Factors Predicting Recall of Mathematics Terms by Deaf Students: Implications for Teaching

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In this study of deaf high school students, imagery and familiarity were found to be the best predictors of geometry word recall, whereas neither concreteness nor signability of the terms was a significant predictor variable. Recall of high imagery terms was significantly better than for low imagery terms, and the same result was found for high- over low-familiarity and signability. Concrete terms were recalled significantly better than abstract terms. Geometry terms that could be represented with single signs were recalled significantly better than those that are usually fingerspelled or those represented by compound signs. Teachers with degrees and/or certification in mathematics had significantly higher self-ratings for the strongest predictor variables, imagery (visualization), and familiarity, as compared with those without such formal training. Based on these findings, implications for mathematics instruction, teacher education, and research are provided.

One of the emphases in the National Council of Teachers of Mathematics' *Principles and Standards for School Mathematics* (NCTM, 2000) is on the importance of teaching students to make connections between new mathematical concepts and prior knowledge as they solve problems. The national standards, as well as findings from research studies with deaf learners, have supported this emphasis and have led to the argument that mathematics should not be taught to deaf students as a discrete series of computational skills. Rather, an approach that emphasizes reasoning based on understanding of the content and follows a constructivist view of learning mathematics is likely to be more beneficial. As Kelly, Lang, and Pagliaro (2003) have summarized, "true problem solving activity" requires more than simple recognition and recall; it involves time spent on high quality and meaningful teaching/learning activities that build knowledge through critical thinking, reasoning, and the synthesis of various information and skills.

Although there is no comparable research conducted in the field of deaf education, Schoenfeld (2002), in a study of 40,000 hearing students in Pittsburgh, reported that minority hearing children (African Americans made up about 56% of the children in this study) and poor children performed much better in learning concepts and in problem solving in classes where the teachers strongly followed national standards in mathematics (NCTM, 2000) as compared to those in classes where the teachers were weak with the implementation of the standards. What is known in deaf education is that while teachers in residential/center schools for deaf students incorporate some reform-like methods in their teaching, traditional methods are still used, especially in the higher grade levels (Pagliaro, 1998a). A more recent study also showed that many deaf education classroom teachers do not base their instruction on national, professional recommendations (Pagliaro & Kritzer, 2005) and that increased reform is needed. These findings illustrate the need to examine both learner characteristics and teacher characteristics in the education of deaf students as we seek ways to enhance mathematics learning.

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It is a common practice in the education of deaf/hard-of-hearing students to assign mathematics teaching responsibilities to teachers who do not have degrees or certification in mathematics education (Kelly, Lang, & Pagliaro, 2003; Pagliaro, 1998b). Indeed, a number of studies have pointed to the need to address teacher preparation and qualifications. Kelly, Lang, & Pagliaro (2003), for example, in a survey of 133 mathematics teachers of deaf students, found that in integrated mainstream classes, 67% of the mathematics teachers had degrees in mathematics or mathematics education (as compared to only 15% in mainstream self-contained classes and 40% in residential/center schools). Seventy-six percent of the integrated class mainstream mathematics teachers held certification in mathematics education, whereas only 9% of those teaching mathematics in self-contained classes and 39% in residential/center school programs held mathematics education certification. The responses of the certified mathematics teachers in several studies support the notion that preparation and certification in mathematics makes a difference in instruction, particularly in the kinds of word problem-solving challenges provided to deaf students. Kelly, Lang, & Pagliaro (2003) found that regardless of instructional setting, deaf students are not being sufficiently engaged in cognitively challenging word problem situations. Pagliaro and Ansell (2002) also found that those teachers with at least some mathematics preparation tended to provide their students with more opportunities to solve story problems.

Other studies recommend changes in teachers' mathematics instruction in order to improve student learning (Kelly & Mousley, 2001; Kelly, Lang, & Pagliaro, 2003; Kelly, Lang, Mousley, & Davis, 2003; Pagliaro & Ansell, 2002). Kelly and Mousley (2001) summarized that factors explaining deaf students' poor problem-solving performance other than reading comprehension of the word problem text include computation errors (rather than procedural errors), leaving word problems blank, and a negative, disengaged approach to the word problem solving tasks. They stressed that teachers of deaf students need to emphasize the complete problem-solving process including the analytical and evaluative components. In a study of relational language in arithmetic compare problems, Kelly, Lang, Mousley, and Davis (2003) concluded that teachers need to provide practice for a greater variety of representational strategies (both written and graphic), multiple-step problems, and increasingly complex compare problems with a variety of comparative language. Pagliaro and Ansell (2002) also discussed general cognitive skills and experience with problem solving as possible reasons for deaf students' poor performance in mathematics in comparison to hearing peers, suggesting that teachers include more problem solving in their instruction as the basis for constructing mathematics knowledge. Such research on the relationships of instructional emphases to problem solving skills development in deaf learners and retention of vocabulary and their meanings might particularly advance our understanding of effective pedagogy.

Memory and Learning Mathematics

The constructivist perspective in learning mathematics and problem solving emphasizes the importance of both short-term (working) memory and long-term (semantic) memory. The quality of the input into working memory and of the operations that take place help determine a student's success as a problem solver, as does the ability to move information from short-term to long-term memory and to "unpack" the information when needed. Critical limitations of working memory include the small number of pieces of information it can handle at once and the short duration of time during which information can remain there (Borich & Tombari, 1997). Semantic memory, on the other hand, is used to activate concepts during mathematical problem solving and to make a representation of these problems.

Marschark, Lang, and Albertini (2002) summarize a number of studies focusing on both working and semantic memory which have shown that deaf and hearing individuals may encode information in qualitatively different ways. Whether we are referring to knowledge of mathematics such as its conventions or the tools of logic and reasoning, often remembered and used for a short while, or lasting months or years and accessed for a wider variety of purposes, understanding the role of long-term memory and any similarities and differences between deaf and hearing learners is essential to good instruction.

In this study with deaf high school students, we chose four factors—familiarity, imagery, concreteness, and signability—to examine as predictors of geometry word recall as a measure of long-term memory. This would allow us to draw implications about concept learning and problem solving and the relationship these factors may have to teacher background variables such as formal preparation in mathematics education and experience with signing.

Sign Language and "Signability"

Marschark et al. (2002) summarize a number of ways that deaf learners may encode information. In terms of working memory, for example, deaf students who are signers often use sign language-based coding, which may be less effective than speech-based codes in some memory tasks. This relationship of sign language to memory is but one of many that should be considered when examining the roles of signing in effective pedagogy in the education of deaf students. For these students and their teachers, reasoning about mathematics not only includes the symbol systems inherent in English and mathematics but also often involves sign language. Various studies have indicated that the way teachers sign technical content have the potential to influence learning by deaf students. In one study, Ansell and Pagliaro (2001) examined sign language variations used within problem type. They discuss how the dynamic, visual nature of sign language can clarify the relationships and/or actions depicted within a problem situation while, at the same time, caution that changes in problem type may result from the interaction of sign language features and teachers' choices which may in turn limit the types of problems deaf students are given to solve. Their findings raise important issues about the preparation of teachers in translating arithmetic word problems into sign language.

Still another aspect of using sign language was studied by Lang et al. (2007). They discuss how the signs teachers select and use in the classroom may be influenced by the teachers' content knowledge. In general, the more familiar teachers are with the content, the more likely they are to adopt ways of signing or explaining the etymologies of signs with conceptual accuracy. Such familiarity appears to be an important factor in the use of visual language in facilitating the construction of knowledge by deaf learners, and it is not surprising that content knowledge has been rated by deaf students as the most important characteristic of effective teachers (Lang, McKee, and Conner, 1993).

Several studies have investigated the relationship between signability of words and recall. In a series of eight study–test trials, Odom, Blanton, and McIntyre (1970) found significantly better recall by deaf students (mean age: 10.4 years) of signable than unsignable words. Conlin and Paivio (1975) examined signability in their study of the effects of visual and sign-based memory coding in a paired-associate learning task with 90 deaf participants between 15 and 17 years old. They found better recall for high- over low-signability words, as did Bonvillian (1983). In a study of words categorized as signable with a single sign, compound or combination of signs, or finger spelling only, Spencer, Dale, and Klions (1989) reported that deaf participants recalled significantly more single-signed words than compound/combination of signs. The deaf participants in this study also recalled more fingerspelled words than compound/combination signed words.

Imagery

In this study, we examine imagery as the ability to perceive mental pictures, not through the retina of the human eye but through the "mind's eye." The evocation of a mental representation when a word is read and a depiction of problems through mental representations of visual information are essential cognitive skills needed for problem solving in mathematics. In this sense, imagery serves as a "mental blackboard," an "active and dynamic information-processing event that can aid the learner in problem-solving activities, especially those that are representative of unfamiliar or novel situations" (Douville, Pugalee, Wallace, & Lock, 2002, p. 107). Douville et al. (2002) write that because mental imagery strategies have been found to assist hearing students in making connections between the abstract symbols of letters/words and concrete concepts within the reading process, "it follows that mental imagery strategies can also serve to help students concretize abstract mathematical concepts in ways that facilitate more effective problem solving" (p. 109).

Although it is widely accepted that imagery plays a role in processing information (concept development), the precise relationship between imagery and other cognitive processes is not well understood. In examining the role of imagery, researchers working with hearing children have explored the use of metacognitive strategies in the classroom in order to enhance meaning-making during learning and problem solving. This has included "induced imagery" strategies and the roles of representations in dynamic problem solving (Sadoski & Paivio, 2001). In mathematics education, imagery skills development, or "visualization" as it is often called, has been advocated extensively. Presmeg (1997) explains that there are visual images in a person's mind which guide the creation of a spatial arrangement (including a mathematical inscription) and that visualization includes processes of constructing and transforming both visual mental imagery and the inscriptions of a spatial nature inherent in doing mathematics.

There is a substantial body of research with deaf students that points to mental imagery as a predictor of long-term memory (Bonvillian, 1983; Conlin & Paivio, 1975; Fusaro & Slike, 1979). Significant advantages in memory are found for high- over low-imagery words (Bonvillian, 1983; Conlin and Paivio, 1975). As Marschark and Surian (1989) explain, Bonvillian's demonstration that imagery apparently played a lesser role for deaf participants in his free recall task than in the paired-associate learning task (cued recall) of Conlin and Paivio agrees with other studies indicating rated imagery to be a far better predictor of memory in cued recall than in free recall tasks. In a study by Fusaro and Slike (1979), 12 words were presented to 40 deaf participants through transliteration to an artificial alphabet to insure the participants' unfamiliarity with the written form of the words. Irrespective of age (which was significant as expected), high-imagery words had a significantly higher number of correct responses than both middle- and low-imagery words.

Based on the importance of imagery in the constructivist approach and the findings about teacher preparation in the education of deaf students, we not only examine the role imagery plays in predicting geometry word recall by deaf students in this study but also take initial steps to address one dimension of pedagogical research related to visualization—the teaching of imagery skills to deaf students. The actual teaching of imagery skills has long been advocated in classrooms for hearing students (Presmeg, 1997). Presmeg wrote that "the teachers who were most successful in the mathematical instruction of the visualizers in my study were those who not only used visual methods such as diagrams, color, pattern identification, and visual gestures, but who also emphasized—and encouraged students to construct—generalized principles in mathematics" (p. 309). Specifically, in this study, we examine whether teachers with and without formal mathematics content training and those with and without sign language experience differ in their self-ratings of imagery. This may lead us to future research on whether the desired deep-level connections can be facilitated in the classroom by teachers who are not trained in the content domain.

Concreteness

There has been little attention given to the effects of concreteness on memory with regard to deaf learners. Studies with hearing participants have presented mixed results (Ruiz-Vargas, Cuevas, & Marschark, 1996). The lack of research with deaf students is surprising in light of the importance of dealing with the abstract, symbolic nature of languages. In the context of this study, this includes English, American Sign Language (ASL), and mathematics. Generally speaking, Mayberry (2002) reports that although the ability of deaf children and adults to discover and use abstract symbols and to follow rules of logic may lag developmentally, there are no atypical patterns. A study of concreteness in this study seeks to expand the knowledge base in this area.

Familiarity

Similarly, there is a dearth of research on the role familiarity may play in regard to memory. Mayberry (2002) also reports that familiar words, whether signed or spoken, are more often recalled by deaf participants than unfamiliar words. This generally agrees with the "expertise effect" found across a wide range of domains, where "experts" are able to remember more domain-relevant material than novices (Brandt, Cooper, & Dewhurst, 2005).

Relationships Between Factors

Research with deaf learners has also pointed to possible relationships among some of these factors. Studies investigating imagery, as it relates to nonverbal language, may be important to mathematics instruction and problem solving. The work of Emmorey, Klima, and Hickok (1998) with mental rotation, for example, examined how ASL conveys spatial information. When spatial scenes are described from the perspective of the signer (the "narrator"), the viewer is often expected to mentally rotate the image 180° in order to correctly comprehend the description. In their study, they found that deaf ASL signers were more accurate when viewing scenes described from the narrator's perspective (even though rotation is required) than from the viewer's perspective (no rotation required). These investigators also found that signers did not show the typical mental rotation effect as they did with real objects. They conclude that habitual use of ASL can enhance nonlinguistic cognitive processes. Other studies have found improved visuospatial cognition in deaf native signers (Emmorey, Kosslyn, & Bellugi, 1993; Parasnis, Samar, Bettger, & Sathe, 1996). The development of mental rotation skills through instructional practices (virtual reality) has also been reported by Passig and Eden (2002).

In the education of hearing students, the development of the theory of semiotics regarding gestures and other signs in mathematics instruction presents another interesting connection between visual representations through signs and gestures and the process of visualization to encourage imageability (Kadunz & Strässer, 2004; Radford, Bardini, Sabena, Diallo, & Simbagoye, 2005; Radford, Demers, Guzman, & Cerulli, 2003). In a study by Radford et al. (2003), the authors write of the cognitive significance of the body. "Signs" (symbols) in mathematics and indexical and iconic gestures were found to reinforce or contradict what was being uttered by a teacher. In addition to key linguistic signs, they explain, comprehension was achieved through pointing gestures and the kinesthetic action of moving a pen along a graph. Their discussion of the hands as a "mediating tool" and how thinking is not only mediated by, but located in, the body, artifacts, and signs merit further investigation by researchers in the education of deaf students where sign language and spatial reasoning are primary elements of communication.

In summary, more is known about imagery and signability as they relate to memory and deaf learners as compared to concreteness and familiarity. In this study, we first examine these four factors in terms of how well they predict geometry word recall by deaf high school students. We then investigate how high school teachers view their own perceptions of the technical vocabulary in terms of these factors. Specifically, this study sought to answer the following research questions:

1. To what extent does familiarity, concreteness, imagery, and signability of mathematics terms relate to recall by deaf high school students?
2. Do deaf and hearing teachers with and without formal preparation in mathematics differ in their recall of mathematics terms and their self-ratings of the predictor variables?
3. How do teachers and deaf students compare with regard to their recall of mathematics terms and their self-ratings of the predictor variables?

Methodology

Seventy-five teachers and 18 high school deaf/hard-of-hearing students participated in the study. The 18 high school students were enrolled in two residential programs in the Northeast. All were presently in, or had previously studied, geometry. The mean age of these students was 17 years 8 months.

Teacher participation was elicited via emails to schools for the deaf, public schools, and teacher education programs at two universities in the Northeast. In order to test factors related to knowledge of mathematics and sign language, teacher participants with and without mathematics background and sign language experience were sought. Teachers were categorized as having a mathematics content background if

Table 1 Proportional analysis of sign type and geometry word recall

	Adjusted *M*	Adjusted SD
Single sign	6.22	1.70
GRAPH, SQUARE		
CIRCLE, DEGREE		
CYLINDER, FUNCTION		
PROPORTION, Y-AXIS		
RIGHT ANGLE		
Compound sign	4.10	2.61
IRRATIONAL NUMBER		
PARALLEL LINE SEGMENTS		
COMPLEMENTARY ANGLES		
COLLINEAR, CONGRUENT		
Fingerspelled	2.83	1.82
ARC, ACUTE		
RATE, PRISM		
FACTOR, ROTATION		

they had a baccalaureate degree or higher in the field of mathematics or mathematics education, and/or were certified in teaching mathematics. They were judged as having sign language experience if they had been using sign language for more than 5 years.

The participants were asked to view a PowerPoint slide presentation, during which each of 20 geometry terms was kept on the screen for 5 s. The terms used in this study were selected randomly from a list of 380 terms identified in high school geometry textbooks. The terms used are included in Table 1. All participants saw the slides in the same order. A 1-min distractor movie with no mathematics content was then viewed. Following this movie, the participants were given 5 min to list as many of the 20 mathematics terms as they could remember. Memory data included the total number of terms remembered out of the possible 20 terms.

Finally, the participants were asked to rate each of the 20 terms on four Likert scales, first for familiarity, next concreteness, then imagery, and finally signability. Familiarity was defined for the groups as how well they knew the meaning of the term (1 = no idea; 7 = very familiar). Concreteness was defined as a real or actual thing that can be grasped with the hands or seen with the eyes—and opposed to a definition of abstractness defined as an idea or concept in the mind—not a thing that can be touched (1 = very abstract; 7 = very concrete). Imagery was defined for the groups as the formation of mental pictures in the human mind. The participant was asked to what extent she/he agreed (1 = strongly disagree; 7 = strongly agree) with the following statement: "When I see this word, my mind develops a mental picture of it." Last, signability was defined as how easy it would be for the participant to use an appropriate sign for the term (1 = very difficult to sign; 7 = very easy to sign).

Analyses of variance (ANOVAs) and *t*-tests were performed to compare the student and teacher ratings and to determine if teacher background characteristics influenced their ratings.

Results

The estimates of reliability for all participants (teachers and students) for the familiarity, concreteness, imagery, and signability scales were r = .97, .89, .89, and .99, respectively. These were calculated using variances generated by ANOVA tables as described by Kerlinger (1973, p. 444).

Student Recall of Mathematics Terms

Table 2 shows the mean score and standard deviation for the number of words recalled by the deaf high school students. No significant difference was found in the memory data for the students from the two high schools, t = 1.61, df =16, p = .13; therefore, these data were combined for all analyses. Table 3 summarizes the regression analyses performed with memory as the dependent variable and familiarity, concreteness, imagery, and signability as independent variables. Imagery was found to have a significant but moderate positive correlation with memory (r = .61, R^2 = .37). Familiarity also had a significant, moderate positive correlation with memory (r = .56, R^2 = .31). Combining imagery and familiarity did not add any variance to the prediction of word recall (r = .61, R^2 = .37). It was concluded that imagery alone was the best predictor of geometry word recall for the deaf students in this study.

The mean ratings of the 20 geometry terms were used to define two groups of 10 terms making up "high imagery" and "low imagery" scales. The process

Table 2 Memory scores and self-ratings of familiarity, imagery, concreteness, and signability of students and teachers

	Hearing teachers		Deaf teachers		
	Mathematics	No mathematics	Mathematics	No mathematics	Deaf students
N	24	34	8	9	18
Memory	10.08 (2.50)	8.56 (2.95)	9.25 (2.32)	9.25 (4.17)	10.83 (3.84)
Familiarity	6.74 (0.44)	6.08 (0.81)	6.82 (0.29)	5.78 (0.79)	5.80 (0.79)
Imagery	5.72 (0.81)	5.26 (0.79)	5.92 (0.85)	5.33 (0.61)	5.40 (0.80)
Concreteness	5.04 (0.80)	4.85 (0.98)	4.22 (1.49)	4.34 (0.82)	4.13 (0.88)
N	7	20	8	9	
Signability	5.83 (0.63)	4.92 (0.68)	5.49 (0.75)	5.51 (0.56)	4.78 (0.76)

was repeated for the other three scales. Student memory for high imagery terms (M = 6.89) was significantly better than for low imagery terms (M = 3.94), t = 6.71, df =17, p < .0001. High familiarity terms (M = 7.11) were also recalled significantly better than low familiarity terms (M = 3.72), t = 7.36, df =17, p < .0001. Students recalled concrete terms (M = 6.56) easier than abstract terms (M = 4.28), t = 5.08, df = 17, p < .0001, and their recall for high signability terms (M = 7.22) was better than for low signability terms (M = 3.61), t = 7.88, df = 17, p < .0001. These four factors were not independent; that is, highly familiar terms had high imagery ratings (r = .830, p < .0001) and were also highly signable (r = .595, p < .01). Imagery also correlated significantly with signability (r = .673, p = .01).

The relationship between signability and memory was examined in a second way. Table 1 groups the 20 geometry terms as commonly represented as "single signs," "fingerspelled," and "compound signs," the latter defined in this study as a combination of either two signs (e.g., PARALLEL LINES + SEGMENTS), or one sign and finger spelling (e.g., I-R-R-A-T-I-O-N-A-L [fingerspelled] + NUMBER). Using a proportional analysis to adjust for unequal numbers of words in each category and repeated measures ANOVA, the 18 deaf high school students' recall of the terms represented by single signs was found to be significantly higher than that of terms represented by compound signs and by fingerspelled terms, $F(2, 17)$ = 6.59, p < .01. The difference in recall between fingerpelled terms and compound signs was not significant.

Teacher Memory and Ratings of Imagery and Familiarity

Table 2 also contains the mean scores and standard deviations for the number of words recalled by the teachers participating in this study.

Recall of mathematics terms. Of the 58 hearing teachers, 24 (41%) had degrees/certification in mathematics, whereas 8 of 17 deaf teachers (47%) had degrees/certification in mathematics. A 2 (mathematics background) × 2 (hearing status) ANOVA showed a main effect for both mathematics preparation, $F(1, 71)$ = 9.28, p < .01, and for hearing status, $F(1, 71)$ = 4.77, p < .05. A Fischer's post hoc analysis revealed that teachers with degrees/certification in mathematics

Table 3 Predictor variables for mathematics word recall

	Coefficients for predictor variables					Dependent variable (total word recall)	
Model	Intercept	Imagery	Familiarity	Signability	Concreteness	r	R^2
3.1	−4.877	2.906**				.61	.37
3.2	−4.974		2.722*			.56	.31
3.3	7.122			0.777		.15	.02
3.4	18.211				−1.785	.41	.17
3.5	−5.933	2.278**	0.767**			.61	.37

*p < .05 and **p < .01.

had significantly higher recall than those without formal training in the content area. Hearing teachers had significantly higher recall than deaf teachers. For this reason, we conducted the remaining analyses with hearing status as an independent variable.

Imagery and familiarity. To determine how the teachers compare in terms of their self-ratings of the two significant predictor variables (imagery and familiarity), a 2 (mathematics background) × 2 (hearing status) ANOVA factorial design was used to examine the data. This analysis revealed a main effect for mathematics background for both imagery, $F(1, 71) = 5.77$, $p < .05$, and familiarity, $F(1, 71) = 21.12$, $p < .001$. Teachers with mathematics degrees/certification appear to be better prepared to teach content, that is more familiar with the terms, and to develop visualization skills (imagery) in problem solving. There was no significant difference in ratings of the deaf and hearing teachers on these two predictor variables.

Concreteness and signability. Using a 2 (mathematics background) × 2 (hearing status) ANOVA factorial design, we also examined how deaf and hearing teachers with and without degrees/certification in mathematics compared on the concreteness and signability measures. For concreteness, there was a significant main effect for hearing status, $F(1, 71) = 6.07$, $p < .05$, but no significant difference related to mathematics training. Deaf teachers tended to rate the terms as more abstract than hearing teachers.

We did not include the hearing teachers without sign experience in the analysis of signability ratings. Of the 58 hearing teachers participating in this study, 27 (47%) had sign language experience. All 17 deaf teachers had sign language experience. Using a 2 (mathematics background) × 2 (hearing status) ANOVA with the sign-experienced teachers in this study to examine perceptions of signability of the 20 geometry terms, there was a significant main effect for mathematics background, $F(1, 40) = 4.14$, $p < .05$. Sign-experienced teachers with mathematics degrees/certification had a significantly higher mean than those without this formal training. There was also a significant mathematics × hearing status interaction effect, $F(1, 40) = 4.48$, $p < .05$. A post hoc analysis revealed that both groups of deaf teachers (with and without mathematics degrees/certification) and the hearing teachers with math degrees/certification had significantly higher signability ratings than the hearing teachers without mathematics degrees/certification.

All the deaf teachers in the study had sign experience, and sign experience could not be examined as a factor for them. The *t*-tests were conducted to examine differences between hearing teachers with and without sign language experience for word recall and for the ratings of imagery, familiarity, concreteness, and signability of the 20 terms. No significant differences were found except for signability. As expected, sign-experienced teachers rated the signability of the terms higher than the teachers without sign experience, $t = 5.86$, $df = 56$, $p < .0001$.

Comparison of teachers and students. A one-way ANOVA compared three groups (deaf teachers with and without mathematics background and deaf students) on mathematics word recall. A significant main effect was found, $F(2, 32) = 5.66$, $p < .01$. The deaf students were found to have significantly better recall than the deaf teachers with no mathematics background, recalling nearly twice as many words. No significant difference was found between the students' word recall and that of the deaf teachers with mathematics degrees/certification. Similarly, one-way ANOVAs were conducted to compare these three groups on their ratings of familiarity, concreteness, imagery, and signability. Post hoc analyses were conducted when significant F values were found. A significant main effect was found for familiarity, $F(2, 32) = 6.47$, $p = .01$. A Fischer's post hoc analysis indicated that the deaf teacher group with mathematics background had a significantly higher rating on familiarity than both the students and deaf teachers without formal mathematics training. There were no main effects found for imagery or concreteness. For signability, both deaf teacher groups were found to have significantly higher mean ratings than the deaf students, $F(2, 32) = 4.43$, $p < .05$.

The comparison of hearing teachers and deaf students was conducted with similar one-way ANOVAs with three groups (hearing teachers with and without mathematics background and deaf students). A significant main effect was found for recall $F(2, 73) = 3.74$, $p < .05$. The deaf students were found to have better recall than the hearing teachers with no mathematics degrees/certification. No difference was found between the students' recall and that of the hearing teachers with mathematics preparation.

Significant main effects were also found for familiarity, $F(2, 73) = 10.23$, $p < .0001$; and concreteness, $F(2, 73) = 5.63$, $p < .01$. For familiarity, Fischer post hoc analyses indicated that the hearing teachers with mathematics knowledge had significantly higher mean ratings than the deaf students and the hearing teachers without mathematics training. For concreteness, both hearing teacher groups, with and without mathematics degrees/certification, had significantly higher means than the deaf students. The students clearly tended to rate the terms as more abstract in comparison to the hearing teachers in this study.

There was no significant difference found in imagery ratings between the deaf students and hearing teachers. When signability ratings were compared between hearing teachers with sign experience and the deaf students using a one-way ANOVA with three groups (sign-experienced hearing teachers with and without mathematics background and deaf students), a significant main effect was found, $F(2, 42) = 5.80$, $p < .01$. Again, teachers with mathematics degrees/certification had significantly higher ratings than both teachers without mathematics preparation and the deaf students.

Discussion

The findings in this study must be discussed in the context of two assumptions. The first assumption is that mental imagery is important to learning mathematics and problem solving. The second is that mental imagery can be taught. As shown in our review of the literature, both beliefs are held by many experts. We will review the findings with these assumptions in mind and respond to the three research questions we posed earlier in this paper.

Research Question 1

To what extent does familiarity, concreteness, imagery, and signability of mathematics terms relate to recall by deaf high school students? The results of this study agree with those summarized in the literature review. That is, of the four factors examined in this study, imagery was found to be the best predictor of geometry word recall. Familiarity (content knowledge) was found to be a comparable predictor, but did not add substantially to the predictive ability of imagery. Neither concreteness nor signability was found through regression analysis to be a significant predictor of geometry word recall.

However, this study supports prior research by Bonvillian (1983) that terms represented by a single sign are recalled by deaf students significantly better than those terms which require compound signs or fingerspelling. High signability terms are easier to recall than low signability terms; the same was found for high imagery over low imagery, high familiarity over low familiarity, and concrete terms over abstract terms.

In a study with hearing students, familiarity and imagery were found to be significantly correlated to retention of technical vocabulary (Johnson & Hwang, 1983). Such research has yet to be conducted with deaf learners. These researchers reported that the hearing students' "learnability"of technical terms (percentage of correct responses on a randomly ordered multiple-choice comprehension test) was significantly correlated with imagery and familiarity. They summarized that, "Learnability of unfamiliar technical terms might be improved by providing some acquaintance with them before explicit instruction, by defining them in simple understandable terms and by using concrete terms high in visual, pictorial or sensory connotations" (p. 767). This may also be worth examining with deaf learners in mathematics.

In light of the predictive relationship of imagery to geometry word recall found in this study, we recommend more research to examine how imagery may be promoted through the use visual materials, especially when unfamiliar and abstract terms and concepts are being taught. The potential of sign language to enhance visualization skills should also be explored. When terms are fingerspelled or represented by compound signs, additional visual materials may also enhance memory.

Research Question 2

Do deaf and hearing teachers with and without formal preparation in mathematics differ in their recall of mathematics terms and their self-ratings of the predictor variables? Whereas the results of this study indicate that deaf and hearing teachers have comparable ratings for the factors that best predict word recall, that is, imagery and familiarity, a general comparison of all deaf and all hearing teachers in this study revealed a significant difference in geometry word recall. However, when comparing only those deaf and hearing teachers with mathematics certification/degrees, no significant differences in word recall or in the ratings of the strong predictor variables were found. The advantage of mathematics content knowledge was found consistently in the various analyses conducted in this study. The results here, thus, support previous research (Kelly, Lang, & Pagliaro, 2003; Pagliaro & Ansell, 2002) showing the importance and benefit of sufficient teacher preparation in mathematics and mathematics education.

Research Question 3

How do teachers and deaf students compare with regard to their recall of mathematics terms and their self-ratings of the predictor variables? The deaf students in this study had comparable word recall to hearing teachers with and without mathematics degrees/certification and to deaf teachers with mathematics degrees/certification. They had better recall than deaf teachers without mathematics degrees/certification. When only deaf teachers with mathematics degrees/certification were compared with students, no significant difference in word recall was found.

In examining these three research questions, we conclude that formal mathematics content preparation, through undergraduate or graduate degrees and/or certification, is of importance in terms of both word recall by teachers and their self-ratings of the significant predictor variables—imagery and familiarity. If these predictor variables are indeed essential to student learning and word recall in geometry, as this study has shown, then it is critical that teachers possess this formal training. As compared to teachers without mathematics content preparation, those with mathematics content preparation had better word recall, imagery, and familiarity ratings, and they were significantly more capable of signing the terms, the latter also having bearing on student word recall. Not requiring this content-related qualification for teachers responsible for mathematics instruction may jeopardize student learning.

Content knowledge and ability to sign content have been found to be important in other studies of effective teaching. Lang et al. (1993) and Lang, Dowaliby, and Anderson (1994) have summarized deaf students' perspectives on the relevance of these characteristics to their content learning and motivation to learn, respectively. In a study by Lang et al. (2007), teachers with content knowledge were found to have significantly better ability to reject conceptually signs that may not be conceptually correct. These findings and the relationship found in this study between sign type (i.e., single, compound, fingerspelling) and word recall also argue for avoiding out-of-field teaching assignments when possible.

Repeatedly, imagery has been found to be one of the best predictors of recall under different experimental conditions. As deaf students learn mathematics, their ability to recall prior vocabulary from long-term memory is a function, in part, of the imagery of the terms. Teachers with strong content knowledge, then, will likely facilitate the acquisition of mental imagery in their students with much more ease because they generally possess the ability themselves.

If imagery skills can and should be taught, as an increasing number of mathematics educators have advocated (Presmeg, 2006), then the results of the present investigation suggest that the effectiveness of teachers without formal content preparation to teach visualization skills should be a concern. Such research may have implications for out-of-field teaching assignments that remain a practice in both teacher education programs and in schools where there is a shortage of qualified teachers.

Regardless of the content preparation of teachers, teacher education programs and professional development coordinators should implement workshops and other offerings that prepare instructors with strategies that work to increase visualization skills and familiarity of content in order to enhance the students' ability to "unpack" concepts and words from long-term memory. As Johnson and Hwang (1983) advocated for teachers of hearing students, those educating deaf students should incorporate instructional strategies that promote the construction of knowledge through mental connections (schemata). Teaching new mathematics concepts and vocabulary, for example, should include making use of pedagogy that builds on prior knowledge and context and relates the new concept/word to a pictorial representation. For teachers of deaf students, when compound signs or finger spelling are used to represent mathematics terms, additional reinforcement through adjunct visual materials may improve recall. Instruction that takes into consideration the deaf learner's cognitive organization and development will likely increase understanding, performance, and ultimately achievement in mathematics.

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