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Teaching Mathematics Vocabulary with an Interactive Signing Math Dictionary

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Abstract

State frameworks and national standards are explicit about the mathematics content that students must master at each grade level. Although the Individuals with Disabilities Education Act and the No Child Left Behind Act mandate that students who are deaf or hard of hearing and communicate in sign language have access to this content, evidence suggests that it remains out of reach for many in this group. The purpose of the implementation research described in this article was to examine use of a Signing Math Dictionary (SMD) to help students who are members of this population access the vocabulary required to master the mathematics content that underlies the topics they are studying. The study included eight separate classes and a total of 39 participants—8 teachers and 31 students—representing grades 4–8. The research design incorporated a descriptive case study methodology that involved observing (a) teaching mathematics without the SMD, (b) preparing students to use the SMD, (c) teaching mathematics with the SMD. The results suggest that, when used in actual classroom settings, the SMD may be a resource that supplements effective teaching and learning of the vocabulary of mathematics. However, further research is needed to study its use by both experienced and inexperienced teachers working with students in schools for the deaf and in inclusion settings, across math topics and grades. (Keywords: deaf, hard of hearing, Universal Design for Learning [UDL], mathematics vocabulary, technology, avatars, mathematics dictionary, signing, American Sign Language [ASL])

Although students who are deaf or hard of hearing are not necessarily considered "print disabled," those who acquire and use sign language to communicate tend to internalize a linguistic structure that differs greatly from English (Rose & Meyer, 2006). This results in significant literacy limitations that lead to the majority of deaf students leaving high school with reading levels at the fifth grade or below (Karchmer & Mitchell, 2006). The mathematics performance of deaf and hard-of-hearing students is similar, with these students "lagging behind" their hearing peers by several grade levels (Pagliaro, 2006). One study reports that deaf students score 5.4 grades below grade level on standardized tests of mathematics (Mitchell, 2008). Another study shows that 30–52% of students with hearing loss score below the 30th percentile for mathematics calculation (Blackorby & Knokey, 2006). Data from the Stanford Achievement Test indicate that when they graduate, 50% of deaf and hard-of-hearing students perform at just below a sixth grade level in computation and at only a fifth grade level in problem solving (Traxler, 2000). Numerous studies have documented similarly weak mathematics achievement in computation and problem solving for about five decades (Nunes, 2004).

Poor achievement in mathematics demonstrated by students who are deaf or hard of hearing may be attributed to several factors, including lack of successful mathematics learning experiences, difficulties with language, and inadequate methods of instruction (Nunes & Moreno, 1998). With regard to language, aspects of English within mathematics—such as multiple ways of expressing an idea and the use of words that have different meanings in and out of the classroom—create barriers to acquiring the mathematical concepts being expressed (Pagliaro, 2006). For all students, not just those with hearing loss, mathematics language and vocabulary pose challenges that are different from ordinary reading situations (Lamb, 1980; Lamberg & Lamb, 1980). A study examined five common problem areas with students who are deaf: (a) words with multiple meanings, (b) technical vocabulary, (c) words with specialized importance in mathematics, (d) varied but related forms, and (e) abbreviations and specialized symbols. The findings indicated that the highest percentage of errors occurred with technical words in mathematics (Kidd, Madsen, & Lamb, 1993).

According to Marzano (2004), direct vocabulary instruction has "an impressive track record" of improving students' background knowledge and the comprehension of academic content. Stahl and Fairbanks (1986) found that vocabulary instruction leads to improved comprehension. For many students who are deaf or hard of hearing, schools implement a bilingual approach that uses sign as the first language of instruction and written English as a second language. Stahl (1999) states that English learners "rely more heavily on direct instruction than native speakers, because they typically need to make up more ground quickly to learn English" (p. 10). Although the need for direct vocabulary instruction is apparent, unique challenges to teaching and learning vocabulary exist for students who are deaf or hard of hearing.

Students often do not know the signs for the mathematical terms they encounter or, even if they can mimic a sign, they do not understand its meaning. For this reason, teachers frequently omit many standards-based mathematics topics from their instruction because they consider them linguistically too complex for their students and, therefore, inaccessible (Pagliaro & Kritzer, 2005). In addition, almost all deaf and hard-of-hearing students face obstacles associated with interpreters assisting them with mathematics learning. Many interpreters lack adequate preparation in mathematics, and few are certified to teach computation and problem solving (Kelly, Lang, & Pagliaro, 2001). Interpreters also may use signs that are conceptually inaccurate (Kurz, 2003). A consequence of such situations is that students who are deaf or hard of hearing often miss many of the age-appropriate mathematics experiences that provide the foundation for developing understandings that are necessary for majoring in science, technology, engineering, and mathematics areas (Nunes, 2004). Thus, those individuals are significantly underrepresented in the career fields of mathematics and engineering (American Association for the Advancement of Science, 2009; Caccamise & Lang, 2000).

State frameworks and national standards are explicit about the mathematics content that students in grades 4–8 must master at each grade level (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010; National Council of Teachers of Mathematics, 2000). Although the Individuals with Disabilities Education Act (IDEA; U.S. Department of Education, 2008) and the No Child Left Behind (NCLB) Act of 2001 mandate that the approximately 45,000 students in grades K–8 who are deaf or hard of hearing (Gallaudet Research Institute, 2009–2010; U.S. Department of Education, 2010) must have access to this content, the research suggests that this goal remains out of reach for many.

Researchers and deaf educators have made efforts to establish potential "best practices" for teaching students who are deaf or hard of hearing. Easterbrooks and Stephenson (2006) examined hundreds of articles to identify 20 such practices, 10 of which they determined to be "highly cited practices" in science and mathematics instruction:

1. Teacher as skilled communicator
2. Instruction through the primary language
3. Teacher as content specialist
4. Active learning
5. Visual organizers
6. Authentic, problems-based instruction
7. Use of technology
8. Specialized content vocabulary
9. Critical thinking
10. Mediating textbooks

Research in support of the use of technology as a promising practice indicated that technology could be used to increase students' comprehension in the content areas. One of the studies referenced, conducted by Lang and Steely (2003), found that when science content was presented in three ways—a short text screen, a corresponding animation explicating the text passage, and an American Sign Language (ASL) movie about the text—significantly greater knowledge gains resulted for students who are deaf than in traditional classroom experiences that did not include this "triad." With regard to the practice of including specialized content vocabulary in mathematics instruction, the supporting research (Easterbrooks & Stephenson, 2006) indicates that "specialized signs show students the context for abstract science and mathematics concepts" (p. 394), and "it is important that specialized vocabulary used in mathematics be presented consistently and in a manner that is standardized (or agreed upon) with students, to increase their comprehension" (p. 394).

Issues Associated with ASL and Technology

For students who are deaf or hard of hearing to have successful mathematics learning experiences, it is critical that they have access to instructional materials and resources delivered via textbooks, the Web, and electronic media. It is also important that they be able to connect with these materials after and outside of class to do homework, prepare for tests, complete research projects, and discuss what they are learning with other students, teachers, and their parents. Yet effective access to and use of the information in these resources presupposes the ability to understand and use the English-based language of mathematics. Although the Internet is a medium that is particularly attractive to this audience because they can use it as a primarily visual medium via reading and writing, it remains inaccessible, because audio content is uncaptioned and text-based content is written at reading levels that far exceed those of adolescents who are deaf or hard of hearing (Smith, 2006).

Prior to advances in Web and mobile technology, the logistics of developing an accurate, efficient, and practical approach to creating a simultaneous and precise display of both sign and English had been daunting (Rose & Meyer, 2006). Now, advancements such as the SigningAvatar technology used in the Signing Math Dictionary (SMD) and video recordings of human signers can be combined with the ever-increasing power of computers and mobile devices to generate instantaneous onscreen translations from one language to another (Rose & Meyer, 2006). For users for whom sign is the primary mode of communication, pros and cons are associated with the use of either of these multimedia solutions. Video recordings have a high production cost; their content cannot be modified after production; and signers cannot remain anonymous, as their facial expressions must be included as a component of the signing (Lu, 2011). Signing avatars can be consistently updated, viewed from different angles and at different speeds, and performed by virtual characters of different ages, ethnicities, and genders. These aspects may make signing avatars preferable to videos (Lu, 2011). However, they are not without limitations.

One recent study conducted in Germany investigated the technical feasibility of using signing avatars for German Sign Language and the acceptance of these avatars among users who are deaf. Findings from focus groups and online surveys revealed that users considered the general appearance of the sign-language avatars to be "stiff, emotionless, and unnatural." The majority of the criticism pointed to nonmanual markers, including facial expression, mouth patterns, and movements of the head, shoulders, and torso (Kipp, Nguyen, Heloir, & Matthes, 2011). Another study found that adding phenomena to ASL animations—such as the establishment of spatial reference points around the virtual human signer to represent entities under discussion and pointing pronoun signs, contrastive role shift, and spatial inflection of ASL verbs—led to a significant improvement in user comprehension of the animations (Huenerfauth & Lu, 2012).

The above well-received components have been integrated into the SigningAvatar technology that is used for creation of the signs for the SMD. Each sign is stored as motions of body joints as a function of time in a reusable library of animations that can be assembled, using Vcom3D's Sign Smith Studio Authoring Tool, to create new passages. The Sign Smith Studio Authoring Tool allows each sign to be "inflected" to indicate spatial references, classifiers, role shifting, emphasis, time, and other elements of ASL grammar. Facial expressions are also stored in a library that can be accessed by the authoring tool, so that grammatical ASL and Signed English (SE) passages can be generated using only the desktop software. Using the authoring tool, an interpreter/author creates easily edited "scripts" that tell the avatar what to sign. Signs animated for one avatar character can be readily applied to other characters. These characters include appearances for different ages, ethnicities, and genders. With regard to facial expression, recent advances now allow for the addition of facial "bones." In a bone-based system of animation, the skin is morphed in response to the rotation of a number of articulation points representing muscle contractions. The addition of facial bones facilitates the development of more anatomically correct expressions.

Developed with funding from the National Science Foundation; TERC, an educational research and development organization; and Vcom3D, developers of the SigningAvatar software, the SMD is a complete assistive tool that includes approximately 1,000 standards-based mathematics terms drawn from instructional materials used in grades 4–8. This interactive assistive technology was "universally designed" according to the principles of the Universal Design for Learning (UDL) framework to maximize its potential to remove any barriers, individualize instruction, and increase access to information for deaf and hard-of-hearing students (Rose, Hasselbring, Stahl, & Zabala, 2005). The UDL framework is based on the neuroscience of learning. Its principles emphasize three key aspects of pedagogy: the means of representing information, the means for the expression of knowledge, and the means of engagement in learning (Rose & Meyer, 2002).

The SignSmith player, an animated interactive viewer, supports integration into the SMD of features that underlie the three principles of UDL. These principles were implemented in the instructional design of the dictionary as follows:

- Representation of terms and definitions as static images, text, human narration, and signing gives learners various ways of acquiring knowledge (Principle 1).
- Allowing students to select ASL or SE translations, illustrations, or voiced text to help them explain their mathematics thinking provides learners with alternatives for demonstrating what they know (Principle 2).
- Offering students opportunities to work in ways that make sense and are interesting to them—such as choosing from a group of avatars of different ages, ethnicities, and genders or changing the signing speed and size of the text—taps into their interests, offers challenges, and increases motivation (Principle 3).

Figure 1 shows a page from the SMD. Each of the interactive features that support the principles of UDL is built into this page and all the dictionary pages.

Although the information cited previously indicates that much is known about the academic achievement of—and challenges for—students who are deaf or hard of hearing, and that potential strategies for increasing accessibility exist, there is an absence of research about the use of interactive digital dictionaries, such as the SMD, and their impact on teaching and learning. The eight case studies, which we conducted as a component of the field-test evaluation of the SMD (Vesel & Robillard, 2011) and presented here, begin to fill this gap. The studies provide insight into how mathematics is taught in each of the eight classrooms and the needs and challenges that exist for the students, how teachers of grades 4–8 who use the SMD for the first time integrate it into their teaching of mathematics vocabulary, how their students use it to learn mathematics terms, and what the potential benefits of the tool might be.

Just as mathematics instruction for hearing students in any two classrooms will not be identical, such is the case as well in classrooms for students who are deaf or hard of hearing. By selecting eight teachers and their respective classrooms as the focus of the case studies and by studying the classroom activity for a limited amount of time, we were able to establish a snapshot of mathematics instruction in grade 4–8 classrooms that offers a broad view of the needs and challenges of students who are deaf or hard of hearing. This approach also serves to investigate initial integration of the SMD in a variety of teaching contexts. To learn as much as possible about SMD use in actual classrooms within the limitations of a modest field test, we designed the case studies to include the following three observations, with an in-depth teacher interview directly after the third observation:

- Observation of the teacher's typical math instruction
- Observation of students' first introduction to the SMD
- Observation of students' SMD use in the context of one day of teacher-planned mathematics instruction

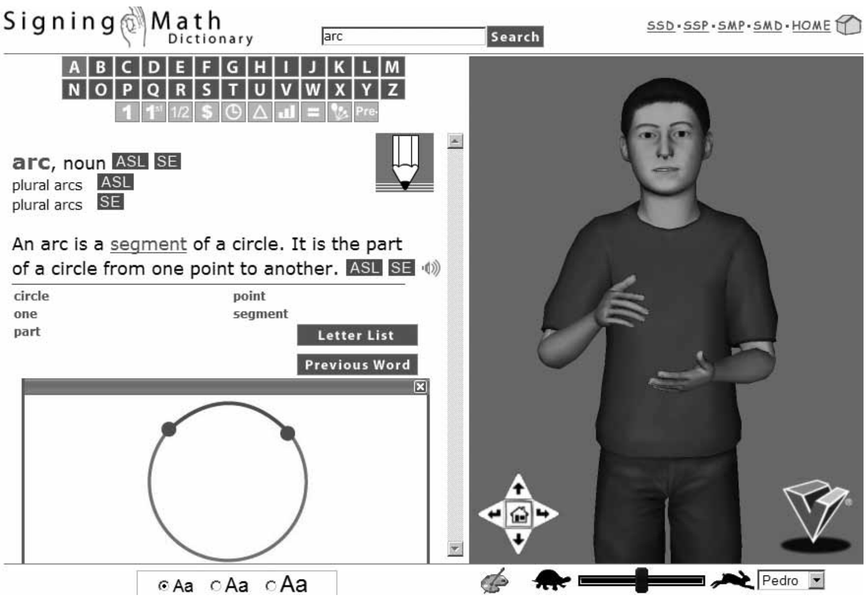

Figure 1. The SMD page for the term arc.

Three research questions guided this implementation research:

1. How does the teaching of mathematics look without use of the SMD?
2. How do teachers integrate the SMD into their teaching of mathematics vocabulary?
3. What are potential benefits of SMD use?

Methods

This article features eight case studies that provide a comprehensive snapshot of the possible classroom applications of the SMD. They included a total of 39 participants—8 teachers and 31 students—from grades 4–8. Each case study represented one classroom and was conducted in a specialized school for the deaf with an experienced teacher who had never before used the SMD. We conducted case studies 1–3 in classrooms in an urban school for the deaf. We conducted case studies 4–8 in classrooms in a suburban school for the deaf. Both schools are located in the Northeast.

Descriptive case study is a methodology used to describe an intervention or phenomenon and the real-life context in which it occurred (Yin, 2009). Whether each case or collection of cases is concentrated on for one day or one year (Stake, 1995), a case-study approach enables the researcher to answer "how" and "why" questions (Baxter & Jack, 2008). For our study, each case comprised three class periods. One class period focused on teaching mathematics without use of the SMD. Another focused on introduction of the SMD, and the third focused on using the SMD as an assistive tool to teach mathematics vocabulary.

With our three research questions serving as a framework, we implemented a five-step protocol:

1. Each teacher completed a Site Data Form that provided demographic information about the school, teacher, and students.
2. We observed teachers teaching mathematics prior to using the SMD.
3. We observed teachers introducing the SMD.
4. We observed students and teachers using the SMD.
5. We interviewed the teachers.

During the observation periods, we photographed teachers and students, collected samples of students' work, and held informal conversations. We hoped to gain insight into the teaching and learning of mathematics vocabulary with and without use of the SMD and to consider any benefits the tool offered, in multiple contexts. We also completed instruments designed to collect data during the observations and interviews. This resulted in a "full variety of evidence" that included artifacts (student work), open-ended interviews, and observations (Yin, 2009). By employing a multiple-case-study methodology to replicate the various modes of data collection in multiple contexts, we were able to rely on a robust set of data to apply toward answering the research questions.

We analyzed data from these sources by initially developing a coding scheme to search for and identify patterns. We then used the coding scheme to code the evidence provided by each data source (Neuman, 1997). Table 1, organized by research question, outlines the primary and secondary codes that we used. To maximize insight gained from the case-study experience, the research design called for a single researcher to conduct all of the observations and interviews and to code the data. This design supported the researcher's ability to discover emergent themes across the data sets due to having observed teachers and students at work and having interviewed teachers. As such, this design eliminated the need to develop a process for reliability among multiple coders.

We used Nvivo, computer-assisted qualitative data-analysis software, for analysis of interview transcripts. We studied outputs to determine whether any meaningful patterns were emerging that we could then connect to the research questions. We carried this process out to "uncover patterns, determine meanings, construct conclusions, and build theory" (Patton & Applebaum, 2003). We conducted cross-case analyses to see how the dictionary is used in a variety of settings with students who are deaf or hard of hearing and who have different needs, challenges, and skill levels. The Results section includes key findings that emerged from analysis of the patterns we detected.

Table 1. Coding Scheme for Identifying Patterns in the Data

Research Question 1: How does the teaching of mathematics look without use of the SMD?	
Primary Code	Secondary Codes
Mathematics Topics Covered	Geometry, Division, Multiplication, Measurement, Problem Solving, Algebra, Addition, Subtraction, Graphing, Decimals, Percentages
Instructional Strategies	Individualized Instruction, Review of Concepts and Skills, Sign Support, Direct Instruction of Mathematics Vocabulary, Review of Mathematics Vocabulary
Vocabulary Instruction	Introducing/Teaching New Vocabulary, Vocabulary Review, Assessment, Word Wall, Student-Created Written Dictionaries/Vocabulary Study Guides
Materials Used	Web Resources, Math Textbooks and Curricula, Math Games, Workbooks, Math Dictionaries, Calculators
Technologies Used	Classroom Computers with Projection Devices, Computers in a Computer Lab, Smart Board, Laptop Computers, Overhead Projector
Challenges	Wide Range of Learners with Varied Needs; Lack of Teacher, Student, or Interpreter Knowledge of Math Signs; Access to English Language Content/Reading Below Grade Level
Research Question 2: How do teachers integrate the SMD into their teaching of mathematics vocabulary?	
Primary Codes	Secondary Codes
Introducing the SMD	Teacher Demonstrates Features, Students Explore Features, Introductory Movie Shown
SMD Lessons/Activities	To Introduce New Vocabulary, To Review Vocabulary, For Reference/Support, For Test Preparation
Technologies Used for SMD Delivery	Classroom Computers with Projection Devices, Computers in a Computer Lab, Smart Board, Laptop Computers
Research Question 3: What are potential benefits of SMD use?	
Primary Codes	Secondary
Value Added	Access, Independence, Individualized Instruction, Standardized Test Preparation, English Literacy Skills, Motivation, Standardized Signs
Student Action/Reaction	Copy-Sign What the Avatar Signs, Watch Signing Repeatedly, Back and Forth Between English and Signed Terms and Definitions, Interested/Engaged with the Technology
Future Use	State and Standardized Test Preparation/Review, Individual Student Use, At Home Use/Assist with Homework

Case Studies 1–3 (Site Location: Classrooms in an Urban School for the Deaf in the Northeast)

Case Study 1. This study involved a class of six sixth graders. Five of the students were profoundly deaf and had been so prior to the acquisition of any language. One had moderate to severe hearing loss. Their overall skill level was below grade level.

Teaching and learning mathematics without use of the SMD. The previous day, students had been introduced to several terms related to the topic of geometric angles. To maintain the focus on mathematics vocabulary for the duration of the year, the teacher had created a Word Wall with terms, definitions, and an example for each term, listed according to topic, on one of the classroom walls. Students were involved in drawing angles of different sizes on a grid. While they were drawing their angles, they referred to information from their notebooks and from the Word Wall to help them label the angles as acute or obtuse.

The teacher stressed during the post-observation interview that, for these students, acquiring an understanding of key mathematics vocabulary for each unit of study was a central component of their curriculum-based work. In addition, the class was working toward taking the pencil-and-paper version of the state standardized mathematics test. The teacher pointed out that having a command of key mathematics terms is also extremely beneficial in helping students better understand standardized test questions. Often when they are able to recognize a term and know what it means in the context of the question being asked, they can "deduce what to do" and "don't have to understand the entire question to get to the correct answer." For these reasons, whenever the teacher introduced a new mathematics term, she would write the term and its definition along with an example on the board. After students had discussed the term and its meaning as a class, they would write it in their notebooks. The teacher then mentioned that after the class had finished the unit they were doing, and before moving on to new material, they would be reviewing all the units they had completed to date in preparation for the state test later in the year. The teacher planned to use the terms written on the Word Wall and in students' notebooks to help them review the vocabulary associated with these units. She also intended to assess their knowledge by giving them weekly quizzes on subsets of the terms.

Preparing to use the SMD. The math classroom was not equipped with computers for projecting the SMD onto a whiteboard. Therefore, the teacher had made plans to introduce the dictionary in one of the school's computer labs. Several days prior to the class, the teacher had worked with the technology staff to download the necessary avatar plug-in and SMD onto each of 15 computers.

Upon entering the lab, the class of six was divided into three pairs. The members of each pair were asked to sit next to one another but at separate computers. Grouping students in this way enabled them to operate their own computers and to discuss their reasoning with a partner. After they were settled at their places, they were each given a packet of information. The first part of the packet included an activity that was designed to introduce them to the SMD. The remaining pages were a vocabulary-review activity they would do using the SMD.

For the introductory activity, each pair of students was to access the SMD by typing its URL into a browser and then spend about 10 minutes investigating its interactive features. Afterwards, they used the following questions to discuss what they had learned:

- How does the ASL signing differ from the SE signing?
- How do you change the signer?
- What do you like about the SMD?

As students explored the dictionary features, the teacher circulated among them and answered their questions.

Teaching and learning mathematics with the SMD. For the vocabulary-review activity following the introduction, the teacher had prepared three pages—one for each pair of students. One page had a list of seven terms derived from the unit on two-dimensional geometry that they had just finished and from units related to measurement and algebra that they had completed earlier in the year. Two lists had eight terms each that were also taken from these units. No term appeared in more than one list. This meant that the review focused on a total of 23 terms and that each pair of students had a unique set.

After distributing the lists, the teacher instructed the class to turn to the page in the packet with the outline of a chart. They were to begin with the first column, titled Word, and list the set of terms one below another. They were then to go to the SMD and find the definition page for the first term in their list. Next, they were to use the interactive features to view the term and its definition being signed and to look at an illustration. They were then to practice signing, defining, and giving an example of the term in ASL. As students completed each task, they were to place a checkmark in the appropriate column next to the word, indicating that they had practiced each of these three things. To wrap up the review, students drew or wrote an idea in the column provided to indicate what each term means. The teacher circulated among pairs of students as they worked to be sure they correctly completed the tasks. She also answered their questions.

As they watched the avatar sign a term or its definition in ASL, they would often "copy-sign" along with it. They also watched the avatar sign terms and definitions again and again and then "played the signing" for their partner. The teacher mentioned that this helped them build their ASL skills as well as comprehend the meaning of the terms.

As one student was watching the definition of equilateral triangle being signed, he missed the phrase same sides in the definition. This was evident when the teacher asked him what the term meant. He signed, "Oh, it's a triangle with three sides." At that point, the teacher told him he was missing something and that he should go back and watch the definition being signed again. The student watched the signing four or five times and then exclaimed, "Oh, the sides are all the same!" The teacher said that this example "illustrates how valuable the SMD is in helping students with comprehension. For that student, being able to keep going back again and again to try to get that one word, which was pretty much the most important word in that definition, was really critical."

Shortly before the class ended, the teacher distributed a homework assignment that involved reviewing the signing and defining of the terms in their charts. The following day, they discussed the terms and definitions and reviewed their signs as a class.

In conversation after the observation, the teacher pointed out that the SMD could be useful in helping her students work more independently.

They are accustomed to having small classes and many adults present to assist them. If she had the requisite technology, she would "have the SMD up and running all the time." When students are working independently and encounter a word they do not know, they could go to the computer and look it up themselves. This would greatly reduce students' dependence on her. Even though her students have access to other resources, such as the Word Wall and vocabulary words and definitions recorded in their notebooks, the terms would be so much more available to them if they could "just go use the SMD on their own." Additionally, she pointed out that the SMD could serve to "generalize" the signs all the students in the school use for mathematics terms. On occasion, they and the teachers "make up a sign" that "fits all the rules of the language" but that may not be an actual accepted or accurate sign for the term. Use of the SMD would make this exercise no longer necessary.

Case Study 2. This study involved a class of three sixth graders. All three had moderate-severe to severe hearing loss. Their skill level was below grade level.

Teaching and learning mathematics without use of the SMD. Students had their workbooks open and were doing division word problems. The teacher encouraged them to do a problem and then check their work on a calculator. She reviewed each problem with them individually before they were allowed to move on to the next one. Occasionally, she would explain a problem to a student or sign terms in ASL.

Preparing to use the SMD. The SMD had been installed on the main classroom computer and was projected onto a large TV monitor. Students sat in chairs in front of the monitor. For the past several years, they had been developing a math dictionary of terms and definitions. They took turns practicing using the features included in the SMD by looking up terms they had recently added to their math dictionary related to geometric shapes, such as quadrilateral and rhombus. As they worked, they discussed different ways to access the terms and how to view the illustrations.

Teaching and learning mathematics with the SMD. Students were using the SMD to play a matching game that served as a review of the terms for geometric shapes that were listed in their math dictionaries. The teacher provided a clue, such as, "I am a shape that is four sided. Whenever I have an angle, it's a right angle." Students wrote the name of the term being described on whiteboards that had been distributed to them at the beginning of class. The teacher then used the SMD to look up the term or terms students had written. The class viewed each signed term and definition and discussed its meaning. They used the information to decide whether their answer was correct. Although the class had played this game before, the teacher thought it was valuable to be able to use the SMD to "check their answers." As they played the game, they also used the dictionary to learn new terms and definitions. For example, the word adjacent came up. They used the SMD list of terms that began with the letter A to find the word and discuss what adjacent means. The students were curious about other words in the SMD list, but the teacher wanted them to focus on terms in their own math dictionaries. Therefore, at this time they did not look up other SMD terms that they were curious about.

In conversation after the observation, the teacher explained that she always introduces new vocabulary words at the start of a unit. She usually writes a word on the whiteboard and has the class discuss its definition. Although she provides print-based math dictionaries for students to use as a reference, she does not allow them to copy the definitions from the dictionary, requiring them instead to write the definitions in their own words. She said, "Since English is their second language, having the SMD up would be really good because then they could watch the signing, understand the term better, and be able to write a better definition in their own words. So, what I'm thinking about doing is, when I have new vocabulary, they could take turns, because we only have the SMD on one computer here, looking up different words and then writing them in their dictionaries. They will continue to keep their written dictionaries and use the SMD as another resource for helping them understand what the terms mean and write definitions in their own words."

Case Study 3. This study involved a class of three seventh graders. All three were profoundly deaf and had been so prior to any acquisition of language. Their skill level was below grade level.

Teaching and learning mathematics without use of the SMD. Students were sitting at a table in their mathematics classroom and taking an exam required by the public school system. During the exam the teacher worked with students individually to explain the questions in ASL. They then solved the problems on their own.

Preparing to use the SMD. Students were reviewing math vocabulary related to geometry in preparation for the standardized state mathematics exam. The teacher had created a worksheet that included a column with a list of vocabulary words on the left-hand side and two additional columns. One was for writing definitions before using the SMD. One was for writing definitions after using the SMD. During the first part of the class, students worked independently to define each term based on what they knew. As the computer in the mathematics classroom was not set up for student use, they moved to a computer lab to use the SMD. The teacher had previously downloaded the Avatar plug-in and SMD onto all of the computers so that students could sit individually and operate their own computers.

The teacher introduced the SMD by instructing students to use the Alphabet Bar to look up a term that was not on the worksheet. They then practiced using the dictionary to look up the term they had selected and to explore its interactive features, including zooming in on the characters, rotating them, and changing the signing speed. They then proceeded to complete the portion of the worksheet that involved use of the SMD.

Teaching and learning mathematics with the SMD. The teacher wanted students to use the signed definition rather than the English text as the basis of their definition. Therefore, he had students cover the English-text definition with a piece of paper and look only at the avatar character signing it. They could lift up the paper to click the icon for ASL or SE but were told not to look at the illustrations. He said that students "played the signing over and over." After they had viewed the signed definition as many times as they wanted, they wrote their definitions on the worksheets.

During the post-observation interview, the teacher said he'd noticed, after looking at students' definitions, that one student preferred viewing the definition in SE, and the others used ASL. He also said that the next time students used the SMD, it would be a good idea to allow them to look at the English-text definition and explore the illustrations. He also thought it would be helpful to add a third column to the worksheet where students could "extrapolate the definition and compare the definitions in all three columns." When asked how he might incorporate use of the SMD into his classroom in the future, the teacher said that they would soon be starting a new list of math vocabulary, and it would be useful to connect the one classroom computer to a TV monitor and give students the opportunity to use the SMD to look up terms individually.

Case Studies 4–8 (Site Location: Classrooms in a Suburban School for the Deaf in the Northeast)

Case Study 4. This study involved a class of three fourth grade students. One student was below grade level. The other two were slightly above grade level. All three were profoundly deaf and had been so prior to any acquisition of language.

Teaching and learning mathematics without use of the SMD. Students were taking a test, sitting at desks arranged in a row facing the front of the classroom. The test covered concepts related to money and time. Several of the questions were word problems. The teacher sat in front of them and helped them read and understand the questions as they worked. This often included signing the questions for them.

Preparing to use the SMD. The teacher had loaded the SMD onto three Macintosh laptop computers equipped with VMware. Students were reviewing concepts related to factoring. All of them were having difficulty reading the problems. The teacher used this as an opportunity to introduce the SMD individually to each student. As they encountered words they could not read or did not know the meaning of, she had them use the Alphabet Bar to look up the word and manipulate the various dictionary features to figure out what they meant. She commented that having the SMD available was beneficial, as students were able to quickly find what they needed to know to begin to work on the problem.

Teaching and learning mathematics with the SMD. Students were using the SMD as a reference to help them complete multiplication problems. They were sitting at their desks with their math workbooks open and the SMD running on the laptop computers. The teacher sat directly in front of their desks. To get things started, she suggested students look up the term multiplication in the SMD. They used the Alphabet Bar, as they had learned previously, to look up the term and view the signed definition and illustration. The teacher then said, "Let's find that word on your workbook page. The illustration for multiplication shows that 6 x 3 = 18 is the same as 6 + 6 + 6 = 18." She then directed the students to one of the workbook problems and said, "If the problem is 9 x 3 = ?, why don't we try to add 9 + 9 + 9?" Before continuing, the students wanted to look up add and equal sign. They were able to use what they had learned from the SMD, with direction from their teacher, to solve the problem. They used this approach to solve the remainder of the problems and to explain their answers.

Case Study 5. This study involved a class of six fifth graders. Five of the students were profoundly deaf and had been so prior to any acquisition of language. One had a cochlear implant and was hard of hearing. The skill level of the students was slightly below grade level.

Teaching and learning mathematics without use of the SMD. Prior to the observation, the teacher explained that she usually selects five math terms each week for the students to learn. At the end of the week, they have a quiz. The lesson observed involved a review of the terms for the week.

The students were seated at their desks in a U-shape facing an interactive whiteboard. Each student had a set of index cards with each term written on a different card. The teacher stood next to an overhead projector that she used to display the words and definitions onto the interactive whiteboard. She took a blank piece of paper and covered up all the definitions except for one. She then read and signed the uncovered definition. Next, she asked the class if they could identify the term that was being defined. The students who thought they knew the answer held up the index card that had the answer written on it. The teacher then selected a term from those being held up and asked the class if they agreed that it was the correct answer. Those who did not agree held up index cards that contained their term of choice. When called upon, each student was asked to explain his or her answer. The teacher then asked the class if they agreed with this alternate answer. The process continued, with the teacher guiding discussion, until the class reached consensus and she confirmed that the correct match had been made.

Preparing to use the SMD. The teacher had loaded the SMD onto a computer that was attached to the interactive whiteboard. She used this setup to display one of the dictionary pages for a term they had studied the previous week. She clicked one of the ASL buttons on the page and gave students time to watch and discuss what they observed. She then clicked another ASL button and waited for students to comment on what they saw happening. They continued in this way to explore all the features together.

Teaching and learning mathematics with the SMD. The teacher was introducing new terms for the week. The computer with the SMD displayed was connected to the interactive whiteboard. Students were seated at their desks in a U-shaped configuration. The words were listed on a sheet of paper near the computer.

To introduce the first word, the teacher stood to the side of the interactive whiteboard and called on a student to go to the computer and use the Alphabet Bar to find one of the terms for the week. When the page appeared, she called on another student to come up to the interactive whiteboard, select an avatar character, and click on the ASL icon so the class could see the definition signed. With the student at the interactive whiteboard in control of the buttons, the teacher guided class discussion to verify that everyone understood what the term meant. She encouraged the student running the interactive whiteboard to click the various icons repeatedly so the class could see the definition, and individual words within the definition, signed several times. She also had the student click on the illustration so everyone could see it and discuss how it showed what was described in the text. Before proceeding to the next word, students wrote the term and definition in their vocabulary study guides and drew an illustration that reflected its meaning. As students entered the terms into their guides, she circulated among them and used the SMD to provide clarification. Later in the week, the class used the SMD to review the terms in preparation for their weekly quiz.

During the post-observation interview, the teacher commented, "Using the SMD is more effective than using the glossary in the back of the mathematics textbook or the classroom dictionary because it provides the terms and definitions in sign. Starting with ASL, their primary language, allows students to develop an initial understanding of the mathematics concept that is embedded in a term before they write it in English, which is their second language. They are also able to see individual terms within a definition signed. When students read a definition or when they are signing a definition, they might not know which word it matches with in English. With the SMD, they can go to the English word if they are not sure and see it signed. Because it is Web based, they can also use it outside of class to review vocabulary."

Case Study 6. This study involved a class of four sixth graders. All four students were profoundly deaf and had been so prior to the acquisition of any language. They were also autistic. Their overall skill level was below grade level.

Teaching and learning mathematics without use of the SMD. Each student was seated at a separate desk facing an interactive whiteboard. They were taking turns going up to the board and solving problems. The problems involved expanded subtraction, filling in missing numbers on a number line, and filling in missing numbers in a fact family.

The teacher stressed that all four students required considerable individual attention for all their academic subjects. Not only did they work below grade level in mathematics, but they also struggled with reading. In general, they needed consistent support to help them successfully complete tasks and understand concepts. This took the form of one-on-one assistance with such things as understanding written directions, setting up work, writing answers in the correct place, formatting homework correctly, breaking down problems into steps, and checking work to catch errors. A co-teacher assisted the primary teacher throughout the day so that all the students could have the support they needed. However, an overarching goal was to help them develop strategies for being able to complete work on their own. Whole-class instruction employed a variety of methods to reinforce the work that took place one on one. For example, students used the interactive whiteboard to demonstrate how to solve problems by setting them up, breaking them into steps, showing their work, and explaining their thinking.

The teaching of mathematics vocabulary was integral to all problem-solving activities. In particular, learning mathematics terms and definitions was critical for enabling these students to understand written directions, as they often had a hard time focusing on them and frequently ignored them. In the case of word problems, they sometimes did not recognize what information was being given and what the problem was that they were being asked to solve. Therefore, when working at the interactive whiteboard, the teachers signed the terms students could not read or did not understand, modeled methods for them to follow to help them complete problems, and drew pictures or provided examples to help them understand and use the terms they encountered. The class did not use text glossaries or dictionaries because such reference tools have a specific structure that usually includes the word, the part of speech, and the definition in sentence form. These students could not read well enough to understand and apply information in this form. The only type of dictionary they used was one with pictures, as illustrations provided a visual way of understanding what words mean.

Preparing to use the SMD. The teachers introduced the SMD to the class one day prior to having them use it to do a mathematics activity. The introduction took place during their academic-support class, which was a study hall that they sometimes used as an extra math class. The technology staff had previously installed VMware and downloaded the Avatar plug-in and SMD on the class's set of Macintosh laptop computers.

To begin, one of the teachers projected the SMD from a computer onto the interactive whiteboard at the front of the classroom. All four students were sitting at their own tables, arranged in a U-shape facing the interactive whiteboard. One teacher stood next to the board and showed the introductory movie that is accessible from the SMD. As the movie played, she provided interpretation and used her finger to point to the actions that were being demonstrated to be sure students were following them. After the class viewed the movie, she asked one student to come up to the computer that was connected to the interactive whiteboard, select a term from the SMD, and find its definition page. She then had the student use the interactive whiteboard to click on the ASL icon and on individual terms as everyone watched the signing. Each student had a chance to select a term and activate the signing. At the end of this introductory process, students were each given a laptop with the SMD running on it to use at their seats. Earlier in the day, they had received a worksheet in their math class to complete for homework. To give them further practice in using the SMD, the teachers worked individually with students to help them identify and look up terms that appeared in the instructions for the assignment.

The teachers commented during the post-observation interview that students seemed fascinated with the signing avatar. One student looked up the word digit, a term he had been taught several times before. Another student became interested in looking up terms in the dictionary; she navigated to the Signing Science Pictionary (SSP), which is accessible from the SMD, to see what science terms she could look up and see signed. While the teachers were excited about the students' initial reactions, they were not sure how long it might take them to "use the SMD strategically with their work" to do such things as identify words in instructions they were not sure about, look them up, and then go back to apply what they had learned. They commented that these particular students did not always understand what was being signed to them, so understanding the avatar would be a skill they would have to develop over time.

Teaching and learning mathematics with the SMD. Students were seated at their tables in a U-shape. Each student had a laptop with the SMD open and running on it. The goal of the activity was for students to complete three worksheets using the SMD for assistance. One worksheet required them to use linear measurements, such as inches, feet, and miles, to specify equivalence, size, and distance. A second sheet required them to calculate the area and perimeter of several rectangles. A third sheet required them to draw rectangles of a given area.

As the class progressed, students worked independently and appeared to be referring to the SMD to look up terms, using the information to help them complete the worksheets. The teachers intervened or assisted them as appropriate. For example, one student, while working on the standard-linear-measurements worksheet, looked up the word tall in the dictionary while trying to answer one of the items, which read, "A tall man could be 6.5 _____tall." After he watched the definition for tall being signed several times, one of the teachers approached and showed him a ruler. She pointed out the divisions for inches on the ruler and then explained that the length of the ruler is one foot. The student subsequently wrote the word feet in the blank as his answer to the question. Other students looked up terms such as inch, foot, and yard. They discovered that the illustrations could help them answer the questions on the sheets. For example, while working on the area-and-perimeter sheet, one of the students encountered a problem that asked him to give the area of a rectangle that was 10 units long and 4 units wide. At first, he wrote that the area of this rectangle was 20. He then looked up the term area in the SMD and examined the illustration. He saw that it depicted area as one larger square divided into 16 smaller squares. He also noticed that the area was equal to the total number of smaller squares inside the larger square. He then went back to the worksheet and counted the number of squares drawn inside the rectangle. He found that there were 40 and changed his answer accordingly.

As students completed the sheets, they called one of the teachers over to check their work. After she had checked their answers, she gave each student two scores: one score for accuracy and the other for working independently. The students continued using the SMD to complete each of the three worksheets.

In conversation after the observation, both teachers shared their thoughts about how continued use of the SMD with these students could help them more independently read instructions, complete worksheets, solve word problems, and do math computations. In particular, they liked the way the dictionary "scaffolds students' understanding" by allowing them to "click each word" within the definition to see it being signed, view the definition signed in its entirety, and perform these actions in whatever order and as often as they like. They added that this "seems to be really helpful for a completely different goal of helping students to someday recognize dictionaries as a source of information about what words mean."

Case Study 7. This study involved a class of three seventh graders. One student was severely deaf, and two were profoundly deaf. They had been so prior to the acquisition of any language. The skill level of the students was slightly below grade level.

Teaching and learning mathematics without use of the SMD. The students sat at desks in rows facing an interactive whiteboard. The teacher had made a list on the board of the air temperature at given altitudes. She asked the students to decide on a graph type that would be the best display of the data. Choices were a vertical bar graph, horizontal bar graph, pictograph, and line graph. These graph types were displayed on the interactive whiteboard using an alternate data set. After discussing the data and graph types, they decided on one to use. With help from the teacher, they created paper versions of the graph.

Preparing to use the SMD. The teacher had installed the Avatar plug-in and dictionary on several Macintosh laptop computers equipped with VMware and distributed them to students to use at their desks. She used the interactive whiteboard and terms related to graphs and graph types to introduce the SMD's interactive features, including changing the background color and the signing speed and using different methods to find terms. Students had opportunities during the week following the introduction to practice using the SMD. Those who had computers with Windows operating systems at home were encouraged to install the dictionary on them and use it when they were not at school.

Teaching and learning mathematics with the SMD. The teacher was introducing the students to new vocabulary for the week. The teacher had projected the terms as a list onto a interactive whiteboard with space after each term for writing its definition. Students had a paper copy of the list in the form of a worksheet. With guidance from the teacher, they worked individually to look up the first term in the SMD and watch the definition being signed. They then discussed its meaning as a class and decided on a definition. Following the discussion, the teacher wrote their definition on the interactive whiteboard in the space next to the term. Students also wrote it on their worksheets. They repeated this process for each term. During the week, they used the SMD in class and at home to review the terms in preparation for the usual end-of-week test.

During the post-observation interview, the teacher said, "Students were very interested in watching the avatar. They liked viewing the signed definitions again and again." She thought that some of the definitions were a bit lengthy, but the objective was to expose students to them and have them be able to put something down on their paper to help cement the words to their meanings. This appeared to be accomplished using the SMD.

Case Study 8. This study involved a class of five eighth graders. All of the students were profoundly deaf and had been so prior to the acquisition of any language. The skill level of the students was near grade level.

Teaching and learning mathematics without use of the SMD. Students were sitting at desks in a wide U-shape facing an interactive whiteboard. The teacher used an overhead projector to display a series of decimals on the board. Students worked individually to convert the decimals to percentages using a method they had learned previously. They met as a group to discuss their answers. The teacher then divided the class into two groups. One group played a game. The game consisted of putting cards face down in rows, turning them over one at a time, and matching the card being turned over with a card that was already face up with an equivalent decimal or fraction written on it. If there was no match, they continued to turn cards over until a match appeared. The game was over when all the cards had been correctly paired.

The other group was given laptop computers and did an online activity using a subscription math resource that they regularly use to practice math skills, prepare for high-stakes tests, and participate in real-time speed and skill competitions. After each group was finished, they switched places and played the game or worked online.

Preparing to use the SMD. The teacher first projected the SMD onto an interactive whiteboard and demonstrated its interactive features using vocabulary from past units. She then distributed laptop computers with the SMD installed so students could use it on their own. She waited to give out the laptops until she'd shown the class the dictionary because, as she explained, her students can be easily distracted and would be inclined to play with the SMD on their own without making sense of what they were doing. Later in the week, they played a game with the SMD projected onto the interactive whiteboard. It involved covering up the English text, playing the avatar signing the definition, and asking students to name the term that went with the definition. This did not work out as planned, because in the SMD the term is included in the definition. Nevertheless, she said, "Students were engaged and looked forward to using the dictionary again."

Teaching and learning mathematics with the SMD. The goal of the lesson was for students to use the SMD as a reference to help them complete a chart. This involved placing terms listed across the bottom of a worksheet in columns according to the symbol (+, -, x, ÷, or =) that went with the term. The teacher began by projecting the worksheet onto the interactive whiteboard and using it to explain the activity. An aide then handed out laptop computers with the SMD running on them. Students first put the terms they already knew into the appropriate column. They then used the SMD to look up the remaining terms and view the avatar signing them before placing them in columns. Working as a class, the teacher called on students to share where they thought a particular term should be placed. For those terms that were not in the SMD, students discussed their ideas about the terms' meanings and then used the SMD to look up related words. This led to being able to accurately assign these terms to the correct column. After everyone agreed on its correct placement, the teacher wrote the term in the column using the worksheet that was projected onto the interactive whiteboard.

In conversation after the observation, she commented, "It was cool because I didn't really anticipate how it was going to turn out. Normally, we wouldn't have any kind of resources. It would be students taking turns going up to the interactive whiteboard and using what they already knew. They would just kind of guess or use what they remembered. With the [terms] that were left, they didn't have a resource to go to. Some of the basic easy ones like added to or subtracted or minus they usually got. The ones they did not know, we would discuss as a class. This was cool, because students could do it on their own and use the dictionary to help them figure out the ones that they didn't know."

Results

Research Question 1: How Does the Teaching of Mathematics Look without Use of the SMD?

Summarized below are the variety of mathematics activities that the case-study teachers incorporated into instruction; strategies they employed to support mathematics learning; and materials, instructional configurations, and technologies they incorporated prior to use of the SMD. Taken together, they provide a snapshot of what teaching mathematics looks like without use of the dictionary.

Activities. These include completing tasks or worksheets that involve computation, solving word problems, and graphing; playing games or using subscription Web sites to practice math skills; reviewing math vocabulary related to a unit of study; and taking end-of-unit or standardized tests.

Strategies. These encompass individualized instruction and one-on-one support to meet the diverse needs and abilities of each student; sign-language support to ensure that students are able to understand instructions, word problems, and end-of-unit and standardized test questions delivered as English text; and direct instruction and review of vocabulary related to the topic being taught and encountered in instructions, word problems, and end-of-unit and standardized test questions.

Materials. Materials include textbooks that vary with school, curriculum sequence, and student needs and abilities as well as supplemental materials and resources such as games and interactive Web sites.

Instructional configurations. These refer to teachers providing whole-class and individual instruction and students working with and without teacher support, alone and in pairs or groups.

Instructional technologies. Technologies used include interactive whiteboards, overhead projectors, and laptop computers with Internet access.

Research Question 2: How Do Teachers Integrate the SMD into Their Teaching of Mathematics Vocabulary?

Teachers who used the SMD for the first time devised ways to effectively integrate it into their teaching of mathematics vocabulary necessary for the math topics their students were studying. They also found ways of effectively integrating it into preparation for upcoming standardized testing. To accomplish this, they used the SMD in combination with interactive whiteboards and projection devices to introduce new mathematics vocabulary to the whole class or to review mathematics vocabulary that had previously been introduced or learned. Teachers also had students use the SMD as a reference to help them complete assignments, such as worksheets that involved doing mathematics computation or word problems, or to complete tasks that included graphing data, drawing and classifying angles, or identifying geometric shapes. Depending on the technology

Table 2. Strategies for Incorporating the SMD into Teaching of Mathematics Vocabulary

Study Number	Student Population	Integration Strategies
Case Study 1	6 sixth graders 5 profoundly deaf 1 moderate-severely deaf	The teacher had students use the SMD installed on computers in a computer lab to review 23 vocabulary terms related to two-dimensional geometry, measurement, and algebra before moving on to new material and preparing for state testing.
Case Study 2	3 sixth graders 3 moderate-severe to severely deaf	The teacher had students use the SMD projected onto a TV screen to play a matching game. This gave them the opportunity to review the terms and definitions for geometric shapes listed in their written math dictionaries.
Case Study 3	3 seventh graders 3 profoundly deaf	The teacher had students use the SMD installed on computers in a computer lab to view the signed definitions of a list of preselected terms. They used what they had learned to complete a worksheet that asked them to write the English definition of each term.
Case Study 4	3 fourth graders 3 profoundly deaf	The teacher had students use the SMD individually at their desks using laptop computers with the dictionary installed as a resource to help them see how to solve multiplication problems in their math workbooks.
Case Study 5	6 fifth graders 5 profoundly deaf 1 hard of hearing (with a cochlear implant)	The teacher had students take turns using the SMD installed on a classroom computer and projected onto an interactive whiteboard to become familiar with the new mathematics terms for the week. They took turns using the various dictionary features and discussing the meaning of the term before incorporating it into their vocabulary study guides.
Case Study 6	4 sixth graders 4 profoundly deaf with autism	The teacher had students use the SMD individually at their desks using laptop computers onto which the dictionary had been installed as a resource to assist them in completing worksheets that involved topics related to linear measurement and the area and perimeter of rectangles.
Case Study 7	3 seventh graders 2 profoundly deaf 1 severely deaf	The teacher had students use the SMD at their desks using laptop computers to look up new vocabulary terms for the week that had been posted on a classroom interactive whiteboard. This involved looking up a term individually, discussing its meaning as a class, and deciding on a definition before recording it on the whiteboard and proceeding to the next term.
Case Study 8	5 eighth graders 5 profoundly deaf	The teacher had students use the SMD individually at their desks using laptop computers as a reference to help them complete a chart. This included placing terms listed across the bottom of a worksheet in columns according to the symbol (+, -, x, ÷, or =) that went with the term. Subsequently, working as a class, they used their work to complete a version of the chart projected onto an interactive whiteboard.

available, students worked individually or in small groups at stations in a computer lab, or individually on laptop computers in the classroom. Table 2 summarizes how each teacher integrated the SMD into his or her teaching of mathematics vocabulary.

Research Question 3: What Are Potential Benefits of SMD Use?

Seven areas emerged from analysis of the case-study data as indicators of potential benefits of SMD use:

Increased access to mathematics vocabulary. Access to mathematics terms and definitions in their first language appears to make a significant difference for students who are deaf or hard of hearing and who use sign as their primary mode of communication. Traditional math dictionaries often contain English-text definitions that are too complicated for this population because most do not read at grade level. With the SMD, students in our study seemed able to find the terms, access the information they needed to learn the terms, and use the dictionary—some with and some without help from a teacher—to solve problems and communicate their understandings.

Increased independence. Students often viewed a signed term and definition over and over as frequently as they liked, without teacher intervention, until they thought they understood what the term meant. This might result in students working more independently to develop a technical mathematics vocabulary, freeing up time for the teacher to work with them on mathematics concepts and principles.

Increased individualized instruction for a range of learners. After having been introduced to the interactive features, students appeared able to use them to learn mathematics vocabulary at their own pace, in their own way, at their own level. Depending on what they needed to understand the meaning of a term, they could click on a word within the definition and see it signed, watch the whole definition signed, and/or view an illustration to help them visualize what was being signed.

Increased acquisition of standardized test vocabulary. Whether students take standardized tests in mathematics with or without accommodations, they are required to do considerable writing and explaining of their answers. They are also required to read and understand written instructions and do word problems. Use of the SMD may contribute to students developing the vocabulary and skills they need to perform all of these tasks.

Increased English literacy. Being able to go back and forth between the signed definitions and the English-text definitions might help students work on their English literacy, not only in English class, but also in the context of mathematics.

Increased motivation to learn mathematics. Students' initial reaction to the Signing Avatar technology was a sense of fascination and wonder about a technology that is just for them. Continued use of the SMD might be a way to keep them engaged in mathematics learning and may result in more active engagement on the part of students who are often passive learners.

Increased access to standardized signs. Considerable class time is often spent inventing signs for mathematics terms because the teacher or interpreter does not know many of the signs used for technical terms in mathematics, or such signs do not exist in ASL. The SMD provides signing that has been carefully researched to accurately represent and convey concepts. Teachers can refer to the SMD to learn signs for terms they do not know or are unsure of and to check the accuracy of signs they have been using. Use of the SMD also might eventually help with the standardization of the signs that are used in mathematics classrooms across the nation.

Discussion

Key Findings

These case studies of first-time users of the SMD show that, when it is used as an assistive tool, it appears to contribute to giving students in grades 4–8 who are deaf or hard of hearing access to mathematics vocabulary in their own language. Such access may enable this population to work more independently as they develop a technical mathematics vocabulary and may result in teachers having more time to focus on the topic content. Findings also indicate that the dictionary's interactive features promote individualized instruction for a wide range of learners with varying levels of hearing loss and learning challenges. Teachers who used the SMD for the first time were able to creatively integrate it into their instruction by using interactive whiteboards and projection devices situated in the classroom to teach to the whole class, or by using classroom or computer-lab desktop computers to teach to individual students or groups of students. The Avatar technology appears to motivate students and fire up their curiosity and interest in learning math. It also provides teachers and interpreters with access to a set of standard signs for technical math terms—terms that they may not have known and that they can immediately integrate into instruction.

Limitations of the Study

The present study has some important limitations. The results of the study cannot be generalized to all students who are deaf or hard of hearing or to all their teachers. A larger, more representative random sample of cases is needed—in an expanded number of sites, in other regions of the country, and in a range of mainstream and specialized settings—to further measure the benefits of SMD use and discover how it is implemented in classrooms. Additionally, the present study focused on the collection of qualitative data that was intended to provide preliminary information and insights into the implementation and benefits of the intervention. A case-study research methodology that includes a quantitative component should be undertaken to supply more extensive information about the use and benefits of the SMD as a tool in a range of settings with students who have varying degrees of hearing loss and academic skills. The research design also needs to be expanded to include use of the SMD with teachers who are teaching similar mathematics content so that implications about its implementation can be more accurately assessed.

Implications for Practice

Our findings begin to show that when incorporated into mathematics instruction, the SMD may help students improve their comprehension of mathematics content (Marzano, 2004; Stahl & Fairbanks, 1986). Findings also begin to show that its use can support several of the "highly cited practices" for science and mathematics instruction for students who are deaf or hard of hearing (Easterbrooks & Stephenson, 2006). For example, building on research conducted by Lang, et al. (2007) showing that conceptually accurate signing in science was able to provide greater science understanding, teachers who use the SMD may be able to integrate more conceptually accurate signs for mathematics terms into their math instruction to provide greater mathematics understanding (Practice 1: Teacher as Skilled Communicator, Practice 2: Instruction through the Primary Language). Also, use of multimedia technology may increase attention through use of imagery and promote retention during academic tasks (Easterbrooks, 2010).

Use of the Signing Avatar technology may increase motivation and engagement of students who are deaf or hard of hearing in the context of learning mathematics vocabulary and may support comprehension and retention during mathematics learning (Practice 7: Use of Technology). Use of the visual scaffolds that the technology affords when paired with printed English text, as well as revisiting information again and again, might help students who are deaf or hard of hearing develop a robust mathematics vocabulary and, subsequently, better knowledge of mathematics concepts (Practice 10: Mediating Textbooks).

Recommendations for Future Research

These findings should be viewed with circumspection. Further qualitative and quantitative research is needed to explore use of the Web-based SMD and of the mobile app version for multiple math units, for an entire year, and from grade to grade in mainstream and specialized settings as well as in informal settings, such as the home and after-school learning centers. Additional qualitative and quantitative research is also recommended to identify differences between students' mastery of vocabulary with and without use of the SMD. Outcomes for students when less-experienced teachers implement the tool also need to be examined. Only then will we begin to discover the true benefit that use of the innovation adds to the teaching and learning of mathematics for our audience.

Conclusions

Conducting case studies in these eight classrooms enabled the researchers to begin to see firsthand the challenges and obstacles that exist for deaf and hard-of-hearing students in the mathematics classroom. We were able to observe how and for what purposes teachers choose to integrate the SMD into their mathematics teaching and gained insight into how interactive digital dictionaries such as the SMD can affect teaching and learning. Although these studies provided important information about the implications that the SMD can have for mathematics instruction and achievement for this audience, additional research in a wide range of settings is needed to explore and assess the dictionary's full potential.

The SMD is available as a CD that can be used as a standalone tool without an Internet connection (http://www.vcom3d.com/index.php?id=smdictionary). It is also available as a Web link for use with an Internet connection (http://signsci.test.terc.edu/math/index.htm) and as an app for use with the iPod touch (http://signingapp.com/smd_desktop.html).

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