Precision Teaching in Developmental Mathematics: Accelerating Basic Skills

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Five students placed in an elementary algebra course as a prerequisite to the university-level mathematics requirement participated in 12 sessions of a fluency-building program designed to accelerate skills in the basic mathematics operations of addition, subtraction, multiplication, and division over a period of six to nine weeks. The interventions consisted of 2 to 8 1-min timings solving single digit mathematics problems. Increases in response frequency were seen for all participants. Results indicated that improvements in the frequency of correct responses in basic mathematics operations were related to increases in the final course grade in the developmental mathematics course of participating students as compared to non-participants.

DESCRIPTORS: Mathematics, Precision Teaching, Fluency

For many years, colleges and universities have struggled with a trend indicating that a portion of students who meet admission standards fail to demonstrate mastery of mathematical skills sufficient for placement into the required mathematics courses (Akst and Hirsch, 1991). There is great variability in how different institutions determine readiness for university-level mathematics instruction. Trends indicate that at least one third of entering college students are placed in developmental mathematics courses through entrance examinations because they fail to demonstrate the necessary preparation for university level mathematics courses (Boylan & Saxon, 1998; McCabe & Day, 1998; Stratton, 1998). The failure of many students to master basic mathematics skills poses challenges not only to university admissions committees, but also to mathematics faculty charged with readying these students for university-level instruction. Students may be attracted to universities by admissions practices that maximize enrollment, but often find that the academic and social supports for their success disappear shortly after their arrival on campus (Jackson and Mallott, 1994).

Developmental mathematics programs have been designed in response to these challenges. The primary goal of developmental mathematics courses must, then, be to improve sufficiently students' mathematics skills to provide them the same opportunity as their peers to successfully complete university mathematics requirements. To bring about such rapid and deep changes in student repertoires, measurably effective instructional practices must be utilized.

Precision Teaching is a method of assessing the outcomes of instruction at the level of the individual that is sensitive to changes in the frequency of behavior over time (White and Harring, 1980). The measurement system that makes these changes detectable is the Standard Celeration Chart. This system allows measurement of progress "toward clearly defined instructional objectives and stated criteria" (Neal, 1981, p. 290). Thus, Precision Teaching does not prescribe content or pedagogy, rather it can be combined with any curriculum or method to sensitively monitor and assess relevant changes in performance and to guide instructional decision-making (Lindsley, 1997).

Precision teachers provide students frequent opportunities to practice skills, called frequency-building exercises, until true mastery, or fluency, is evident in learners' performances. "Fluency building refers to the process of promoting more fluent responding," thus occurring after skills have already been acquired (Wolery and Sugai, 1988, p. 281). Increasing rapid and accurate responding is

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important because we often assume that a learner's failure to achieve a particular learning goal is a function of their motivation or dedication to the goal. However, it is more often the case that the learner lacks the foundation skills, adequate supports, or prerequisite knowledge to manage the level of task difficulty that they face. Given that the function of developmental mathematics courses is to prepare learners for advanced studies, the development of fluency in basic mathematics is a vital component of meeting these course goals.

Through years of research and practice, practitioners of Precision Teaching have discovered a relationship between expert performances and later retention and application of knowledge. When behavior is fluid, automatic, or effortless, it is referred to as fluent. Fluency of a skill is important not only because it better describes true mastery of a skill than does accuracy alone (Binder, 1996), but it is also predictive of a number of significant outcomes of learning. For example, "retention and maintenance of skills and knowledge; endurance or resistance to distraction; and application or transfer of training" are consistent outcomes of learning that is fluent (Binder, 1993, p. 9). Cumulative disfluency can result from failure to develop true mastery of foundation skills (Johnson & Layng, 1992; McDowell & Kennan, 2001).

Universities are often faced with students who have this unbalanced collection of skills and must find ways to be effective in spite of absent student foundation skills. Fluency of basic skills is important if more complex skills are to also reach fluency, thus expectations for basic skill mastery must be stated in light of terminal goals. Research has indicated that correct response frequencies for simple skills such as writing the number 1 or naming pictures can be expected at levels of 200 per minute (Johnson and Layng, 1992); studies directly measuring solving mathematics equations indicate that up to 125 correct responses per minute can be expected in learners who are fluent (Wolery and Sugai, 1988).

The purpose of the present study was to determine if increases in component skill frequency would increase the mastery of composite skills. This question was addressed through the addition of brief, rapid practice sessions of basic mathematics operations outside the context of a not-for-credit university course in algebra. The effect of this intervention was evaluated through the measurement system of Precision Teaching. All students were expected to master mathematical computations with the appropriate experience.

METHOD

Participants

Seven undergraduate students enrolled in a developmental mathematics course taught by the second author volunteered to participate. Five students completed the study.

Students enrolled in the developmental mathematics course for one of two reasons: it was required by a university placement evaluation, or they were self-selected for additional skill building before enrolling in the required university-level mathematics course. Students required to take this course were identified by a score of 45 (out of a possible 120) or less on the Accuplacer mathematics entrance test, or through a need detected in the evaluation of their application for admission to the university. Participants' average Accuplacer score was 42.37 (SD = 5.76).

All volunteers were female and taking courses at this university for one semester or less as either entering freshman or transfer students. Participants were from one of the following two age groups: 17 to 19 year olds, or 30-40 year olds.

Participation was voluntary and was compensated only by the opportunity to develop basic mathematics skills and the chance to receive tutoring and support in the completion of developmental mathematics coursework from the research assistants.

Matched Control Non-Participants

Seven students from the same course and section of the developmental mathematics who did not participate in the study were selected as matched controls. Because control non-participants were directly matched to study participants, when two participants left the study, their matched controls were also removed from all analyses, thus data from five matched control participants are presented.

Control non-participants were selected because they most closely resembled a study participant on the following three criteria, in order of importance: score on Exam 1 in the developmental mathematics course, class attendance, and Accuplacer placement test score (when available). As can be seen in Table 1, the average first examination score for participants in the study was 75.72 (SD = 12.92) and the average score for the matched control group was 74.28 (SD = 8.34). Both participants and non-participants had less than two absences from the developmental mathematics course at the onset of the study. Matched control non-participants' average Accuplacer score was 38.80 (SD = 8.92).

Materials

Worksheets were generated for the study by computer. Each page consisted of one hundred single digit problems on the mathematics operations of addition, subtraction, multiplication, or division. Four versions of each worksheet containing each operation were developed, varying the numerals in each problem, the sequence of problems, and the numerals in the final answer to control for practice effects during repeated administrations.

Procedure

Participants were randomly assigned to one of two groups. Participants met with a research assistant two times per week for approximately 45 minutes per session over a period of six to nine weeks, depending on their availability, to complete a total of 12 sessions. All practice sessions were held individually in a small room equipped with a table and two chairs. Volunteers were informed of the purpose of the project and provided written consent to participate. In all sessions, participants were instructed to work through the materials as accurately and rapidly as possible, skipping problems that they could not readily solve and writing over, rather than erasing errors. One-min timings were completed beginning when the participant began work on the first problem.

Baseline. A baseline measure of the participant's number of correct responses per minute on basic mathematics problem solving was taken. The baseline included two to three one-min timings on the four basic mathematics operations. Breaks were provided between one-min timings to prevent fatigue. The purpose of this session was to familiarize participants with the format of later sessions. No feedback was given during the baseline session.

For participants Anne, Elizabeth, and Jane, the baseline was taken for each operation across two one-min timings during four of the odd numbered sessions where session one tested addition, session three tested subtraction, session seven tested multiplication, and session nine tested division.

Baseline for participants Alicia and Lucy was conducted for all four mathematics operations during session one and repeated in session 12 with three one-min timings per operation.

Frequency-Building Intervention. Participants Anne, Elizabeth, and Jane received 8 timings per session. They received two sessions containing three timings each with the following sequence of problems: addition, subtraction, mixed addition and subtraction, multiplication, division, and then mixed multiplication and division. Table 2 details the operations that these participants experienced in each session. Their goal was to reach 80-100 correct responses per minute (Johnson and Layng, 1992).

Participants Alicia and Lucy completed between three and 12 timings (with a modal score of eight) per session. They were scheduled to practice each basic mathematics operation during two timings per session. The number of timings and type of mathematics operation included on the worksheet for each participant per session can be seen in Table 2. Their goal was to make successive

Table 1.
Between Group Pre-Intervention Measures

Pre-Intervention Measures	Participants		Matched Controls	
	Mean	SD	Mean	SD
First Examination*	75.72	12.92	74.28	8.34
ACCUPLACER Placement Test Score **	42.37	5.76	38.8	8.92

Note: * = On a scale from 0 to 100, ** = Scores on an ACCUPLACER Test have a possible high score of 120

Table 2.
Mathematics Operations and Number of Timings by Participant During Intervention

<table>
<tr><th rowspan="2"></th><th colspan="12">Participant</th></tr>
<tr><th colspan="4">Anne</th><th colspan="4">Elizabeth</th><th colspan="4">Jane</th></tr>
<tr><th>Session</th><th>Add</th><th>Sub</th><th>Mult</th><th>Div</th><th>Add</th><th>Sub</th><th>Mult</th><th>Div</th><th>Add</th><th>Sub</th><th>Mult</th><th>Div</th></tr>
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</table>

Note: In phases 5, 6, 11, and 12, participants Anne, Elizabeth, and Jane received practice on both of the previous operations in a single timing.

	Participant							
	Alica				Lucy			
Session	Add	Sub	Mult	Div	Add	Sub	Mult	Div
1	3	3	3	3	3	3	3	3
2	2	1	3	0	3	0	0	0
3	3	0	0	0	3	0	0	0
4	3	0	0	0	3	0	0	0
5	2	2	2	2	2	2	2	2
6	2	2	2	2	2	2	2	2
7	2	2	2	2	2	2	2	2
8	2	2	2	2	2	2	2	2
9	2	2	2	2	2	2	2	2
10	2	2	2	2	2	2	2	2
11	2	2	2	2	2	2	2	2
12	3	3	3	3	3	3	3	3

increases in the number of correct responses per minute by achieving a total score per session that was ten percent greater than their best score on the previous session for each mathematics operation. If a participant did not meet their goal for one operation, they did not move on to practice the remaining operations in that session. After three sessions where a learner did not meet this goal, it was changed to 80-100 correct responses per minute.

Encouragement and praise was provided to all participants upon completion of each timing. At the end of each session, the research assistant identified participant's strengths and areas for improvement on the development of basic mathematics skills. Participants were thanked for their time and offered additional worksheets to practice these skills at home. Participants were also offered the opportunity to discuss course work and to develop skills in their algebra class.

Measures

The effect of the frequency-building intervention on the development of the component skill of basic mathematics operations was evaluated on the Standard Celeration Chart by plotting the highest number of correct responses on a single timing for each operation in each session. Performance on the composite skill of mastery of elementary algebra was evaluated by examining scores on the in-class quizzes, examinations, and student grades in this and other courses.

RESULTS

Learners in this study were enrolled in a developmental mathematics course to address skill deficits in elementary algebra. Following the first examination in this course, an intervention to increase foundation skills necessary for success in the course was offered. Five students completed the intervention. In order to evaluate the effect of the frequency-building exercises for basic mathematics operations on participants' performance in the developmental mathematics course, within-subject and between-group analyses were conducted.

Within-Subject Analyses. The number of correct and incorrect responses per one-min timing on each of the four basic mathematics operations is depicted on a Standard Celeration Chart for each participant. Learners Anne, Elizabeth, and Jane experienced one operation per session for two successive sessions and had a goal of performing 80-100 correct movements per minute. As can be seen in Figure 1, gains in the frequency of correct responding were seen for Anne in addition, subtraction, mixed addition and subtraction, and division problem solving. The frequency of correct responding decreased for multiplication and remained unchanged for mixed multiplication and division problem solving over the course of the intervention.

Elizabeth showed increases in the frequency of correct responding for each of the operations in isolation (e.g., addition, subtraction, multiplication, and division). Responding to mixed timings for addition and subtraction remained unchanged during the course of the intervention, while the mixed multiplication and division scores actually decreased. Figure 2 depicts these results.

In Figure 3, gains in the frequency of correct responding were seen in all operations for Jane, in isolation and in the mixed timings.

Alicia and Lucy were expected to experience each operation each session. However, both participants failed to meet the performance goal of a 10% increase over their previous score on a given operation for the first three intervention sessions. This procedure was designed to reduce frustration when a goal was not met. Results indicated that failure to meet this goal also functioned to reduce the opportunity to practice other operations and was, therefore, abandoned after three sessions. Thus, Figures 4 and 5, representing the performance of Alicia on addition and subtraction, and multiplication and division, respectively, show no data for the sessions where operations were not practiced. The same results can be seen for Lucy in Figures 6 and 7. Thereafter, they practiced each operation twice each session from session five to session 12. Their goal was a frequency of 80-100 correct responses per minute. Overall increases in the frequency of correct responses were seen for addition, subtraction, multiplication, and division problem solving for both participants.

Only one participant in one operation obtained the performance goal of 80-100 correct responses per minute: Lucy for subtraction problem solving. Errors remained at low rates throughout the study for all participants.

The average number of problems correct on each of the four mathematics operations at the beginning of the study and the corresponding average at the end of the study for each participant is depicted in Figure 8. An average increase of 6.14 (SD = 4.98) correct responses per minute was seen for addition problem solving, 7.66 (SD = 6.53) for subtraction, 5.44 (SD = 7.71) for multiplication, and 8.04 (SD = 4.12) for division across the five participants.

Between-Group Analyses. Students in the developmental mathematics course who entered the study and the matched control students who did not participate

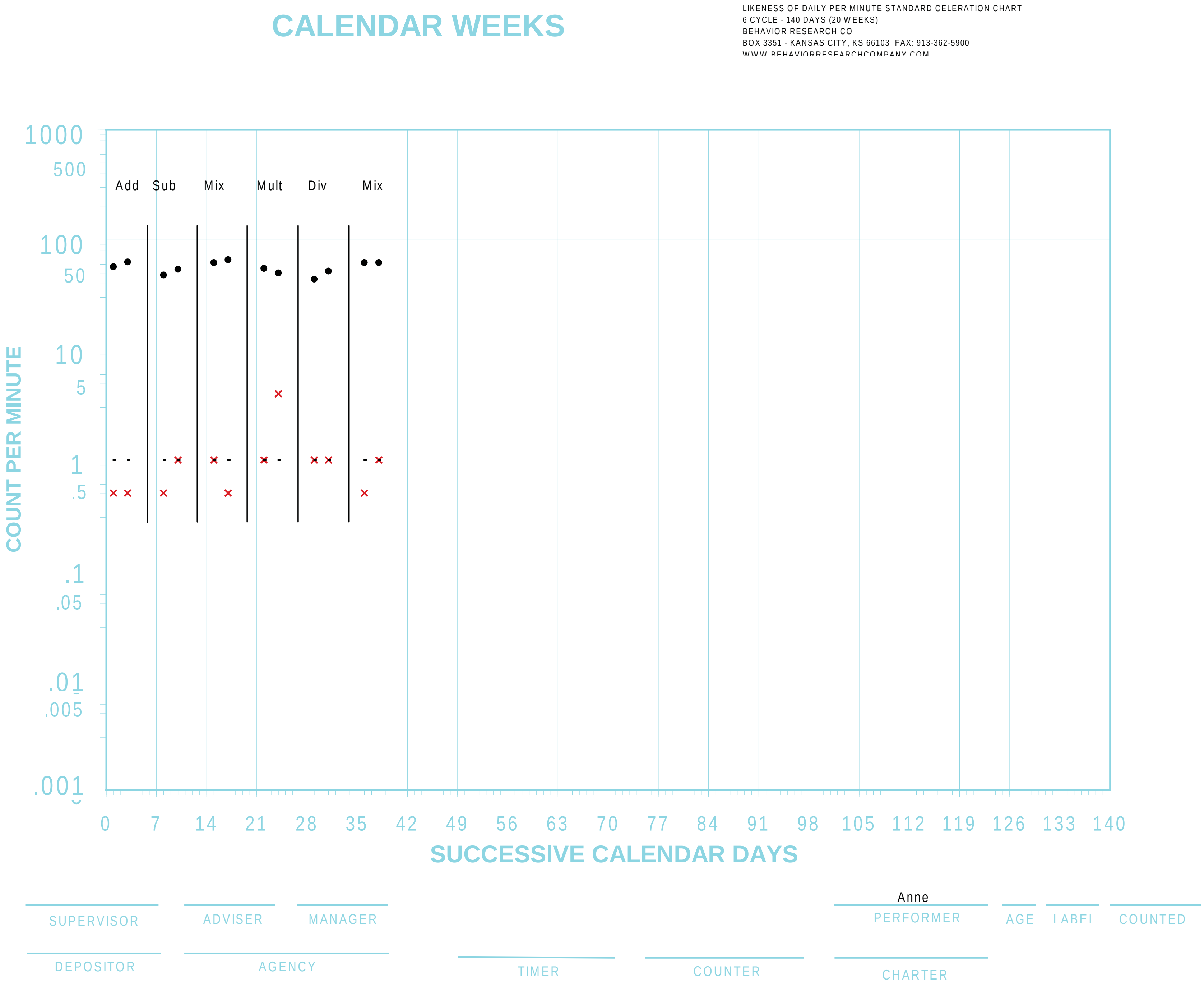

Figure 1
Standard Celeration Chart for Anne: Addition, Subtraction, Multiplication, and Division

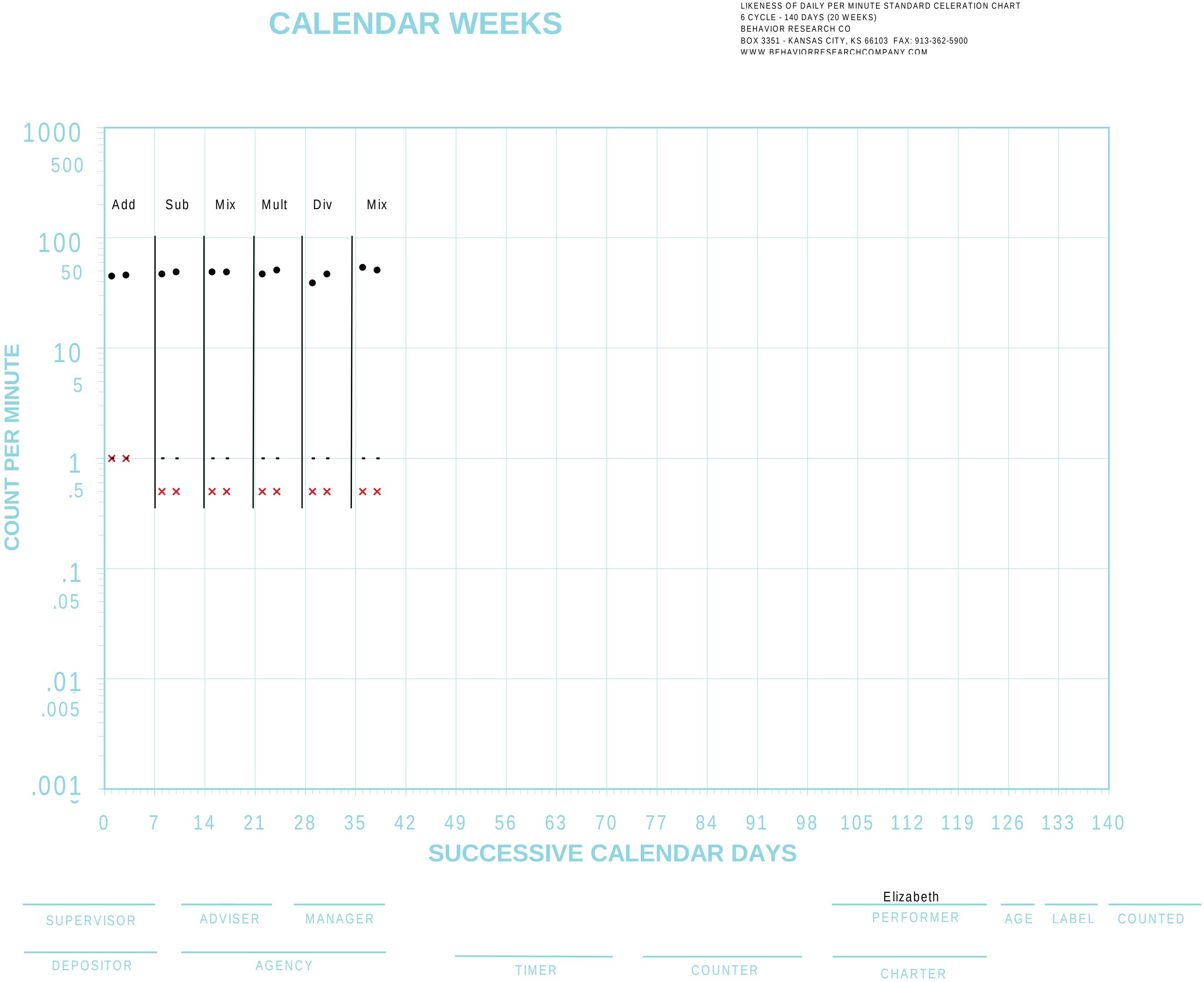

Figure 2
Standard Celeration Chart for Elizabeth: Addition, Subtraction, Multiplication, and Division

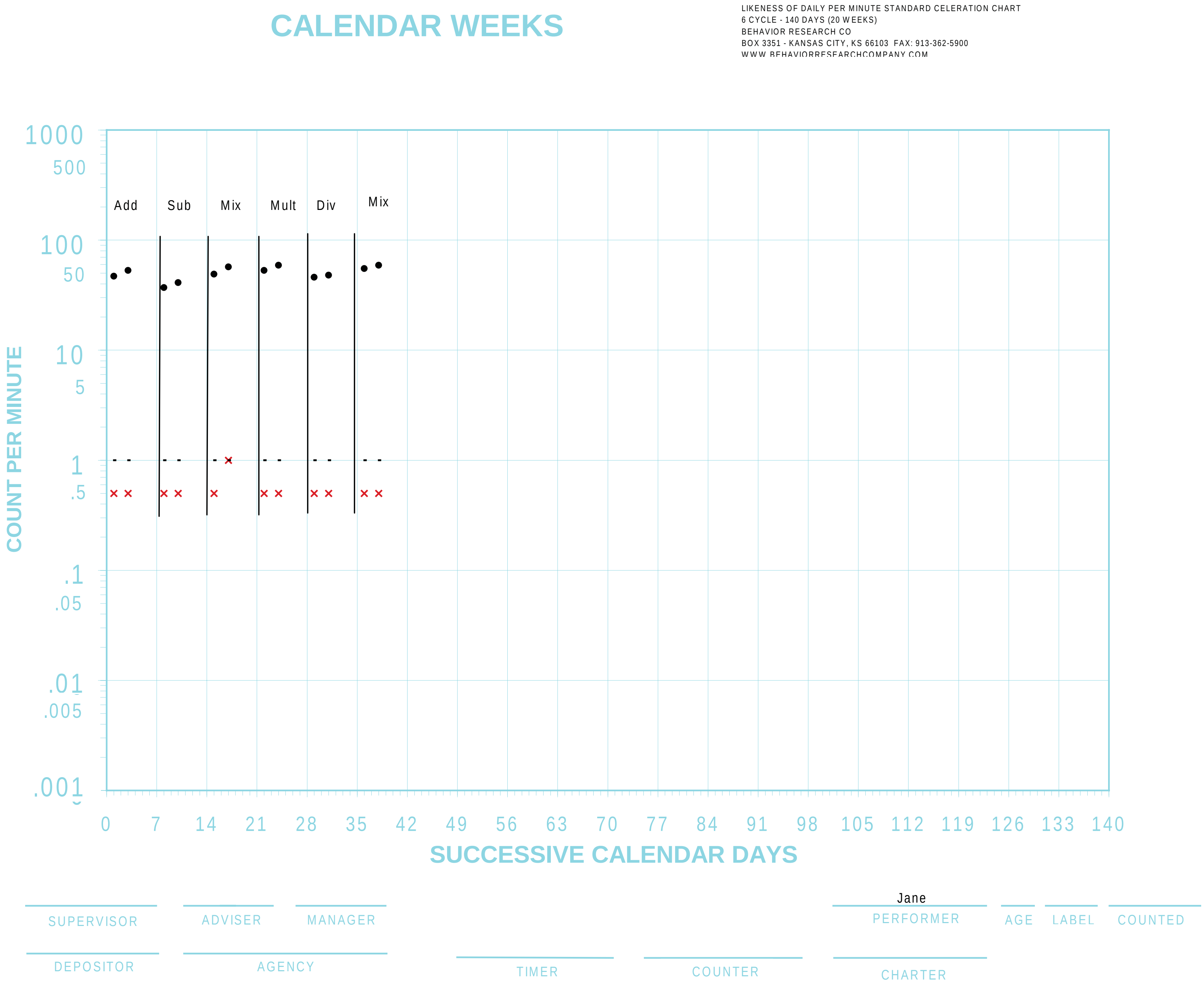

Figure 3
Standard Celeration Chart for Jane: Addition, Subtraction, Multiplication, and Division

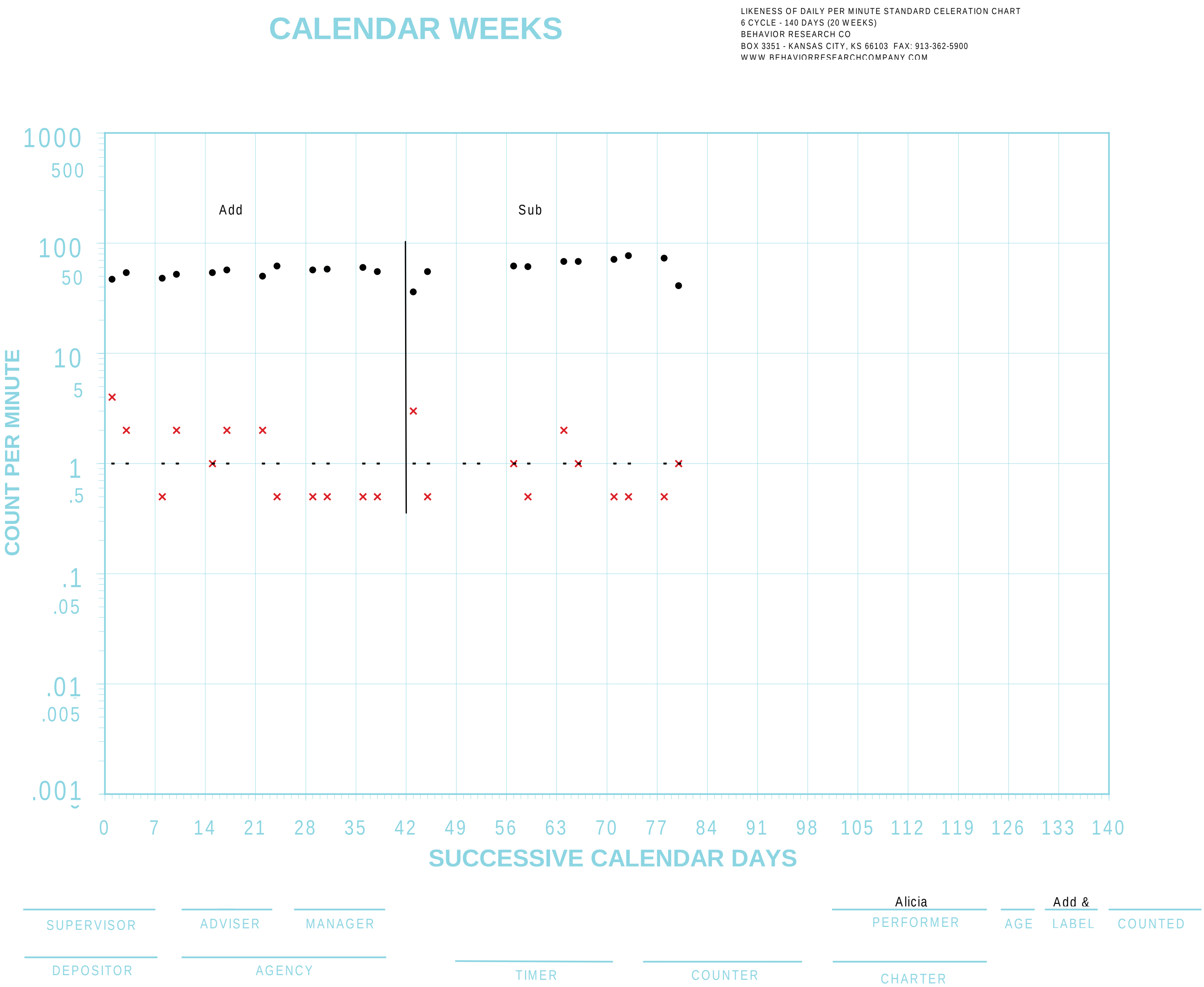

Figure 4
Standard Celeration Chart for Alicia: Addition and Subtraction

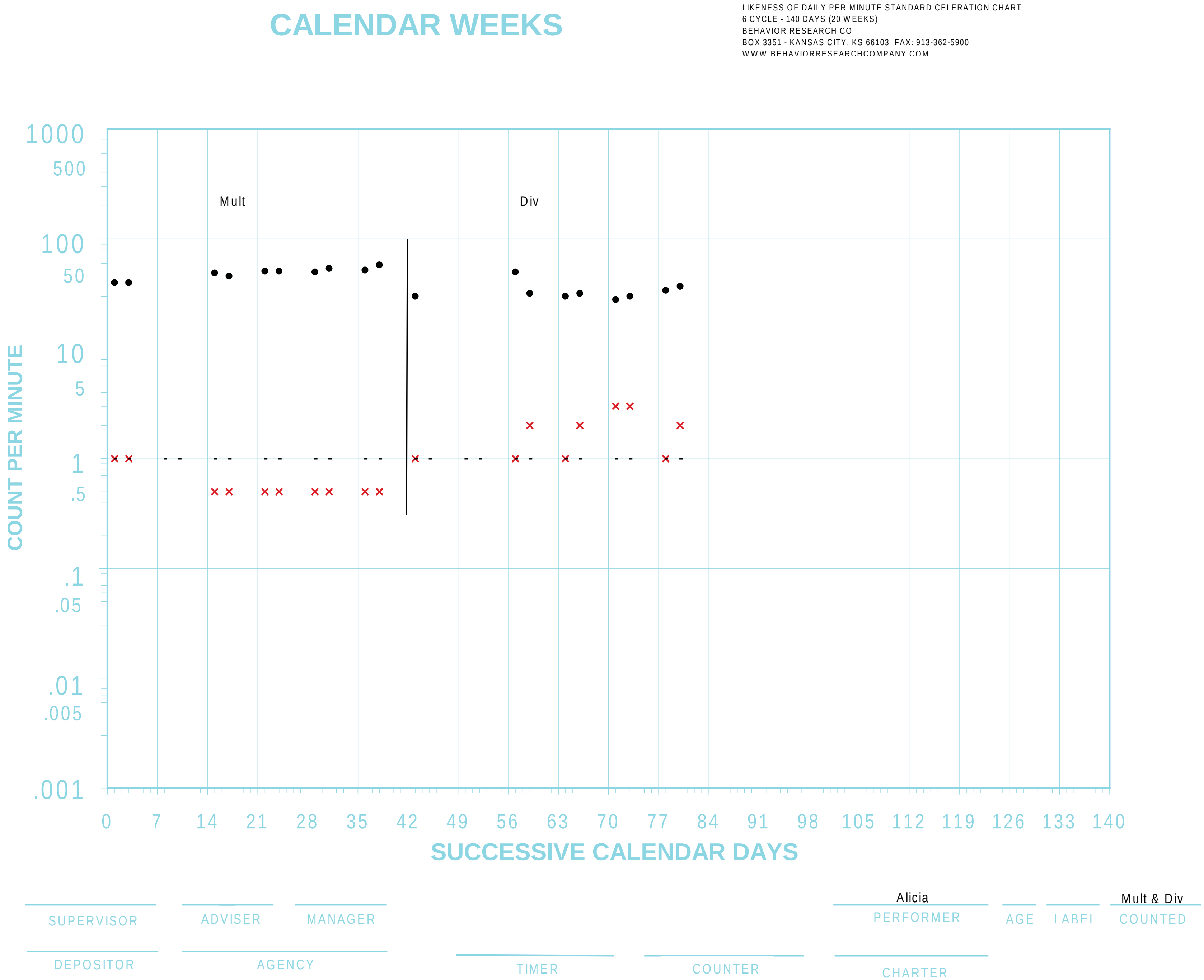

Figure 5
Standard Celeration Chart for Alicia: Multiplication and Division

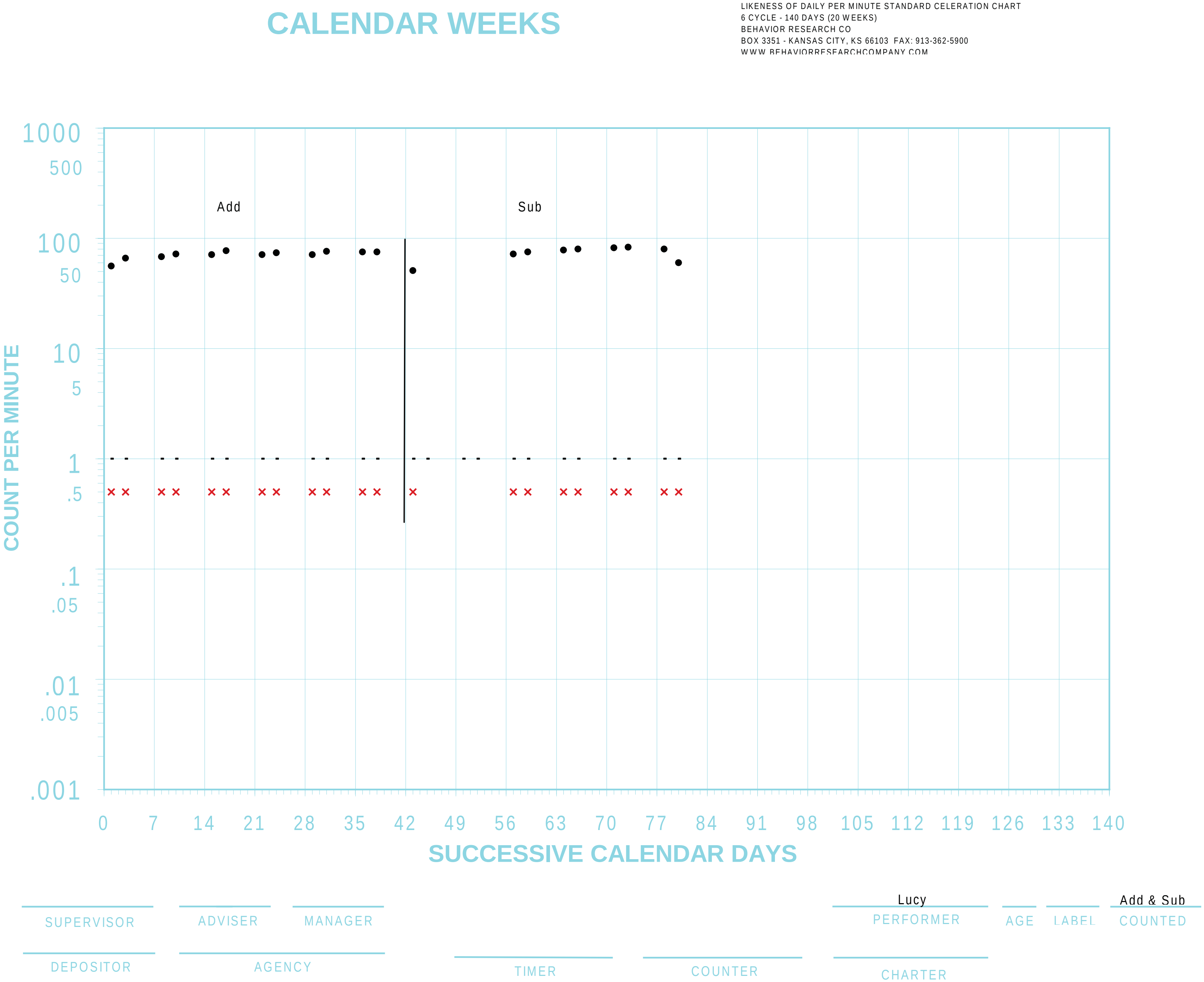

Figure 6
Standard Celeration Chart for Lucy: Addition and Subtraction

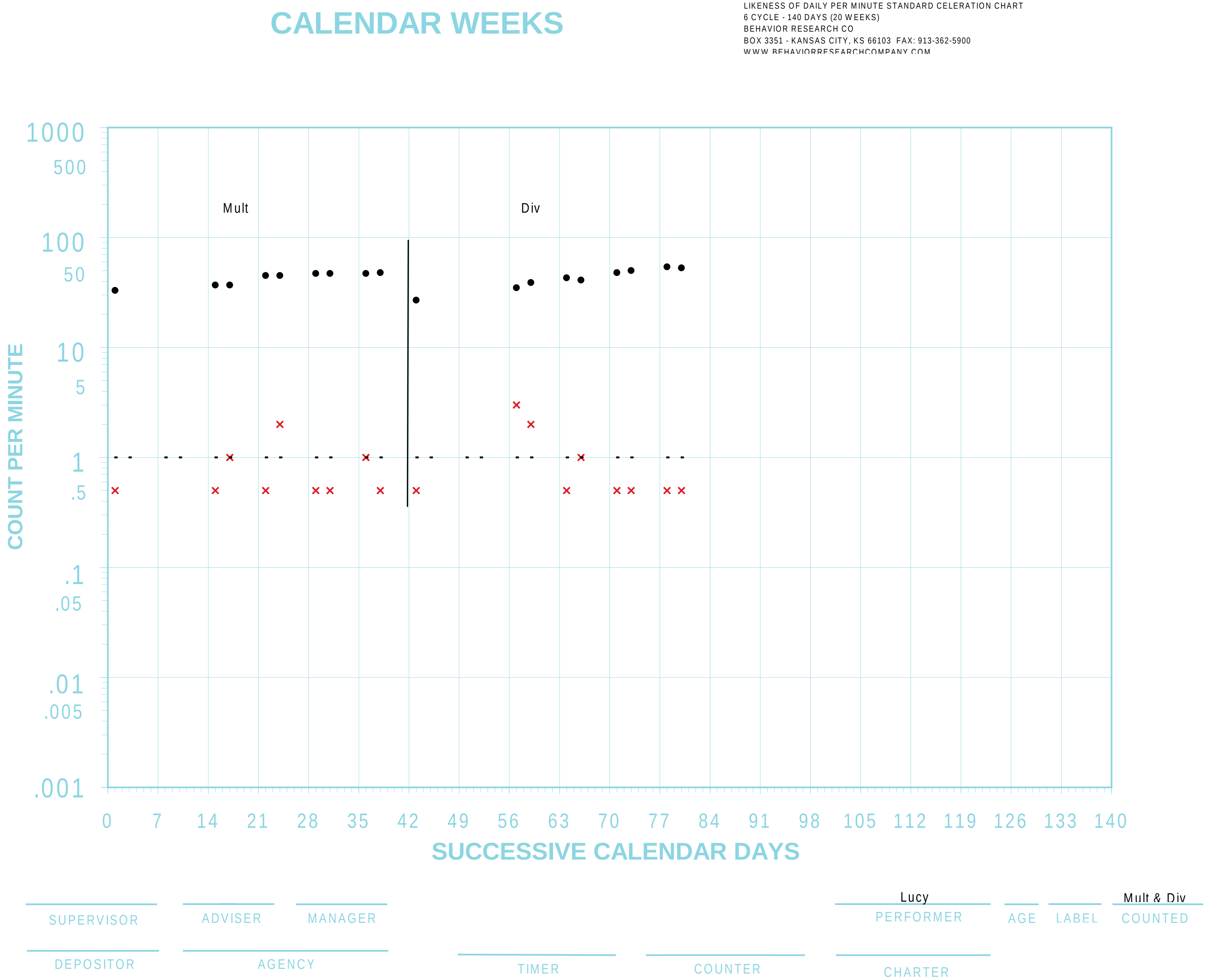

Figure 7
Standard Celeration Chart for Lucy: Multiplication and Division

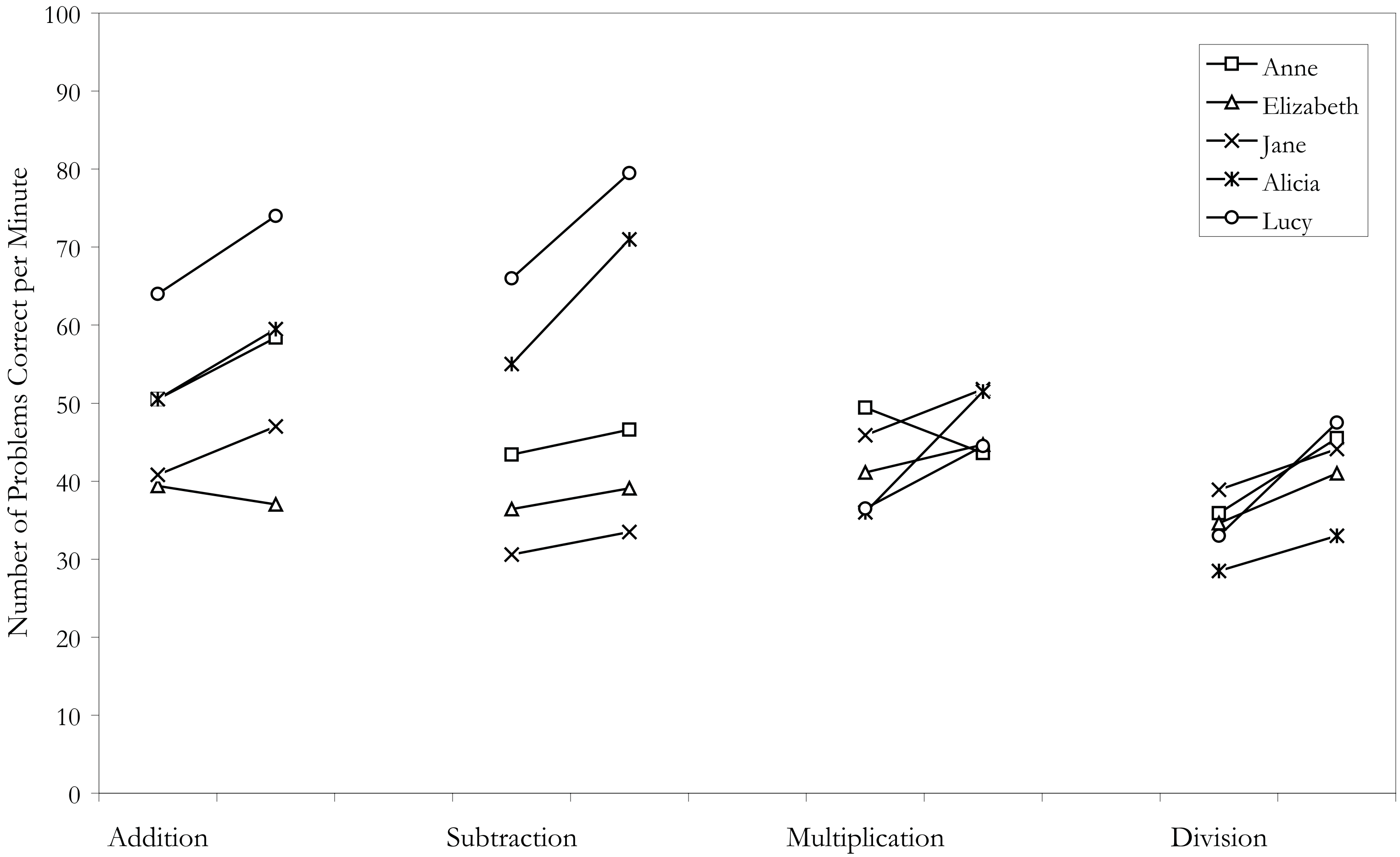

Figure 8
Learning Gain in Basic Mathematics Operations Across Participants

had similar rates of class attendance, and similar scores on the placement test for mathematics upon entering the course. However, when comparing performance of the participants in the study to subjects selected as matched controls, important post-intervention differences became evident (Table 3 contains the between-group post-intervention comparisons).

Students in both groups completed two examinations, a cumulative final examination, and 13 quizzes in the elementary algebra course. Performance on the first examination averaged 75.72 percent for participants (SD = 12.92) and 74.28 (SD = 8.34) for matched controls. The intervention began after the first examination.

On the second examination, the average performance of the participants in the study exceeded the matched control group by 15 percentage points (X = 81.46%, SD = 12.01, and X = 66.50%, SD = 13.81, respectively). Scores on the cumulative final examination also differentiated the two groups, with the average score for participants in the study 11 percentage points higher than that of the matched control group (X = 87.02%, SD = 14.19 and X = 76.92%, SD = 9.75, respectively). A difference was also observed between participants in the study and the matched control group on the average quiz grade, favoring participants by 16 percentage points (X = 85.30%, SD = 8.03 and X = 69.88%, SD = 9.51, respectively).

Final course grades for participants were also higher than those in the matched control group. This difference in performance is represented by an average grade in the elementary algebra course of a 3.28 on a 4.0 scale (SD = 1.11), for the participants and a 2.26 (SD = 0.65) for the matched control group. These scores represent letter grades in the course of nearly B/B+ (3.30 is a B+) for participants and C/C+ for non-participants. Further increases were noted in the participant's cumulative grade point average at the university. Participants in the study earned an average cumulative grade point average of 3.41 (SD = 0.30), as compared to 2.97 (SD = 0.53) in the matched control group at the end of their first semester of college.

DISCUSSION

The goal of the current project was to increase the component skills of learners in a developmental mathematics course to increase their mastery of more complex composite skills in math through the application of short, frequent, and fast practice with frequency-building aimed at achieving expert levels. Results indicated that although the gains in the fluency of basic mathematics operations were meager (a few correct responses per minute, and still appearing at less than expert levels), meaningful increases in course mastery beyond the predicted preintervention levels were observed as compared to the matched control group. Precision teachers often analyze the component skills necessary for success in a composite performance. Using this method, it can be said that increases in composite skills were noted, despite small gains in the frequency of component skills. Precision Teaching utilizes a measurement system designed to detect changes in the development of a skill that will ensure later retention of concepts, even with periods of no practice; endurance over longer and longer periods of time; stability in the face of distraction or frustration; application of basic skills in working through more complex tasks;

Table 3
Between Group Post-Intervention Measures

	Participants		Matched Controls	
	Mean	SD	Mean	SD
Average of 13 Quizzes*	85.30	8.03	69.88	9.51
Second Examination*	81.46	12.01	66.50	13.81
Cumulative Final Examination*	87.02	14.19	76.92	9.75
Course Grade**	3.28	1.11	2.26	0.65
Cumulative GPA**	3.41	0.30	2.97	0.53

Note. * = On a scale 0 to 100, ** = On a 4.00 scale and the generation of new skills through uninstructed combinations of different fluent skills (Johnson and Layng, 1992). The frequency-building program provided an efficient and effective means of strengthening the skills necessary for success in the developmental algebra course.

The results of the current study have far reaching implications for educators and administrators in supporting and retaining quality student populations. Universities may find that providing support for student learning and mastery of basic skills will have large payoffs for the development of more advanced skills in a number of subject areas. Such improvements could be made available to a wide array of students with minimal expense to the university. Supported practice such as that provided in the current study could be provided through new student entry programs, tutoring available in student services, or through computerized learning programs.

In addition to demonstrating the effectiveness of the intervention, the current study offers an extension of the data-based instructional practices of Precision Teaching to university students, a population for which limited application of effective practices has been noted (Austin, 2000). Remedial education programs receive criticism from those who advocate increasing standards for program admission. However, to reach the learning goals that we have for our students, we must add to the skills they have at the present time, rather than hoping that they have had more fully developed skills (Hackworth, 1994). As such, we choose to examine how best to bring the skills of these learners up to a level necessary for success. The means of creating more skilled learners will surely involve utilizing teaching methods with demonstrated effectiveness, not being more selective in the population that we choose to instruct. The current study reiterates the finding that Precision Teaching provides a sensitive measure of increases in skill performance and that frequency of responding is key to achieving true mastery. Creating more skilled learners not only increases their success in academia, but also in the social and economic venues for which they are seeking training.

Participants in the study showed improved mastery of basic mathematics concepts. These improvements represented an average increase of between five and eight problems correct per minute across the four mathematics operations. Although this is seemingly a slight increase, development of a basic skill, such as solving addition problems, is a prerequisite component skill for elementary algebra. Thus, even a slight improvement is important. The effect seen by this intervention may have actually been the introduction of systematic practice and measurement for basic skills in a student population who likely found this subject aversive and may have lacked appropriate study skills. This possibility is supported by anecdotal feedback from participants that indicated that participation in this study functioned to model effective student study behavior. It is possible that the habits established during the intervention may have been generalized to participants' independent study behavior in the elementary algebra and other classes. In particular, the use of short but frequent practice sessions dedicated to increasing speed of certain skills was a useful adaptation to participants' regular study habits and helped them to emphasize the importance of basic skills.

The reasons that more remarkable gains in the frequency of basic mathematics skills were not observed are numerous. First, it should be noted that the intervention included a maximum of 16 minutes per week of practice developing basic skills outside of the required coursework aimed at producing these learning gains. This is a very striking change in learning for a very minimal effort. These gains were produced outside of class with peer tutors, thus no additional demands were placed on the professor. This procedure should be replicated in future research with the learners managing their own tasks. This could be effected through the use of the computer, or even by adding this work as a homework requirement. As such, future research should pursue additional avenues to increase the use of individualized, frequent basic skill building in larger groups of students, even considering university-wide applications.

It is also likely that students placed in the developmental mathematics course have long-standing and cumulative deficits in their mastery of basic mathematics concepts. Given that participants were adult learners, they may in fact, have been practicing errors for many years, further blocking the acquisition of appropriate skills. Future research might address this issue by presenting the materials in a format that has little overlap with previous math learning programs. For example, many of these learners had completed worksheets in the course of other math learning programs, but few would have used the computer as medium for such skill acquisition. Computer-based precision learning has not only been demonstrated to be an effective means of increasing mastery of specific tasks and the content of a variety of disciplines, it also has produced significant increases the retention and graduation rates of at-risk college students (McDade and Goggins, 1993; Kulik and Kulik, 1991). As such, presenting information in a format that does not evoke the learner's history with respect to the concepts may allow educators to work around these histories of failed mastery. Also, new and innovative ways to present materials have the possibility of creating a better match with the learning style of the student, given that use of typical formats (e.g., worksheets) in the past were unsuccessful.

These deficits in basic mathematics skills may have produced a second effect. That is, a great amount of emotional behavior was also observed in the practice sessions. These behaviors ranged from extreme anger and frustration to resignation that the learner just could not master these skills. Anxiety was common to all of the participants. This was reported both in the practice sessions, in class, and in other settings where the student engaged in math-based activities. These emotional reactions could have further interfered with the acquisition of skills, as they are not optimal conditions under which to learn (Craig, 1998; Goolsy, Dwinell, Higbee, and Bretscher, 1994). Although these emotional reactions decreased dramatically over the course of our sessions, the addition of relaxation exercises may have further reduced this source of interference. Even a few minutes of physical or thought-based exercises in which the learner has demonstrated success could change the tone of the learning sessions. The concept of behavioral momentum best illustrates this point. Behavioral momentum is the relation between the persistence of behavior and the rate of reinforcement for that behavior in a given setting (Mace, 1996, p. 557). The application of behavioral momentum to teaching of mathematics in the future studies could include interspersing a number of brief exercises where learners have a high probability of success, followed by a brief, but more challenging mathematics skill building exercise. In such a scenario, the probability that the learner readily engages in the more challenging activities is increased since a high density of reinforcement has been previously established in that setting.

Finally, it is possible that characteristics of volunteers differed from those who did not volunteer in ways that affected our results. Because the participants were freshman or transfer students and had no available academic history on which they could be compared, we chose to match students on their in-class test scores, their attendance during the class, and considered placement test scores. These measures ensured equal preparation in the subject matter prior to the course and equal exposure to the material during the course, but did not control for differences in study skills, time management, motivation, or other important differences in the effectiveness of these students.

The addition of just 16 minutes of practice for six weeks improved course outcomes in mathematics a whole letter grade above non-participating peers. Research should continue to address ways to increase the efficiency and effectiveness of different methods of accelerating learning and promoting transfer to relevant settings.

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