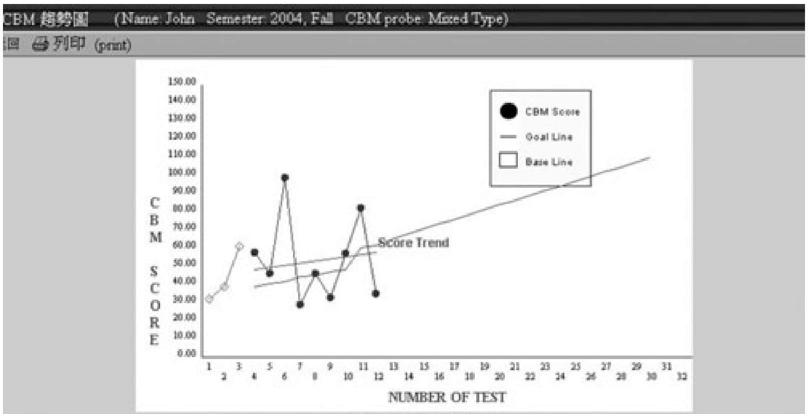
To examine the reliability and validity of the single and mixed types of CBM probes generated by the ECBM system, we enlisted the participation of 163 students in grades 4 and 5 (10–11 years old). During 1 week, all subjects were given three single-type and three mixed-type CBM probes, the Key–Math Diagnostic test, the WISC III test and the school math-achievement test. The results supported the adequacy of the reliability ($r = 0.63$–0.76, $P < 0.05$) and the validity ($r = 0.4$–0.84, $P < 0.05$) of the CBM probes in ECBM system (Tsuei 2001).

CBM performance diagnostic system

A core component of the ECBM system, the CBM performance diagnostic system, provided teachers with both qualitative and quantitative information via the diagnostic evaluation of individual and class-wide math performances.

Mathematics Individualized Education Program (Math-IEP) report

ECBM generated an individual student's annual Math-IEP, which specified the mastery level of learning objectives according to his or her grade level.



統計分析 Statistics												
測驗次別 Number of Test	1	2	3	4	5	6	7	8	9	10	11	12
天數 Days	1	3	7	10	14	16	21	24	28	30	35	37
分數 Score	32	39	61	58	46	99	29	46	33	57	82	35
進步趨勢參照 Growth Modeling	Classwide Dynamic Growth Modeling 班級與常模預測平均值 (Mean of Growth Rate)：2.63											
預測值 Growth Rate	--			1.53	1.00	2.65	1.00	2.16	1.00	12.31	1.00	1.00

平均每天成長分數 (Growth Rate: score/day)：0.44 分

平均每週成長分數 (Growth Rate:score/week)：3.10 分

回歸方程式為 (Linear Regression): Y=44.01 +0.44 X

CBM得分平均數 (Mean of CBM scores): 51.42

Fig 1 Example of the graphic analysis of John's curriculum-based measurement performance by using dynamic-growth modeling.

Graphic analysis of linear-growth modeling graph vs. class-wide dynamic-growth modeling

ECBM automatically generated individual student's CBM graphs, which featured a baseline, a trend line and a goal line. The baseline was drawn from three pre-test scores. The median score was chosen as a good approximation of a child's initial performance level. The goal line was drawn from the child's initial score connecting with weekly growth scores in math that the child was expected to achieve during the monitoring period. The trend line represented the student's actual progress. That is, the trend line was the index of the growth rate a student was achieving, represented as the slope, which was calculated through a least square regression analysis by each student's CBM scores. To avoid the variation of scores across CBM tests, comparing the student's trend line with the goal line is necessary. The instructor may use the slope as the one in the regression equation generated by ECBM to expect a student's CBM score on a specific day or week. In Fig 1, if the pupil's daily slope in CBM test was 0.44, the teacher then multiplied 0.44 by 50 days and obtained 66.01 ($44.01 + 0.44 \times 50 = 66.01$) as his expected CBM score on the 50th day while the same intervention was implemented. The slope played an important role in CBM determination (Deno *et al*. 2001). When comparing between individual student's slope (trend line) and the goal line, teachers obtained valuable information on where to make instructional adjustments, or identifying learning problems for the students with and without learning disabilities (Shinn 1998).

ECBM used the linear-growth and class-wide dynamic-growth modeling criteria as individual and class-wide graph analyses, respectively. In traditional CBM research, the linear-growth modeling graph was used as a linear graph. The linear-growth modeling was the expected growth rate based on the normative growth rate achieved by the students at the same grade level. Previous studies indicated that the normative increasing CBM math scores as weekly growth rates for general students in Taiwan were 2 digits (Tsuei 2001; 2004). Therefore, we used this criterion as the weekly CBM growth rates for linear-growth modeling graph. ECBM also provided the normative growth rate as 1 digit per

CBM test for teachers who administered CBM twice a week. In ECBM graph analysis (Fig 1), the horizontal axis was provided for teachers to choose the different modes to indicate the number of weeks or CBM tests monitored, allowing for data to be entered 2 times per week.

Previous research indicated that a linear relationship does not model the academic growth across school years adequately (Fuchs *et al*. 1993; Howard 1999). Moreover, the linear relationship does not contribute significantly to the modeling of student progress for more than 50% of the general student population (Fuchs *et al*. 1993). Therefore, the proposed study presents the class-wide dynamic-growth modeling graph analysis, which was the strongest feature of ECBM.

Class-wide dynamic-growth modeling allows one to anticipate each student's increasing CBM scores based on the class-wide normative comparison. This study used the larger number scores between the normative growth rate (1 digit) and the mean plus one standard deviation (mean $\pm$ *sd*) of the class-wide growth rate in the previous CBM test as the next anticipated CBM score. The class-wide dynamic-growth modeling statistic was represented mathematically using the following function:

$$\mathrm{Score}_{(G)(N+1)} = \mathrm{Score}_{(N)} + \mathrm{Max}\left[\mathrm{M}_{(\mathrm{slope})(N)} + sd_{(\mathrm{slope})(N)}, 1\right]$$

(G: predicated score, N: number of CBM tests)

For example, the mean score and the standard deviation of the third CBM test in a class were 2.34 and 0.34, respectively. Thus, the next anticipated growth rate for the fourth CBM test for every student in this class was their individual third CBM score plus 2.68. For example, if a pupil's score on the third CBM test was 27, his or her anticipated score on the 4th CBM would be 29.68 based on his or her class-wide growth modeling. Therefore, the growth rates in the general classroom depended on every class-wide CBM score. Clearly, the class-wide growth modeling was formulated in dynamic ways (Fig 1).

Mathematics concept-skill profile

The skill analysis aggregated an individual student's mastery level on each concept-skill code during each interval of the CBM performance (e.g. half month). According to the aggregated CBM concept score of total concept scores, five levels of mastery were derived: non-mastered (less than 20%), partially mastered (less than 40%), nearly mastered (less than 60%), almost mastered (less than 80%) and mastered (above 80%) (Fig 2). Teachers can analyse an individual student's performance on an item-by-item basis across CBM tests to determine which skills the student is performing well or having difficulties with.

Instructional recommendation sheet

Corresponding to each concept skill code, effective instructional strategies in elementary mathematics were gathered into the ECBM database from three resources (Tsuei 2004). First of all, the effective teaching strategies regarding specified mathematics concept domains were searched from the past literature. Second, two mathematics educational experts were interviewed about the instructional strategies in elementary mathematics. Third, 12 domain-expert teachers were case-based interviewed about how to teach specific mathematics concepts while students were inadequate. As a result, ECBM provided instructional recommendation sheets for what and how to teach students according to the mathematics concept-skill profile.

For example, Ted's math concept skill profile was drawn in Fig 2. It indicated that his performance in computation with integers was marked non-mastered during the first to third CBM tests. In Fig 3, ECBM provided Ted's teacher with an instructional recommendation sheet. She then identified the division computation with integers as problematic based on Ted's concept skill profile. Ted's teacher conducted the instruction in subtraction computation as recommended by ECBM. In the second period (Tests 4–6), Ted's math concept in D7 was improved as partially mastered. This time, his teacher provided remedial instruction in estimating quotient strategy in division computation with two-digit dividend. With this intervention, Ted's mathematics concepts in D5 and D6 were improved during the third period (Tests 7–9). After the ninth CBM test, however, his mathematics concept did not perform well in D6 and D7. His teacher listed the non-mastered mathematics skill codes in next semester's learning objectives for Ted.

ECBM was important for educational practices in that it freed teachers from the time-consuming tasks. It automatically generated CBM tests, administered scores, analysed and diagnosed students' math performance and provided instructional suggestions. In addition, consistency in measurement across tests was

Fig 2 Example of mathematics concept-skill profile. The skill codes were grouped by the mathematics domains. The circle represented an individual's mastery level on each concept-skill code at each interval of curriculum-based measurement. The triangle indicated that the specific concept-skill code was not shown on the tests. The bar chart was the percentage of scores on each mathematics domain.

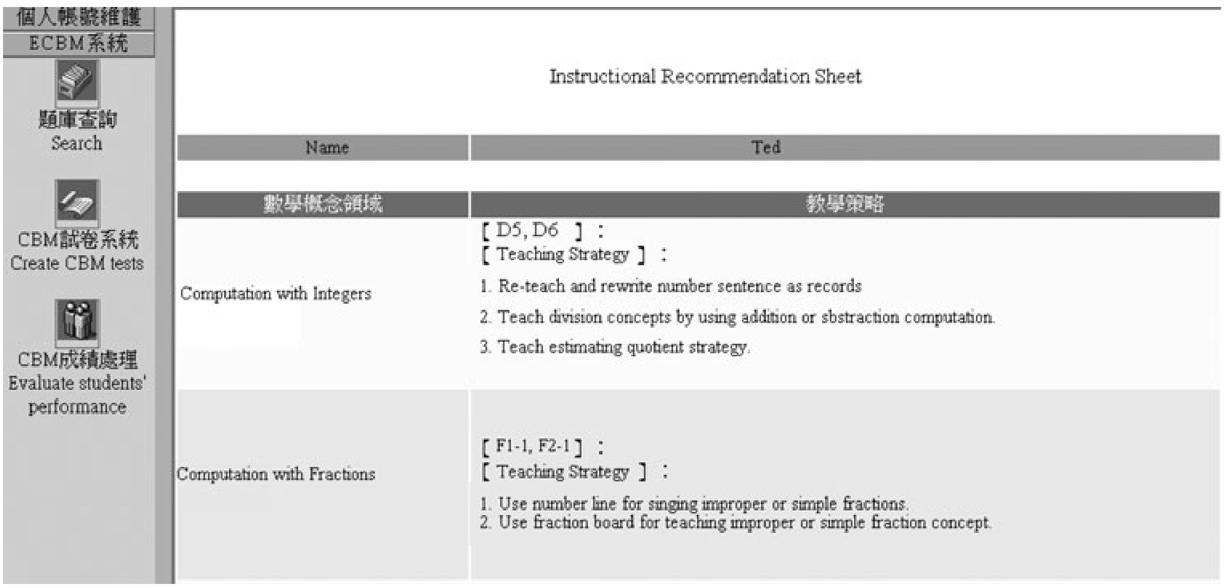


Fig 3 The instructional recommendation sheet was generated by the system based on the analysis of students' mathematics concepts.

enhanced, and the amount and quality of information teachers received was increased. Teachers' roles may change to instructional expert to inspect students' performance and make instructional decisions.

Effectiveness of ECBM on students' mathematical achievements

The ECBM is popular for elementary special educators to implement CBM in Taiwan. Research questions addressed in this study were: How are the new features of ECBM for general educators used in class-wide ongoing assessments? What are the effects of using different types of CBM math probes and growth models on students' mathematical achievements in the general classroom settings?

Participants

One hundred and thirty-four third-grade students in four classes of an elementary school located in Taipei, Taiwan participated in this study, which utilized a two-way quasi-experimental design. The four classes were assigned randomly into one of four groups with different types of CBM probes and different types of growth modeling. The groups included a CBM single-type and dynamic-growth modeling group (SD), a mixed-type CBM and dynamic-growth modeling group (MD), a mixed-type CBM and linear-growth modeling group (ML) and the contrast group, which featured a traditional single-type CBM and a linear-growth modeling strategy (SL). All of students participated in this study were taught in their original classes.

Measures

Using the ECBM, the teachers participating in this study administered the CBM tests to all students for 12 weeks. The Basic Mathematics Concepts Test (BMCT) was used for measuring the students' mathematics competencies and for screening the students with regard to mathematics difficulties in Taiwan. Criterion validity for scoring the math-achievement test ranged from 0.43 to 0.83 for the second to sixth grade subtests and internal consistency reliability was 0.93. Each student completed a paper and pencil group-administered BMCT, which consisted of 120 mathematics concept and computation items. Students were given 30 min to complete the test.

Teacher training

All teachers participated in three full-day workshops. We explained to them the CBM concepts, the student feedback and the teacher reports. The ECBM was used by teachers individually in the workshop for CBM administration and for analysing the students' performances according to their assigned groups.

CBM treatment

All teachers implemented the CBM for 12 weeks in whole-class format. Using the ECBM and standard measurement tasks, the teachers assessed the students' performances weekly. Each time, an alternate form of the CBM probe that was generated by the ECBM represented the grade-level curriculum. Students in the SD and the SL groups were required to complete a single-type computation CBM probe in 4 min, a CBM concept probe in 4 min and a CBM application probe in 6 min. These three single-type CBM probes were administered in the SD and the SL groups over the course of 3 days during 1 week. Students in the MD and the ML groups had to complete a mixed-type CBM probe in 6 min. Two mixed-type CBM probes were administered over the course of 2 days during a week.

All of CBM probes were scored by the research assistants (RAs). Performance was scored in terms of the number of correct digits. The correct digit was the right numeral in the right place including the numeral written in reverse form. For a student answering $31 \times 5 = 155$, he or she was awarded three correct digits. If the student did not show his or her work but got the correct answer, he or she was given credit for the longest method used to solve the problem. Thus, every question in CBM probe was not worth equally. Students gained more digits on multi-step problems. The digits earned on each test item were recorded into ECBM system. The ECBM system summed correct digits across problems for a total score in each CBM probe.

Teachers used the ECBM-*performance diagnostic system* to track their pupils' progress toward mathematics goals, beginning in October, 2004 and continuing until January, 2005. A traditional linear-growth modeling strategy was used as the expected CBM goal line for students in the ML and the SL groups. Class-wide dynamic-growth modeling was used for students in the SD and the MD groups. The ECBM also automatically recorded the frequencies of teachers' usage of each ECBM component, including the Math-IEP, the graphed analysis of student progress, and the mathematics concept-skill profile.

The effect of instructional strategies was controlled in this study. To ensure all instructional strategies implemented by teachers in the four groups were consistent, the instructional recommendations provided by ECBM were identical for four teachers, that is, one instructional strategy for one mathematics concept skill code. The consistency and accuracy with which the teachers implemented the treatment was assessed by classroom observations. Besides, every 2 weeks, the researcher conducting this study discussed the performance of the class with the teachers individually. The assessment of class performance included the students' class-wide progress and individual progress on the ECBM graphs, as well as the class-wide mathematics concept-skill profile, the class-wide slopes and the instructional recommendation sheets. Teachers can know quickly whether the instructional modification made in the last 2 weeks was effective or not.

Twice monthly, teachers used ECBM system to teach students to read and interpret their own graphs and concept-skill profiles on ECBM system for 5 min.

Data collection

To index students' achievement, the BMCT and the six mixed-type CBM probes that were divided into two sets were administered as pre- and post-test.

Results

Fidelity of treatment

The accuracy with which the teachers implemented the treatment was assessed by direct observations along the following four dimensions: CBM, periodic evaluations by students, small group vs. whole groups' instructions and the number of ECBM interactions. Four RAs were trained in two 1-hour sessions to conduct and score the observations along the first four dimensions. By checking 'yes' or 'no' biweekly, the RAs judged whether a teacher had conducted the first two elements correctly. The RAs conducted observations on the time arrangement of the mathematics group instructions, which were conducted by selecting one class (40 min) randomly biweekly. The percentages of agreement, accessed by the first three observations, were, respectively, 100.0%, 100.0% and 99.6%.

Our results indicated that the teachers implemented the CBM and the periodic evaluations fully (Table 1). The mathematics instruction with regard to small-group and whole-group instruction performed comparably between groups. In terms of the ECBM interactions, the teachers were more likely to navigate the mathematics concept-skill profiles. An ANOVA was conducted on the four dimensions of observations, but revealed no significant differences among treatments ($P > 0.05$).

Pre- to post-treatment changes in CBM mathematics performance

To assess the impact of the growth modeling and the CBM probes on a students' CBM performance, we conducted a two-way ANCOVA in this study. The first factor had two levels corresponding to the dynamic- or linear-growth modeling of the students' CBM performances. The second factor had two levels that, by using the ECBM, reflected the mixed- or single-type CBM probes. The mean scores of CBM pre- and post-test for the four groups were illustrated in Fig 4. There was an increase in CBM scores for all groups. Students in the MD group gained more with respect to CBM mathematics tests than other groups. We met all of the fundamental assumptions upon which the ANCOVA was based, including homogeneity of regression.

The ANCOVA for the students' CBM mathematics scores yielded a significant main effect for growth modeling, $F_{(1,129)} = 16.47$, $P < 0.001$, a significant main effect for the CBM probe, $F_{(1,129)} = 38.66$, $P < 0.001$ and a significant interaction between the growth modeling and CBM probe components, $F_{(1,129)} = 13.36$, $P < 0.001$. The effect size for the CBM probe was 0.23, while that of the growth modeling was 0.11. The effect size for the interaction between the growth modeling and CBM probe was 0.09. A significant interaction indicated that differences across the levels of growth modeling are not the same across the levels of a CBM probe. Therefore, two sets of simple main effects of ANCOVA were performed by using formulas recommended by Huitema (1980).

Table 1. Fidelity of treatment for CBM groups ($n = 134$).

Variable	Dynamic-growth modeling				Linear-growth modeling				F	P
	Mixed-type Probe (MD) ($n = 33$)		Single-type Probe (SD) ($n = 35$)		Mixed-type Probe (ML) ($n = 33$)		Single-type Probe (SD) ($n = 35$)			
	M	*sd*	M	*sd*	M	*sd*	M	*sd*		
CBM[a]										
CBM probes generation	12.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	0.00	1.00
Number of CBM measurement	12.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	0.00	1.00
Periodically evaluation[a]										
Help students to read personal profiles	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00
Group rearrangement	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00
Mathematics group instruction[a]										
Small group instruction	13.29	0.68	12.92	0.54	13.13	0.72	13.21	0.66	0.36	0.78
Whole group instruction	22.46	0.70	22.13	0.70	21.96	0.73	22.04	0.27	0.70	0.56
Number of ECBM interactions[b]										
Mathematics IEP	9.00	3.74	9.17	4.22	8.67	3.20	8.50	3.51	0.04	0.99
Graphed analysis	17.50	3.39	16.83	3.92	17.50	3.40	17.50	3.37	0.53	0.98
Mathematics concept skill profile	20.17	2.99	19.83	2.56	20.50	2.95	20.33	2.94	0.59	0.98

[a]Each mean reflects the average number of four observers by bi-weekly basis.
[b]Each mean reflects the average access number of ECBM system by bi-weekly basis.
CBM, curriculum-based measurement; ECBM, Web-based, curriculum-based measurement; IEP, Individualized Education Program.

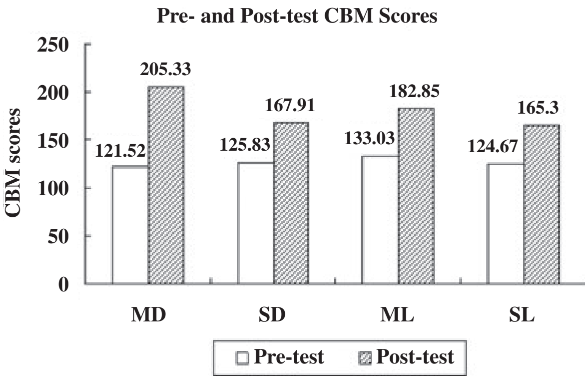


Fig 4 Mean pre- and post-test CBM scores by experimental groups.

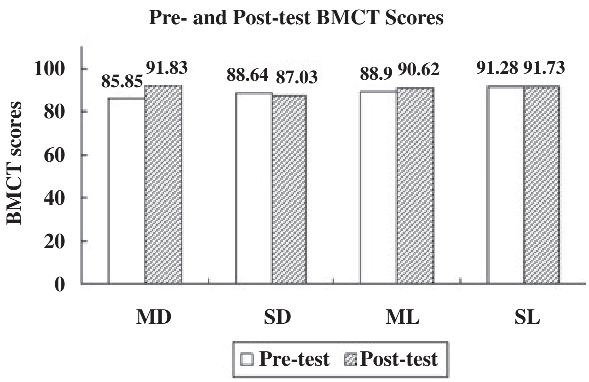


Fig 5 Mean pre- and post-test BMCT scores by experimental groups.

Under the effects of CBM probes, the adjusted means for students in the MD group ($M^d = 209.33$) outperformed those in the SD group ($M^d = 168.27$), $F_{(1,65)} = 64.15$, $P < 0.001$. The effect size for the CBM probe was found to be 0.50. No such effects were found with the linear-growth modeling group. In terms of growth modeling conditions, students in the MD group outperformed those in the ML group ($M^d = 177.13$), $F_{(1,63)} = 31.30$, $P < 0.001$. The effect size for the CBM probe was determined to be 0.33.

Pre- to post-treatment changes in the Basic Mathematics Concepts Test performance

The mean scores of the pre- and post-test of the Basic Mathematics Concepts Test for the four groups were illustrated in Fig 5. Students in the MD group showed a moderate increase in BMCT tests. However, students in the ML, SL and SD groups showed almost no or even negative improvement in test scores after intervention. This phenomenon may come from the math measures for the grade-level tasks in BMCT were too general. This finding was consistent with the construct validity in CBM research that correlations between CBM math and general math achievement were moderated (Helwig *et al*. 2002).

A two-way ANCOVA was conducted on the pre- and post-BMCT scores. Statistically significant main effects were obtained for the outcome of growth modeling $F_{(1,129)} = 4.93$, $P < 0.05$, with the dynamic-growth modeling groups (MD and SD) outperforming the linear-growth modeling groups (ML and SL). Statistically significant main effects were also obtained for the CBM probes, $F_{(1,129)} = 4.67$, $P < 0.05$, with the groups in the mixed-type probes (MD and ML) demonstrating the improved performance. No reliable interactions were obtained between the growth modeling groups and the CBM probes.

Rates of improvement by different skill levels

For comparing slopes by skill level, a subsample of students was selected representing different skill levels. Students with CBM pre-test scores below the 20th percentile and above the 80th percentile were analysed by two separate ANCOVAs. The covariate was the students' CBM pre-test scores.

As displayed in Table 2, the statistically significant main effects of the CBM probes on the slopes of students with different skill levels were obtained, $F_{(1,56)} = 15.35$, $P < 0.001$; no reliable interaction effects were found for the different skill level groups. Students with high- and low-skill levels in the mixed-type CBM probe groups (MD and ML) performed better than those in the single-type CBM probe groups (SD and SL). The effect size for the CBM probes was 0.22.

Significant main effects of growth modeling on the students' CBM slopes of students with different skill levels were found by a two-way ANCOVA, $F_{(1,56)} = 4.70$, $P < 0.05$. No significant main effect was determined for the different skill level groups. Overall, the students with high- and low-skill levels who participated in the dynamic-growth modeling groups (MD and SD) significantly outperformed those in the linear-growth modeling groups (ML and SL). For growth modeling, the effect size was relatively small, at 0.08.

Table 2. ANCOVA analysis of CBM slopes by different skill levels.

Treatment	Group								F		
	LG				HG				Treatment	Group	Treatment × group
	N	M	*sd*	M^d	N	M	*sd*	M^d			
CBM probe											
Mixed-type	(14)	1.66	0.65	1.37	(16)	1.33	0.39	1.58	15.35**	0.22	0.07
Single-type	(15)	1.13	0.52	0.90	(16)	0.83	0.44	1.04			
Growth modeling											
Dynamic	(15)	1.64	0.62	1.45	(17)	1.17	0.58	1.31	4.70*	0.01	1.60
Linear	(14)	1.12	0.56	0.96	(15)	0.98	0.33	1.16			

Note: CBM pre-test scores used as covariate.
$*P < 0.05$ $**P < 0.001$.
M^d, adjusted means; LG, low ability group; HG, high ability group; CBM, curriculum-based measurement.

Discussion

ECBM, the web-based CBM system, represents a well-developed measurement and diagnostic system that generates adequate, reliable and valid CBM tests. As a corroboration of previous research on computerized CBM systems, we eliminated the amount of time that teachers devoted to the implementation mechanics of CBM. This action alone enhanced teacher satisfaction with the process (Fuchs *et al*. 1988). Moreover, teachers can gather the assessment information at any time and in any location. Teachers appeared to use the mathematics concept-skill profiles more often than the other features. More research is required on the feasibility of the ECBM system to determine instructional information exchange and its effects on teachers' professional development.

In addition to the main effects of the CBM probes and the growth modeling treatment, an interaction was found between these groups on the students' CBM scores. With the dynamic-growth modeling treatment, the students in the mixed-type CBM probes groups significantly outperformed those in the single-type CBM probes groups. This outcome was not seen with the linear-growth modeling treatment. In the mixed-type CBM probes treatment, the dynamic-growth modeling groups significantly outperformed the students in the linear-growth modeling groups in achievement gains. There was no such effect found with the single-type CBM probes treatment.

Changes in CBM and BMCT mathematics achievement growth were found among students in the class-wide dynamic-growth modeling groups and those in the linear-growth modeling groups. Students who participated in the dynamic-growth modeling group had more math achievement gains than those in the linear-growth modeling group, as reflected in their CBM and BMCT scores.

These findings are encouraging because the class-wide dynamic-growth modeling combined with CBM mixed-type probes enabled the students to perform better than they would have using single-type CBM probes. The evidence pertaining to the content of mathematics tests is extensive. The previous study concerning the validity of CBM mathematics computation probes indicated that mathematics with computations and applications were distinct, though related constructs (Thurber *et al*. 2002). CBM was designed to enable teachers to measure students' mathematics 'proficiency on the global outcomes toward which the entire curriculum is directed' (Fuchs & Deno 1991, p. 493). The mixed-type CBM probes including computation, concept and application are evident in the scope and sequence of typical math textbooks (Salvia & Ysseldyke 1991), as well as in math assessments (Helwig *et al*. 2002; Thurber *et al*. 2002). From this point of view, the use of mixed-type math CBM probes reflects a 'truly curriculum-based' assessment, and has great potential for improving students' mathematics proficiency in the general classroom. Similar potential for special students still requires empirical testing.

Previous research indicated that the linear relationship adequately modeled math-proficiency growth within an academic year (Fuchs *et al*. 1993). However, the results of this study constitute strong evidence that the class-wide dynamic-growth modeling strategy was more effective for students in mixed-type CBM probes than it was for students in single-type CBM probes. Relative to their classmates, the students in the dynamic-growth modeling groups were aware of their mathematics performance, and this awareness thus promoted their self-expectations. Therefore, class-wide dynamic-growth modeling holds the promise of peer model effects. The peer model conveys information about the functional value of behaviours and serves to motivate an individuals' behaviours and achievements (Jessor 1993; Slaughter-Defoe 1995; Ma 2001). This study revealed a strong positive treatment effect concerning the class-wide peer modeling approach by using more optimistic growth rates for general students. The class-wide dynamic-growth modeling provided 'ambitious goals' for math proficiency growth in the general classroom, particularly when using the mixed-type CBM probes. These findings have been encouraging in light of the adoption of higher expectations in CBM for students with learning disabilities (Deno *et al*. 2001) as well as for students in general.

With respect to skill level variance in student progress, the main effects of both CBM probes and growth modeling were found for both low- and high-level students' CBM slopes obtained on a weekly basis. No statistical interactions were observed between the treatments and skill factors. The lack of any interaction suggests that the higher and lower levels of CBM math did not yield treatment effects. Overall, both lower and higher CBM math students in the dynamic-growth modeling group significantly outperformed those in the linear-growth modeling group. Such effects were also found between the class-wide dynamic-modeling groups and the linear-growth modeling groups. Consistent with previous research (Spicuzza *et al*. 2001), our findings indicated that computerized CBM intervention was effective across skill levels including high- and low-performing students in the general classroom. Because the effective study size was relatively small, additional evidence is needed to corroborate these findings.

ECBM provided a model of integrating education, technology and CBM ongoing assessment. More specifically, ECBM was a set of processes for monitoring students' progress toward the instructional objectives in the ongoing assessment. As Deno (1985) noted, CBM is the curriculum-based assessment process whereby assessment results are used to monitor student progress and improve instructional programs. Using ECBM in the classroom increased the amount of feedbacks given to the teachers and students. The variation of students' math performance in the four groups may be due to the use of ECBM feedbacks. Previous study indicated the positive links between corrective feedback and achievement outcomes (Gettinger & Stoiber 1998). Further research can be examined if variations on teaching and learning strategies may have effects on students' achievement in ECBM ongoing assessment.

Conclusions

This paper has outlined the ECBM, its architecture and effectiveness. Taking advantage of previously developed and validated components, computer networking technology adds substantial and important value to the CBM. The relational database systems and network technologies provide advantages over traditional tools, as they provide dynamic techniques that teachers can use to manage, implement and interpret individual and class-wide CBM performance. Additional strategies for using web-based technologies to promote teachers' professional development and improve class-wide performance should be pursued. Based on the analyses presented in this study, it appears that students gain more mathematics proficiency by using mixed-type CBM probes than they do with single-type CBM probes. Accordingly, the use of computation, application and concept components in CBM has the potential to generate significant instructional changes in classrooms.

In conclusion, our work has provided innovative ideas in technology-based assessments, especially related to CBM research. The approach of the class-wide dynamic-growth model in this exploration demonstrates optimistic weekly growth rates for students in the general classroom setting. That is, students can achieve higher growth rates through a class-wide dynamic-growth model than through a linear-growth prediction model. This study expands previous research by exploring the dynamic features inherent in ECBM, which are reliable and beneficial for technology-based assessments for elementary mathematics progress.

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