Investigating Formative Assessment Strategies to Support Differentiation via Digital Technology in Elementary Math Classes

Hsuehi Lo, St. Cloud State University, United States
John Hoover, St. Cloud State University, United States

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Abstract
In this study we investigate how digital technologies can support educators' differentiation and students' learning through formative assessment (FA) strategies. A three-dimensional assessment framework is developed via a European project FaSMEd (2022) by eight experienced elementary teachers, familiar with digital technology, who received instructions (and support) for FA mathematics strategies. Five FA strategies were used to invest differentiation and assess how digital technology facilitated the following FaSMEd strategies: (1) clarify and sharing learning intentions; (2) enhancing effective classroom discussions and participating in learning tasks; (3) providing feedback to students; (4) activating students as instructional resources; (5) activating students as the owners of their own learning (Thompson & Wiliam, 2007). Eight in-service teachers observed student behavior in their math classes via three codings, (1) sending and sharing; (2) processing and analyzing; (3) providing an interactive environment, in the five FA strategies. We explored to what extent does digital technology supported teachers' differentiation and students' learning by using a qualitive observation checklist and interviewing teachers. We found that digital technology can function as a support for enhancing and increasing classroom discussions and participation in learning tasks. Through digital technology, teachers proved more effective as facilitators, provided more and better feedback to students and extended the use of learning resources. Students initiated more meaningful mathematics discussions and showed increased ownership of learning tasks.

Keywords: Formative Assessments, Differentiation Strategies in Mathematics, Technology Integration

Introduction

Researchers have identified differentiated instructions as a primary indicant of effective instruction (Alshareef, et al., 2022; Standford, et al., 2010); in fact, the ability to individualize instruction-based student variability demonstrates one of the largest effect sizes in educational research. For this reason, differentiated instructions play a primary role in performance-based assessments of educators (Ruchniewicz & Barzel, 2019). The investigation of our practice as teacher educators leads us to concur with the importance of helping teachers develop the set of skills associated with instructional individualization.

In this study, we perform a comprehensive literature review investigating what we see as the crucial nexus between the teaching process with formative assessments and the effective employment of digital technologies used in the elementary math classes. Because of the centrality of assessments in producing effective differentiation (Thompson & Wiliam, 2007), comprising the core of individualization, we concentrate on the teaching process observation with five formative assessment aspects that will predict the ability of elementary math teachers to best select support technology. We implemented the FaSMEd (Aldon et al., 2015) framework to investigate how digital technology can support educators' differentiation and students' learning performance.

Formative Assessment Strategies

Formative assessment (FA) strategies may have different concepts between the U.S. and the European countries. FA may be defined as "the process used by teachers and students to recognize and respond to student learning in order to enhance that learning, during the learning." (Bell & Cowie, 2001, p. 540). U.S. prefers to use "informal assessment" (Boston, 2002) to describe students' on-going performance. In this study, formative assessment strategies provide different processes of teaching and learning with evidence collected from teachers' checklists. From the checklist report, we are looking for the level of using technology in the process of teaching and learning.

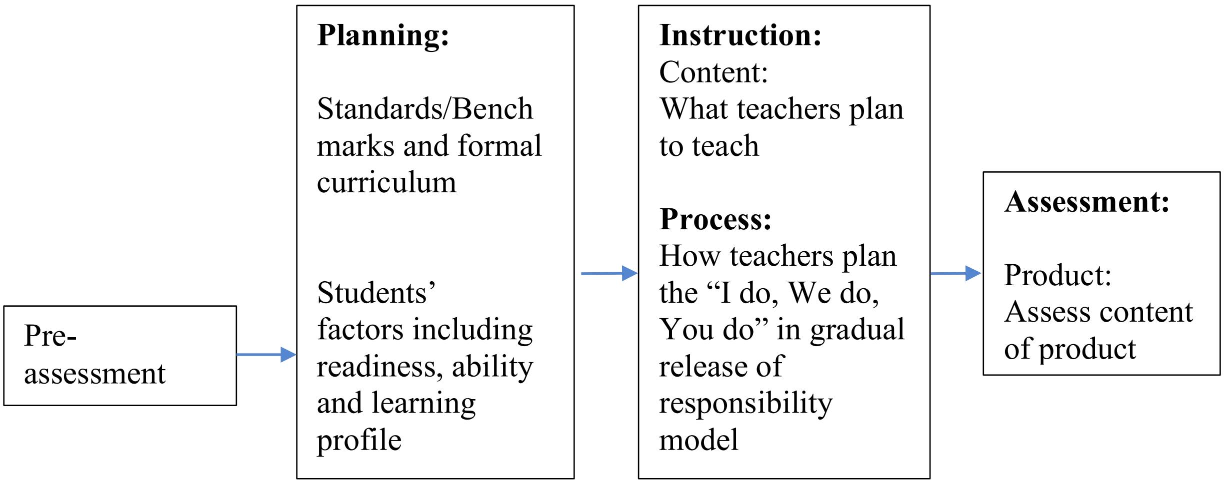
In recent years, especially with the impact of COVID striking the world, digit technology used in educational approaches have become a popular trend in the U.S. According to Breiner et al. (2012), technology involves "the replacement of traditional lecture-based approaches' (p 3). While researchers focus on how digital technology can be used in the current classroom, seldom has research explored if the digital technology can effectively help teachers' differentiation and students' learning performance. The purpose of this study is to investigate to what extent digit technology can support teachers and students in processing 4-week math units. To do that, five formative assessments in the FaSMEd project provide five different process aspects. In this study, we investigate how digital technology can facilitate the on-going processes of the five aspects.

The Meaning of Differentiation

The common term differentiation is introduced by Tomlinson (2001) to meet the needs of individual or small groups of students. Overall, five different types of differentiations (Tomlinson & McTighe, 2006; Tomlinson & Allan, 2000, Mann & Willis, 2000, Reis et al., 2011) may determine students' needs of readiness, interest, and learning style. The types of differentiation may be differentiation of content, process, and product (Tomlinson, 2001). In addition, differentiation of affect can refer to learners' feelings about the learning task and themselves. Differentiation of learning environment may be related to individual, small or large group learning, learning task with or without technology, or learning in face-to-face, online (synchronous or asynchronous learning), or hybrid instruction.

Figure one represents a learning cycle and teachers' decision factors in differentiation instruction. It may include pre-assessment, planning, instruction, and assessment. Eventually, the aim of differentiated instruction is to enhance different students' learning ability in the same class.

Figure 1. Learning cycles and decision factors used in planning and implementing differentiated instruction



(Adapted from Oaksford & Jones, 2001)

The study emphasizes the process of differentiation from traditional classroom settings to see how technology can facilitate teachers' differentiation instruction and students' learning performance. Especially, in the instruction section, teachers use the gradual release of responsibility model "I do, We do, You do" (Fisher & Frey, 2008).

Curriculum-based Assessment as Relevance

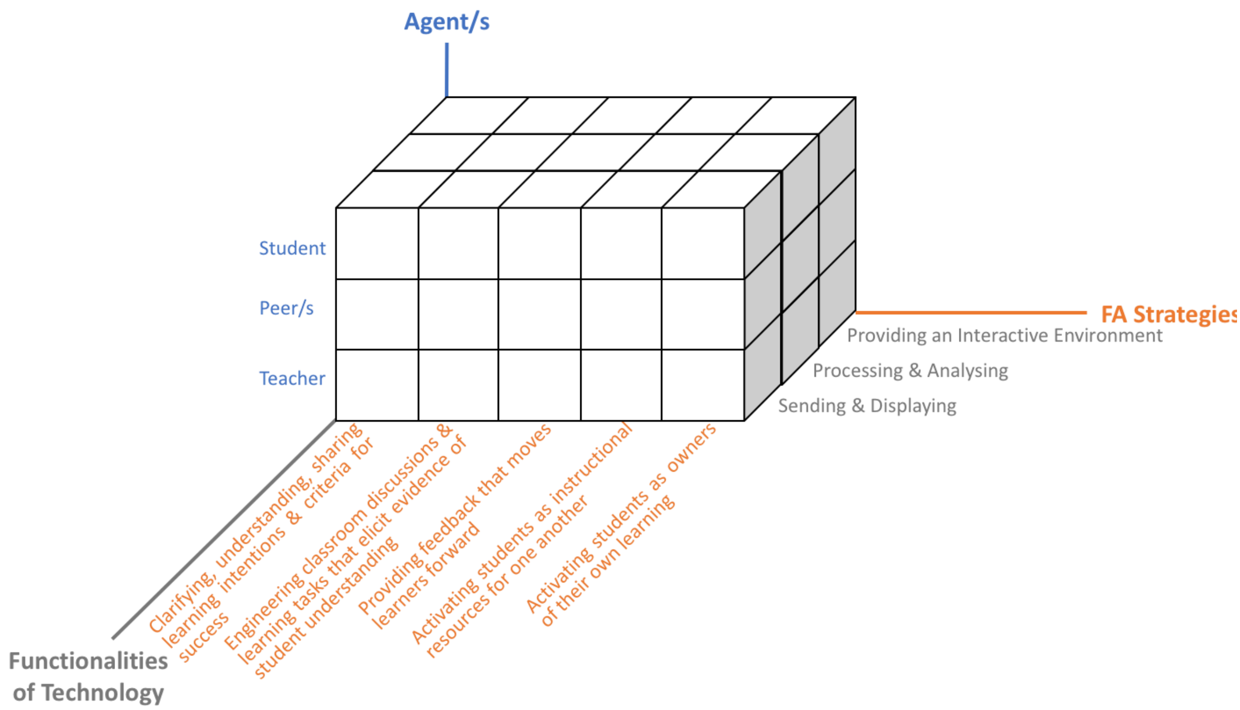
The concept of curriculum-based assessment (CBA) was used in understanding the level of teachers' and students' performance with the curriculum (Hinze, et al., 2006). Table 1 represented teachers' roles and students' responses during the curriculum process. Under the process of instruction, CBA play the role to describe teachers' and students' performance in lessons. The formative assessments investigate how digital technology can support the differentiation for students.

Table 1. The Curriculum-based Assessment Levels

	Teacher's role	Students' performance
Level 0	Knowing students' needs	Demonstrate level of current understanding
Level 1	Present new knowledge correctly	Demonstrate they understand the new knowledge in the whole class interaction
Level 2	Walk around and observe students' performance (find errors and think why)	Apply new knowledge in a project-based, problem-based, or research-based model Students work together to teach each other, peer-assess each other in their group
Level 3	Listen to students' group presentation Discuss with students (ask students how to get the answer) Share errors from observation Summarize the class performance	Present their project or right answer Learn from other students' errors Receive teacher's feedback Take summery from teachers

Formative Assessment in FaSMEd
Figure 2 represents five Formative Assessment (FA) strategies showed in Science and Mathematics Education (FaSMEd) three-dimension framework.

Figure 2. The FaSMEd framework



Note. Adapted from Aldon, Cusi, Morselli, and Sabena (2017)

Three dimensions include Agents, Functionalities of Technology, and FA strategies. Agents may include students, peer/s, and a teacher which are the three factors. Functionalities of Technology may include digital technology used in three aspects, which are Sending & Displaying, Processing & Analyzing, and Providing an Interactive Environment. The five FA strategies are showing in the following on-going teaching process by first stage: Where the learner is going, the second stage: Where the learners is right now, and the third stage: How to get there. Figure 3 represents the five FA strategies within the three stages with the role playing of teacher, peer(s) and learners.

Figure 3. Deriving the five key strategies of assessment for learning

	Where the learner is going	Where the learner is right now	How to get there
Teacher	1. Clarifying learning intentions and criteria for success	2. Engineering effective classroom discussions, questions, and learning tasks that elicit evidence of learning	5. Providing feedback that moves learners forward
Peer/s	Understanding learning intentions and criteria for success	3. Activating students as instructional resources for one another	
Learner	Understanding learning intentions and criteria for success	4. Activating students as the owners of their own learning	

Note. Adopted from Thompson and Wiliam (2007)

In this study, we imbedded FaSMEd's five formative assessments to the gradual release of responsibility model (Fisher & Frey, 2008) of I do, we do, you do and closure (See figure 4) to see how technology can facilitate teacher's differentiation and student's learning performance. Under this model, all teachers observe what level of digital technology can be used in the five FA.

Figure 4. Transfer FaSMEd to graduate explicit model

I do:	We do:	You do:	Closure:
1. Clarifying learning intentions and criteria for success	2. Engineering effective classroom discussions, questions, and learning tasks that elicit evidence of learning	3. Activating students as instructional resources for one another 4. Activating students as the owners of their own learning	5. Providing feedback that moves learners forward

Note. Adopted from Fisher and Frey (2008).

Methods

Participants:

Eight 4th-grade in-service teachers participated in the study. They had between 24-27 in their own classroom. The eight in-service teachers were in three different elementary schools, located in central Minnesota of the U.S. They were looking for the level of digital technologies to support teacher's differentiation instruction and students' learning performance in elementary math lessons. The eight teachers had the experience to differentiate their math lessons by using digital technologies. Data collection mainly included in-service teachers' classroom observation with a checklist. Five formative assessments strategies, implemented in FaSMEd (Thompson & Wiliam, 2007) were transferred to be five observation points in each lesson process which checked what levels of digit technology were used in math units (see Appendices A).

Research Question:

To what extent, can digital technology support teachers' differentiation and students' learning in elementary math classes? The data were collected by three codings related to digital technology used for 1). sending and sharing; 2) processing and analyzing; 3) providing an interactive environment (FaSMEd, 2022) in the five FA strategies. The data were analyzed by qualitative observation and an interview in grounded theory to investigate if digital technology can be used in advanced levels to facilitate teachers' differentiation instruction and students learning needs in elementary math units. The eight in-service teachers were familiar with the gradual release of responsibility teaching model (Fisher & Frey, 2008). They taught math units (polygon, place value, and fraction computations) in math class over a duration of 4 weeks.

Process of the Study and Data Collections:

Stage One:

Pre-assessment of students: Eight in-service teachers used their students' standardized test data (MCA II math test, showed in Table 2) to know each student's math performance and know each student's strength and weakness of mathematics in their last academic year (3rd grade). On average, each classroom has 2-3 IEP students, 16-22% of students' math performance below average, and 70-75% of students were performing on average. Based on the data set, 8 in-service teachers designed different math learning tasks for different students.

Table 2. Pre-assessment of this study (Students' standard test)

Fourth grade teachers	Students' 3rd grade math performance		
	Above average (%)	Average (%)	Below average (%)
Teacher 1	10	73	17
Teacher 2	9	75	16
Teacher 3	14	70	16
Teacher 4	6	75	19
Teacher 5	8	71	21
Teacher 6	6	74	20
Teacher 7	12	71	17
Teacher 8	8	74	18

Design digit technology integrate in 4-week math units: Eight in-service teachers are familiar with the gradual release of responsibility model (Fisher & Frey, 2008). They distributed the five FA strategies using the process of "I do, We do, You do and Closure" (see Figure 3 above) in their math lessons. Learning activities represented in the "We do" and "You do" sections of the lessons had students grouped together using different kinds of technology (e.g., iPads, laptop, computer, or smartboards) to explore knowledge, to do game-based activities, or to take pictures of hands-on projects.

Stage Two:

Implementation of the 4-week math units: The eight in-service teachers in this study did not let their 4th graders knew there was research being conducted during their lessons. As usual, they began their math lesson following I do, We do, You do, and Closure process. The differences included digital technology in their differential instructions. For example, smartboards were used as interactive tools (with students' iPads) not only to present what new knowledge is but also use game-based digital technology (e.g., Kahoot, math games in iPads) to clarify students' level of understanding, which may reach FA first strategies: clarifying learning intention. In the "We do" and "You do" portion of the lesson, students used iPads to work on math projects or play math games, which may reach FA second strategy: Classroom discussion. With students working in groups, teachers walked around with their iPad to collect students' mis-concepts, pattern of errors, and facilitate their misunderstanding, which met FA third strategy: Activating students as instructional resources for one another, FA fourth strategy: Activating students as the owners of their own learning, and slightly FA fifth strategy: Feedback to students by teachers/technology. In the closure portion of the lesson, teachers shared their observation of students' performance with the class and then wrapped up a lesson. Students took iPads home to finish their homework and turned their homework in to Schoology, an online management system used by schools. Teachers provided feedback and graded students' papers in Schoology, allowing students and parents to monitor work. After that, teachers could make a review game using technology or summarize what they have learned in the beginning of next day's lesson. This processed reached FA fifth strategy: Feedback and Summery of what students learned. Feedback to students played an important role to facilitate students in "We do" "You do" and "Closure" portion (Hattie & Temperley, 2007).

Observation checklist: During the whole teaching process, teachers filled out their observation checklist (See Appendix A) to report to what extent teacher and students used digit technology during the math lessons. The checklist is one part of data collection in this study.

Stage Three:

Interview questions: After the 4-week math lessons, each in-service teacher accepted an interview individually conducted by researchers. The main interview questions were:

- How does digital technology support differentiation in teaching?
- How does digital technology support feedback for students?
- To what extent does digital technology support students in exploring new knowledge--especially in their group projects?
- To what extent does digital technology support your students to present their projects?
- To what extent does digital technology help you provide feedback to students and make meaningful class summaries for students?

Data Analysis:

Descriptive statistics may represent eight in-service teachers' checklists. It may show how frequently digital technology tools (Smartboards, iPads, technology-based online games, and Schoology) were used in "I do", "We do" You do" and "Closure" which represented the on-going teaching process with FA 5 strategies in math lessons. Interview questions explored eight teachers' perspectives in using digit-technology in their differentiated instructions for different math level students. Those questions also explored to what extent digital technology can support their teaching and students' learning.

Findings and Conclusions:

Eight In-service Teachers' Checklist Report:

The findings showed digital technology plays a big role in processing and analyzing in the FaSMEd five aspects, especial in "We do" portion (FA second strategies) of enhancing effective classroom discussion and "You do" portion (FA fourth and fifth strategies) of ownership and teamwork in learning tasks. Eight teachers provided compelling evidence that they can enlarge students' rich discussions when students are allowed to get online through their iPads to explore some math topics (e.g., the meaning of polygon, the different ways to do two digits multiplication, the fraction concept etc.) and bring back to the class to share what they found. Figure 4 shows their favorite technology tools used in their lesson process using "I do, We do, You do, and Closure."

Overall, Digital technology (e.g., Smartboard, iPads, online games, and Schoology) provided the resources for teachers to differentiate their traditional teaching process to better address different students' needs. Technology can be used to record, collect, and check students' understanding and clarify students' learning intention for the next day.

Figure 5. Eight in-service teachers' checklist report

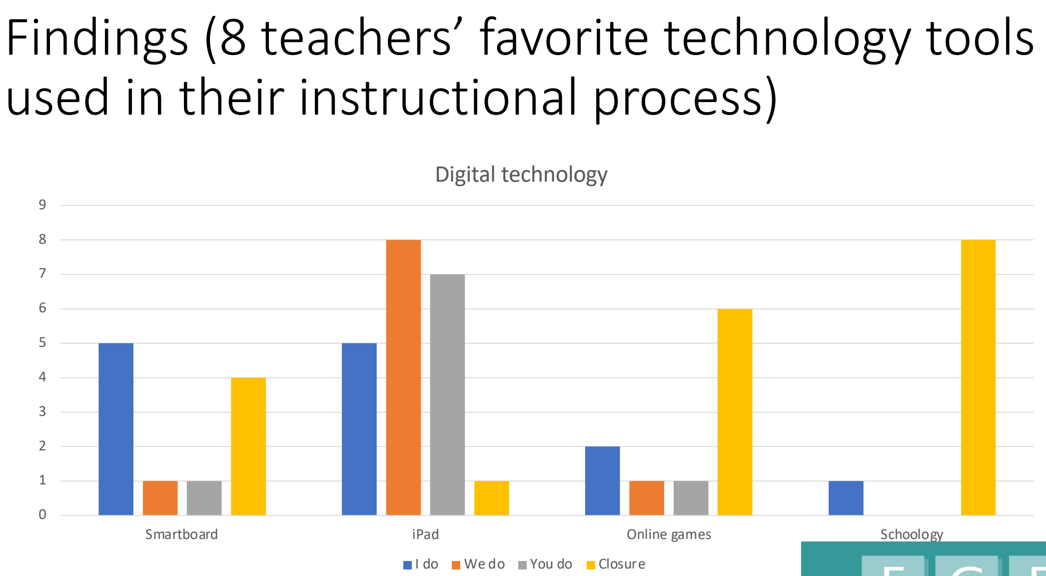


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Figure 5 showed iPads are the most effective tools teachers and students use in “We do” and “You do” portion of instruction, which represented how digital technology can effectively support students’ learning through classroom discussion and teachers’ feedback to students by (collecting students’ pattern of errors or misunderstanding). Online games played a big role in the “You do” portion of instruction when used to review and summarize the lesson. Schoology helped teachers to collect students’ homework and reflect their next day’s lesson as well as share scored homework with students and parents.

The interview of this study explored detailed reasons of *what* digital technology tools the teachers chose, *why* they chose certain digital technology, and *how* they implemented those technologies to help their differentiated instruction for different math level students. Interview data represents how teachers and students implement digital technology in the 4-week math units.

Summary of Interviews

Interview Question One: *How Does Digital Technology Support Differentiation in Teaching?*

In the past, the eight in-service teachers have implemented several digital technologies tools in their class to teach different subjects. Through this study, most of them reconsidered those tools and systematically designed their 4-week math unit to rethink how digital technology can facilitate their differentiation in teaching so they can help students with different math abilities enlarge their learning outcomes. One teacher, for example, mentioned that the Smartboard was not used as traditional white boards anymore. She made the Smartboard be an interaction tool by doing game-based activities. She said, “Smartboard interaction really helps me deliver new knowledge with interaction.” She downloaded a math-related dice game (a place-value game to order different numbers) on the Smartboard. Students came up to front and hit the dice to get a new number (for example, 3,718 to compare the previous number, 3,687). Students used academic language (showed in the Smartboard as___ is greater than ___ because___) to say “3718 is greater than 3687 because the hundreds place “7” is great than “6” and the number “3” in thousands place is the same. Students demonstrated their new knowledge of number comparison by themselves. She felt “The math game can motivate students and it is much better than when I lecture them.”

Five teachers agreed and extended the game-based idea into the “I do” portion to do differentiated instruction. For example, when the teaching process moved to station learning activities, they can keep below average students in front of Smartboard and make sure they understand how to do number comparison by playing easier math games or lecture them. They knew some students preferred to get knowledge from close access to the teacher. This was especially true for students whose math ability was below average.

All eight teachers appreciated the Schoology technology which allowed them to collect all students’ homework, provide feedback to students’ homework, and prepare some review questions for next day class. In addition, Schoology also collected all teaching materials and students’ learning outcomes for students’ parents. One teacher made a comment “Those math games we played are showed in Schoology so students and parents can review and know what math lesson are doing in today’s math lesson.” Schoology helped teachers know different students’ performance in each math lesson so teachers can prepare their differentiated instruction next day for different students’ needs.

Interview Question Two: How Does Digital Technology Support Feedback for Students?

Group projects and station teaching were implemented in the "We do" portion. All eight in-service teachers in this section walked around to make sure each student was on the right track and approached target students to maximize their learning ability. One teacher commented that "During the project time, I use my own iPad to collect students' errors [take pictures] and do error analysis." All eight teachers did the same action during the "We do" portion. Five teachers may only give above-average students a hint, not answers. All of them took the opportunities to help below average and special needs students more direction with the iPad as a whiteboard. Teachers' iPads played an effective role as they walked around, monitored different groups and provide different feedback to them.

One teacher stated, "My iPad supports me to monitor student errors. She took a picture of student errors. When another group had the same error, they may directly show the picture in her iPad to them. "It is so beneficial, because the previous group might have corrected their errors and the errors disappeared. All teachers commented the digital technology really supported them to give students feedback and collected students' performance. When the class was in the "You do" or "Closure" portion, teachers can represent their observations and pictures to the whole class so everyone can learn from the pattern of errors. Also, teachers can share students' projects and ask group members, "how did you get the answer?" to provide some feedback to students. Some teachers may like to use Schoology to provide feedback to induvial students based on students' different math ability. Here has showed that digital technology can support CBA-level 2 and level 3 to make sure all students were on the right track to do effective learning.

Interview Question Three: ***To What Extend Does Digital Technology Support Students in Exploring New Knowledge--Especially in Their Group Projects?***

All eight teachers agreed that iPads played a key role to support students in exploring new knowledge. Five teachers used iPads in the "I do" portion. All of them used iPads in the "We do" portion and seven teachers used iPads in the "You do" portion. One teacher used iPads in closure. When I asked them how they use iPads, they all agree that iPads have met "providing an interactive environment" the most. One teacher said, "In the "We do" portion, iPads are used in students' group project so effectively. They can do play-based teaching in math and facilitate students to do math projects. One teacher commented that, "Students in their group Googled the meaning of polygon and had rich conversations about the definition of the term." iPads engage their learning activities strongly.

All eight teachers prepared different level of math games for different students' needs. From this point of view, iPads also play a role of sending and displaying knowledge for different students. One teacher commented, "I see iPads can motivate students to learn math through group projects. I also see some students like to do projects individually. I appreciate that some apps in the iPad can provide individual projects for different students." The teacher found iPad math games helped one student with autism in her class strongly, so she designed an individualized lesson plan with many math games and projects for the student. The teacher only needed to occasionally go to check the student's self-learning process. The student demonstrated the best math performance during this 4-week math unit.

Interview Question Four: ***To What Extend Does Digital Technology Support Your Students to Present Their Projects?***

When teachers showed the term “polygon” on the Smartboard and asked students to explore the meaning, shapes and where polygons are found in real life, different groups may take turns to present what they found. The iPad can collect all students’ works and connect their iPad to the Smartboard so they can present their work to the whole classroom. After the presentation, students can directly turn in their works to Schoology. Eventually, students did not even use traditional paper/pencil in their learning task. One teacher said, “It is so effective to have technology doing this.” Technology potentially will take over the traditional teaching and learning model. Technology also provided more possible spaces for teachers to design play-based, project-based instructional models in the interactive environment.

From teachers’ perspectives, when teachers collected students’ patterns of errors by taking a picture or making notes in their iPad, they can show their collection in visualization to the Smartboard very well for whole class discussion opportunities. One teacher said, “I also collect students’ errors in their presentation to my iPad so I can show their errors in visualization and ask them questions.” It is obvious that digital technology can support both students’ presentations and teachers’ effective data collection.

Interview Question Five: ***To What Extend Does Digital Technology Help You Provide Feedback to Students and Make Meaningful Class Summaries for Students?***

Seven of eight teachers used digital games to do displaying, processing, and analyzing tasks in “You do” portion effectively. All eight teachers expressed that game questions were great tools to do the learning summary for students because questions can collect students’ answers (showed correct and wrong answers’ %). One comment from a teacher was “I put inquiry questions in the game so students and I can answer questions together as review or summary of the lesson.” One comment was “I love to use a game called Kahoot because it shows how students are learning.”

Schoology is one of most useful technology tools to provide feedback to students. All teachers put their homework in Schoology. Students brought their iPads home to do their homework and submitted their homework in Schoology. Teachers can provide feedback and grade students’ work in Schoology. This tool also allows teachers to collect different student’s math performance and prepare their lesson for the next day.

One teacher said if needed, she may use Schoology in the next day “I do” portion to show a pattern of error in the whole classroom. Overall, digital technology like online games (e.g., Kahoot, online math games) and Schoology can effectively play as sending, displaying, processing, and analyzing tools in teaching and students’ learning outcomes.

Conclusions

The conclusion of this study is effective deployment of digital technologies is dependent upon meaningful teaching process (based on FaSMEd’s five FA strategies) and that differentiated instruction is the primary mechanism producing positive effects from digital technology. We believe that while a thorough working knowledge of tools is a necessary condition for differentiated instruction, it is not sufficient. The most important missing element is helping educators develop meaningful teaching processes to know how much technology can help their students' content knowledge learning.

From teachers' observation and interviews with them, responses clearly showed students initiated more meaningful mathematical discussions and increased students' ownership of learning tasks when digital technology engaged in the whole teaching process. We may concern a causal relationship between "teachers use" and student's learning. This study all depended on the 8 teachers' report of their students' performance, and interviews after they complete the math unit. The effective size may be concerned. If we stand on students (4^{th} graders) point of view with first time using a lot of digital technology and many project-based, game-based learning activities, the Hawthorne effect may need to be considered. Students may feel fresh, new, and fun by using digital technology in the 4-week math unit. Students may reduce their learning performance when technology turns to be a basic equipment in the next math unit.

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Appendices A

Five FaSMEd formative assessments (with CBA levels) and levels of digital technology

FA and CBA levels	Levels of digital technology used in the five FA		
	sending and sharing	processing and analyzing	providing an interactive environment
1. Clarify and sharing learning intentions CBA 0-1 level			
2. Enhancing effective classroom discussions and participating in learning tasks CBA 1-2 level			
3. Providing feedback to students CBA 3-4 level			
4. Activating students as instructional resources CBA 3-4 level			
5. Activating students as the owners of their own learning CBA 3-4 level			

Appendices B

The template of observation checklist

Tech tools used in this lesson:	**Sending/displaying**	**Processing/analyzing**	**Providing/interactive**
"I do" stage CBA: Level 1			
"We do" stage CBA: Level and 2			
"You do" stage CBA: Level 2 and 3			
"Closure" stage CBA: Level 3			

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