

# **The Role of American Sign Language(ASL) in Paired Deaf Signers' Mathematics Learning through Computer Games**

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## ***Abstract***

Many researchers have investigated how hearing kindergarteners explore technology-based tools (e.g., mathematics computer games) and interact with each other while playing computer games. However, we still know very little about how deaf kindergarteners interact and sign with each other while using technology-based tools. We conducted a case study of paired deaf signers learning number concepts playing mathematics computer games. We observed three different pairs for five months and videotaped sessions between two signers working on on-line mathematics computer games. The paired students' American Sign Language competency was found to be critical for deaf kindergarteners' interaction to solve mathematical questions such as number concepts. Our findings also indicate that mathematics computer games can be a tool which can motivate deaf signers to communicate with each other and that in technology-based learning environments pairing would be a strategy to encourage deaf signers to interact with each other.

*Key words: computer games, deaf, interaction,  
kindergarten, mathematics*

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## I. Introduction

The National Research Council (2009) stated that developmentally appropriate early childhood mathematics education for very young children should start early in homes and child care centers depending on the children's cultural and linguistic backgrounds. Many researchers also indicate that understanding early mathematics is a strong predictor of later academic success (Duncan et al., 2007). However, there is clearly a big gap in academic performance between hearing children and deaf or hard of hearing children. For instance, when compared with hearing students' academic performance, many deaf and hard-of-hearing students show a significant delay in learning major subject areas such as English and Mathematics (Blatto-Vallee, Kelly, Gaustad, Porter, & Fonzi, 2007; Kritzer, 2009; Stewart & Kluwin, 2001; Traxler, 2000). According to data from the Stanford Achievement Test (SAT) administrations in 1974, 1983, 1990, 1996, and 2003, most eight-year-old deaf and hard-of-hearing students (normally third graders) achieved below the second grade level in both reading comprehension and mathematical problem solving; most eighteen-year-old deaf and hard-of-hearing students achieved below the fourth grade level in reading comprehension and below the sixth grade level in mathematical problem solving (Qi & Mitchell, 2012).

Deaf or hard-of-hearing students' academic performance is already lower than hearing students in the beginning of their school life, and their academic performance continues to be gradually and significantly lower than hearing students' although Qi and Mitchell (2012) pointed out the necessity of alternative assessment strategies (e.g., adding American Sign Language (ASL) presentation of test questions for the deaf) for obtaining more reliable and valuable assessment data sets of the deaf. Kritzer (2009) examined 28 four- to six-year-old deaf children's early informal/formal mathematical knowledge (i.e., word/story problems, skip counting, number comparisons, the reading/writing of two to three digit numbers, and addition/subtraction number facts) and found that more than fifty percent of them received scores significantly below average or behind normative age-equivalent scores on the Test of Early Mathematics Ability (TEMA-3). For

reliability and validity of the test, Copple and Bredekamp (2009) indicated that developmentally appropriate assessment tools are in need as Kritzer also explained that some test items could confuse or challenge deaf children. Thus culturally and linguistically appropriate instruction and assessment are needed for deaf or hard-of-hearing students in the beginning of or prior to their school life.

Since the American School for the Deaf (ASD) was founded in 1817, there has been at least one state-funded residential school for the deaf in most states (except for three states such as Nebraska, Nevada, and Wyoming). However, these schools face various challenges to recruit qualified teachers. For example, the No Child Left Behind Act (NCLB) of 2001 and the Individuals with Disabilities Education Improvement Act (IDEA) of 2004 require that teachers of deaf students need to have appropriate training, experience, and certification in the content they are teaching. In particular teachers of deaf students should be proficient in American Sign Language (ASL), as many deaf students' first language is ASL and the students receive classroom instruction through ASL (Easterbrooks & Stephenson, 2006; Mitchell, 2004). Many students who sign do have limited English proficiency as well (Bosso, 2008; Jones, 2008; Kelly & Barac-Cikoja, 2007), so many schools for the deaf have tried to focus on bilingualism (i.e., ASL and English) (McBurney, 2006) and hire both a deaf teacher and a hearing teacher who signs fluently to be equally responsible for classroom management and instruction and act as role models of ASL and deaf culture (i.e., deaf teacher) and English (i.e., a hearing teacher). This is especially common at the preschool and kindergarten level from our observation at a school for the deaf.

## **II. Mathematics Education for the Deaf**

In spite of the movement of Mathematics Education reform of deaf and hard of hearing students (Pagliaro, 1998), many mathematics teachers for the deaf students tend to focus more on drill and practice exercises than on true problem solving (Kelly, Lang, & Pagliaro, 2003). However, the mathematics teachers for the deaf may deal with the daily

challenges of a variety of deaf child/children's language competency of ASL and/or English and the competency of content knowledge (e.g., mathematics) when they instruct mathematics to the deaf children at school. Additionally, some deaf students may have additional challenges such as medical conditions related to the cause of their hearing loss and other multiple disabilities (Marschark et al., 2002).

Although the National Council of Teachers of Mathematics (NCTM) emphasized both content and process standards in mathematics education from Pre-K to 12<sup>th</sup> grade (NCTM, 2000), several studies of mathematics education for the deaf show the importance of process standards (Kelly, Lang, & Pagliaro, 2003). Considering the NCTM process standards, mathematics teachers for the deaf can be active in their instruction. For instance, Pagliaro and Ansell (2002) stated that mathematics teachers for the deaf could use visualized authentic examples using problem-solving skills in their instruction because many deaf children use these skills when they solve word problems. In addition, Easterbrooks and Stephenson (2006) analyzed ten of the most cited research papers on how to educate deaf or hard-of-hearing students about mathematics and addressed six recommendations for mathematics teachers. In sum, they suggested that mathematics teachers for the deaf should have competencies in mathematics content knowledge, appropriate pedagogy, and ASL. Specifically, if teachers observe any gap in deaf students' content knowledge (i.e., mathematics), they need to use scaffolding techniques including tools such as graphs, charts, visual maps, and graphic organizers because deaf children are visual learners. Thus the way of educating deaf children mathematics should be concrete and visualized. It is necessary for educators to think about diversity and flexibility in teaching strategies and educational tools for deaf children.

Computer-assisted instruction has been investigated and found to be effective for teaching mathematical skills to hearing children in the early grades (Clements, 1997, 2007; National Mathematics Advisory Panel, 2008). Many researchers have proven that the use of technology can assist young children to learn number concepts effectively (Clements et al., 2004; Park, 2012). In addition, both the NCTM and the National Association of Educating Young Children (NAEYC) have

made it clear that a learning area with computers equipped with developmentally appropriate content such as computer games is necessary for young children to expand their knowledge in mathematics. It can be assumed that the effective use of mathematics computer games would also be beneficial for deaf children to aid in their learning of number concepts. For example, text and graphics used in such games are important visual representations for deaf kindergartners.

Technology has influenced changes in both deaf school educators' teaching styles and deaf children's learning styles. Individuals with Disabilities Education Act (IDEA) defines "assistive technology devices" as tools for "increasing, maintaining, or improving functional capability of individuals with disabilities (p. xiii)" (IDEA, 2004). Many studies of deaf students have shown that assistive technology (e.g., computer use) can provide benefits to their lives and learning (Bowe, 2007). On-line mathematics tools have been designed to offer a rich virtual learning experience for deaf or hard of hearing students. For instance, there are on-line mathematics games with American Sign Language focusing on number and operations and 3-D simulated mathematics experiences for deaf or hearing impaired elementary students (Adamo-Villani, Doublestein, & Martin, 2005). The games and their use in the study showed the importance of visualization in the learning of deaf students. However, many developers of on-line mathematics tools have focused on upper elementary grade level students instead of the primary graders such as kindergartners. In general, there is little known about how paired kindergartners with deafness or hearing impairments interact with each other while using computer-based mathematics instructional materials, nor have there been specific descriptions and satisfactory methods of helping deaf or hard of hearing students overcome their learning difficulties by characterizing their unique learning habits.

Clements and his colleagues developed a research-based mathematics curricula from their "Building Blocks Project" (from Pre-K to grade 2) using the scientific process: (a) setting up objectives, (b) designing a curriculum and software based on theory and research (Clements et al., 2004), (c) scientifically testing the curriculum and software in a pilot test (Clements, 2007), and (d) producing the

materials and retesting the products on a large scale (Clements & Sarama, 2007a). The materials consisted of print curricula, computer games, and hands-on manipulatives which were linked together according to content area (mainly number and geometry). This curriculum was published as a package called *Real Math* and was targeted to students in Pre-K through 2<sup>nd</sup> grade (Clements & Sarama, 2007b).

In this case study, we decided to use the preschool and kindergarten leveled mathematics computer games, a part of *Real Math*. The instrument (the computer games) contained research-proven learning materials for hearing students, not for the deaf, so the computer games did not provide an ASL option, only simulation with verbal direction. We carefully selected several developmentally and intuitively appropriate computer games from among the computer mathematics games for deaf kindergarteners. The games are *Number Snap Shots*, *Build Stairs*, and *Build a Bridge*, which consist of introductory, intermediate, and advanced level.

### III. American Sign Language (ASL)

The theoretical framework of this study is Vygotsky's social interaction, in which we use as a lens to analyze the interaction of deaf kindergartners in the context of learning mathematics and how their social interaction affects their understanding of number concepts as they play with mathematics computer games in pairs. Their interaction while using mathematics computer games can create opportunities to collaborate with a partner to form a deeper understanding of number concepts. The proper form of social interaction with cultural tools for the deaf (in this case, computer games and ASL) may improve their learning experiences of number concepts. For proper interaction in learning number concepts, ASL communication plays a major role for the deaf kindergartners. Some researchers have indicated that competency in mathematical communication is significant to the success of mathematical learning (Fisch, 2008; Sfard, 2001), and the importance of mathematical communication is already addressed by

NCTM (2000). In order to communicate meaningfully, deaf children need competency in ASL as an interpersonal communication tool.

#### **A. ASL as an interpersonal communication tool**

ASL is the language used in the deaf cultural context in the United States. In this study, it is important to understand the differences between ASL and English because the participants (i.e., deaf kindergarteners) used ASL rather than English for communication while they played the computer games. ASL can be defined as a visual/gestural language that uses not only hands but also facial expressions, arms, and specific positions of neck and upper body parts.

*In ASL, the symbols are specific hand movements and configurations that are modified by facial expressions to convey meaning. These gestures or symbols are called signs. ASL, formed of a fusion between sign languages already in existence (including the imported French Sign Language), did what most languages do: it evolved. (Tennant & Brown, 1998, pp. 9-10)*

It is important to recognize the significance of signs and gestures in the daily lives of deaf people, including their learning environments. In order to interpret the culture of deaf education, the child who has the primary disability can experience a completely different process of development and learning depending on the social context (i.e., within the deaf school using ASL vs. within the inclusive setting using only English as a tool; Bodrova & Leong, 2007). From Vygotsky (1986)'s point of view, sign language should be one of the alternative communication tools for deaf children and it should be mastered by deaf children. In addition, "Vygotsky was acknowledging that sign language is a natural means of inter-personal communication among deaf people and, as a result, one of the means of acquiring social experience" (Zaitseva, Pursglove, & Gregory, 1999, pp. 9-10). Therefore, many schools for the deaf aim for "bilingualism" (i.e., learning both ASL and English), including the school for the deaf where we collected the data.

### B. Numbers in ASL

ASL is different from English in terms of expressing number systems, as the grammar in ASL (e.g., ASL grammar historically affected by French) is enormously different from English. For instance, for the number and mathematical system in ASL, there is the difference between number patterns in ASL and hearing children's finger counting skills. Many hearing preschool or kindergarten students use ten fingers (two hands) for finger counting strategy up to ten, but many deaf kindergarten students use only five fingers (one hand) for counting up to ten. In other words, instead of using each finger for one-to-one correspondence from one object to ten objects, small numbers (i.e., one to ten) in ASL are represented using a symbol for each number (see Figure 1.).

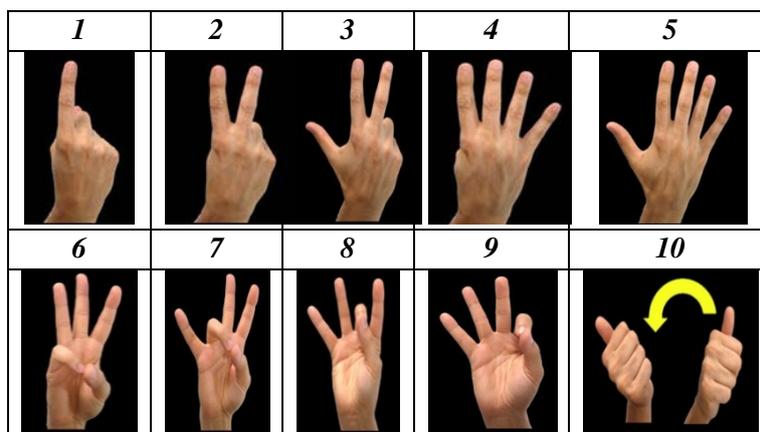


Figure 1. ASL Number Chart from one to ten (Retrieved on October 20, 2014, from <http://www.lifeprint.com/asl101/pages-signs/n/numbers.htm>)

There are very few studies of how deaf children apply number patterns in ASL to solve mathematical questions in using a technological tool. Thus, the purpose of this case study is to describe how ASL competency level affects characteristics of interpersonal communication of paired deaf kindergarteners in exploring on-line mathematics games.

## **IV. Methodology**

### **A. Research questions**

In this study, the main research question is how deaf kindergartners use ASL to explore on-line mathematics computer games (focusing on number concepts). There are two research questions:

1. What are characteristics of interpersonal communication of paired deaf kindergartners in computer-supported collaborative mathematics learning?
2. How does ASL competency level affect the characteristics of interpersonal communication in computer-supported collaborative mathematics learning?

### **B. Subjects and settings**

This case study was conducted at a school for the deaf located in an urban area in the Midwestern United States. Parents of thirteen students agreed to allow their children to participate in the study, but because ASL competency is a significant factor in the students' interaction for this study, we selected only six target students. For target students' ASL competency level, based on the informal interview about target students' head teachers, we grouped the students into three different groups (see Table 1). For instance, among six target students, the students with highest ASL competency belonged to Group A, and the students with lowest ASL competency belonged to Group C. Group B was in the intermediate level between Group A and C. Based on initial outcomes using online mathematics games related to number concepts (i.e., a part of *Real Math*), we also categorized individual child's mathematics competency levels.

Table 1. Students' background

Name	Group	Deafness/ Hard-of-hearing	Mathematics Competency	ASL Competency
Amy	A	Deafness	High	High
Beth		Deafness	Intermediate	High
Cathy	B	Deafness	High	Intermediate
Deborah		Deafness	Intermediate	Intermediate
Eva	C	Deafness	Intermediate	Low
Frank		Hard-of-hearing	Low	Low

### C. Data collection and analysis

The data were collected for two times a week over a five-month period in the school library, which was a space within the school that the children were accustomed. At the site, we set up three camcorders, one flat-screen television set, and one video mixer which captured the participants' facial expressions, upper body parts, and hand gestures while simultaneously videotaping the computer screen of the on-line mathematics games. At that time, each pair played the on-line mathematics games for number and operations parts of the *Real Math* curriculum. Each pair spent 20 to 30 minutes for each session.

The data was analyzed collaboratively with the target children's classroom teachers (as assistants to help children play games) and one ASL interpreter, reviewing transcripts and videotapes (e.g., what each child signed during each session) to obtain insight on each session through triangulation. All the transcripts were read and coded by hand according to coding methods suggested by Huberman and Miles (1994). For instance, three people (two authors and one ASL interpreter) discussed our respective coding schemes and any discrepancies. We identified the factors (e.g., the children's most frequent ASL expressions and gestures) jointly after reflecting on the discussion and reviewing the video clips for Group A, B, and C from each session. There were complete transcripts for 15 sessions of this study, including 80 video clip segments. The data were coded using factors and themes that were common in the on-line mathematics games.

## V. Results

The results from the qualitative data analyses revealed three common themes of the paired deaf kindergartners' interaction for the first research question. For the second research question, we described how the level of ASL competency affected the characteristics of interpersonal communication. To answer the first research question, we summarized the data in table 2 below. We found that there were three types of interaction: spontaneous correction, challenges of understanding the content of computer games, and various ASL number patterns while playing the computer games.

Table 2. Types of Interaction and their turns

Types of Interaction	Group A	Group B	Group C
Showing spontaneous correction	60 times	35 times	5 times
Showing challenges of understanding computer games	20 times	30 times	50 times
Showing various ASL number patterns	65 times	35 times	0 times
Total	145 times	100 times	55 times

### A. Showing spontaneous correction

Spontaneous correction patterns occurred when children spontaneously corrected each other's errors of mathematical problems or questions from the on-line mathematics games. Many more patterns of spontaneous correction were observed in Groups A (60 times in turns) and B (35 times) compared with Group C (5 times). Turns were coded according to the order in which conversation takes place. The paired kindergartners from Group A (high level of ASL) and Group B (intermediate level of ASL) spontaneously corrected their partner's errors (e.g., about counting or addition problems). This pattern was the most frequently observed in the sessions. We selected three segments from Group A, B, and C to show the differences in mathematical communication.

**Group A**

The Computer Game: Number Snap Shots

Task: Selecting one of five choices: matching a picture which contains the same amount of dots or number with the picture from the camera

On monitor, the digital camera screen showed the image of one index finger from one hand and one index finger, one middle finger, one ring finger, and one little finger from the other hand.

Amy: [gestures to monitor] FIVE (points; "here")

Beth: My turn!

Amy: [nodding her head] Okay!

Beth: [clicking the choice with four dots]

Amy: [frowning, pointing at the right choice which has five dots] [pointing at the choice with four dots] It is four. [pointing at the choice with five dots] Five. [off-screen] NO, NO, FIVE!

Beth: [when the screen shows both choices and the image of fingers] [one hand] ONE [same time other hand] FIVE [holds the hands together] [FIVE hand changes to FOUR]

Amy: "Hey, hey," FIVE. [one hand] FIVE [same time other hand] ONE [quickly making FIVE hand correction to FOUR] ONE MORE FIVE.

Beth: ME KNOW ("I know!")

Amy: WRONG ("you'll be wrong")

Beth: [shaking head] [mouthing] "no" ("No, I will not!")

Amy: "Hey," ME-SAID WRONG, ACCIDENT ("I didn't mean to tell you you'd be wrong, it was a mistake") MISTAKE, MISTAKE.

**Group B**

The Computer Game: Build Stairs

Task: Creating missing stairs for a mouse to reach up to the food on the table

New game started with the missing stair, the seventh.

Deborah: [without counting stairs, looking for the number which

can be matched with the missing stair, the seventh stair]  
[clicking the number, 2]

Cathy: [shaking head] (“no”)

Deborah: [counting each stair using ASL counting skills] One, two, three, four, five, six, seven! Seven! Seven!

Cathy: [at the same time, with her index finger, pointing at the sixth stair and the missing space for the seventh stair] “Here.” [counting each stair using ASL counting skills] One, two, three, four, five, six, seven!

Deborah: [on monitor, clicking the number, 5]

Cathy: [in the meantime, counting each stair using ASL counting skills] One, two, three, four, five, six, seven! Seven! Seven! Seven!

Deborah: [looking at Cathy’s sign for the number, 7]

Cathy: SEVEN! (“it is seven”) SEVEN!

Deborah: SEVEN, YES! [clicking the number, 7]

### **Group C**

The Computer Game: Build Stairs

Task: Creating missing stairs for a mouse to reach up to the food on the table

The Screen shows the missing stairs such as the fourth, fifth, and sixth stairs to the table with food and also shows choices of the stairs.

Eva: [pointing at the fourth stair from the choices using her index finger]

Frank: [standing up and closely watching the choices] [moving his mouse] [pause]

Eva: [pointing at the fourth stair from the choices using her index finger again]

Frank: [clicking the choice, the fourth stair first] [later on, clicking the sixth stair and dragging it to the missing spot for the fourth stair] [when his choice moves back to the choice area, looking at Eva]

Eva: [with her index finger, pointing at the choice, the fourth

stair] [when Frank failed to grab the choice, the fourth stair, holding his mouse and moving the fourth stair to fill in the missing spot below] [suddenly turning around and asking her teacher to move her choice]

Teacher: [clicking the fourth stair and filling it in the missing spot below]

From the entire sessions, Amy almost always tried to communicate with Beth and help Beth count correctly using ASL, which includes ASL counting skills. Group B showed a similar pattern to Group A. The peer who was more knowledgeable about number concepts, Cathy, helped the less knowledgeable peer, Deborah, to count correctly. Compared with Group A and B, Group C did not show much communication using ASL. The peer who was more knowledgeable about number concepts, Eva, tried to help Frank select the correct choice, pointing at the right answer using her index finger, but neither of them used ASL. They often asked for the teacher's help instead of solving the tasks with their partner. Therefore, the students' ASL competency level affected their spontaneous communications. Groups A and B communicated with each other using ASL and used ASL for solving math tasks. As a group, they used ASL frequently to help their partners count accurately. Group C did not use ASL much although the more advanced partner tried to help the other.

### **B. Showing challenges of understanding computer games**

There was no ASL direction of the games. There were several counting and addition games which were appropriate for hearing children's counting patterns, not for the deaf children. Thus the deaf kindergarteners could not clearly understand the game directions and faced the challenges from the games. At that time, paired kindergarteners' interactions occurred to deal with the challenges. Group A (20 times), Group B (30 times), and Group C (50 times) showed challenges understanding the content of computer games. For instance, one of the interesting results was an interaction from Group A. As shown in the segment below, Amy had difficulty understanding the

math question in the Number Snap Shots game even though she had the most advanced ASL competency and highest Mathematics competency.

Amy: [When the image from the digital camera on the screen disappears and five multiple choices appear, **looking above the monitor with a frown [long pause]** [one hand] THREE [same time other hand] ONE [showing Beth three fingers from one hand and one finger from the other hand, after that, showing four fingers using one hand] FOUR ... FOUR (“it’s four”) [after that, counting her four fingers on the right hand using her left hand using ASL counting skills]

Beth: [clicking the choice which has four dots to match the four fingers from the image on the digital camera] [when the image of fingers and the choice were shown, looking at down her fingers using two hands] [one hand] THREE [same time other hand] ONE

Computer: [highlights the choice of number 4 as the right answer]

When the game showed the hand images for a simple addition question, most of the paired deaf kindergarteners paused for a moment. Although Amy was the more advanced student in Group A, she was confused at first (see the bold words from the segment above.) when she saw the image of fingers on the screen (see figure 2). In the ASL counting system, the image means  $1 + 6$ . Thus 7 is the right answer based on numbers in ASL, but there was no choice of 7 among the multiple choices on the screen.

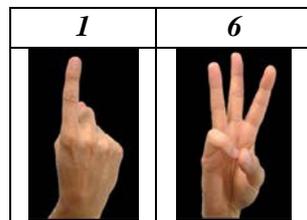


Figure 2. 1 and 6 in ASL Number Chart

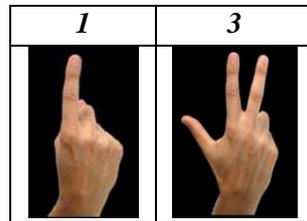


Figure 3. 1 and 3 in ASL Number Chart

From our previous observation, hearing students did not hesitate to select the option with four dots as the right answer in that situation, but we assume that the deaf kindergartners need to spend extra time and think about two situations (see figures 2 and 3) to figure out the answer after looking at the images of fingers. That is why Amy showed her finger patterns like figure 3 to Beth although she saw the finger patterns like figure 2. This means that Amy already thought about two different patterns for the images (i.e., one from ASL and the other from hearing children's finger counting patterns). As a much more knowledgeable peer, Amy helped Beth, the less knowledgeable peer, understand the finger addition question. Although the content of the games challenged the deaf students' thinking process, Amy, the more knowledgeable peer, was eventually able to distinguish between hearing children's finger counting system and numbers in ASL and help Beth, the less knowledgeable peer.

### C. Showing various ASL number patterns

Four target students (i.e., Group A and B) showed new ASL number patterns in playing on-line computer games. While playing the computer games, the students from Groups A (65 times) and B (35 times) frequently showed various ASL number patterns when they communicated with each other. In order to explain the changes, we selected a segment that illustrates the case of signing general number patterns like Figure 1 and a segment that illustrates the case of signing changed number patterns. Intermediate and advanced ASL groups (i.e., Group B and A) frequently showed general ASL number patterns in their interaction, but Group C did not. The four children in Groups A

and B frequently used regular ASL number patterns as they played the computer games, as shown below.

Case 1: A new game started with the missing stair, the sixth. The students need to find out the number, 6, which can be matched with the quantity of the stair which consists of six boxes.

Cathy: [touching Deborah's lap gently, numbering in ASL from one to six, and then showing her sign of "six" to Deborah] [to self] ONE, TWO, THREE, FOUR, FIVE, SIX ... [at the computer table] SIX! Your turn! [looking at Deborah]

Deborah: [after looking at the mouse going up to the table] ONE, TWO, THREE, FOUR, FIVE, SIX [with a big smile] ... "Yeah."

The children in Groups A and B also showed frequently modified number patterns in ASL when they interacted with each other in the context of mathematics computer games, touching the screen with one finger and simultaneously moving the other fingers in the air for numbering from one to ten in ASL.

Case 2: A new game started with the missing stair, the seventh.

Deborah: [without counting stairs, looking for the number which can be matched with the missing stair, the seventh stair] [clicking the number, 2]

Cathy: [shaking head - "no"]

Deborah: [counting each stair using ASL counting skills] One, two, three, four, five, six, seven! Seven! Seven!

Cathy: **[at the same time, with her index finger, pointing at the sixth stair and the missing space for the seventh stair] "Here." [counting each stair using numbers in ASL] One, two, three, four, five, six, seven!**

Deborah: [on monitor, clicking the number, 5]

Cathy: [in the meantime, counting each stair using ASL] one, two, three, four, five, six, seven! Seven! Seven! Seven!

Deborah: [looking at Cathy's sign for the number, 7]  
Cathy: SEVEN! ("it is seven") SEVEN!  
Deborah: SEVEN, YES! [clicking the number, 7]

Thus, two different ASL numbering patterns were observed. Compared with hearing students' counting skills, many focal students frequently used one hand for signing small numbers in ASL. The most interesting thing was that four of the focal students created modified ASL number patterns such as counting by a set and pointing at each set using one finger on the screen simultaneously. For instance, although Cathy used the general ASL number patterns in many cases when she counted up to six, her finger pattern of 6 from ASL was not the same. Her thumb did not touch the little finger for 6 in ASL which she was supposed to do. Her little finger touched the image of a set of 6 objects on the screen and her thumb did not touch either the screen or the little finger.

## VI. Discussion

Groups A and B showed frequent patterns of correction, but Group C did not. The paired students who have high and intermediate ASL competency helped each other understand the number concepts, but the paired group with low ASL competency did not. As a communicative tool, ASL was critical for the paired kindergartners' interaction. For instance, as a more knowledgeable peer of mathematics competency from Group B, Cathy helped Deborah correct her miscounting. When Deborah just guessed and said "ten" without counting visual objects instead of the right answer, "eight," Cathy demonstrated how to get the right answer using ASL number patterns and touching each image on the monitor. As Vygotsky (1978) points out, it indicates that a child like Deborah can reach a higher level of the zone of their understanding of knowledge with appropriate assistance from a much more knowledgeable peer like Cathy than by herself. However, in the beginning of the study, correction between the paired kindergartners did not happen automatically. Many deaf kindergartners need time to

understand how to interact with each other in a computer area. We found that the target deaf kindergartners gently tapped or touched the partner's lap or shoulder with one hand when they wanted to communicate with each other in ASL. During the data collection period, sometimes a kindergarten teacher or teacher's assistant guided the paired kindergartners to interact gently with each other in ASL. Thus, we think that the classroom teacher needs to teach students how to communicate with each other with good attitudes in ASL before they begin solving mathematics questions when they play mathematics games.

Findings from the current study support the possibility suggested by Easterbrooks and Stephenson (2006) that the teacher needs to use a variety of authentic mathematics problems in promoting deaf students' higher-order critical thinking and problem-solving skills and that teachers need to use scaffolding techniques including tools such as graphs, charts, visual maps, and graphic organizers because deaf children are visual learners. The graphic images used for the computer games can be good examples, but one of the results of this study was that the image of fingers for addition questions can confuse deaf kindergartners because of the difference between hearing students' finger counting strategy and ASL number patterns. Amy, who had high mathematics and ASL competency, could distinguish between hearing students' finger counting strategy and ASL number patterns after some initial confusion. Kritzer (2009) mentioned that "deaf children (regardless of their parents' hearing status) have less constant exposure to information" (p. 418). This finding may imply that the content of computer games should be appropriate for deaf language and culture. Nevertheless, the computer games used for hearing students might help deaf kindergartners think about multifaceted possible outcomes through confusion and comparison. Overall, the paired kindergartners in this study showed their basic interest in the computer games, signing to us, "I played a similar game before." Sometimes, they had a hard time figuring out how to play the game, especially *Build a Bridge* because the game rules were not presented or simulated using ASL but only verbal direction. One child "whispered" to the other partner that "it is for hearing people not for us." This implies that computer game

designers need to add ASL or simulation options for explaining the game rules for deaf or hard-of-hearing three to five year olds who have not fully developed English competency.

The certified ASL interpreter and mathematics teacher for the deaf, who translated our video data into English, mentioned that it is very striking that the target deaf kindergartners (Group A and B) used modified ASL number patterns for the computer games. The teacher said, "In my teaching career, this is the first time to observe their ASL number pattern changes with the computer screen. It is very interesting!" For example, for group B, two different ASL number patterns were observed. Both Cathy and Deborah used a regular ASL number pattern strategy at first at the computer table and later used a strategy of touching the monitor. At that time, Cathy was counting unit stairs (each column of a chunk of cubes) using ASL finger counting strategy. She did not count each box using her index finger.

We found that the main factor, ASL competency level, could be correlated with the frequency of social interaction. ASL competency level can affect paired deaf kindergartners' interaction including the frequency of correction between partners and understanding number concepts in a computer-based environment. This result supports the possibility suggested by Vygotsky (1986) that sign language is an "alternative cultural tool" for deaf children that they should master. ASL competency level could influence their social interaction and their understanding of number concepts. For example, although Qi and Mitchell (2012) indicate that deaf or hard-of-hearing students' academic performance in mathematics has been significantly lower than hearing students', the paired deaf kindergartners with high and intermediate ASL competency did not have any serious difficulty solving questions of number concepts from the Pre-K to early kindergarten level through the mathematics computer games, while the paired kindergartners with low ASL competency clearly had difficulty. This implies that improving ASL competency is necessary before the expected social interaction during mathematics education can occur in a computer-based classroom setting. When a teacher groups or pairs deaf kindergartners for the interactive computer games in a classroom, it is important to consider their ASL competency levels. Although we

made an effort to create the ideal pairing for the deaf kindergartners in the beginning of the study, it was hard for us to find many deaf kindergartners with advanced ASL competency among kindergartners. We dropped seven participants out of the original thirteen because of their low level of ASL competency.

## **VII. Conclusion**

At school, technology can be an effective tool for deaf students depending on how they are guided to use it and whether the appropriate content aligned with classroom instruction is selected. We need to further explore the potential of technology for the deaf as a teaching/learning tool in a classroom setting or in different pairing/grouping strategies. Physical settings such as Internet speed can present challenges when the mathematics games are online. Another challenge is turn-taking. Turn-taking in a computer area is a challenge even for hearing children. Thus Clements (1997) recommends a developmentally appropriate computer learning environment including at least one computer for two or three children and using a sign-up sheet and a clock to facilitate peaceful turn-taking. In the beginning of data collection, we observed that the paired deaf kindergartners showed a little bit of conflict of the turn-taking, so we set up a laptop with a USB mouse for each kindergartener in the pair. This strategy could be useful for future studies because it sparked the paired kindergartners to communicate with each other. With regard to technology use in learning environments, we need to address the necessity of educational policies for deaf children who show individual differences and individual needs (Marschark, Lang, & Albertini, 2002). Educational computer game designers need to take differences into account and adapt their products appropriately. For instance, they can consider ASL presentation or specific simulation options for the educational computer games. Furthermore, the pairing strategy for the deaf kindergartners in a computer area may provide insight into how deaf kindergartners explore computer-based learning environment of understanding number concepts through their ASL conversations.

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