Using the TouchMath Program to Teach Mathematical Computation to At-Risk Students and Students with Disabilities

Ryleigh Ellingsen *Elias Clinton*

Black Hills State University

This manuscript reviews the empirical literature of the TouchMath© instructional program. The TouchMath© program is a commercial mathematics series that uses a dot notation system to provide multisensory instruction of computation skills. Using the program, students are taught to solve computational tasks in a multisensory manner that does not require memory retrieval of arithmetic facts or potentially stigmatizing strategies such as finger counting. This review targets two specific research questions: (1) Does TouchMath© improve the computational skill repertoires of students with, and at risk for, disabilities? (2) What population of students has the TouchMath© literature included (e.g., age, gender, disability type)? Based on the collected data from the collective literature, this review espouses that the TouchMath© program should be considered an evidence-based practice for teaching math computation to students with, and at-risk for, disabilities. Implications for practice and future research are discussed.

Introduction

The task of improving students' math performance is a perennial challenge for many educators. Approximately 5% to 10% of the school-age population exhibits consistent difficulty with comprehension of mathematical constructs and algorithmic procedural fluency (L. Fuchs, Compton, D. Fuchs, Paulsen, Bryant, & Hamlett 2005; Geary, 2003; Gersten, Chard, Jayanthi, Baker, Morphy, & Flojo; 2009; Gross-Tsur, Manor, & Shalev 1996). These students often do not meet established criteria (i.e., content standards) associated with basic mathematical proficiency at the primary level and continue to struggle with math into adulthood (Butterworth, Varma, & Laurillard, 2011; Fischer, Moeller, Cress, & Nuerk, 2013; Shalev, Auerbach, Manor, & Gross-Tsur, 2000). An inadequate mathematical skill repertoire can be detrimental to students' academic progress, vocational opportunities, and overall quality of life (Fischer et al., 2013; Parsons & Bynner, 2005). That is, math skills are used for a variety of vocational, functional, academic, and leisure tasks including: counting money, reading a clock, calculating elapsed time, understanding sports scores, and interpreting news-related statistics (Fischer et al., 2013). Further, mathematics competence explains variance in employment, income, and work proficiency after reading and intelligence have been accounted for (Fuchs et al., 2008; Rivera-Batiz, 1992).

Research has long documented the difficulty educators face when challenged to accelerate the development of academic skills for struggling students. For example, it is extremely rare for third grade children who demonstrate pronounced difficulties in math to meet mastery criteria for future grade-level academic skills (Marchand-Martella, Martella, & Przychodzin-Havis, 2005). Given the aforementioned statistics it is imperative that teachers provide intensive learning opportunities, using methods rooted in empirical research, for struggling students in order to increase their academic performance. When utilized with efficacy and consistency, evidence-based instruction can ameliorate many, if not all, deficits in mathematical performance, and therefore reduce the likelihood of future academic struggles for struggling students (Cook & Odom, 2013).

Purpose of the Study

There are three processes that are involved in solving math problems: (1) the ability to process numerical symbols and arithmetic processes to be performed; (2) the ability to retrieve needed operations from memory; (3) and the ability to execute the operations (Berry, 2009). This paper will focus on the latter: the ability to execute operations (i.e., computations, algorithms). Improving computational skills is not sufficient in and of itself for improving the long-term mathematical proficiency of struggling students; however, much like decoding is one cursory step in the complex process of reading comprehension, learning to complete algorithms accurately and fluently is a critical primary step for developing early and enduring mathematics competence. Some scholars theorize that basic mathematical concepts must be acquired before students can be expected to learn complex operations (Dev, Doyle, & Valente, 2002). That is, difficulty recalling basic math facts (e.g., counting and number sense) is a possible cause of persistent math difficulties (Dev et al., 2002; Garnett, 1987; Schoen, Fey, Hirsch, & Coxford, 1999). Given the fundamental role that computation plays in long-term math achievement, it is critical for teachers to be cognizant of evidence-based methods for teaching math computation in conjunction with numerical constructs and quantitative reasoning.

Several authors have examined the use of the TouchMath© program (TMP) as an instructional method to provide struggling students with a concrete strategy for performing algorithms accurately and fluently. This review compiled and examined the current literature of empirical studies that have examined the effectiveness of using the TMP. The purpose of this review was to address the following research questions: (1) Does use of the TMP improve the computational skill repertoires of students with, and at risk for, disabilities? (2) What population of students has the TMP literature included (e.g., age, gender, disability type)? (3) What implications for practice can be drawn from the coalesced data of the collective TMP literature? (4) What are the implications for future research based on paucities in the existing TMP literature?

Overview of the TouchMath© Program

The TMP is a commercial program that involves a multisensory technique for solving math problems. The TMP was developed by an elementary school teacher named Janet Bullock in 1975 (Green, 2009). As an experiment for her struggling students, Bullock placed dots on numbers in a format similar to the patterns found on dice and dominoes. The visual manipulative strategy employed by Bullock was similar to a dot notation approach for teaching computation originally introduced by Kramer and Krug (1973). As a result of her experimentation with the dot notation system, Bullock found that making the transition from concrete to symbolic learning helped her students noticeably.

It has been hypothesized that the success of the TMP is due to the multisensory approach of the method (Bullock, 2011; Bullock, Pierce, & McClellan, 1989; Scott 1993). Additionally, it has been proposed that the TMP is effective because it provides a concrete accommodation for students with working memory and long-term memory deficits (Avant & Heller, 2011; Simon & Hanrahan, 2004). Students with, and at risk for, disabilities frequently demonstrate difficulty with working memory and memorization of basic math facts (Gersten et al., 2009). When performing computations, those students often rely on finger counting and/or using other concrete manipulatives to accurately solve the problem. The TMP allows students to solve mathematical algorithms using a representational strategy that does not require memory storage of arithmetic facts, finger counting, or the use of other concrete manipulatives such as base ten blocks (Calik & Kargin 2010).

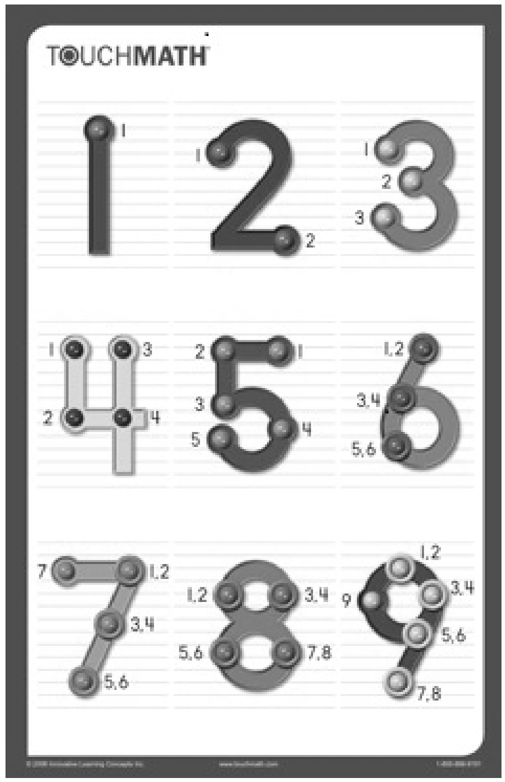

Figure 1. **Example of the touch points (i.e., dot notation system) used in the TouchMath© Program. By permission of J. Bullock (2011) and Innovative Learning Concepts Inc., Colorado Springs, CO. All rights reserved.**

TouchMath procedures begin with a student learning positions of dots on numbers 1-9 in a specific pattern. By using the dot notation on printed digits, the TMP is designed to direct students' attention to the numbers themselves (i.e., the relevant stimuli) instead of external manipulatives (Strand, 2001). That is, the printed numbers are programmed to be the discriminative stimuli that elicit the complex behavioral sequence of performing the computation (i.e., stimulus control is established). Once students have mastered the dot notation system, single-digit computations are usually taught. For example, the student would start by counting and touching all the dots on the first number and then continue counting by touching all the dots on the second number until all dots on both numbers have been counted. For example, when adding the numbers 3 and 6, students are taught to count all the dots on number 3 and continue counting until all the dots on number 6 have been counted and touched. To assist in long-term memorization, students are also taught to verbally repeat the problem and the solution upon completion. Once this initial phase has been mastered, dots are removed from the largest number given (i.e., stimulus fading). Students are taught to touch the largest number, say it verbally, and then continue counting all dots on the second number to reach the solution. After this subsequent phase has been mastered, dots are removed from all numbers. Students are encouraged to touch the "dots" with their pencils using their memories even when the dots are visually removed.

Methods

Search Procedures

Studies were located using a computer-based search of peer-reviewed literature from the online databases Google Scholar, EBSCOhost, and Web of Science – Cross Search. The terms used in the search included: TouchMath, Touch Math, multisensory, computation*, at-risk, disabilit*. The search parameters included only peer-reviewed studies that were written in English. The abstracts of the resulting studies were reviewed for inclusion in this review.

Inclusion and Exclusion Criteria

Studies for the review were chosen based on the following criteria: (1) the study involved a quantitative measurement of the effects of the TMP on increasing math skills, (2) the participants were school-age students identified with disabilities, or at-risk for academic failure or a disability, and (3) the publication was from a refereed journal (i.e., dissertations or other studies not submitted to peer-review were not included). Papers were excluded from this review if the study used a qualitative methodology, or if the manuscript was a theoretical/overview publication that did not include an experimental manipulation of a dependent variable using the TMP. Application of the aforementioned inclusionary and exclusionary criteria via the specified online databases yielded a total of 7 articles. Two of the initial 7 articles were eliminated due to the papers' use of a qualitative methodology, resulting in a total of 5 articles from the original search. After the initial pool of 5 articles was identified, the authors performed an ancestral search by examining the references of each identified article for relevant studies. The ancestral search of articles resulted in 4 more articles for a total of 9 articles. Next, the authors identified 1 more study by conducting a forward ancestral search using the "cited by" function in Google Scholar for each of the 9 identified articles. Finally, the authors performed a hand search of the journals in which the identified studies were published; however, this search resulted in no new studies. Thus, the application of the preliminary search, the ancestral search, the forward ancestral search, and the hand search yielded a final total of 10 relevant studies.

Data Extraction

In order to create an organized representation of the extracted data, the identified publications were examined and classified based on (1) number of participants (2) gender of participants, (3) age of participants, (4) disability type, (5) experimental design, (6) dependent measures, and (7) results of the study. The results of the TMP for each study were rated as effective, mixed, or ineffective. Intervention results were classified as effective for studies that used a single-case research methodology if use of the TMP demonstrated a therapeutic effect on the dependent variable for all participants based on visual analysis. Visual analysis was also used to determine if the intervention results for studies that used a single-case experimental design were classified as mixed (i.e., the TMP was effective for some, but not all, participants), or ineffective (i.e., the TMP was ineffective for all participants). Intervention results were classified as effective for studies that used a group design methodology if statistically significant differences were calculated by the authors. Further, the significance testing for group design studies were used to determine if the intervention results were mixed (i.e., statistical significance was demonstrated for some dependent measures) or ineffective (i.e., no statistical significance was demonstrated).

Inter-rater Reliability

The first author and the second author conducted measures of inter-rater reliability for data analysis and extraction. The two researchers independently recorded participant information (number of participants, age, gender, and disability type), experimental design, dependent measures, and intervention results for 5 studies that were randomly selected from the 10 included studies (50%). This resulted in a total of 35 items on which agreement or disagreement of data analysis and extraction could be compared. Inter-rater reliability was calculated by dividing the number of agreements (i.e., identical items identified by both researchers) by the total number of possible agreements (i.e., the 35 items listed above), then multiplying the quotient by 100 to yield a percentage. The authors compared the extracted data and determined that agreement was obtained on all 35 items. Thus, inter-rater reliability for data analysis and extraction was 100%.

Results

Table 1 provides information on each of the 10 studies reviewed in this manuscript. Specifically, table 1 provides information related to (1) publication year, (2) participant information: age, gender, disability status, (3) experimental design employed by the researchers, (4) dependent measure(s) of the study, and (5) the results of the study.

Publication year.

The 10 studies identified for this review were published between the years of 1993 – 2014. Specifically, the studies were published in the years 1993 (*n* = 1), 2002 (*n* = 1), 2004 (*n* = 1), 2008 (*n* = 1), 2010 (*n* = 2), 2011 (*n* = 2), 2013 (*n* = 1), and 2014 (*n* = 1).

Participants.

The 10 studies included a combined total of 96 participants who ranged in age from 4 – 16 years. Three studies included preschool-age (i.e., 4 - 5 years) participants (*n* = 60), five studies included elementary-age (i.e., 6 – 11 years) participants (*n* = 30), and two studies included secondary-age (i.e., ≥ 12 years) participants (*n* = 6). Seven studies included participants with disabilities (*n* = 21), and three studies included participants considered at-risk for academic failure/disabilities (*n* = 75). The following populations were included in the studies that involved children with disabilities: autism spectrum disorder (ASD) (*n* = 3), mild intellectual disabilities (MID) (*n* = 12), moderate intellectual disabilities (MoID) (*n* = 1), comorbid moderate intellectual disabilities and ASD (*n* = 2), physical disabilities (*n* = 3), specific learning disabilities (SLD) (*n* = 4).

Experimental Design

A variety of experimental designs were used in the reviewed studies including: A-B (*n* = 1), alternating treatments (*n* = 2), group experimental design (*n* = 1), multiple probe (*n* = 5), pre-test/post-test (*n* = 1).

Dependent Variables

The 10 studies measured the effectiveness of the TMP on increasing proficiency across an assortment of dependent measures including: single-digit addition algorithms only (*n* = 5), multi-digit addition algorithms only (*n* = 1), multi-digit addition algorithms with decimals (*n* = 1), multi-digit addition algorithms and multi-digit subtraction algorithms (*n* = 1), various (undefined) computation algorithms (*n* = 2).

<u>Single-digit addition.</u>

Five studies measured the effectiveness of the TMP on increasing participants' (*n* = 72) accurate completion of single-digit addition algorithms (Avant & Heller, 2011; Calik & Kargin, 2010; Cihak & Foust, 2008; Fletcher, Boon, & Cihak, 2010; Mostafa, 2013). Participants in the studies that targeted single-digit addition were either preschool-age (*n* = 60) or elementary-age (*n* = 12) students. These studies included participants with physical disabilities (*n* = 3), MID (*n* = 3), ASD (*n* = 3), MoID only (*n* = 1), MoID with comorbid ASD (*n* = 2), or considered academically at-risk (n = 60). Students were identified as academically "at-risk" based on consistent performance that was below grade level as measured by mathematical computation tasks (e.g., curriculum based measurement; standardized achievement tests).

<u>Multi-digit addition.</u>

Two studies measured the effects of the TMP on participants' multi-digit addition computational performance. One of the two studies measured the effectiveness of the TMP on increasing participants' accurate completion of multi-digit addition computations (Simon & Hanrahan, 2004) using whole numbers (i.e., numbers without decimals) only. All participants in the study (*n* = 3) were elementary-age students with SLD. One study measured the effectiveness of the TMP on increasing participants' accurate performance on multi-digit addition algorithms involving decimals (Waters & Boon, 2011). All participants in the study by Waters and Boon (2011) were secondary-age students with MID (*n* = 3).

<u>Mixed computations.</u>

Three studies measured the effects of the TMP on participants' performance on mixed computational tasks. One study evaluated the effects of the TMP on participants' performance on multi-digit addition and multi-digit subtraction algorithms (Scott, 1993). Participants in the aforementioned study were elementary-age students with MID (*n* = 2) or SLD (*n* = 1). Two studies evaluated the effects of the TMP on various computation tasks that were undefined by the authors (Dev, Doyle, & Valente 2002; Valenzuela, Gutierrez, & Lambros, 2014). All participants in the two aforementioned studies were elementary-age students identified as at-risk for disabilities (*n* = 15).

Intervention Procedures

Implementation of the TMP varied across studies. In six studies (Calik & Kargin, 2010; Mostafa, 2013; Scott, 1993; Simon & Hanrahan, 2004; Valenzuela et al., 2014; Waters & Boon, 2011) the TMP was deployed using a direct instruction approach (i.e., explicit modeling, guided practice, verbal praise, immediate corrective feedback). Two studies (Cihak &

Foust, 2008; Fletcher et al., 2010) used the TMP in conjunction with an adapted model-lead-test procedure and a least-to-most prompting hierarchy. Two studies (Mostafa, 2013; Valenzuela et al., 2014) incorporated the use of a token economy to promote participants' on-task behaviors while receiving direct instruction of the TMP. Two studies (Avant & Heller, 2011; Scott, 1993) incorporated a variety of assistive technologies based on participants' idiosyncratic needs (e.g., laminated flashcards, write-on/wipe-off boards, color cues, positional supports) in conjunction with the TMP. Table 2 provides specific information related to the intervention procedures of the 10 reviewed studies.

Outcomes

The results of studies were classified as effective, mixed, or ineffective. The results of no studies were classified as ineffective. The TMP was effective for all participants in 8 studies (Avant & Heller, 2011; Calik & Kargin, 2010; Cihak & Foust, 2008; Fletcher et al., 2010; Mostafa, 2013; Scott, 1993; Simon & Hanrahan; 2004; Waters & Boon, 2011). Two of the aforementioned 8 studies (Cihak & Foust, 2008; Fletcher et al., 2010) used an alternating treatments design to compare the effectiveness of the TMP to a number line strategy for increasing participants' computational performance. Results of both studies indicated that both methods were effective, but the TMP was the most effective treatment. The results of 2 studies (Dez et al., 2002; Valenzuela et al., 2014) indicated the TMP had mixed outcomes on participants' computational performance; however, the TMP was effective for 10 of the 11 participants (91%) in the study by Dez et al. (2002), and the program was effective for 2 of the 4 participants (50%) in the Valenzuela et al. (2014) study. Incidentally, the results of the two studies for which the results were classified as mixed (Dez et al., 2002; Valenzuela et al., 2014) should be interpreted with caution because the authors employed

Table 1. Description of Studies Targeting Computational Skill Development using the TouchMath Program

Reference	Participants	Gender	Age	Disabilities	Experimental Design	Dependent Measure(s)	Results
Avant & Heller (2011)	$N = 3$	female ($n = 1$) male ($n = 2$)	7 – 9 years	PD	multiple probe	percent correct of single-digit addition facts	effective
Calik & Kargin (2010)	$N = 3$	female ($n = 2$) male ($n = 1$)	8 years	MID	multiple probe	percent correct of single-digit addition facts	effective
Cihak and Foust (2008)	$N = 3$	female ($n = 2$) male ($n = 1$)	7 – 8 years	ASD	alternating treatments (TouchMath compared to number line strategy)	percent correct of single-digit addition facts	TouchMath was most effective treatment for all participants

Dev et al. (2002)	$N = 11$	not reported	6 - 7 years	AR	pre-test/post-test	percent correct of various computation facts (undefined)	mixed
Fletcher et al. (2010)	$N = 3$	female ($n = 1$) male ($n = 2$)	13-14 years	MoID ($n = 3$) comorbid ASD ($n = 2$)	alternating treatments (TouchMath compared to number line strategy)	percent correct of single-digit addition facts	TouchMath was most effective treatment for all participants
Mostafa (2013)	$N = 60$ control ($n = 30$) experiment-al ($n = 30$)	control: female ($n = 9$) male ($n = 21$) experi-mental: female ($n = 7$) male ($n = 23$)	4 - 5 years	AR	experimental group compared to control group	percent correct of single-digit addition facts	effective

Scott (1993)	$N = 3$	female ($n = 1$) male ($n = 2$)	9 – 11 years	MID ($n = 2$) SLD ($n = 1$)	multiple probe	percent correct of multi-digit addition facts, and multi-digit subtraction facts	effective
Simon & Hanrahan (2004)	$N = 3$	female ($n = 2$) male ($n = 1$)	10 years	SLD	multiple probe	percent correct of multi-digit addition facts	effective
Reference	Participants	Gender	Age	Disabilities	Experimental Design	Dependent Measure(s)	Results
Valenzuela et al. (2014)	$N = 4$	female ($n = 2$) male ($n = 2$)	7 – 8 years	AR	A-B	percent correct of various computation tasks (undefined)	mixed
Waters & Boon (2011)	$N = 3$	male ($n = 3$)	14 – 16 years	MID	multiple probe	percent correct of multi-digit addition facts	effective

***Note*. AR = At-Risk; ASD = Autism Spectrum Disorder; MID = Mild Intellectual Disabilities; MoID = Moderate Intellectual Disabilities; SLD = Specific Learning Disability; PD = Physical Disabilities**

Table 2. Description of Intervention Procedures for Each Reviewed Study

Reference	Frequency of Instruction	Duration of Instruction	Setting	Paired Components
Avant & Heller (2011)	once daily	not reported	one-on-one instruction resource classroom	enlarged materials positional supports: footrest color cues
Calik & Kargin (2010)	twice daily	not reported	one-on-one instruction separate room	direct instruction
Cihak & Foust (2008)	once daily	not reported	one-on-one instruction resource classroom	model-lead-test procedure least-to-most prompting
Dev et al. (2002)	once daily	25 – 55 minutes	whole group instruction general education classroom	not reported
Fletcher et al. (2010)	once daily	5 – 15 minutes	small group instruction self-contained classroom	model-lead-test procedure least-to-most prompting

Mostafa (2013)	once daily	not reported	not reported	direct instruction token economy
Scott (1993)	once daily	15 – 30 minutes	one-on-one instruction resource classroom	direct instruction laminated flashcards
Simon & Hanrahan (2004)	three times weekly	40 minutes	one-on-one instruction separate room	direct instruction
Valenzuela et al. (2014)	twice weekly	30 minutes	small group instruction separate room	direct instruction token economy
Waters & Boon (2011)	once daily	10 – 15 minutes	one-on-one instruction self-contained classroom	direct instruction

experimental designs that did not effectively control for all explanatory variables. The study conducted by Dez et al. (2002) used a pre-test/post-test design with no control group, and the study by Valenzuela et al. (2014) used an A-B single subject design. Thus, the data from the studies can only be interpreted as correlational phenomenon given the quasi-experimental designs employed by the researchers.

Discussion

Eight of the 10 reviewed studies indicated that the TMP effectively led to positive, therapeutic effects on participants' computational skills, and 2 studies indicated mixed results. Horner et al. (2005) outlined specific criteria for identifying evidence-based practices in education including: (a) at least 5 quality studies have been conducted on the intervention, (b) at least 3 independent researchers are represented in the collection of studies, and (c) at least 20 participants have been represented across the studies of this intervention. This review identified 8 quality studies of the TMP based on valid experimental design (i.e., designs that controlled for extraneous explanatory variables), 8 sets of independent researchers, and 96 total participants. Given that the TMP was effective for 93 of the 96 participants across the studies (97%), the TMP should be classified as an evidence-based practice for teaching math computation to students with, or at-risk for, disabilities.

Implications for Practice

Based on the analysis of this review of the literature, the TMP is an instructional tool that educational practitioners should consider when working with students that struggle with accurately performing mathematics computations. Several implications for practice were extracted from the 10 reviewed studies. First, many of the reviewed studies indicated that direct instruction of the dot-notation system was a critical component of the TMP intervention (Calik & Kargin, 2010; Mostafa, 2013; Scott, 1993; Simon & Hanrahan, 2004; Valenzuela et al., 2014; Waters & Boon, 2011). Thus, practitioners should deploy the TMP using clear, explicit instruction that involves modeling, guided practice, frequent corrective feedback, and specific praise for accurate use of the strategy. Further, practitioners might use other evidence-based methods of instruction in conjunction with the TMP such as the model-lead-test procedure or a least-to-most prompting system (Cihak & Foust, 2008; Fletcher et al., 2010). Next, for those students that demonstrate deficits in attention or disruptive behaviors, practitioners might consider the use of the TMP in tandem with a token economy to promote task compliance and math performance (Mostafa, 2013; Valenzuela et al., 2014). Finally, practitioners should consider incorporating various assistive technologies (e.g. positional supports, color cues, enlarged materials) to augment the TMP program based on idiosyncratic needs of the targeted learner(s) (Avant & Heller, 2011; Scott, 1993). Assistive technologies and modifications to the TMP materials (i.e., positional supports and/or enlarging printed items) may be especially necessary for students with visual impairments, physical/orthopedic disabilities, and/or fine motor deficits.

Implications for Research

The current literature base has demonstrated the success of the TMP to improve the mathematical skill repertories of school-age learners with, and at-risk for, disabilities. Thus, the analysis of this review espouses that the TMP be considered an evidence-based practice for improving math computation performance for specific populations of learners; however, recommending the TMP as an evidence-based practice must be paired with a caveat. That is, the research reviewed herein has demonstrated the positive effects of the TMP with specific populations and for a specific group of computational tasks. Future researchers should address the paucities identified by this review in order to enhance the literature base regarding the full potential of the TMP.

First, the literature has primarily targeted the effects of the TMP on the computational performance of students identified as at-risk for disabilities or school failure, and students with intellectual/developmental disabilities. Some studies have targeted the effects of the TMP on the math skill development of students with ASD, PD, and SLD. Future researchers should examine the effectiveness of using the TMP for learners with a variety of disabilities not yet examined in the literature such as students with emotional/behavioral disorders, students with other health impairments (e.g., attention deficit hyperactivity disorder), and/or students with visual/hearing impairments. Future research should also examine the effectiveness of the TMP for typically developing students. That is, the TMP should be compared to other commercial math programs as a grade-level mathematics curriculum for teaching typically developing students in general education settings.

Next, the majority of studies in this review used the TMP to teach addition and subtraction skills to students. Future research should evaluate the effectiveness of using the TMP to teach a wider variety of computation tasks such as multiplication and division. Many of the reviewed studies targeted single-digit computational tasks specifically. Future research is needed to investigate the effectiveness of the TMP on more advanced computational tasks. For example, researchers could examine the effects of using the TMP to teach multi-digit computations with regrouping to students with and without disabilities. Further, future research should evaluate the effects of using the TMP combined with a specific problem solving strategy (e.g., *Solve It!* strategy, *Survey, Question, Read* strategy) as a support for teaching struggling students to complete the computational tasks necessary to solve math word/story problems. Essentially, future research should target the following question: can practitioners use the TMP as an augmentative tool that allows students to gain access to more complex mathematical tasks?

Future research should also examine the use of the TMP in authentic environments (i.e., community based learning). For example, researchers might evaluate the effectiveness of using the TMP to teach money skills necessary for purchasing products in natural settings (e.g., supermarkets, convenience stores). In addition, research should investigate non-stigmatizing and portable means of using the TMP such as using the dot notation system via a smartphone/electronic tablet application. Given the proliferation of mobile technology, examining the effectiveness of using the TMP via a mobile device in authentic learning environments (i.e., community based learning) seems an obvious and potentially beneficial endeavor for researchers, practitioners, and learners alike.

Some studies in this review involved the use of the TMP in conjunction with various assistive technologies or instructional methods. Given the specific experimental designs of the aforementioned studies, the researchers did not clearly isolate and delineate the differential effects of the TMP compared to the effects of the assistive technologies or instructional methods/strategies. Future studies should seek to compare the independent effects of the TMP used alone as opposed to the TMP paired with ancillary accommodations such as assistive technology, adapted materials, or positional supports.

Four of the 10 reviewed studies did not report the duration of time allotted for daily TMP instruction. Thus, more studies should be conducted on the minimum amount of time (i.e., frequency and duration of instruction) required to yield positive results from the TMP. Knowing the minimal amount of daily instructional time that should be devoted to using the TMP would allow teachers to design instructional programming for their students with efficacy.

Some of the reviewed studies used the TMP alone, and other studies used the TMP in addition to general math instruction. Future studies should explore the utility of using the TMP as a standalone mathematical instructional program as opposed to using the TMP as an augmentative support in addition to general mathematics instruction. Specifically, future research should investigate the role of TMP within a multi-tiered model of support such as a Response to Intervention mathematical program.

A noticeable finding from this review was that the majority of participants from the population sample were pre-school age students (62.5%). The large representation of pre-school students in this review can be explained by the inclusion of the Mostafa (2013) study which included a sample size of 60 pre-school students. The majority of the other reviewed studies employed single subject research designs and did not included sample sizes larger than 4 participants per study. Regardless, the large inclusion of pre-school students in this study does provide implications for research. The results of the study conducted by Mostafa (2013) indicated that the TMP was effective for teaching single-digit addition algorithms to pre-school students considered at-risk for academic failure/learning disabilities. Future research should investigate the role of the TMP in developmentally appropriate practice to teach mathematical skills to pre-school age students. Specifically, researchers should evaluate the use of the TMP as a standard treatment protocol approach for students who struggle with mathematical tasks at the pre-school level. Research involving the TMP implemented via a Response to Intervention framework could provide practitioners, diagnosticians, and school psychologists with information regarding disability assessment and determination. That is, pre-school students' response to the TMP and explicit instruction in other developmentally appropriate mathematics skills (e.g., counting, quantity discrimination, naming numbers, identifying shapes) could provide indicators of potential learning disabilities in the area of mathematics.

Conclusions

Based on the data from this review, the TMP is an effective tool for teaching specific computational tasks to certain populations of learners. The dot notation system is likely useful for students who struggle with rote memorization because it provides a tool for calculating math algorithms if the correct response cannot be retrieved from memory. It is important that students calculate the correct answer to computational tasks, but it is equally important that they understand the explanation behind the correct answer. The use of visual supports and tangible manipulatives can facilitate students' comprehension of abstract math concepts by providing a concrete exemplar of the concept; however, using manipulatives may be ostracizing for students past early elementary grades. I.e., it may be perceived as acceptable to use base ten blocks to work math problems in first grade, but using tangible manipulatives might be embarrassing for struggling students in sixth grade. The TMP gives graphic representation of numerical concepts that can be used in a potentially non-stigmatizing manner for learners of all ages (Green, 2009).

The TMP provides students with a method for learning math operations that also takes advantage of all learning modalities. The aforementioned statement does not promote the ubiquitous educational concept of *learning styles*. That is, the concept of idiosyncratic learning styles (i.e., visual learner, auditory learner, kinesthetic learner) is a widely popular hypothetical construct that is scientifically unproven

(Kirschner & Merriënboer, 2013; Pashler, McDaniel, Rohrer, & Bjork, 2008; Rohrer, & Pashler, 2012). Therefore, educational practitioners should not focus on individual learning styles, but instead provide explicit instruction that combines a configuration of visual, auditory, and tactile stimuli in the modality that best matches the learning task. If introduced via a direct instruction approach, practitioners can deploy the TMP using a multi-modal method of teaching that is likely to benefit struggling learners.

In sum, providing learners with training and strategies for accurately completing basic computation facts is essential for future academic success. Mastery of basic math facts is critical for future development of complex mathematical skills such as using money and completing math problem-solving/reasoning tasks (Cihak & Foust 2008). Essentially, complex math tasks are critical for both academic success and independent functional life skills. Based on the demonstrated effectiveness, potential benefits, and ease of implementation, practitioners should consider employing the TMP for teaching computational tasks to struggling students.

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