Diversified Applications of the TouchMath Technique in Teaching Multiplication to Students with Intellectual Disabilities

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Zihin Yetersizliği Olan Öğrencilere Çarpma İşlemi Öğretiminde Nokta Belirleme Tekniğinin Çeşitlendirilmiş Uygulamaları

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Abstract
This study examines differences in effectiveness and efficiency between tablet-based and paper-and-pencil implementations of the TouchMath (TM) technique for teaching multiplication to students diagnosed with intellectual disabilities. A secondary aim was to gather teachers' and students' perspectives on these instructional processes. Participants were four students aged 14–15 with identified intellectual disabilities. The study employed an adaptive alternating-treatments model within a single-subject research design. Findings indicate that TouchMath, delivered via both tablet and paper-and-pencil formats, effectively supported acquisition of basic multiplication skills. Moreover, students generalized and maintained these skills across tools and settings. Efficiency analyses showed that, for all but one participant, tablet-based TM yielded advantages in total time and number of errors relative to paper-and-pencil. Social validity data reflected positive perceptions of the TM-based instruction among participating students and teachers.

Keywords: *Intellectual disabilities, mathematics education, basic multiplication, TouchMath technique, digital learning tools.*

Öz
Bu araştırma, zihin yetersizliği tanısı almış öğrencilerin çarpma işlemlerini öğrenmesinde Nokta Belirleme (TouchMath) Tekniği'nin tablet ve kâğıt-kalem uygulamalarının etkililik ve verimlilik farklarını incelemiştir. Ek olarak, öğretim süreçlerine ilişkin öğretmen ve öğrenci görüşleri belirlenmiştir. Katılımcılar, zihin yetersizliği tanılı ve 14–15 yaş aralığındaki dört öğrenciden oluşmaktadır. Araştırmada tek denekli desenlerden uyarlamalı dönüşümlü uygulamalar modeli kullanılmıştır. Bulgular, Nokta Belirleme Tekniği'nin hem tablet hem de kâğıt-kalemle sunulduğunda temel çarpma işlemlerinin öğretiminde etkili olduğunu göstermiştir. Ayrıca öğrencilerin edindikleri becerileri farklı araç ve ortamlara genelleyip sürdürdükleri görülmüştür. Verimlilik karşılaştırmalarında, bir katılımcı dışında, tablet bilgisayarla sunulan uygulamanın süre ve yanlış tepki sayısı açısından kâğıt-kaleme göre daha avantajlı olduğu bulunmuştur. Sosyal geçerlik verileri, araştırmaya katılan öğrenci ve öğretmenlerin Nokta Belirleme Tekniği ile yürütülen öğretim sürecine ilişkin olumlu görüş bildirdiklerini göstermiştir.

Anahtar Sözcükler: *Zihin yetersizliği, matematik öğretimi, temel çarpma işlemi, Nokta Belirleme Tekniği, dijital öğrenme araçları.*

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Introduction

Mathematics plays a critical role in special education because it supports independence in daily life for individuals with intellectual and developmental disabilities (Mushtaq et al., 2023). Mathematical competencies enhance problem-solving and communication skills, while also fostering personal and professional success by developing essential life skills. Core mathematics skills such as managing time and finances are indispensable for sustaining independent living (Fletcher et al., 2010; Mushtaq, 2023). Furthermore, mathematics contributes substantially to cognitive development by strengthening reasoning and problem-solving abilities (Rivera & Bryant, 1992).

However, teaching mathematics presents significant challenges, especially when it comes to abstract skills such as the four fundamental operations (Mushtaq, 2023). Curriculum constraints, coupled with teachers' limited pedagogical knowledge, often result in instruction that focuses predominantly on functional skills (Rivera & Bryant, 1992). This situation highlights the need for comprehensive professional development programs that can enhance educators' conceptual understanding and ability to implement diverse instructional strategies. For effective mathematics instruction to occur, teachers require both robust professional development and strong pedagogical content knowledge (NCTM–CEC, 2024).

Mathematics is an inherently abstract domain composed of symbols, relationships, formulas, and rules. To make this abstract framework accessible to students, mathematics instruction must be concretized. This is achieved by providing learners with materials they can see, manipulate, and physically engage with. Such an approach enhances comprehension for both typically developing students and those with special needs. Modern mathematics education emphasizes students' active construction of knowledge, prioritizing conceptual understanding before procedural fluency (NCTM, 2000).

Students with intellectual disabilities face considerable difficulties in learning mathematics. Research shows that these students struggle to grasp complex concepts, exhibit high error rates in arithmetic, and generally perform below their peers (Djuric-Zdravkovic et al., 2011). They require more intensive support, particularly for advanced operations such as multiplication and division (Rivera & Bryant, 1992; Mushtaq, 2023). Thus, equipping these learners with functional mathematics skills is vital to helping them achieve independence and navigate daily activities effectively.

A review of the literature identifies a variety of instructional approaches for teaching multiplication to students with special needs, including the Concrete–Representational–Abstract (CRA) sequence (Flores et al., 2014; Flores & Hinton, 2019; Morin & Miller, 1998; Özlü & Yıkmış, 2019), the Virtual–Representational–Abstract (VRA) approach (Bouck et al., 2018; Satsangi & Sigmon, 2024), Direct Instruction (Wilson et al., 1996), the Cross-Line Method (Mun & Abdullah, 2023), Constant Time Delay (Cybriwsky & Schuster, 1990; Koscinski & Gast, 1993; Mattingly & Bott, 1990), and Cover–Copy–Compare (Alptekin, 2019). In the present study, TouchMath (TM) was selected because it facilitates the concretization of abstract mathematical concepts and has been widely used to teach mathematical skills to students with intellectual disabilities.

TM is a visually based teaching method that develops arithmetic skills by placing dots on numbers corresponding to their value and counting these dots to perform operations. The method integrates tactile, auditory, and visual elements to strengthen learning, enabling students to engage with mathematics through both visual and kinesthetic experiences (Nuhoğlu & Eliçin, 2012). Concrete materials, a core feature of the technique, engage multiple senses and make learning more accessible. As a result, students can develop mathematical proficiency more quickly and effectively (Vinson, 2005). The multisensory design of TM supports diverse learning styles, deepens conceptual understanding, and reduces mathematical errors while promoting durable learning (Avant & Heller, 2011; Can-Çalık & Kargın, 2010; López, 2017; Simon & Hanrahan, 2004). Therefore, TM is not simply a method for teaching mathematics; it represents a comprehensive pedagogical approach grounded in multisensory learning strategies (see Figure 1 for TouchMath reference numbers).

Figure 1. TouchMath Reference Numbers

The literature includes a wide range of studies examining the use of TouchMath to support academic skills, with consistently positive findings. TM has been widely applied in teaching addition (Al-Hmouz, 2018; Avant & Heller, 2011; Carreño Gutierres & Salazar Anillo, 2022; Can-Çalık & Kargın, 2010; Demir et al., 2023; Eliçin et al., 2013; Fletcher et al., 2010; Kot et al., 2016; Kot et al., 2017; Mostafa, 2013; Simon & Hanrahan, 2004; Şentürk, 2021; Wisniewski & Smith, 2002; Yıkmış, 2016; Yıldız, 2020), subtraction (Badır-Polat & Yıkmış, 2019; Keskin, 2016), and both addition and subtraction (Ayden, 2022; Berry, 2007; Dombrowski, 2010; López, 2017). By contrast, fewer studies have investigated the effectiveness of TM for multiplication (Aydemir, 2017; Bakan, 2017; Kuh Akgün et al., 2023) and division (Kot, 2019; Minjun, 2016). Furthermore, relatively few studies have explored TM delivered through digital tools (Çakmak-Ekici, 2023; Demir et al., 2023; Öztürk, 2016), with most relying on paper-and-pencil tasks. This highlights the need for additional research, particularly involving technology-enhanced applications of TM, to expand its use in multiplication and division instruction.

Technology integration in mathematics instruction has been shown to increase student motivation, extend attention spans, and make abstract concepts more accessible (Aruk, 2008; Firdausi, 2024; Hussain et al., 2024; Kumar & Chaturvedi, 2014; Tanju, 2004). Guidelines from NCTM (2000) and NCTM–CEC (2024) emphasize technology as a tool that supports conceptual learning, enriches instructional experiences, and increases student participation. Indeed, tools such as virtual manipulatives have demonstrated particular effectiveness for teaching functional skills (Bouck et al., 2018). Technology has shifted the paradigm in mathematics education by improving visualization, enriching engagement, and enabling interactive, personalized learning opportunities (Aruk, 2008; Kumar & Chaturvedi, 2014; Tanju, 2004). In this context, comparing technology-based instruction with traditional pen-and-paper applications is an important area for evaluating instructional effectiveness. Given that multiplication and division are foundational for both academic achievement and daily life, the multisensory supports offered by technology can provide richer learning opportunities than traditional approaches.

Overall, evidence suggests that TM improves students' mathematical achievement. While its effectiveness is well established for addition and subtraction, research on multiplication and division remains limited. Moreover, despite the growth of technology-supported TM studies, few directly compare tablet-based and paper-and-pencil formats in terms of effectiveness and efficiency. The present study seeks to address this gap.

Specifically, the study aims to determine whether TouchMath, delivered through direct instruction to teach multiplication to students with intellectual disabilities, differs in effectiveness and efficiency when implemented via tablet computer versus paper-and-pencil. To this end, the following research questions were posed:

1. In teaching multiplication to children with intellectual disabilities, is there a difference in effectiveness between tablet-based and paper-and-pencil applications of the TouchMath technique in terms of acquisition, maintenance, and generalization?
2. In teaching multiplication to children with intellectual disabilities, are there differences between tablet-based and paper-and-pencil applications of TouchMath in terms of sessions to criterion, number of trials, number of errors, and total time to criterion?
3. What are the views of participating teachers and students regarding the use of TouchMath in teaching multiplication?

Method

Participants

The study was conducted in two special education classrooms located in the city center of Bolu Province. Four students diagnosed with intellectual disabilities participated. Participants were selected from among students already enrolled in special education classes who demonstrated the prerequisite skills identified for this study. The inclusion criteria were as follows: a) the ability to follow verbal instructions; b) the ability to write numerals from 0 to 50; c) the ability to count rhythmically up to 50; d) the ability to skip count by twos, threes, fours, and fives up to 50; and e) the ability to match dotted numerals with non-dotted numerals using the TouchMath technique.

These criteria were considered fundamental for defining the study's scope and ensuring the appropriateness of participant selection. All potential participants were evaluated against these prerequisites, and only those meeting the criteria were included. Table 1 presents the demographic characteristics of the participants.

Table 1. Demographic Characteristics of the Participants

Participants	Age	Gender	Type of Disability
Bilge	15	Female	Intellectual disability
Esra	14	Female	Intellectual disability
Dilek	14	Female	Intellectual disability
İsmail	15	Male	Intellectual disability

Research Model

The study employed the adaptive sequential applications model, a single-subject research method. This model enables comparison of the effectiveness of two or more independent variables across two or more dependent variables (Gast, 2010; Tekin-İftar, 2012). This study was approved by Abant Izzet Baysal University Ethics Committee for Human Research in the Social Sciences (Date: 08.03.2017; No: 2017/52). Informed consent was obtained from the parents/legal guardians of all student participants.

Dependent and Independent Variables

The dependent variable was defined as the percentage of correct basic multiplication operations. Two distinct teaching sets were prepared to establish the fundamental multiplication operations used in the study. In creating these sets, meticulous attention was paid to ensuring that the skills were functionally independent while maintaining equivalent difficulty. The following factors were considered: the nature of the reference points (single or double) and the commutative property of multiplication. Multiplication operations involving the number "1" were excluded. Accordingly, two teaching sets containing an equal number of basic multiplication operations were designed using logical and experimental analyses.

During the experimental analysis phase, a 14-year-old student with mild intellectual disability, enrolled in a special education class at a state school affiliated with the Ministry of National Education and exhibiting characteristics similar to the study participants, was selected. The number of sessions to criterion, total duration, and percentage of correct responses per session were analyzed. These data demonstrated that the two teaching sets created for multiplication operations were equivalent in difficulty.

Based on the experimental analysis, two distinct teaching sets were finalized and served as the dependent variables in the study. These sets, each containing 10 basic multiplication facts, were structured methodically for implementation during instructional sessions.

Two independent variables were manipulated for each dependent variable: (a) the application of TouchMath (TM) using paper-and-pencil, and (b) the application of TM using a tablet computer. Following the experimental analysis, one teaching set was assigned to each independent variable. During instructional sessions, participants were permitted to respond only to the teaching set designated for that session. The distribution of teaching sets is shown in Table 2. The objective was to systematically analyze the effects of the independent variables.

Table 2. Distribution of Multiplication Operations by Participants and Teaching Sets

Participants	Teaching Set 1	Teaching Set 2
Bilge	Tablet computer presentation	Paper-and-pencil presentation
Esra	Paper-and-pencil presentation	Tablet computer presentation
Dilek	Tablet computer presentation	Paper-and-pencil presentation
İsmail	Paper-and-pencil presentation	Tablet computer presentation

Setting

The research was conducted in the special education classrooms of two primary schools affiliated with the Ministry of National Education, located in the center of Bolu Province. The requisite official permissions were obtained from the Bolu Provincial Directorate of National Education. Applications were carried out in the schools' guidance service rooms, which were arranged according to study requirements.

The first application environment comprised a table, four cabinets, a side table, eight chairs, and a computer. The second environment comprised a table, a cabinet, a side table, five chairs, and a computer. Both environments were designed to align with the study objectives and to ensure seamless implementation

Materials

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five chairs, and a computer. Both environments were designed to align with the study objectives and to ensure seamless implementation.

Applied Program

Two distinct instructional presentations, tablet and paper-and-pencil, were implemented to allow comparative analysis. For the paper-and-pencil condition, the researcher developed A4-size worksheets. The worksheets contained randomly selected multiplication operations determined during the experimental analyses. Operations were formatted with dots placed above numerals and set in a 48-point font. Field experts reviewed the worksheets, and revisions were made based on their feedback before finalization.

For the tablet condition, detailed teaching scenarios were prepared, and the software steps to be used in these scenarios were specified. The scenarios were presented to two faculty members specializing in TM; feedback was incorporated, and the revised scenarios were integrated into the application in collaboration with a software engineer. The application interface was reviewed by a faculty member in Computer and Instructional Technology Education, with attention to figure–ground relationships and ease of use; interface adjustments were made as recommended. To enhance accessibility and usability, in-app instructions were narrated by a male student in the final year of a Special Education program. Figure 2 illustrates the tablet application, and Figure 3 illustrates the paper-and-pencil application.

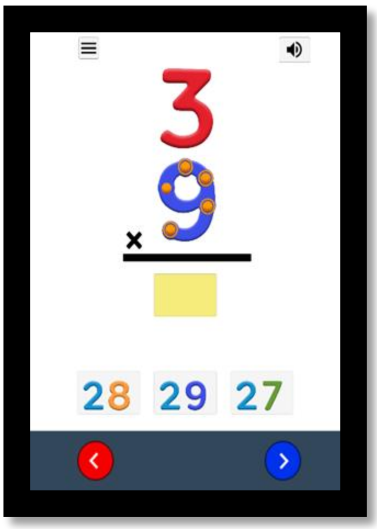

Figure 2. Tablet Application Example

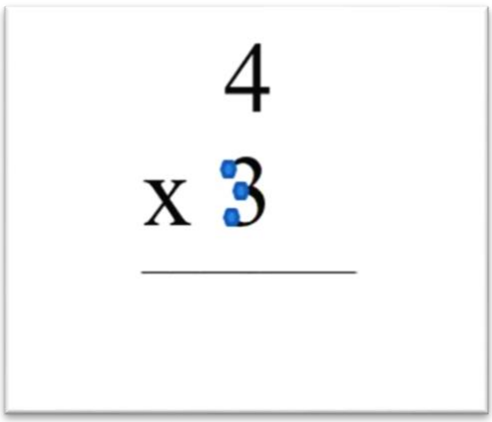

Figure 3. Paper-Pen Example

Process

The study compared TM presented via tablet and paper-and-pencil in teaching multiplication to children with intellectual disabilities. The application process consisted of four stages: assessment, teaching, maintenance, and generalization sessions.

Assessment Sessions. Baseline and daily probe sessions were used to evaluate the efficacy of instruction for basic arithmetic operations. In probe sessions, the researcher and participant sat face-to-face. The researcher placed the assessment sheet—formatted according to the designated presentation—in front of the participant and gave the instruction: *"Solve the multiplication operations in front of you."* No assistance was provided; only the instruction was given. The assessment session ended when all items were completed.

Teaching Sessions. Participants were taken from their classrooms to individual study environments prepared for the research. Each participant completed one teaching session per day in each condition (two sessions total per day). Sessions were scheduled with a minimum one-hour interval between applications to optimize learning by allowing time to consolidate newly acquired skills. Instruction in both conditions followed three segments: modeling, guided practice, and independent practice.

- **Tablet - Modeling Phase.** The student and researcher sat face-to-face. After a brief orientation, the researcher explained the objective and the structure of the presentation, confirmed student readiness, reviewed session rules, and noted that the student could select from a reward basket at session end contingent on following rules. The researcher modeled a problem on the tablet (e.g., *"What is three times five? I will touch each dot one by one with my finger, count rhythmically as many times as the top number, stop at the last dot, and drag the result below the line."*). The student then performed the same operation on their tablet.
- **Tablet - Guided Phase.** The researcher asked, *"What operation is this?"* and *"What numbers are we going to multiply?"* Correct responses were reinforced; incorrect responses were corrected. The directive was then given: *"Touch the dots above the bottom number and count rhythmically as many times as the top number."* Correct responses were reinforced; incorrect responses were modeled.
- **Tablet - Independent Phase.** The researcher instructed: *"Solve the multiplication operations in front of you."* Correct responses were reinforced; incorrect responses received corrective feedback. The student completed the tasks on the tablet.
- **Paper-and-Pencil - Modeling Phase.** The same sequence was followed. After orientation and consent, the researcher modeled on the worksheet (e.g., *"What is three times four? I will touch each dot with my pen one by one, count rhythmically as many times as the top number, stop at the last dot, and write the result below the line."*). The student then performed the operation on their worksheet.
- **Paper-and-Pencil - Guided Phase.** With a worksheet provided, the practitioner asked, *"What operation is this?"* and *"What numbers are we going to multiply?"* Correct responses were reinforced; incorrect responses were corrected. The directive was given: *"Touch the dots above the bottom number and count rhythmically as many times as the top number."* Correct responses were reinforced; incorrect responses were modeled.
- **Paper-and-Pencil - Independent Phase.** The student was instructed: *"Solve the multiplication operations in front of you."* Correct responses were reinforced; errors received corrective feedback. Tasks were completed on the worksheet.

Maintenance Sessions. A series of follow-up sessions was planned to assess long-term retention of acquired skills. Materials used during assessment were repeated to examine the continuity of performance. The researcher placed the assessment sheet in front of the participant and instructed: *"Solve the multiplication operations in front of you."* No affirmative or corrective feedback was provided. The session ended when all items were completed.

Generalization Sessions. These sessions assessed the extent to which participants could apply learned skills in different environments and with different materials. Conducted in the students' classrooms with different operations, procedures mirrored those of assessment sessions. The instruction was: *"Solve the multiplication operations in front of you."* No feedback was provided. Sessions ended upon completion of all items.

Data Analysis

Effectiveness data were presented in line graphs and analyzed visually. The horizontal axis represented the number of sessions; the vertical axis represented the percentage of correct responses. Baseline data were compared with data obtained after the teaching intervention. Increases observed following introduction of the independent variable demonstrated the effectiveness of the technique used. Maintenance data were compared with post-teaching data to examine level changes.

Efficiency for the two teaching methods was determined by comparing: (a) the number of sessions to criterion; (b) the number of trials to criterion; (c) the number of incorrect responses to criterion; and (d) the total time for each participant to meet criterion within teaching sessions. These data were tabulated and interpreted.

To ascertain social validity, structured interviews were conducted using a Social Validity Questionnaire developed by the researcher. Data were collected from teachers, who were asked: (a) Did the student show improvement in multiplication skills? (b) Would you consider using TM with other students? (c) Is the TouchMath technique a useful method? (d) Is the likelihood of generalization of skills taught with TM high? (e) Is the maintenance of skills taught with TM high? (f) Has TM increased the student's classroom adaptation? (g) Would you recommend TM to other teachers?

To determine students' interest in mathematics, the researcher prepared a questionnaire titled "Mathematics for Me." The questionnaire was administered individually before and after the implementation phase. Data were analyzed to determine changes in participants' views of mathematics. The survey used a three-point Likert scale with items: (a) I like mathematics. (b) I think I am successful in mathematics class. (c) I want to be successful in math. (d) I think I am improving in math. (e) I think learning math is important. (f) I think I am good at multiplication. (g) I like the tablet computer application more than the paper-and-pencil application. (h) I like the paper-and-pencil application more than the tablet computer application. Separate frequency and percentage distributions were calculated.

Reliability

Reliability data were collected by two special education experts trained in mathematics instruction for students with intellectual disabilities and who had published on TM. Observers were provided comprehensive information regarding all study phases, including the research objective, participant characteristics, baseline procedures, implementation stages, and the steps to be followed in generalization and maintenance sessions. The data-collection forms used in the research were introduced to ensure observer competence.

All assessment, instruction, maintenance, and generalization sessions were video-recorded. Inter-observer reliability and procedural (application) reliability were calculated from 30% of the recordings. Inter-observer reliability was computed using the formula agreement / (agreement + disagreement) × 100 (Tekin-İftar, 2012) and was 100% for all participants. Procedural reliability was calculated using Observed Practitioner Behavior / Planned Practitioner Behavior × 100 (Tekin-İftar, 2012). Procedural reliability for multiplication instruction ranged from 93% to 100%, within acceptable limits, with a weighted average of 96.5%.

Findings

Effectiveness and Efficiency of Multiplication Instruction Sessions

Within the scope of the study, the percentage of correct responses for each participant in each instructional session was calculated to compare the effectiveness of TouchMath (TM) presented via tablet computer and paper-and-pencil on basic multiplication operations. The data are presented as separate graphs for each participant and encompass baseline, intervention, generalization, and permanency phases for both teaching techniques.

For efficiency, the following indicators were examined for each participant until the criterion was met: number of sessions, number of trials, number of incorrect responses, and total time. The participants' performance levels in basic multiplication operations across sessions for both instructional applications were as follows.

Bilge. Bilge's baseline level in basic arithmetic operations, end-of-teaching assessment, permanency, and generalization findings are shown in Figure 4.

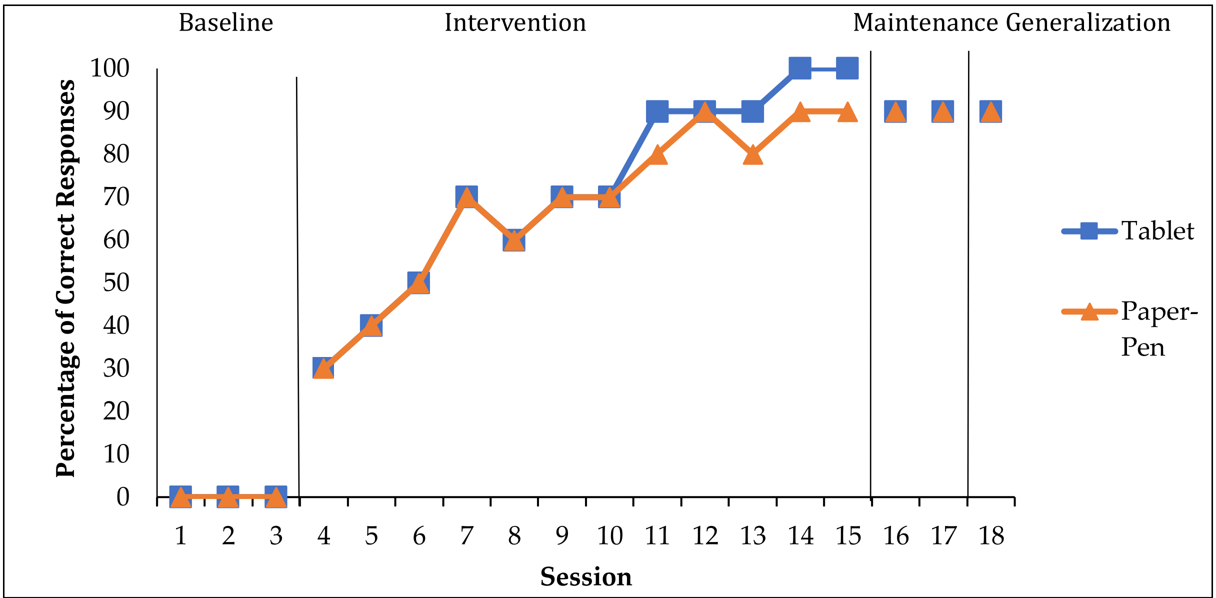

Figure 4. Bilge's Correct Response Percentages for Basic Multiplication Operations

An analysis of Bilge's baseline data revealed no correct responses on fundamental multiplication operations in the sets presented with either teaching technique (0%). Examination of Bilge's intervention sessions indicates clear improvement in both trend and level of correct responses under both formats. The acquisition criterion was met in the tablet condition (90%, 100%, 100%) and in the paper-and-pencil condition (80%, 90%, 90%). Subsequent analysis of permanency and generalization showed that performance was sustained and generalized at 90% correct. Efficiency-related data for Bilge are presented in Table 3.

Table 3. Bilge's Efficiency Data for Basic Multiplication Operations

Participant	Independent Variable	Teaching Session		Probe Sessions		
		Number of Sessions	Total Duration	Number of Sessions	Incorrect Response	Total Duration
Bilge	Tablet	12	116:23	15	34	50:41
	Paper-Pen	12	121:51	15	38	52:49

As indicated in Table 3, 12 instructional sessions were conducted for both the tablet and paper-and-pencil presentations of TM. The total duration of tablet-based teaching sessions was 116 minutes 23 seconds, while paper-and-pencil sessions totaled 121 minutes 51 seconds. Fifteen assessment (probe) sessions were conducted until the predetermined criterion was met. The total duration of tablet probes was 50 minutes 41 seconds; for paper-and-pencil, 52 minutes 49 seconds. Bilge produced 34 incorrect responses in tablet probe sessions and 38 in paper-and-pencil probe sessions.

Esra. Esra's baseline level in basic multiplication operations, end-of-teaching assessment, permanency, and generalization findings are shown in Figure 5.

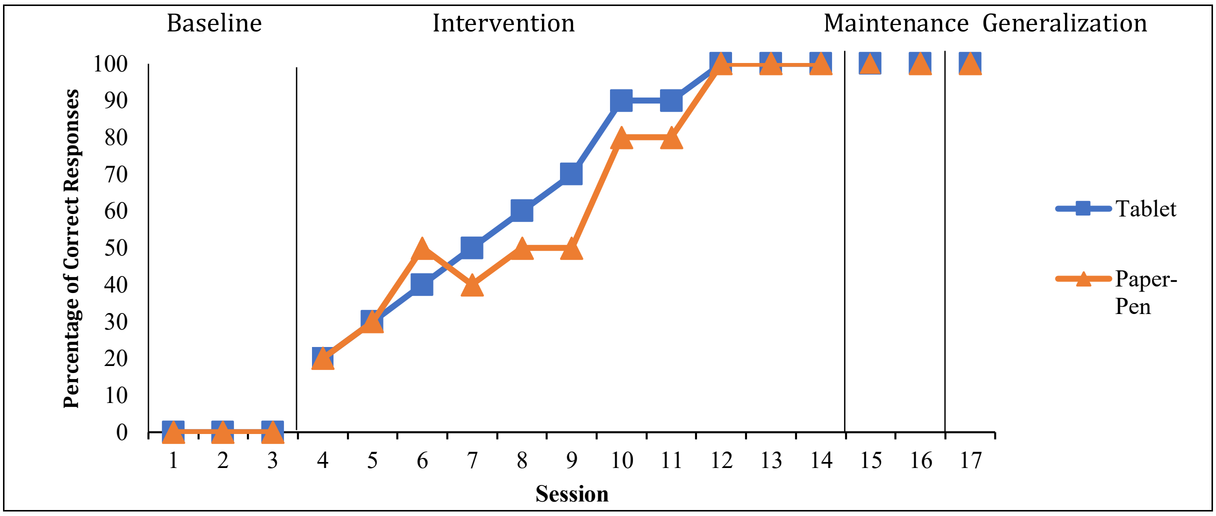

Figure 5. Esra's Correct Response Percentages for Basic Multiplication Operations

At baseline, Esra also showed 0% correct in both teaching formats. During intervention, accuracy increased and reached criterion under both tablet (100%, 100%, 100%) and paper-and-pencil (100%, 100%, 100%) conditions. A thorough examination of permanency and generalization revealed sustained performance and generalization at 100% correct. Esra's efficiency-related data are presented in Table 4**.**

Table 4. Esra's Efficiency Data for Basic Multiplication Operations

Participant	Independent Variable	Teaching Session		Probe Sessions		
		Number of Sessions	Total Duration	Number of Sessions	Incorrect Response	Total Duration
Esra	Tablet	11	85:21	14	35	30:57
	Paper-Pen	11	87:12	14	40	33:29

As indicated in Table 4, 11 instructional sessions were conducted in each format. Total teaching time was 85 minutes 21 seconds for tablet and 87 minutes 12 seconds for paper-and-pencil. Fourteen probe sessions were conducted until criterion; total probe time was 30 minutes 57 seconds (tablet) and 33 minutes 29 seconds (paper-and-pencil). Esra produced 35 incorrect responses in tablet probe sessions and 40 in paper-and-pencil probe sessions.

Dilek. Dilek's baseline level in basic multiplication operations, end-of-teaching assessment, permanency, and generalization findings are shown in Figure 6. An analysis of Dilek's baseline data revealed no correct responses on fundamental multiplication operations with either teaching technique (0%). Examination of Dilek's intervention sessions showed a clear progression in her accuracy for basic multiplication operations under both formats. The criterion was met in the tablet condition (100%, 100%, 100%) and in the paper-and-pencil condition (80%, 100%, 100%). Permanency and generalization data indicated sustained and generalized performance at 100% correct. Dilek's efficiency-related data are shown in Table 5.

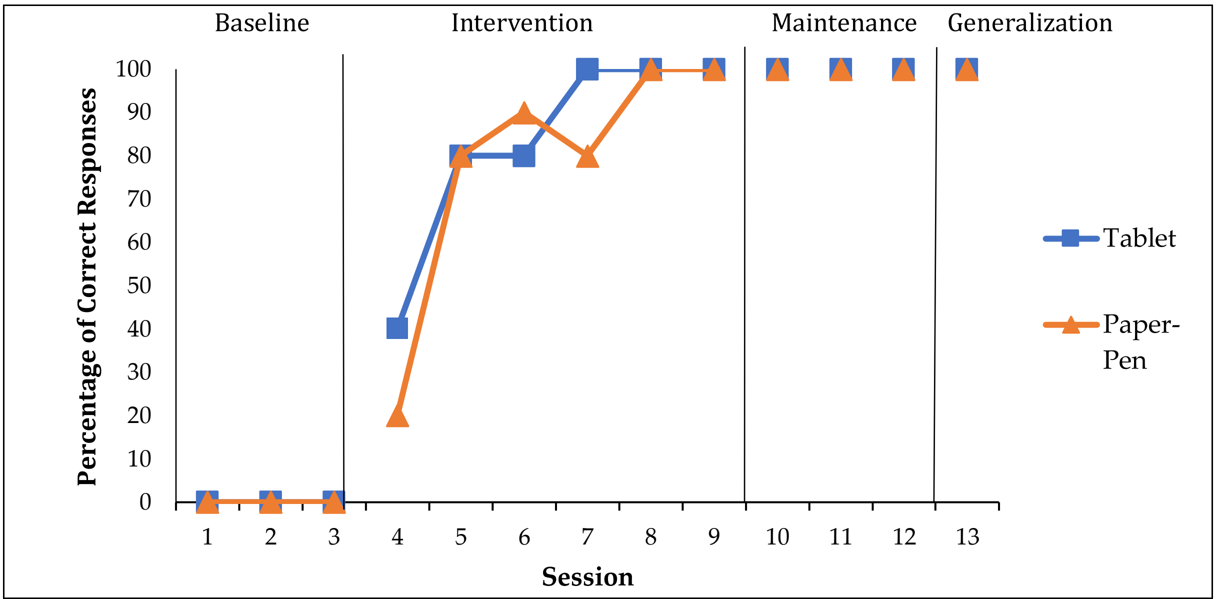

Figure 6. Dilek's Correct Response Percentages for Basic Multiplication Operations

As indicated in Table 5, six instructional sessions were conducted in each format. Total teaching time was 55 minutes 3 seconds for tablet and 56 minutes 47 seconds for paper-and-pencil. Nine probe sessions were conducted until the predetermined criterion was met. Total probe time was 18 minutes 52 seconds (tablet) and 19 minutes 55 seconds (paper-and-pencil). In probe sessions, Dilek produced 10 incorrect responses (tablet) and 13 incorrect responses (paper-and-pencil).

Table 5. Dilek's Efficiency Data for Basic Multiplication Operations

Participant	**Independent Variable**	**Teaching Session**		**Probe Sessions**		
		Number of Sessions	**Total Duration**	**Number of Sessions**	**Incorrect Response**	**Total Duration**
Dilek	Tablet	6	55:03	9	10	18:52
	Paper-Pen	6	56:47	9	13	19:55

İsmail. İsmail's baseline level in basic multiplication operations, end-of-teaching assessment, permanency, and generalization findings are shown in Figure 7.

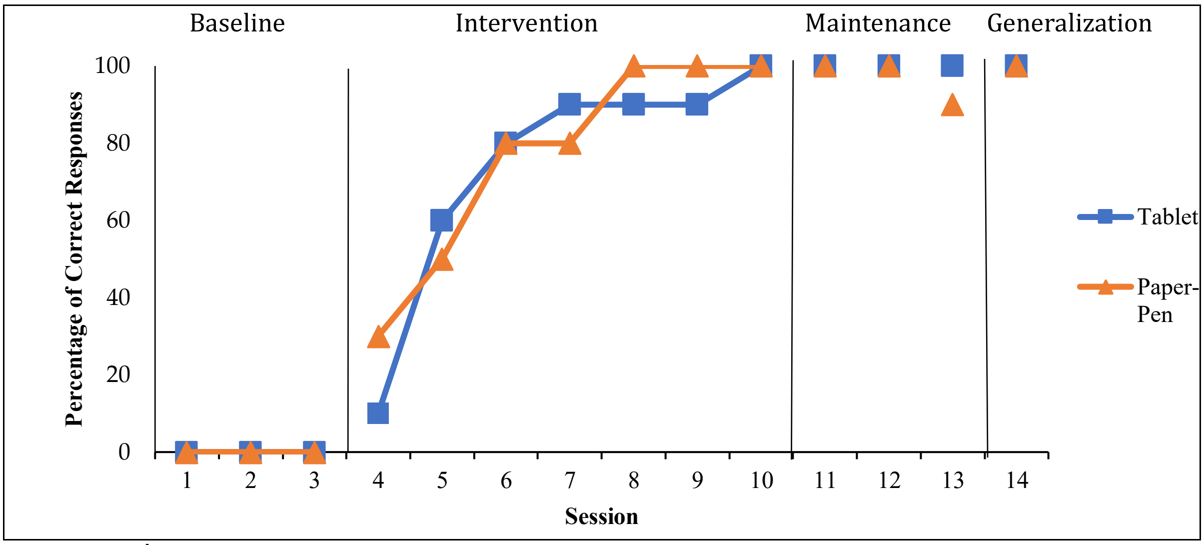

Figure 7. İsmail's Correct Response Percentages for Basic Multiplication Operations

Analysis of İsmail's baseline data showed no correct responses for either teaching technique (0%). During intervention, accuracy improved and reached criterion for the tablet condition (90%, 90%, 100%) and for the paper-and-pencil condition (100%, 100%, 100%). Generalization data indicated 100% correct responses. Regarding permanency, tablet sessions achieved 100% accuracy, whereas paper-and-pencil sessions averaged 96.66% accuracy. İsmail's efficiency data are listed in Table 6.

Table 6. İsmail's Efficiency Data for Basic Multiplication Operations

Participant	Independent Variable	Teaching Session		Probe Sessions		
		Number of Sessions	Total Duration	Number of Sessions	Incorrect Response	Total Duration
İsmail	Tablet	7	62:24	10	18	28:37
	Paper-Pen	7	60:32	10	16	27:36

As indicated in Table 6, seven instructional sessions were conducted in each format. Total teaching time was 62 minutes 24 seconds for tablet and 60 minutes 32 seconds for paper-and-pencil. Ten probe sessions were conducted until the predetermined criterion was met. Total probe time was 28 minutes 37 seconds (tablet) and 27 minutes 36 seconds (paper-and-pencil). In probe sessions, İsmail produced 18 incorrect responses with the tablet and 16 with paper-and-pencil.

Social Validity Findings

Social validity data were collected through questionnaires developed for teachers and students. Teacher responses indicated that TM is an effective pedagogical tool for teaching multiplication and can also be applied to other mathematical competencies, including number concepts, addition, and subtraction.

Student evaluations showed that all participants reported positive attitudes toward mathematics, perceived success in the subject, and emphasized its importance. Students who demonstrated lower achievement on the pretest showed notable gains in multiplication skills on the posttest. Three students preferred the tablet application over paper-and-pencil; one student who initially preferred paper-and-pencil subsequently indicated a preference for the tablet application. Overall, the findings indicate that TM is an effective, applicable, and preferred method for instruction.

Discussion

The results indicate that all participants successfully met the established criteria for basic multiplication instruction. Acquisition, permanency, and generalization were achieved, demonstrating robust learning and transfer across settings and materials. These findings align with the extant literature on the efficacy of TouchMath (TM) for teaching core computation to individuals with intellectual disabilities, including multiplication (Aydemir, 2017; Bakan, 2017; Kun-Akgün, et al., 2023; Min-Jyun, 2016). In particular, the combination of explicit instructional sequences (modeling–guided–independent) and the multisensory features of TM likely supported both initial learning and subsequent maintenance/generalization.

A comparative analysis of delivery formats showed that the tablet-based implementation of TM generally yielded greater efficiency - reflected in reduced total time and fewer incorrect responses - than paper-and-pencil, with one participant as an exception. Notably, the participant for whom paper-and-pencil initially appeared more efficient reported lower preference for tablets at pretest; after exposure, their posttest preference shifted in favor of the tablet application. This pattern suggests that familiarity and initial attitudes toward technology may influence early performance and perceived efficiency. It is plausible that the tablet interface reduced motor demands (e.g., writing, placing numerals) and supported sustained attention (e.g., guided touch points, immediate visibility of dot paths), thereby decreasing errors and time to criterion. Educational technologies such as structured applications and online platforms can enable pacing that matches learner needs and can bolster motivation and understanding (Firdausi, 2024; Hussain et al., 2024). At the same time, uneven access to devices and connectivity may create equity gaps that shape who benefits from digital formats (Hussain et al., 2024; Sembiring et al., 2024). Thus, while tablets may confer efficiency advantages, implementation should be planned with access and infrastructure in mind.

Social validity data gathered from students, parents, and teachers were positive and consistent with prior reports on the acceptability and perceived usefulness of TM (Can-Çalık ve Kargın, 2010; Eliçin, et al., 2013; Öztürk, 2016; Badır-Polat ve Yıkmış, 2019). Students who scored lower at pretest demonstrated improved performance at posttest and reported more favorable attitudes toward mathematics, which suggests gains not only in skill but also in self-efficacy. This affective shift echoes previous findings that TM can strengthen learners' confidence (Bakan, 2017; Green, 2009). Preference data also favored the tablet application for three students, and one student shifted from preferring paper-and-pencil to preferring tablets after exposure—again highlighting the potential impact of experience with the medium.

Researcher observations further indicated heightened motivation during tablet sessions; for example, a student's comment, "Teacher, is it paper and pencil again? Can't we work with a tablet?" reflects greater engagement with digital presentation. This response is consistent with prior work suggesting that technology-supported applications can increase interest in mathematics (Aruk, 2008; Kumar & Chaturverdi, 2014; Tanju, 2004). From an instructional design perspective, the visual–kinesthetic affordances of tablets (e.g., direct touch on dot locations, dynamic dragging of results) may reduce cognitive load by externalizing steps in the operation and scaffolding working memory during counting and mapping. These features could partly explain the efficiency advantages observed for the tablet condition.

At the same time, several interpretive cautions are warranted. First, although an experimental analysis established equivalence between the two multiplication fact sets and the adaptive sequential applications model minimizes some threats to internal validity, sequence and carryover effects are still possible in alternating formats. The study mitigated this risk with at least one-hour intervals between sessions and by assigning distinct fact sets to each condition; nonetheless, residual practice or fatigue effects could differentially influence performance. Second, the same researcher delivered instruction across conditions. High procedural fidelity (93%–100%, M = 96.5%) and perfect inter-observer agreement (100%) reduce concerns about experimenter expectancy and inconsistency, but the single-instructor context may still limit generality to other implementers. Third, efficiency measures were computed at the session level (e.g., total time to criterion); future work could add trial-level fluency metrics (e.g., response latency per item, correct-per-minute) to complement accuracy and time-to-criterion indices and to capture automaticity more precisely.

The study also contributes to practice by underscoring the importance of prerequisite skills. Observations indicated that some students who could count rhythmically without supports nevertheless had difficulty when required to synchronize rhythmic counting with dot touching. This finding suggests practitioners should assess and, if necessary, explicitly teach skip counting with concrete objects and the coordination of counting with pointing/touching before initiating multiplication instruction with TM. Additionally, results support the recommendation to use both tablet and paper-and-pencil formats: tablets can provide efficiency and engagement benefits where available, while paper-and-pencil ensures access in low-tech settings and may better match certain students' preferences or accommodations.

This study has several limitations. The sample consisted of four students with intellectual disabilities enrolled in special education classes in Bolu Province; while small-N is characteristic of single-subject research, external validity is necessarily bounded. The instructional content focused on multiplication with natural numbers within 50 and on the semi-concrete and abstract phases of TM delivered via a direct-instruction sequence. The duration and scheduling of maintenance sessions were sufficient to document maintenance, but longer-term follow-up (e.g., multiple weeks or months) would strengthen conclusions regarding durability. Finally, the technology condition used tablets; results may not fully generalize to other devices (e.g., smart boards) or to different software implementations without additional evaluation.

Implications for practice include (a) integrating TM in both digital and paper formats, with deliberate attention to prerequisite skills and to student preference; (b) leveraging tablets to scaffold counting and symbol mapping while monitoring for potential overreliance on prompts (e.g., gradually fading dot supports); (c) providing teacher professional development focused on multisensory routines and on aligning TM with curricular standards; and (d) planning for equitable access to technology to avoid exacerbating opportunity gaps.

Future research can extend this work by including students with different disability profiles and a broader age/grade range to examine the generality of effects; expanding the dependent variables to multi-digit multiplication, word problems, and division, and evaluating how tablet versus paper formats affect transfer to more complex skills; comparing TM with other evidence-based methods (e.g., CRA, VRA, Constant Time Delay) in head-to-head single-case comparisons to identify contextual moderators of effectiveness and efficiency; incorporating standardized single-case effect size indices (e.g., non-overlap metrics, trend-corrected statistics) alongside visual analysis to complement conclusions about level, trend, and variability; examining longer-term maintenance and far transfer (e.g., applying multiplication in functional tasks such as money and time), as well as classroom-wide or small-group implementations; and evaluating implementation supports (e.g., teacher training dosage, fidelity coaching) and cost–benefit considerations for scaling tablet-based TM, including applications to smart boards and inclusive classrooms.

In summary, the present study adds to the evidence base that TouchMath supports acquisition, permanency, and generalization of basic multiplication for students with intellectual disabilities. The comparative results suggest a practical advantage for tablet-delivered TM on efficiency for most learners, while reinforcing that both formats are feasible, acceptable, and instructionally valuable. Planning for prerequisite skill development, equitable access, and sustained implementation supports will be critical to realizing these benefits at scale.

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Author's Declarations

Authors' Contributions: The authors contributed equally to this article.

Ethics Approval and Consent to Participate: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by Abant Izzet Baysal University Ethics Committee for Human Research in the Social Sciences (Date: 08.03.2017; No: 2017/52). Informed consent was obtained from the parents/legal guardians of all student participants.

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