A Study of Technical Signs in Science: Implications for Lexical Database Development

Harry G. Lang
National Technical Institute for the Deaf,
Rochester Institute of Technology

Mary LaPorta Hupper
Denise A. Monte
American School for the Deaf

Scott W. Brown
University of Connecticut

Ivar Babb
National Undersea Research Center,
University of Connecticut

Pete M. Scheifele
University of Connecticut

Both classroom instruction and lexical database development stand to benefit from applied research on sign language, which takes into consideration American Sign Language rules, pedagogical issues, and teacher characteristics. In this study of technical science signs, teachers' experience with signing and, especially, knowledge of content, were found to be essential for the identification of signs appropriate for instruction. The results of this study also indicate a need for a systematic approach to examine both sign selection and its impact on learning by deaf students. Recommendations are made for the development of lexical databases and areas of research for optimizing the use of sign language in instruction.

Studies of perceptions of the characteristics of "effective teachers" have shown that deaf students highly value an instructor's ability to use sign language clearly. This finding emerged in both a structured response study in which effective teaching was defined in terms of content learning (Lang, McKee, & Conner, 1993) and in a study based on unstructured responses (critical incident technique) in which the interviews with deaf students focused on effective teaching in terms of motivation to learn (Lang, Dowaliby, & Anderson, 1994). In the former study, both ratings and rankings of teacher characteristics revealed sign clarity as a top priority. In the latter study, the sign language skills of teachers appeared as the most frequently mentioned characteristic out of 33 characteristics emerging in the 839 critical incidents described in the interviews.

Student preferences for teachers who sign clearly are well documented and a growing body of literature is now available on the linguistics of American Sign Language (ASL). Furthermore, findings from research in science education for deaf students support student-centered, active or interactive learning with an emphasis on cognitive engagement (Lang, 2002; Lang and Steely, 2003). Little is known, however, about the dimensions of teaching through sign language, which may actually influence student learning in the classroom. For example, does sign selection by teachers (and interpreters) influence cognitive engagement and the construction of meaning in deaf students during a learning experience? Does the student's own selection/production of signs reflect understanding of the concepts represented by the signs, or is such selection more an arbitrary process? Are deaf students able to mentally repair signing errors made by teachers, interpreters, and peers during the course of lectures or classroom dialog? These are some questions that relate to pedagogy and the nature of signing.

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Teaching Through Sign Language

Research studies have identified several dimensions of signing that may influence learning in the classroom. These include the etymology of signs, signability, and

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imagery. Although there are other dimensions that may influence learning, a brief summary of some research on these three factors will serve well to introduce this study. Studies on etymology (origins or roots of a sign), signability, and imagery illustrate, in particular, that the selection and/or production of a technical sign, as well as how it is introduced to learners, may play a role in the student's later unpacking of the term or concept and its associated sign from long-term memory.

Maynard, Slavoff, and Bonvillian (1994) reported that hearing undergraduate students unfamiliar with ASL who received the sign etymologies while learning sign–word pairs demonstrated significantly better delayed recall than those who learned through sign motor rehearsal and those who received no coding instructions. If emphasizing clear motivational links to referents for technical signs help *deaf* learners unpack information from long-term memory, then teachers would do well to incorporate the approach into their instruction. Yet, until there is an adequate base of knowledge developed from research with deaf learners, the effectiveness of emphasizing etymologies as a teaching approach in the science classroom remains untested.

With regard to the signability and imagery of terms, Bonvillian (1983) found that deaf students' recall was better for words that had sign language equivalents and high imagery values. In another 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 subjects recalled significantly more single-signed words than compound/combination of signs. The deaf subjects in this study also recalled more finger-spelled words than compound/combination signed words. Similarly, in a study involving 20 geometry terms, Lang and Pagliaro (2006) found that deaf high school students recalled significantly more words categorized as signable with a single sign than compound or combination of signs, or finger spelling only. Mathematics terms with high imagery ratings were also recalled better than those with low imagery ratings.

Additional studies may reveal patterns in memory performance, which may influence the way teachers introduce concepts and how they promote student dialog in the classroom. In reviewing research on working memory, Marschark, Lang, and Albertini (2002) summarized that, overall, it is the use of memory strategies, not the modality (e.g., spoken language, printed word, ASL, total communication), that most influences deaf children's memory performance.

Sign Variation and the Development of Lexical Databases

Sign variation in the classroom has been recognized since the earliest days of formal education of deaf students in the United States. Not long after Thomas Hopkins Gallaudet and Laurent Clerc established the American Asylum (now the American School for the Deaf) in Hartford in 1817, the first state-sponsored residential school for deaf students in the United States, instructors there observed how students entering from different locales often brought unique signs, thus requiring adjustments by teachers and pupils alike (Lang & Stokoe, 2000). Over the past 30 years, sign language variation has been studied in much more depth. In their examination of regional differences in ASL, Shroyer and Shroyer (1984) reported, for example, 7 variations for CAT, 8 for CHICKEN, 10 for the color BROWN, 12 for LIGHT (electric), and 16 for SQUIRREL. Recently, lexical variation has been summarized in more detail by Lucas, Bayley, and Valli (2003) within the context of their more extensive analysis of variation in ASL. Within that volume, Lucas, Bayley, Reed, and Wulf (2003) demonstrated that variations are not only regional but also associated with specific users (African American and Caucasian) within regions.

In an effort to establish some convention among educators and other professionals, there have been projects that have focused on collecting, evaluating, and systematically recording technical signs. Caccamise and his National Technical Institute for the Deaf (NTID) Technical Signs Project (TSP) colleagues helped lay the groundwork for systematic study of technical signs in the United States, calling for additional research to support direct classroom instruction and interpreting (see, e.g., Caccamise, Ayers, Finch, & Mitchell, 1978; Caccamise & Hicks, 1978; Caccamise et al., 1977). Their work included an examination of sign collection and invention, the use of synonyms, and the development of guidelines for standardization and development of technical signs. The TSP at NTID resulted in a series of videotapes, books, and other products, including the book, *Signs for Science and Mathematics: A Resource Book for Teachers and Students* (Caccamise & Lang, 1996).

Over the past few decades, there have been similar efforts to develop lexical databases as resources in other countries. The products resulting from these efforts have included dictionaries and other collections of signs in print, and other lexical databases on videotapes, CDs, and the World Wide Web. There is little documentation, however, on the extent to which the developers of such databases have followed the rules of a country's dominant sign language in collecting and recording the signs. The question of the extent both research on sign language and research on teaching and interpreting should influence the development of lexical databases warrants investigation. With optimizing learning the goal for teachers in many different environments, it is essential that ASL linguists and others involved in the pragmatic dimensions of teacher education collaborate to systematically explore the most efficient and effective methods to provide instruction through sign language.

The Classroom of the Sea Project

Whether ASL or English-like signing is used, both classroom teachers and sign language interpreters working in academic content areas such as science seek to know how to sign technical terms with as much conceptual accuracy (i.e., meaning) as possible in different contexts. The authors of this study, coprincipal investigators on the 3-year National Science Foundation–sponsored project "Classroom of the Sea" (COS), include four university scientists/educators and two high school science teachers. We recognized from the start that there is a lack of clearly identified technical and scientific signs that are essential to communication clarity and, we assumed, to enhancing science education for deaf students. We operated under the assumption that exploring ways to optimize functional communication in teaching science through sign language would provide further insight into making instruction more effective.

We began by identifying concepts and terms in the general science curriculum and searched for available signs in published ASL dictionaries and various sign language resources, including printed materials, videotapes, CDs, and Web-based lexical databases. Our objective was to build a lexical database to facilitate communication among the project staff and students who would be communicating about the scientific information in 3 years of the project. First, more than 25 class sessions involving the project's science teachers and deaf students were videotaped in classroom and laboratory settings at the American School for the Deaf. Field research activities aboard a research ship, the RV Connecticut, were recorded with a digital camera. The recordings were studied to identify key challenges teachers and students face in communicating science through sign language. Using this process, several hundred science-related terms were identified. ASL dictionaries and other commercially produced sign resources were then searched for signs for these terms. No analysis of the quality of the signs was conducted during the first phase of this project.

In the COS project, we recognized that even if a sign's meaning is agreed upon by convention, that sign is free to vary in form. One difficulty we faced, however, was that the teaching of science content was frequently disrupted by discussions of sign variations. Variation in signs is accepted, of course, and it can be argued that variation in a spoken language is also common and that hearing students are no different in that regard. In the teaching–learning context, however, the frequent discussions of sign variations may place undesired cognitive demand on the deaf students. That is, in addition to learning the meaning of terms and/or concepts in science, their spellings, and connections with one another, the deaf students must adjust to different teachers using different signs throughout the day. In the COS project, during video transmissions among deaf students in different parts of the country, regional variations were also experienced.

On the other hand, perhaps discussions of signs and their variations may reinforce imagery and, hence, long-term memory. Thus, we sought to explore sign convention in science education, at first within a small language community—one school—and then study conventionality among the staff and students from other schools involved in the COS project. As interactions with other teachers and students across the country expanded, the initial work with the lexical database led to the development of several research questions and an investigation, which are addressed in this paper. One goal of this study was to examine how sign selection may relate to the role of abstraction in this form of visual representation of concepts. A second goal was to study the relationships among teacher preparation in a content area (science), experience with signing, and sign selection. Third, we sought to identify factors related to sign selection, which may assist developers of lexical databases to be used for instructional purposes. A systematic study of these issues in the context of an academic discipline such as science may shed light on the importance of research-based pedagogy in the education of deaf students.

Experiment 1: Perceptions of Technical Signs

Participants

Fifty-five teachers with varying backgrounds and professional preparation were invited to participate in the two experiments in this study (Table 1). Because one goal of this study was to examine whether formal content training and experience with sign language make a difference in how teachers accept or reject technical signs, we included teachers without degrees/certification and/or without sign language experience. The findings may therefore have implications for teacher induction programs, teacher preparation programs, and for out-of-field teaching assignments (i.e., the assignment of nonscience teachers to science courses).

The teachers in this study were identified as having content knowledge if they had obtained either a degree in a field of science, certification in science/science education, or both degree and certification in science. "Sign-experienced" teachers in this study had 6 or more years experience. As shown in Table 1, the sample included four groups. Fourteen teachers had both formal science degrees/certification and experience with signing (YCYS; "Yes Content, Yes Sign"), 14 had formal science degrees/certification and no experience signing (YCNS; "Yes Content, No Sign"), 12 had no formal science degrees/certification and sign language experience (NCYS; "No Content, Yes Sign"), and 15 teachers had neither formal science degrees/certification nor sign language experience (NCNS; "No Content, No Sign").

Table 1 Background characteristics of teacher respondents

Teacher group profiles	Number
Group 1. Yes Content and Yes Sign (YCYS)	14
Group 2. Yes Content and No Sign (YCNS)	14
Group 3. No Content and Yes Sign (NCYS)	12
Group 4. No Content and No Sign (NCNS)	15

Materials

An online survey was developed, which referenced QuickTime™ movies categorized in three ways: (a) standard signs, (b) selection errors, and (c) invented signs. Each QuickTime™ movie is a movie file format compatible with the QuickTime™ Player distributed free of charge on the Internet. The individual signs are recorded in a studio with a digital camera and converted to QuickTime™ format using iMovie software.

The six widely used standard signs were found in published ASL resources. They included CLAM (both hands cupped, meeting at the wrists, opening and closing as bivalves), ENVIRONMENT (*E* handshape of dominant hand encircling index finger of nondominant hand), FISH (dominant hand with palm flat, thumb on top, wiggling forward as in the motion of a fish), SURFACE (four fingers of dominant hand together gently rubbing the back of the nondominant hand whose palm faces downward), TEMPERATURE (forefinger of dominant hand perpendicular to forefinger of nondominant hand with slight up-and-down motion to indicate scale), and WEATHER (*W* handshapes meeting near thumbs and moving back and forth).

The second group included six signs with incorrect or questionable referents. We defined these "selection errors" in this study from a science, rather than linguistic, perspective. DISTANCE was signed as DISTANT (*A* handshapes as in FAR). These two terms have distinctly different meanings in physics. HABITAT was signed as HABIT (*S* handshape of dominant hand on *S* handshape of nondominant hand at wrists; both moving downward together). SHRIMP was signed as LOBSTER (thumbs of each hand meeting four fingers as in pincer motion). Although shrimp have very small pincers, they are not a prominent characteristic of this marine animal.

Three anthropogenic signs were also included in this group. These signs are more appropriately applied to humans and had questionable referents from a scientific perspective when applied to marine animals. VOCALIZATION (whale) was signed as VOICE (*V* near the throat area). Whale sounds either emanate from the top of the head (melon) or the blowhole area. RESPIRATION (fish) was signed as BREATHING (in the human chest area). The intake and outtake of gases in fish does not occur through lungs. The sign MATING (fish) was made similar to MATING for humans. The latter sign, also used for INTERCOURSE, used the human legs classifier (index and middle finger extended) and misrepresents the mating of bony fish, which do not join bodies in the process.

The third group, invented signs, were developed and used by the COS project staff and students for the terms CURRENT (water), BEARING (direction), COLONY (seal), TITRATION, and TRAWL. Signs for these terms are difficult to locate in published resources. The signs emerged through natural communication during the course of the laboratory sessions on the research vessel RV Connecticut while at sea.

Procedures

Signing teachers with and without degrees/certification in science were recruited by e-mail invitations. These teachers were either teaching in residential/center school programs or student teaching in graduate school. Nonsigning teachers were teaching in public schools and recruited through invitations sent out from several teacher education programs to their graduates. Subjects were paid $10 for their participation.

Participants were first asked to test their QuickTime™ software to make sure they had access before beginning the online study.

For the first experiment, the five-point Likert scales used in this study were worded as follows: "I would be willing to adopt and regularly use this sign when discussing this term with students and faculty in my school." Ratings included 1 (strongly disagree), 2 (disagree), 3 (undecided), 4 (agree), and 5 (strongly agree). After each sign movie was viewed and a rating recorded, the participants were provided an open-ended question: "If you are not willing to incorporate this sign into your daily teaching, please explain why in the box below."

Analyses of variance (ANOVAs) were performed to study the perceptions of the four groups of teachers for each of the three groups of signs.

Experiment 2: Perceptions About Variations in Technical Signs

In the second experiment, the same participants were asked to view two or three movies illustrating sign variations for a term. They were then provided an open-ended question: "Please identify which of these signs you like best. If possible, give reasons why you like this sign more than the other choices."

Results

There were 26 teachers with sign experience and 29 teachers with no sign experience in this study. The former group included 10 hearing and 16 deaf teachers with sign experience in this study. None of the teachers without sign experience was deaf. The hearing teachers with sign experience had a mean of 10.3 years experience teaching deaf students, and the deaf teachers had a mean of 8.4 years. A preliminary ANOVA of the ratings of the 26 deaf and hearing teachers with sign experience indicated no significant differences for any of the three groups of signs. Therefore, we combined the hearing and deaf teachers for the remaining analyses in the first experiment. Also shown in Table 1, 28 teachers in this study had formal degrees or certification in science and 27 did not.

Experiment 1: Perceptions of Technical Signs

The mean ratings and standard deviations for each of the three groups of signs used in this study are included in Table 2. The results of the ANOVA for the standard signs indicate a significant main effect for groups, $F(3, 325) = 10.43$, $p < .0001$. Newman–Keuls

Table 2 Perceptions of science signs by group: terms

Group 1, YCYS ($N = 14$)		Group 2, YCNS ($N = 14$)		Group 3, NCYS ($N = 12$)		Group 4, NCNS ($N = 15$)	
M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Standard signs: CLAM, SURFACE, ENVIRONMENT, TEMPERATURE, FISH, WEATHER							
4.60	0.71	4.11	0.93	4.24	1.04	3.83	0.94
Sign selection errors: SHRIMP signed as LOBSTER, MATING (fish), HABITAT signed as HABIT, RESPIRATION (fish), DISTANCE signed as FAR, VOCALIZATION (whale)							
2.63	1.47	2.80	1.33	2.55	1.40	3.55	1.02
Invented signs: COLONY (seal), TITRATION, BEARING, CURRENT (water), TRAWL							
3.39	1.28	3.62	1.17	3.25	1.02	3.43	1.03

post hoc analyses indicated that for the standard signs the group of teachers with both formal science training and sign experience (YCYS) had a significantly higher mean rating of acceptance than the group with sign experience and no formal science training (NCYS). The YCYS group also had a significantly higher mean rating than both groups of teachers with no sign experience (YCNS and NCNS). In addition, the group NCYS had a significantly higher rating than NCNS. There was no significant difference between YCNS and NCYS. The finding that the teachers in the YCYS group were more willing to accept and regularly use these signs in their instruction probably reflects the confidence of this group in the signs based on their experience with both content and signing.

A significant difference was found in the analysis of the selection errors, $F(3,\ 324) = 5.52$, $p = .001$. Newman–Keuls post hoc analysis indicated that the means of both groups of sign-experienced teachers (YCYS and NCYS) were significantly lower than the two groups of teachers with no sign experience. That is, the sign-experienced teachers rejected the sign selection errors with more confidence due to their knowledge of sign language. A significant difference was also found between YCNS and NCNS. Having both content knowledge and sign experience appears to lead to the best rejection rate for sign selection errors.

Results of the ANOVA of the invented signs indicated no significant differences associated with sign experience or content training in terms of the perceptions of the five invented technical signs, $F(3,\ 267) = 1.86$, $p = .136$. The sign-experienced teachers appeared to be more cautious in their acceptance of invented signs. The lower ratings may reflect their uncertainty with the invented signs because these signs, having been invented by the COS project staff, were likely completely new to the experienced signers in this study. Comments accompanying the ratings (summarized below) also indicate that the sign-experienced teachers disagreed with some of the invented signs, and this lowered their ratings accordingly. As shown in Table 3, however, the difference between the means for the standard signs and invented signs as rated by NCYS was more than twice the difference between these means for groups YCNS and NCNS. Compared with these latter two groups of teachers having no sign experience, the difference between the means for YCYS was *three* times larger. Again, having both science knowledge and sign experience appears to optimize the ability to accept and reject signs appropriate for use in instruction.

Comments on Ratings

Standard signs. The qualitative data collected after each sign was rated was helpful in interpreting the

Table 3 Comparison of means for standard and invented signs

	Standard signs	Invented signs	Difference
Group	M_{SS}	M_{IS}	$M_{SS} - M_{IS}$
1 (YCYS)	4.60	3.39	1.21
2 (YCNS)	4.11	3.62	0.49
3 (NCYS)	4.24	3.25	0.99
4 (NCNS)	3.83	3.43	0.40

results of the ANOVA above. The standard signs were generally accepted by the sign-experienced teachers. There were only a few comments offered about these signs by any of the groups. One teacher commented that the sign SURFACE used in this study is appropriate for most surfaces, but if specifically referring to water, it might be preferable to change this sign.

Initialization is the process of using the first letter of an English word as the handshape for a sign. Five teachers commented that there is a noninitialized sign for the term ENVIRONMENT, spreading the flat hand palm down as in a field that could be, when appropriate, preceded by the type of environment (space, ocean, land, etc.).

Selection errors. The generally accepted technical sign for SHRIMP found in published resources is distinctly different from that for LOBSTER. HABITAT has no widely used sign. Even experienced signers will be cautious in applying a sign to this term and will usually finger spell it. The term HABIT, in contrast, has a distinct sign and a distinctly different meaning from HABITAT. The term DISTANCE has many possible signs, which depend on the context. The term, however, does not have the same meaning or sign as DISTANT.

The sign-experienced teachers, regardless of their science background, were generally able to identify the sign selection errors for DISTANCE, SHRIMP, and HABITAT. Their comments showed their disagreement. Nine teachers specifically mentioned that the sign shown for DISTANCE was incorrect and it should be the sign for DISTANT.

Initialization emerged as an issue in the comments about the sign DISTANCE. Seven teachers suggested using the letter *D*. One teacher wrote, "Since symbols are used often in science, consider the science sign with the [dominant] hand signing 'D'." One of these seven teachers expressed mixed feelings about initialization, "I do use noninitialized signs routinely; however, when teaching physics, I think the initialized sign (with the letter 'd') for distance might be clearer."

Eighteen of the 26 sign-experienced teachers who offered written comments described the error in the sign HABITAT, specifically commenting that this was the sign for HABIT.

The three anthropogenic signs, VOCALIZATION, RESPIRATION, and MATING, used referents to the human body, including the vocal tract beneath the mouth, the lungs on the chest area, and the coupling of two bodies during mating, respectively.

MATING (fish). Sixteen teachers who offered written comments clearly rejected this sign. However, only two teachers specifically mentioned the conceptual inaccuracy. One wrote, "Fish do not have internal fertilization and therefore do not mate in the same manner as most terrestrial animals. This sign conveys the over generalized concept of mating as intercourse." Another explained, "Fish do not mate sexually . . . the female fish lays the egg and the male comes over to release the sperm." This latter teacher, however, then offered an alternative: "The sign for MATING (fish) is to first sign the word FISH and second, the left hand (index finger and thumb touching together) remains stationary . . . while the right hand index finger takes the shape of the sperm . . . swimming toward the egg (left hand)."

This comment raises the issue of the etymology or meaning of a sign and how this relates to instruction. The processes of MATING (pairing of a male and a female for the purpose of reproduction) and FERTILIZATION (union of male and female gametes to form a zygote) are not the same in all species, and the question arises whether using the sign for FERTILIZATION accurately conveys the meaning of MATING.

Two teachers rejected the sign MATING purely on the basis of the use of an incorrect ASL classifier. As one teacher summarized, "The sign used incorporates the classifier for legs, which is inaccurate for fish, which do not have legs."

The remainder of the 16 teachers felt that the sign was inappropriate to use with students because it also has a potentially vulgar connotation. One teacher wrote, "I don't know how the school administrator will react if you sign this way." These teachers did not offer an alternative sign.

Only three teachers showed acceptance of this sign in their written comments. One noted that it is commonly used for MATING, but explained, "further explanation needs to be given to clarify the specific type of mating or fertilization."

RESPIRATION (fish). Using the sign for human breathing may misrepresent to students the important concept in science that the intake and outtake of gases in fish does not occur through lungs. An alternative sign would include the flat palms of both hands, fingertips pointing to the ears, undulating at the cheekbones. Seventeen teachers commented that the referent was faulty. "Fish do not respire using lungs." "It doesn't agree with how fish respirate—this sign refers to humans and mammals." An additional four science teachers were more analytical. As one wrote, "I have not yet seen a sign I like for respiration because it does not necessarily mean 'breathing' per se. Respiration can mean catabolism of biomolecules to get ATP." Another teacher explained, "The sign depicts breathing but does not show the chemical reaction in which oxygen is taken in and chemically changed with other compounds to produce energy for the organism to use." These latter two teachers would argue that a conceptually accurate sign for RESPIRATION would not be interchangeable with the sign for BREATHING.

Three teachers felt that the sign for human breathing would be acceptable if more explanation were added.

VOCALIZATION (whale). Whales make sounds either for communication or echolocation (toothed whales only). As mentioned earlier, their "vocalizations" or phonations (sounds) are made by passing air from one nasal sac to another across a set of nasal plugs. The sound then either emanates from the top of the head (melon) or the blowhole area. Whales do possess a larynx that is roughly five times larger than that of a human and which contains vocal folds. However, the whale larynx produces no sound. Its primary purpose (as it is in any other mammal) is to keep food from entering the airway. Thus, the human sign for VOICE (made below the mouth area) would not be an appropriate representation for whale VOCALIZATION. Nor would a sign be appropriate if it indicates the sound coming directly from the mouth (e.g., YELL or CALL OUT).

Only eight of the sign-experienced teachers offering comments on this sign noted this incorrect conceptual representation. One teacher wrote, "This sign indicates voicing rather than the sounds specific to whales." Another wrote, "But they don't do it that way! They make 'sounds.' They 'communicate' . . . I don't know a better way to sign it but I would like to see some ideas." Three teachers expressed concern that the sign "over generalized—students might misunderstand the concept."

The comments from the teachers in this study generally show the relevance of content knowledge in regard to sign selection. Teachers with no science background offered suggestions that were conceptually incorrect. As one teacher with 26 years of signing experience but no science teaching experience wrote, "I would sign 'EeeeEeee' out from my throat area." Three teachers wrote that they would add the word WHALE to VOCALIZATION, keeping the sign VOICE.

Invented signs. The invented signs also elicited a variety of comments that provide insight into why there was more caution on the part of experienced signers to adopt and regularly use them in teaching. There are several possible reasons why the invented signs elicited lower mean ratings as compared to the standard signs. First, there is unfamiliarity with regard to the referents (meanings). Second, there is disagreement about the assumed referents.

BEARING. This term was signed as COMPASS and was meant to represent a direction of movement calculated using a map or compass. The index finger of the dominant hand, representing a compass needle, is placed over the *O* handshape of the nondominant hand. Respondents mentioned that there are other meanings for this term outside of the marine science context, including a relation to something or a support for a beam or girder. The teachers indicated that even in the marine science context, the invented sign was too specific and that there might not be an appropriate sign that would accurately capture the full concept of the process of calculating a direction of movement or geographic location with a map or compass. Thus, we concluded that this is a term that should be finger spelled when used in the marine science context.

COLONY (seal). The invented sign indicated a movement or migration to a specific location, followed by the *C*-handshape sign for GROUP. The deaf students in the COS project were studying migration of the seals, keeping a census on a periodic basis, and graphing the results over time. Seven sign-experienced teachers specifically mentioned their concern about the sign indicating movement of the seals. One teacher asked, "Is a colony just a place to gather? Or more? A living space? Would the sign for COMMUNITY be better?" Another teacher wrote, "The first part of the sign indicates movement and when you are speaking about a colony you are not always referring to moving organisms." Thus, an analysis of the comments suggested that a better sign would be established by eliminating the movement and using only the ASL sign GROUP (with *C*-shaped classifier) to represent COLONY.

CURRENT (water). The invented sign indicated a flow in one direction. Both hands, palms downward, move away from the body. In general, the teachers accepted this sign, although five teachers cautioned that the sign would depend on the context. A water current may change directions or have other types of movement (i.e., varying form, referent). It may be under the surface. One teacher wrote, "This sign for FLOW gets at part of the idea, but there is more to a current. The word current refers to the strongest area of flow. How to show that?"

TITRATION. The sign we used in the Classroom of the Sea project, invented by the students in concert with their teachers, implied a dripping process from a syringe-type instrument. The index finger of the dominant hand is pointed downward toward the *O* handshape of the nondominant hand, indicating an injection action. On the RV Connecticut and in the science laboratory at the American School for the Deaf, we employed a digital titrator (HACH Test Kit for Salinity, Model SA-DT) to measure the salt content of the water. The students and teachers saw in the invented sign an accurate and natural representation of the process they used to titrate. However, many teachers with sign experience and science content preparation in this study were not acquainted with the specialized equipment and rejected this sign. Comments were offered such as "Titration is not always done in the manner shown in this sign." Eight teachers expressed confusion about the sign. They were not familiar with the specific equipment. In addition, 11 teachers specifically commented that the invented sign looked too dissimilar to titration done through glass pipettes.

TRAWL. Our invented sign was based on the trawling net used in this project, a net which was weighted down and dragged over the ocean floor by the ship to collect specimens for classification and discussion. This included a variety of animals, which were returned to the ocean after their examination. The two hands overlap, indicating the mesh net, and are pulled toward the body.

Most teachers were unfamiliar with the term. There were only five comments from the respondents in which changes were suggested. One teacher detailed two types of trawling, which might be represented by different signs.

> The generic sign is fine, but to introduce the topic or to be specific about the equipment, I'd modify the sign depending on they type of trawl. If it is a benthic trawl (otter trawl) where we are picking things up off the ocean/sound floor I would invert my hands to indicate the raking motion. If it was a planktonic trawl (cone) where we are skimming the surface with a fine mesh net that has a narrow mouth tapering to a point, I'd change the shape of my hands to indicate that.

We felt that the classifier (raking) did not represent the benthic trawl (a weighted-down net that collected marine life). The cloudy water and noise produced by the dragging net not only captured animals *on* the ocean floor but also attracted some *near* the ocean floor. There is also mid-water trawling. The sign we invented would appropriately apply to either benthic or mid-water trawling.

Summary of Experiment 1

The results of Experiment 1 showed the importance of collecting multiple perspectives on a sign for a lexical database being used for instructional purposes. Both content knowledge and experience with sign language were found to be particularly helpful in gaining further insights regarding signs used for teaching. Lexical database developers may need to more specifically clarify meanings of signs through the use of notes, particularly when the lexical database would be used by new signers with and without content training, as well as with experienced teachers. With regard to initialization, the jury is still out in terms of benefits to teaching and learning. Current use of initialized technical signs appears largely arbitrary in nature, and arguments for or against their use are not based on substantial systematic inquiry. This is further elucidated in Experiment 2.

Experiment 2: Perceptions About Variations in Technical Signs

In the second experiment, the 55 participating teachers were presented several variations for the signs for five marine animals (SEAL, CRAB, WHALE, DOLPHIN, and SHARK). They were asked to choose the sign they liked most and to give reasons why they prefer that sign. The open-ended format again provided qualitative data that allowed us to use inductive analysis to identify factors which influence teachers' thinking in selecting and using signs in the classroom.

In conducting this experiment, we also introduced two widely accepted signs for SEAL, formed by two hands flapping, and SHARK, using the *B* handshape with the wrist resting on top of the head. The etymology of the former sign is in the representation of the flapping of the mammal's rear fins (Sternberg, 1998). We are uncertain of the etymology of the latter. It is a universal sign used by many divers and has also been adopted by some teachers in the education of deaf students. Although one may argue that signs are more or less arbitrary, as we show in this experiment, there are other signs that do not risk the possible introduction of a misconception about the anatomy of a shark, that is, a fin on the animal's head. We included these two signs in order to see if teachers would offer comments reflecting conceptual representation when asked to choose one they liked best.

Results

In responding to an open-ended question asking their preference for each sign, nonsigning and signing teachers were free to comment on why they chose a particular form. The results are presented in Table 4. Teachers without sign language experience and science content preparation generally focused on aspects of the signs that best represented the animal's movement through water, characteristics of the animal being represented by the sign (referent), or else they chose the sign that they perceived as easier to produce. They commented that they chose signs based on their being "visually appealing" or what they thought children would best remember in terms of associations. Although we report the frequencies of non-sign-experienced groups, we will focus the following analyses primarily on the teachers with sign experience.

Teachers experienced with signing gave a broader and more analytical array of reasons explaining their preference for signs. There was more discussion of handshape as a formational parameter of particular interest. Their explanations also reflected regional sign variations. The results summarized below for each sign reveal some of the factors that come into play when signs are selected for instruction.

Crab. Sign 1 for CRAB (thumb and forefinger meeting at fingertips) was popular, with two thirds of all teachers expressing preference for it. The curved claws appeared more appropriate, and the motion of the fingers looked more representative. As shown in Table 4, all four groups showed less preference for Sign 2 (index and middle fingers opening and closing). Three teachers commented that this sign used an ASL classifier that better represents a cutting process or the sign for SCISSORS.

Four comments about the sign for CRAB showed unexpected variations. Three teachers who were experienced signers with science degrees noted that one of the signs we used for CRAB was used for LOBSTER

Table 4 Preferred signs by group

	Sign #1				Sign #2				Sign #3			
Group	1	2	3	4	1	2	3	4	1	2	3	4
CRAB	10	11	5	7	2	2	1	3	N/A			
DOLPHIN	3	5	3	4	8	7	3	8	N/A			
SEAL	9	11	5	11	1	2	0	2	N/A			
SHARK	4	3	1	0	3	3	2	8	4	6	1	6
WHALE	8	3	4	2	3	8	3	5	1	2	0	7

Note. N/A, not available.

in their schools. As one of these teachers wrote, "I prefer Sign 1. Sign 2 is used for lobster (the Pacific variety without the huge claws." A fourth science teacher experienced with signs noted that one of the signs used for CRAB in this study was the sign for SHRIMP in the school where this teacher taught.

In comparison to a crab, the pincers of a shrimp are usually not as prominent a feature to justify use of that sign. We believe that the more standard sign for SHRIMP (index finger undulating across sign space) would be a more appropriate one.

Dolphin. Sign 1 used an *R* handshape moving across sign space as a dolphin would swim. The *R* handshape was an ASL classifier indicating the animal's snout. Sign 2 also used this motion but with the initialized *D* handshape. More than 60% of the 26 experienced signers expressed a preference for the initialized sign for DOLPHIN as compared to the sign which used an ASL classifier. This preference was similar for both deaf and hearing teachers. The most common reason may be summarized in the words of one teacher, "This is an English sign, but to me it is more clear and isn't confused with SHARK or WHALE." Some teachers use the initialized sign because it has become conventional. "I like Sign 1," one teacher wrote, "but I have used Sign 2 for many years. A whole culture of students has grown up using the 'd'."

Only one teacher conjectured that initialization might aid learning, "I like the d handshape; it recalls the word for the students." A few teachers were decidedly negative as they considered initialization "not ASL," but "English-like" signing.

Seal. Variations of Sign 1 are found in a number of sign language resources. Sternberg (1998) refers to a "flapping of the mammal's rear flippers" (p. 608) and suggests a closing and opening of the two hands joined at their bases. Costello (1998) recommends a similar sign, but "with the backs of both open hands together in front of the chest, palms facing in opposite directions and fingers pointing down, bend the fingers in repeated movement" to indicate a "clapping movement often made by seals with their flippers" (p. 396).

Sign 2 was made with the hands near the side of the body to represent the small fore fins of a seal. As shown in Table 4, overall, the teachers in this study overwhelmingly (88%) favored the first sign (flapping hands) for SEAL. The six teachers who described their preference for the same sign in terms of the clapping of fore flippers, a trained show behavior, were probably not aware that it is physically impossible for a seal (except for the fur seal) to clap its small fore flippers against one another. A sea lion, which is just one type of seal, may be trained to do this in captivity. For a science teacher interested in communicating specific characteristics of pinnipeds, the distinctions between these animals, their signs, and etymologies, may be important. This may be especially relevant in discussions of taxonomy.

The artificial show behavior that originated at marine studios in order to entertain people is unnatural. Only one teacher in this study made note of this, commenting that "While Sign 1 is the one I use most often, I prefer sign 2. Sign 1 depicts something that seals do in captivity and not in their natural habitat. Therefore I would prefer to use the more accurate sign 2."

Shark. Both Sign 1 and Sign 3 show the prominent feature of the dorsal fin breaking the surface of the water. Sign 3 emphasized the predatory nature of the shark circling its prey. Five teachers experienced with sign language described their preference for Sign 2 (*B* handshape with wrist resting on top of head) only because it is widely used. As one teacher wrote, "It is closest to true ASL." Another summarized, "I like Sign 2 because I have been using it for years—a habit." A third teacher explained, "It is the sign I already use and is the easiest to make."

Only two teachers noted that this sign misrepresents the animal's features. One wrote, "Sign 2 implies that the fin is on the head." Another explained, "Sign 2 seemed like it could be construed as a horned animal."

Over all four groups of teachers, there was no clear preference among the three signs for SHARK. About 40% of the teachers chose Sign 2 and 40% chose Sign 3. Sign-experienced teachers with training in science divided their preference about equally for all three signs.

Whale. Sign 1 included the *Y* handshape (ASL classifier) indicating the whale's tail with the thumb and pinky finger extended. Sign 2 used the initialized *W* handshape moving in a whale-like swimming pattern across the front of the body. Sign 3 emphasized a spouting from the blowhole on top of the head.

As shown in Table 4, the science teachers with sign experience seem to prefer the two signs for WHALE which do not use the ASL classifier for the tail, whereas the teachers with sign experience and no science background have a stronger preference for the sign using an ASL classifier. Comments offered by teachers from all four groups show the need for follow-up research. In terms of content knowledge, for example, a teacher without science training wrote, "I like the third sign the best because it mimics something that even small children know a whale does, blowing water out of its spout." This teacher did not realize that it is air, not water, that is expelled by the whale through its blowhole.

Summary of Experiment 2

The results of Experiment 2 show that in general, teacher preferences for one sign over another do not follow any clear pattern. With the exception of the sign for CRAB, there was no detectable pattern in the qualitative data. In some cases, a sign was preferred because it was conventional, even though the respondent liked another sign better. As one teacher wrote, "I choose Sign 2 since it is a common sign in the Florida area."

Even experienced signers with science training showed inconsistent preferences, supporting the initialized sign for DOLPHIN, but not for WHALE. To examine whether teaching experience played a possible role in influencing the preference for initialized signs, we compared 12 sign-experienced teachers with less than 2 years teaching experience with 9 sign-experienced teachers having 8 or more years experience. The less experienced teachers had a 50% preference for initialized signs for WHALE and DOLPHIN. For the more experienced teachers, 75% preferred the noninitialized sign for WHALE, but, surprisingly, 100% of these teachers preferred the initialized sign for DOLPHIN. Additional research is needed to better understand why initialization is acceptable in some cases but not in others.

Discussion

Although recognizing the arbitrary nature of language, including sign language, especially over time and among communities, research is nevertheless needed on the role of abstraction in signs as they relate to sign selection in the context of teaching. Mishra (2004) examined this issue in relation to other forms of visual representations of science concepts (in particular, scientific illustrations) as interpreted by hearing students. Mishra (2004) writes that apart from artistic conventions,

> . . . scientific illustrations function within this matrix of science—with its hidden assumptions and biases. Quite often these biases are invisible to us at this moment in time and thus are quite insidious in their effect. Illustrations in a given domain [also] have a contingent, zig-zag history and their copying and recopying leads them to evolve from what they began with . . . Apart from the above factors, we must also consider the fact that illustrations are treated (created/read) differently by different domains or sub-disciplines within science.. . . Thus, understanding how illustrations work in science cannot be done in a generalized manner—it must be grounded in the dynamics of a specific discipline. (p. 193)

Mishra (2004) provides many examples of how visual representations of science concepts may lead to misconceptions. Textbook illustrations of the orbit of the earth around the sun, for example, frequently exaggerate the elliptical nature (the ratio between the major axis and the minor axis is close to unity). Similarly, a distorted scale may show the sun as smaller than the earth when its diameter should be 100 times larger.

As this study has shown, visual representations of some abstract concepts through signs, such as fertilization and mating, may vary according to context. Similarly, use of technical signs to visually represent animal features, such as the fore fins of seals and sea lions, may introduce the risk of developing misconceptions. Some teachers in this study, especially those with less content training, may have developed the misconceptions themselves and may be introducing incorrect etymologies when teaching. Research on sign selection and production and their relationships to learning by deaf children may add to our understanding of how to best use technical signs with ASL in instruction.

Variations in signs in a small language community such as an individual school program may place unnecessary cognitive demand on deaf children, who must adapt to different signs used by different instructors (or peers) while learning the already challenging vocabulary of a subject such as science. Additional research on sign language convention or standardization as a dimension of communication in pedagogy may enhance learning in all content areas of the curriculum.

At the end of this study, we asked the participants if they had any comments on the standardization of signs in science. The responses were overwhelmingly in support of such an approach. As one teacher wrote:

> There is definitely a need for this. We constantly discuss this issue in our school and often three of us will have three different signs for the same word, but we discuss it and agree on a common sign. We also have difficulty with students coming from middle school and other schools that have different or inaccurate signs when they come into high school. This is a huge task and hopefully this [survey] is a good start.

Another teacher wrote, "We definitely need standardization. I think many students see one sign in elementary school and another in high school and never realize it's the same concept! Groups of teachers of the deaf, including members who are native speakers of ASL could set the standards as far as I am concerned—and I'd adopt them."

The teachers also supported an online approach such as the one used in this study. "Networking and websites like this site are the most efficient way," one teacher wrote. Another offered, "I would love to work on a committee that was serious about coming up with ASL signs for science. This survey is a perfect example to get a majority agreement." A third suggested, "Set up a webpage like this, let teachers observe the website to give them ideas which signs to use. This is a productive step toward standardizing signs among schools."

Linguists have been experimenting with online and CD-ROM-based resources for several years. Hanke, Konrad, and Schwarz (2001), for example, developed a multiuser sign language lexical database using digital movies to support a compilation process for specialist dictionaries. Users always have immediate access to the video clips as the compilers enter new data collected from informants. In another project titled "Signbase," Schermer, Brien, and Brennan (2001) describe the development of both a CD-ROM British/English dictionary and the educational CD-ROM Nature and Environment, which was a bilingual material for children between the ages of six and eight. They discuss how the repository includes sources for the signs, sign representation (contexts), sign usage (etymology, historical background, etc.), grammatical information, and other lexical parameters. Such approaches allow for feedback from the signing community, and ultimately, preferred signs are determined from such user perspectives. The development of technical signs for effective instruction is essentially an exercise in language planning with sociolinguistic implications.

As a follow-up to this study and a first step toward this approach to such language planning in science and mathematics education for deaf students, eight experienced deaf teachers with degrees in science and mathematics and two linguists, one deaf and one hearing, are evaluating over 800 technical sign video clips over the Internet and discussing them on a Bulletin Board. Semantic and phonological criteria are being discussed as part of this Internet-based interactive dictionary.

Additional research questions arise from this study. First, we recommend that the process of embedding etymological explanations when introducing signs in science should be examined more closely. For example, if an invented sign for whale vocalization is explained using a sign similar to that for SOUND, but emanating from the top of the head, will deaf students more effectively learn that whales do not vocalize from the area below the mouth?

Second, the role of content knowledge of teachers in sign selection and the instructional process of teaching through the use of the etymology of signs should be examined. In this study, we found that the less qualified teachers are in terms of degrees and/or certification in science, regardless of sign experience, the more likely will be the risk of sign selection errors. This recommendation, however, relates to the previous one. Whether sign selection has relevance to deaf students' learning also remains to be investigated.

Third, the qualitative data in this study provide evidence that some teachers are thinking about associations that students make when they see signs and learn concepts in science. There were comments, for example, about whale and shark signs being preferred in relation to how these animals are frequently observed in movies. The sign selections and associations, which lead to better mental imagery, especially bear further investigation. Because imagery has been shown to be a predictor of long-term memory, we also need to investigate how teachers may best promote the development of imagery skills.

Fourth, the use of initialized signs appears to be particularly controversial, but there is insufficient research to determine if there is any value in terms of teaching and learning. Do initialized signs enhance memory associations with the concepts/terms being learned? Do certain age groups more readily form associations with the vocabulary they are learning if signs are initialized, such as *D* for DOLPHIN, *W* for WHALE, and *P* for PORPOISE? How do these associations compare with those formed by ASL classifiers such as those used in this study for DOLPHIN and WHALE?

There is a distinct perception among some teachers that the use of initialization is not ASL. Standard ASL dictionaries, such as Sternberg (1998) and Costello (1998), have many signs collected by deaf informants that are initialized (e.g., FAMILY, AUNT). Research on initialization in ASL and in English-based sign systems and, especially, the relationship to long-term memory would provide clarification for educators regarding its use.

Fifth, the majority of scientific terms, approximately 60% of those we initially identified, have no published or recorded signs. The extent to which signs should be invented is also a question meriting further research. As this study has shown, the process of inventing signs is fraught with complexities. Special efforts should be made to search for quality technical signs, which may already be in use by experienced signers, but not recorded in existing lexical databases.

If a goal for the development of a lexical database of technical signs is to enhance teaching and learning in a science classroom, careful consideration needs to be given to both sign selection and production factors. One typical strategy for identifying signs for terms unavailable in published resources appears to be through consultation with experienced teachers. Yet, as this study has shown, even experienced teachers may suggest signs that may not be appropriate representations of the concepts or terms. *Multiple* perspectives from both content experts and those experienced with linguistics of ASL should be sought in order to arrive at appropriate signs for instructional purposes. In this study, an Internet online survey was found useful in eliciting a variety of points of view, which shaped our decisions to revise some of the signs we used in our instruction. Teachers with science degrees and sign experience, both deaf and hearing, are in general the best resource for this process.

Over time, this process of discussion in the context of instruction, and with ongoing influence from both linguistic and educational research, will result in database changes. Both ASL in general and technical signs in particular also evolve through time. Thus, when resources are available, a lexical database should be dynamic rather than static, allowing revisions as research and discussions shed new light on sign selection and production.

Teachers, interpreters, and developers of technical sign lexical databases should recognize that as with many ASL signs in general, there are natural variations in technical signs and more than one sign may accurately represent the associated term or concept. Variations in technical signs may also be due to regional adaptation and use. The variations may include valid referents (such as the WHALE reference to the blowhole or the *Y*-handshape classifier for the tail). Variations may also be the result of different meanings of a single term (e.g., laboratory TABLE vs. tide TABLE). Science signs vary according to contexts (e.g., discussing DENSITY in terms of molecular arrangement vs. discussing the variable DENSITY when used in a formula), or they may use a borrowed equivalent sign (such as signing AQUATIC using the sign for WATER). From a morphological perspective, there are also related terms, which may use the same sign (e.g., PHYSICAL, PHYSICALLY). Also common are initialized variations (such as the *W* letter for WHALE to distinguish it from a *P* for PORPOISE or *D* for DOLPHIN).

To address this issue of variation in a lexical database, terms may be defined more specifically using parentheses (e.g., TRAWL [benthic]; VOCALIZATION [whales]); or through the use of multiple entries in the lexical database, such as in the case of one term having completely different signs in its noun and verb forms (e.g., FISH [n] and FISH [v]).

In summary, effective teaching through sign language recognizes the value of finger spelling, the printed word, graphics, and clear explanations, among other factors, and it would not be prudent to assume that signs are needed for most terms. Teacher education and in-service professional development programs need to address these issues in collaboration with linguists and educational researchers.

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