Instructional Science 31: 277–298, 2003.

Web-based science instruction for deaf students: What research says to the teacher *

HARRY G. LANG[1] & DONALD STEELY[2]
[1]*Department of Research, National Technical Institute for the Deaf, Rochester Institute of Technology, 96 Lomb Memorial Drive, Rochester, NY 14623-5604, USA, e-mail: hgl9008@rit.edu;* [2]*Oregon Center for Applied Science, 1839 Garden Avenue, Eugene, OR 97403, USA, e-mail: dsteely@orcasinc.com*

Abstract. Web-based science education often involves activities that may enhance deaf students' learning. Research efforts to date indicate great potential for web-based instruction, while simultaneously revealing precautions which need to be considered when developing materials for use with students who are deaf. Educators of deaf students need to be particularly aware of such factors as reading ability, motivation engagement of the students, and the need for visual reinforcement of the science content.

In this paper, three empirical research studies related to earth science, chemistry, and physical science are summarized. The results of these studies, as well as those from related empirical research, support the view that there may be a beneficial synergistic learning effect obtained by the careful interspersing of text and American Sign Language explanations with animation and other graphic organizers, and by encouraging the deaf learner to interact with the materials through such techniques as the use of adjunct questions.

Keywords: adjunct instructional aids, deaf, Internet, mathematics, multimedia, science, web-based instruction

Introduction

Educational technologies often involve the kind of learning activities, interactions, and opportunities to accommodate individual needs that may be of immense benefit to deaf[1] learners. These include, the use of visual materials to support the comprehension of text and the opportunities for the deaf learner to become actively involved in the instructional process. Unfortunately, touted "advances" in technology have historically placed people who are deaf at a great disadvantage. Prior to the invention of the voice telephone, for example, deaf and hearing people experienced equitable access to the then existing long-distance communication forms. The voice telephone introduced many benefits to society, yet deaf people had to struggle for more than 90 years before even minimal access became available through the acoustic

* All appendices may be found at http://www.isspecissue.uconn.edu

TTY-telephone coupler (Lang, 2000). When the sound track was added to films in the 1920s, the "talkies" deprived deaf people of the subtitles generally accepted in the genre of silent film, another medium with potential for accessing information and learning. Subsequently, the development of radio and television placed deaf people at a disadvantage in terms of news, entertainment, and other learning opportunities through these forms of media. It took more than 50 years for deaf people to gain access to television through closed captioning technology. Today, web-based instruction in the science classroom may be fraught with barriers as well. In order to avoid a "digital divide" between deaf and hearing learners, as described by Ely (2001), quality research and evaluation studies are needed to assure access and to support the claims made by educators regarding the value of technology in the teaching-learning process.

Over the past decade, an increasing technological focus has led to a wide range of instructional delivery approaches over the Internet. Learners are able to select more educational opportunities on an individual basis. The trends characterizing online education in science include personalization, interaction, and asynchronous learning. Duderstadt (1998) describes "digital age Education" as learner-centered, affordable, providing lifelong learning, a seamless web of all levels of education, and serving an increasingly diverse population with diverse needs. This includes students who are deaf.

Various features of web-based learning may make information inaccessible to deaf learners, however, or inhibit their participation. These factors may impact learning and motivation and need to be carefully considered in developing online instructional activities and materials. The obstacles include, for example, a lack of visual text alternatives for audio information or the use of certain sentence structures, which have been found to be especially difficult for deaf readers. Several key considerations are briefly described below.

Reading comprehension

Probably the most important factor influencing access and participation for deaf students in online learning opportunities is reading comprehension. The lags of deaf students relative to their hearing peers increase through the school years. By the time deaf students are 18 to 19 years of age, their measured reading ability is generally no better than the average 8- or 9-year-old, normally-hearing student. The language barriers continue into the college years and beyond. Many deaf students experience complications in their career preparation and technical skills development due to inadequate functional literacy levels for reading and writing (Marschark, Lang & Albertini, 2002). Thus, there is a strong need to examine through empirical research the role that reading comprehension may play in web-based learning in science for deaf students and the impact that multimedia and interactive approaches may have on learners with different reading abilities.

At present, there is much information on websites and in distance learning course components that is purely auditory in nature. Learners frequently have access to the information only through hearing lecture material delivered through audio clips, annotated graphic presentations on a web page, video-clips mounted on websites through videostreaming, or video files to be downloaded for viewing. Often, there are no *visual* text alternatives for deaf learners to access this information through captioning or other text presentation.

Captioning research has been shown to assist deaf students in comprehending science course materials. However, a principal research concern is the effects on learning when verbatim or edited captions are used. In one study, Hertzog, Stinson and Keiffer (1989) asked 32 deaf students to view two captioned versions of a film about cement manufacturing. Both high and low reading groups benefited from instruction when the captions were on an 8th grade level, while only the high reading group benefited from the 11th-grade level captions.

Jackson, Paul and Smith (1997) concluded from their research on captioning that prior knowledge of a topic is a significant predictor of passage comprehension level for deaf students. Jelinek Lewis and Jackson (2000) found that when hearing and deaf students are at equivalent reading levels, the hearing students still perform significantly better on a comprehension test. Even with training of the junior high school deaf students to be attentive to certain types of information by enhancing their ability to acquire knowledge and critical viewing skills, no increase in captioning comprehension was observed, leading the authors to question the accessibility and utility of captions. Jelinek Lewis and Jackson (2001) also found that reading grade level is highly correlated with caption comprehension scores, and that captioned video provided significantly better comprehension of a script as compared to captions alone, suggesting that the visual stimuli provide additional information.

Thus, verbatim captions of an audio message in a web-based course may not be enough to provide meaningful access to the information to deaf learners. While we may assume that captions can enhance literacy in general, these studies indicate that the development of instructional technology must be accompanied by a program of research and evaluation to ensure optimal teaching and learning.

Engagement of the deaf student in the learning activity

In Lang's (2002) summary of research on support services for deaf mainstreamed students on the postsecondary level, he described the difficulties these learners have in interacting with hearing peers and the instructor, and in participating on an equitable basis in the classroom activities. The research summarized is very similar to the findings reported for secondary students who are deaf. Some of the inhibiting factors to full participation include pace (rate of presentation by instructor), the number of speakers involved, language and cultural difference, and the use of space (physical arrangements in the classroom). The approach employed to communicate course content may also influence participation, such as when an instructor uses sign language as compared to presenting by voice only and having a sign language interpreter translate the lecture. Participation in discussions may also be inhibited for deaf students when interpreters are not available, not familiar with the content, not visible from where the student is sitting, or not using a mode of signing that is similar to the student's (Foster, Long & Snell, 1999).

Interaction in computer-based learning, a quality most often credited with contributing to effectiveness (Hanafin & Peck, 1988), may also be problematic for deaf learners. When chat rooms, e-mail exchanges with instructors, threaded conversations, and other forms of online written communication are employed, deaf students may be reluctant to participate. As Meath-Lang, Caccamise and Albertini (1982) have discussed, deaf students are sometimes self conscious about their English writing skills. With regard to online education, Rogers (1990) summarized that although the interconnection of deaf students through telecommunication networks offers great potential, and a variety of print and video technologies are available, communications difficulties between deaf learners and their instructors and peers continue to be problematic.

Engagement also relates to independence and self-reliance in students. The results of some distance education experiments with deaf students have also shown the need for further research. We do not yet have an adequate understanding of how to facilitate motivation and the development of independent learning skills, both which may influence deaf students' achievement in online courses. After offering a course to deaf students using computer conferencing, for example, Coombs (1989) hypothesized that deaf students shied away from the course because they had become dependent on the human support system. This may have inhibited their developing the degree of self-direction demanded by distance learning.

The need for organization and structure

Lang, Stinson, Basile, Kavanaugh and Liu (1998) reported that deaf adolescents are highly "dependent" learners, which means that they rely heavily on organization and structure in the instructional environment. These findings are similar to those reported by Grasha (1996) for hearing students. He defined dependent learners as those who look to authority figures for guidelines on what to do. Dependent learners find it difficult to develop skills for autonomy and self-direction. The implication for online instruction is that deaf students may benefit from various forms of graphic organizers and other adjunct instructional aids to facilitate comprehension of text.

Web-based science instruction of deaf learners: A review of the literature

Early efforts with synchronous distance education of deaf learners focused on videoconferencing over ISDN lines. Coombs (1989) used video materials to teach distance learning courses to both deaf and hearing students. Formative evaluation of these tele-courses included an examination of the perceptions of 66 deaf learners. McKee and Scherer (1992) reported high satisfaction with the sharing of ideas and the use of media. But these students were evenly divided on whether the course encouraged more interaction with the instructor and other students. Most students in these two courses missed face-to-face situations and half of them felt "sometimes isolated."

A survey on distance learning of postsecondary educational institutions serving deaf learners a decade ago showed only a moderate level of interest in pursuing degree programs and courses via distance learning. Interest was higher for science and technology areas, however (Scherer & McKee, 1993). The comments offered by the deaf respondents suggested that some were having trouble understanding what support they would be able to receive in the distance education format. It may be surmised that the preconceived idea of needing a separate support system to facilitate communication of content may deter some deaf learners from seeking continuing education through web-based instruction. Research is needed to examine whether secondary-level students may also have concerns about web-based instruction as it relates to their special needs. This may help educators plan appropriate orientation to the online activities.

Over the past five years, a wide range of synchronous and asynchronous (any time, any place) web-based science activities have been piloted with deaf learners. Online courses have been taught with little face-to-face meeting time, and hybrid learning or "web-enhanced" courses have emphasized live, face-to-face communication using embedded online materials and activities (Kennedy, 2001). Combined use of videoconferencing and asynchronous websites with deaf students has also shown some promise. Daniele, Aidala, Parrish, Robinson, Carr and Spiecker (2001) described an eight-session physics project in which physics was offered to six deaf high school students. Four of the lessons were single-concept lecture-demonstrations using videoconferencing over ISDN lines while homework assignments were handled asynchronously on a website. Additional simulation software (Interactive Physics by MSC Software) was used and Wacom Graphire tablets enabled the students to draw sketches and tables of data with electronic pens over the Internet. Modest pretest-posttest gains were reported by these educators.

Daniele et al. (2001) also offered a similar series of five videoconferencing lessons in mathematics, again with an asynchronous website and additional technology (a TI-83 Graphing Calculator). During the times the document camera was used, communication through sign language was not possible since the room was not equipped for a split-screen. Nevertheless, while all five students scored 0 percent on the pretest, two received 60 percent and three received 80 percent on the posttest. Daniele et al. (2001) conclude:

> Unquestionably, distance learning is increasingly recognized as a valid method of delivering instruction. Equally certain is the fact that educational tradeoffs and compromises will be involved when distance learning is employed. Although there was a great deal that was positive about our joint . . . experience, the lessons were different from what typically transpires during self-contained classes . . . . All of us interested in effective teaching of deaf students need to ask what circumstances make the educational compromises required by distance learning worthwhile (p. 10).

Ellsworth and Huckleberry (2001) summarized a one-year course in Earth Systems Science jointly offered at three schools serving deaf students. The SOAR-High Distance Learning Project utilized both ISDN computer-based videoconferencing and the Internet, along with a variety of other technologies, including computer-based video cameras. Students accessed the instructional units on the Web. Barman and Stockton (2002) reported an improvement among these students in using science process skills, independent learning skills, as well as their technology literacy and motivation. Some students encountered difficulty with the reading levels of the SOAR-High materials.

A variety of technological hardware and software applications have been tested for online science/technology learning by deaf students on both the secondary and postsecondary levels. Craig and Ting (2001), for example, described the use of IdeaTools^{TM}, a web authoring/course management system, to teach chemistry. IdeaTools^{TM} was used in combination with other tools to make the course material more interactive. These included Chime^{TM}, for visualization of proteins, Chemsketch^{TM}, for chemical drawings, and WebEQ^{TM}, for preparation and submission of chemical and mathematical equations online.

Mallory and Lang (2002) discussed how high-speed connections are changing the capability of carrying large amounts of text, voice, and video data over existing telephone and cable lines. As the quality and speed of computer networks increase, so do demands for higher levels of interaction. Such use of "Internet Conferencing" with deaf students may present pedagogical and technological challenges. As described earlier, these include the use of captions or other reading materials and, for many deaf students, interactions with teachers and peers will eventually include increasing use of sign language over the Web.

Some experiments have been conducted to investigate web-based transmission of sign language, which features significant motion of the arms and hands, and requires a frame rate high enough for smooth motion perception. The Classroom of the Sea is a National Science Foundation sponsored grant project with a collaborative team from the National Undersea Research Center for the North Atlantic and Great Lakes, University of Connecticut, American School for the Deaf in Hartford, and the National Technical Institute for the Deaf at Rochester Institute of Technology. To develop a means for communicating in sign language with high quality transmissions over the Internet, VBrick from VBrick Systems was used to set up a "vbx server." A digital video camera was used with the deaf students on a ship, the *RV Connecticut*, on the Atlantic during a water sampling activity. This signal was fed into the *RV Connecticut's* network and then transmitted from the vessel to the antenna on the Marine Sciences building on shore five miles from the ship at sea into the building's Local Area Network (LAN). From there it was picked up/split to one or two Vbricks to test the high quality imagery coming to the shore. One of these signals was sent to the vbx server which transcoded the signal to Windows Media. This was the streaming format for viewing the web video with Streamplayer2. The transmissions could also be viewed remotely on the project's web page.

Both a static video camera and a mobile camera were used to transmit over the Internet the messages in American Sign Language (ASL) describing the at-sea research by the deaf high school students. Initial experiments proved successful. The sign language over the Internet was of sufficient quality to continue planning for two-way transmissions on an ongoing basis. Experiments with classroom lectures, including the use of Power Point slides, using this system were also successful. This will allow the team of scientists and educators in four different locations to interact during various science learning excursions with deaf students (Lang, Babb, Scheifele, Brown, LaPorta-Hupper, Monte, Johnson & Zheng, 2002).

Mallory and Lang (2002) also summarized an experiment with tutoring remote deaf students via a QuickCam Desktop Camera in conjunction with Microsoft's NetMeeting as a tool for clarifying concepts with one deaf student and one teacher. This is often referred to as point-to-point video conferencing, where only two people can talk and see each other at a time. There are many choices for implementing web-based conferencing. Desktop Video Conferencing (DVC) includes a video conferencing camera, such as the QuickCam camera, a microphone, and a speaker mounted to the local computer. DVC can be used to link two or more participants at different sites by using computer network(s) to transmit data. The Codec (compressor-decompressor) technology compresses and decompresses digital data in video, audio, or text-based formats. High processor speeds and fast Internet connections are preferable for such conferencing. A Local Area Network with Roadrunner™, Integrated Services Digital Network (ISDN™), the Digital Subscriber Line (DSL™), or T1 connection would be optimal. Without such processor speeds and Internet connections, video data may especially appear choppy. When a digital movie has a data rate higher than the video data rate of the capture drive, the computer will drop frames, causing jerky movement when played. This has special implications for communication via sign language or speech-reading (lip-reading). Mallory and Lang (2002) reported that DVC, when combined with the other tools, provided an adequate environment for successful remote tutoring sessions with deaf learners. They described DVC as a widely available, practical technology that can be used in synchronous, online tutoring/teaching sessions, although the limited throughput on the Web makes it challenging to observe sign language in a fluid and practical manner. With the increase in digital compression technology and students increased connectivity at high-speed, broadband access speeds, use of digital video conferencing will continue to grow.

In addition to educational experiments with live transmission of sign language and with sign language video clips, some creative new technologies are being developed. Sims (2000) reported on a study of "Signing Avatars™," which are humanoid and other characters digitally created to accompany text in a lesson or conversation. In one evaluation study, a group of deaf eighth graders with low reading ability answered, on average, only one out of six questions after reading only text, but four out of six after seeing the story signed by the Avatar (Sims, 2000).

What empirical research says to the teacher

The science education experiments with small groups of deaf students reported above have generally not included detailed evaluation designs. To gain further insight into ways to optimize learning, we must look to empirical studies with deaf students in science, as well as those involving adjunct multimedia instructional aids. Although not online, such research reveals critical elements which need to be considered when developing web-based education for this particular group of learners.

Little empirical research has been conducted to identify the best approaches for use in web-based instruction with deaf learners in science. Several studies, however, have laid a foundation for future research. These empirical studies will be summarized in the section below.

Multimedia study at the National Technical Institute for the Deaf (NTID)

Studies of interaction of deaf learners with computerized instructional materials have shown promising results. In a multimedia research study with 144 deaf students, Dowaliby and Lang (1999) examined the influence of four types of adjunct instructional aids on immediate factual recall of science content in a series of 11 lessons about the human eye. Students were grouped by standardized test scores as low, middle, and high ability readers and were assigned to conditions which included: (1) reading text plus viewing "content movies" (animation), (2) text plus sign language translations of the text, (3) text plus answering adjunct questions about the text, and (4) all conditions together (text, sign language translations, animations, and adjunct questions). The study demonstrated that low-reading-ability students studying science through computerized instruction that included text with adjunct questions performed on a test of immediate factual recall as well as high-reading-ability students learning through text only. While the sign language translation movies and animations resulted in increases in factual recall, the increases were not statistically significant in comparison with the control group, which received only text. The authors attributed the improved recall to the engaging nature of the adjunct questions. The results of this experiment indicate that the interaction of deaf learners with course materials programmed on a computer bears further investigation.

Studies conducted by the Oregon Center for Applied Science (ORCAS)

The Oregon Center for Applied Science has conducted three very successful field tests ($p < 0.001$) of multimedia science programs showing that science learning by deaf middle school and high school students can be greatly enhanced. The three studies included non-web-based earth science and physical science and web-based chemistry. All have been funded by federal NIH grants and all are based on a similar set of curriculum design features. Since the results of these studies have not been previously published, additional details are provided on the design and evaluation of these programs.

Design of ORCAS science programs for deaf and hard-of-hearing students

In an attempt to ameliorate the growing encyclopedic problem of science instruction, general science instruction has turned toward a focus on explicitly teaching the underlying networks of concepts. Kameenui and Carnine (1998) have referred to these underlying conceptual networks as the "big ideas" for organizing facts and knowledge and simultaneously emphasizing higher-order thinking. The efficacy of this approach with hearing students has been supported by numerous studies (Carnine, Engelmann, Hofmeister & Kelly, 1987; Grossen & Carnine, 1990; Kameenui, Carnine, Darch & Stein, 1986; Moore & Carnine, 1989; Muthukrishna, Carnine, Grossen & Miller, 1993; Niedelman, 1991; Woodward & Noell, 1991). The extension of this approach specifically to teaching science to deaf and hard-of-hearing students has been recommended by several researchers (McIntosh, 1995; McIntosh, Sulzen, Reeder & Kidd, 1994).

This "big idea" approach is central to all three ORCAS programs. For example, in earth science, the most important big idea is convection. The process of convection allows a central organization that explains the movement of heat in the earth, in the oceans, and in the atmosphere. In physical science, one of the important big ideas is that all energy is the result of three basic attractions that, for the most part, operate in the same manner – gravitational, chemical (protons and electrons), and nuclear (up and down quarks). Another important physical science big idea is that energy can change between different forms (electrical, chemical, mechanical, heat, etc.) without being destroyed. By understanding the big ideas, students are able to organize facts and concepts into a larger meaningful whole, are able to relate seemingly disparate information, and are able to use this structure of knowledge to solve problems and integrate new knowledge.

To facilitate student mastery of the facts and knowledge needed to understand the big ideas, the ORCAS programs make extensive use of carefully-sequenced lessons, considerate text, graphic organizers, animations, and a rigorous quiz and testing schedule.

Sequenced lessons. The programs are typically designed so that concepts are partially developed in a lesson and reinforced in subsequent lessons. The teaching of concepts and the associated facts across lessons provides more opportunity for practice in learning the skills and knowledge.

Considerate text. All text presentation is written to be "considerate." Sentences are kept fairly short with relatively simple structure. The vocabulary load is reduced by using only those new terms that are necessary to the explanation. Vocabulary work is included before students begin the lesson. This includes review of new terms from prior lessons as well as introduction/discussion of words that students may not be familiar with (but typically not the terms that are introduced and taught in the lesson). Frequent interspersed questions are included as a way to help students identify the most important parts of the text and to give them immediate feedback on their understanding of the text.

Graphic organizers. Multiple graphic organizers are used throughout each program as a means of helping students keep track of the important content they learn. Graphic organizers are a type of schematic that includes the core vocabulary, facts and concepts they have learned. Furthermore, graphic organizers are designed so they provide a clear diagram of how this knowledge is organized and related. If students master the content and understand the relationships contained in the graphic organizers, they will have a good grasp of the basic core content. Graphic organizers are also used as a concise way to review the important information.

Animations. Animations are provided to reinforce and demonstrate all of the important content. When new content is first introduced, the animations are simplified to clearly show the intended process or interaction with very little distracting detail. In later lessons, after students understand the basic processes and interactions, the animations for this content can be more realistic and visually rich.

Questioning. In addition to the frequent interspersed questions in the text, the programs include summary questions, quizzes, and cumulative tests. At the end of each part of a lesson is an extensive set of questions to check student understanding of the entire lesson part. Typically, this set of questions also includes a series of criterion questions. If students do not meet criterion on these questions (usually 75% correct), they are guided back through a review of selected portions of the content. On the subsequent lesson, students are given a quiz covering the most important parts of the previous lesson. Again, if they do not meet criterion, a review is provided. Finally, every 5th or 6th lesson is a cumulative test over the preceding lessons and this too has a criterion and reviews if needed.

The triad presentation

Presenting the content to hearing students is fairly straightforward – audio narration is presented simultaneously with the animation. However, to effectively present this material to deaf and hard-of-hearing students, significant modifications must be made. Embedding quarter-screen ASL in the animation attenuates the presentation because students must simultaneously visually attend to both the ASL and the ongoing animation. Furthermore, quarter-screen ASL is often unreadable due to size restrictions. Captioning, instead of adding ASL, presents the same dual visual attention problem and further compounds the problem by requiring that students read well and fluently.

To address these problems, the content of each lesson consists of a lengthy series of triads. Each triad contains a short text screen, a corresponding animation explicating that passage of text, and an ASL version of that text. Students typically first read the text screen, then view the ASL movie, and then watch the animations. Students can repeat any parts of a triad in any order.

The amount of text presented on any single text screen is determined by the content. Text screens explaining new or complex content is kept to about 10 seconds of normal reading. Text screens for familiar or review content is longer, about 15–20 seconds of reading. A second factor determining the amount of text presented on any one screen is coherence – the short text passage presented on any single screen must compose a coherent message that can be reasonably explicated with a brief animation.

The sequence of triads is frequently interrupted with the interspersed questions. Some of the programs also include audio narration of the animations and ASL for the benefit of students with some residual hearing and for hearing teachers.

Multimedia program development

The development and production of these three programs was a lengthy and elaborate process. For each program, an existing and field tested instructional program was used. Two of the programs used existing Systems Impact Inc. videodisc programs – *Earth Science* (Systems Impact, Inc., 1986) and *Understanding Chemistry and Energy* (Systems Impact, Inc., 1987). The third used a physical science text developed by Steely and currently being prepared for publication by McDougal-Littel (in progress).

The first step in developing multimedia programs for deaf and hard-of-hearing students was to write scripts detailing what each text screen would show, what the corresponding ASL movie would say, and exactly what the animation would show. The requirements for each segment of the script was that it: (1) was short enough so that students could retain the content until they saw the subsequent animation, (2) contained enough content to be a coherent message, and (3) contained enough animation to explicate the content. For the earth science program, ASL scripts were also prepared for all of the questions that were interspersed within a lesson, for questions that followed the lesson, for questions that were to be used in quizzes and tests, and for questions that are used for review when criteria were not met. At this point, it was also possible to develop lists of potential vocabulary that deaf students may not know or may not know the sign for. These lists were edited and revised by deaf science teachers.

As the scripts were developed in the second phase of the project, they were reviewed by the ASL signers and the consultants to identify any potential problems with translating the script into ASL. At the same time, the list of potential vocabulary words were refined. The scripts were also reviewed for content accuracy and any anticipated difficulties in producing the indicated animations.

The final version of the ASL scripts was signed by a native signer and taped during a series of studio sessions. An interpreter ensured that the signers followed the script exactly. The taping was then digitized for final editing. As the final ASL taping was conducted, any in-studio modifications to the script were noted. An audio version of this final ASL script was then recorded in a studio with professional talent. Final editing combined the ASL video and audio into Quicktime movies.

Animations, both 2-D and 3-D, were developed for each of the text screens using AfterEffects and 3-D Studio Max. Still frame text screens and screens for all questions were constructed in Photoshop. Additional needed navigation and instruction screens were also developed along with vocabulary screens and graphic organizer screens. Independent worksheets were developed to accompany each lesson and covered lesson content, vocabulary, and parts of graphic organizers that were covered in the lesson.

In the third phase on the project, the computer program was designed to present the program – the vocabulary preview, the sequence of triads, the interspersed questions, the end-of-lesson questions, the quizzes and the tests. Navigation was controlled by a series of buttons at the bottom of each screen. Management functions typically included keeping track of lesson progress.

Investigation 1: Earth science

Program content and format

A 72-lesson multimedia program for teaching earth science to middle school and high school deaf students was developed. It provided the majority of the science instruction for one year. The program was designed to be used by individual students, small groups of students, or by the teacher for whole-class presentation. The lessons took approximately 20–30 minutes for the teaching and 10–15 minutes for independent completion of the worksheets. The program ran simultaneously on a computer monitor (for the teacher or individual student) and a large screen TV.

The program content was developed approximately 22 graphic organizers (listed in Appendix A) that summarize the important content. A student workbook contained a short text summary of each unit along with unit questions and cumulative review questions. A teacher's guide accompanied the program and provided program rationale, lesson by lesson coverage, supplemental lab experiments, and a worksheet answer key.

Subjects. The subjects were 49 students in grades 6, 7, and 8 at three different schools serving deaf students in Midwestern and Western states. Six classrooms were randomly assigned to condition. Twenty-six of the subjects were in three treatment classrooms and 23 were in three control classrooms. The combined student population was approximately 50% Caucasian, 30% Hispanic, 10% African American, and 10% Native American.

Measures. Pre-test and posttest content measures included the science subtest of the Stanford Achievement Test (Harcourt/Brace, 1995) as a standardized measure of science knowledge and a 50-item Earth Science Test (Woodward, 1994). The Earth Science Test is a criterion-referenced test designed to evaluate student retention of the key conceptual information covered by the interactive program and the normal-care curricula. Woodward (1994) found internal consistency reliability (coefficient alpha) of 0.86 for this instrument. At pre-test, the reading comprehension sub-test of Stanford Achievement Test was also administered to allow matching students on reading level.

Procedures. It took approximately 8 months to complete the science material contained in the curriculum. The students receiving the interactive earth science program were scheduled to work three days a week using the interactive program in teacher-directed groups. The control subjects received the normal earth science curriculum taught three days a week by that teacher. At the end of the school year, the science sub-test of the Stanford Achievement Test and the criterion-referenced test for overall content were re-administered.

Results. In this school-based study classroom was the unit of randomization. The major analysis issue common to school-based research in which the classroom is the unit of randomization is that the data for individuals within any intact social group (e.g., classroom) will be positively correlated (i.e., intraclass correlation). This indicates the need for a hierarchical analytic

Table 1. Earth science program results: Generalized estimating equations analysis

	Est Beta	Robust SE	Robust Z	p	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	N
Earth science criterion test									
GEE Analysis	6.414	1.006	6.373	<.001					
Treatment					10.958	4.027	17.083	4.558	24
Control					10.111	3.756	10.333	2.722	18
SAT science sub-test									
GEE analysis	0.813	0.687	1.183	NS					
Treatment					3.388	1.561	4.386	2.218	13
Control					2.441	1.851	3.233	2.370	13

approach. In this study, Generalized Estimating Equations (GEE) methods were used to control for intraclass correlation because when the unit of randomization is a cluster (e.g., classroom) the data within the classroom is often correlated (Duncan, Duncan, Hops & Stoolmiller, 1995; Zeger & Liang, 1986).

Program effects were assessed using the 50-item Earth Science Test (Woodward, 1994), and the science sub-test of the Stanford Achievement Test. There were 42 subjects with both pre-test and posttest data on the Earth Science Test. There were no significant differences between treatment and control subjects on either measure at pre-test. As shown in Table 1, the mean scores at posttest on the Earth Science Test were significantly higher in the treatment group than in the control group at posttest (Robust Z = 6.373, $p < 0.001$).

Because one site was not able to include the Stanford Science sub-test, there were only 26 subjects with both pre-test and posttest data on this test. While the treatment group showed greater pre-test to posttest gains than did the control group (See Table 1), these differences did not attain statistical significance.

Investigation 2: Physical science

Program content and format

A six-lesson multimedia program was developed for teaching gravity and the phenomenon of orbiting the earth. The six lessons were developed under a Phase I grant. The program was designed to be used by individual students, small groups of students, or by the teacher for whole-class presentation.

The lessons took approximately 20 minutes for the teaching and 10–15 minutes for independent completion of the worksheets. The program ran simultaneously on the computer monitor and a large screen TV.

Subjects. A randomized control evaluation was conducted with 37 deaf students in three school programs. The programs involved were a middle school in the South (N = 15), a mainstreamed high school program in the Midwest (N = 7), and a mainstreamed high school program in the West (N = 16). One teacher from each school participated in the study.

Measures. The pre-post-test designed for this study was an 18-item short answer criterion-referenced test on gravity (the direct relationship of mass to gravity, the inverse relationship of distance to gravity, the effects of drag on acceleration, the dynamics of both free fall and non-free fall, and the reasoning behind the minimum requirements for an object to orbit the earth).

Procedures. Prior to beginning the program, students in each school were rank ordered based on an equally weighted composite of (1) the reading comprehension sub-test of the Stanford Achievement Test and (2) ASL fluency. The ASL fluency was determined by having two teachers rate each student's ASL ability on a scale of 1 (low) to 4 (high).

Matched pairs of deaf students within each school were randomly assigned to either the treatment condition or the control condition. Treatment students worked through the multimedia program with the teacher directing program progress but not providing any direct teaching. Control students received instruction from the teacher covering the same subject matter using conventional materials and methods.

Students in each school completed the criterion-referenced at pre-test. Both treatment and control students spent the same amount of time covering the materials. The time required by each site to complete the lessons varied between 8 and 12 days. Following completion of the six lesson program, all subjects completed the criterion-referenced test.

Results. To examine the efficacy of the physical science curriculum, a two-way factorial analysis of covariance was conducted with experimental condition and school-level (middle school and high school) as main effects. The pre-test measure was the covariate used to adjust for any pretest differences across condition. As shown in Table 2, the treatment student test scores at post-test were significantly higher that the normal-care control student test scores ($F(1,30) = 44.16$, $p < 0.001$) after controlling for initial difference at the time of the pretest. The treatment students showed pre-test to post-test gains of 6.85 compared to normal-curriculum control student gains of

Table 2. Physical science program results: Analysis of covariance of scores on criterion-reference test

Condition	Pre-test *M*	Pre-test *SD*	Post-test *M*	Post-test *SD*	*F*	*p*	Effect size (Cohen's f)
Treatment	3.10	2.71	9.95	2.89	44.16	0.001	1.22
Control	3.12	2.76	5.82	2.94			

2.70. The curriculum effect size was extraordinarily large, *Cohen's f* = 1.22, accounting for 60% of the variance (r^2) (Cohen, 1988). Cohen (1988) defines a *Cohen's f* = 0.4 as a large effect.

The analysis of covariance also indicated that the interaction between condition and school was not significant. That is, the program was equally effective at both the middle school and high school levels. In addition, the analysis found a significant main effect for school-level ($F(1,30) = 7.49$, $p < 0.002$), indicating that middle school students in both conditions improved more on the physical science test than did high school students. Middle school students had a pretest mean of 1.73 (SD = 2.40) and a post test mean of 7.00 (SD = 2.10). High school students had pretest mean of 4.04 (SD = 2.53) and a post test mean of 8.77 (SD = 4.16).

Investigation 3: Chemistry

Program content and format

A six-lesson, web-delivered multimedia program was developed for teaching basic atomic structure and bonding (covalent and ionic). The six lessons were developed under a Phase I grant. The program was designed to be used by individual students or small groups of students at a single monitor. The lessons took approximately 15–20 minutes for the teaching and 10–15 minutes for independent completion of the worksheets.

The basic lesson content was presented via a web browser as HTML and Javascript. If sufficient bandwidth was available at the school, all material was delivered via the Web. Text screens, still frame screens and animations were delivered on demand while the full-screen ASL was preloaded as students worked through the still frame text screens. Where bandwidth was insufficient, the ASL movies and the animations were downloaded lesson by lesson before the student began working on a lesson.

Table 3. Web-based chemistry program results: Analysis of co-variance of scores on criterion-reference test

Condition	Pre-test		Post-test				Effect size
	M	*SD*	*M*	*SD*	*F*	*p*	(Cohen's f)
Treatment	3.29	3.12	14.9	6.09	54.3	0.001	1.12
Control	2.96	2.65	4.25	3.43			

Subjects. Forty-five middle school and high school students from three schools serving deaf students participated in the study. Two schools were on the East coast and one in the West. There were 37 eighth graders, 7 tenth-graders, and one eleventh-grader.

Measures. The pre-post-test designed for this study was a 20-item short answer criterion-referenced test on knowledge of basic chemistry. The test items covered the principles of atomic structure, the differences between elements and compounds, the nature and value of atomic charges, electron composition of different energy levels, and determination of simple ionic and covalent bonding principles

Procedures. Students were randomly assigned to either receive the web-based curriculum or standard instruction. One week prior to start of instruction, students were given the pretest version of the criterion-referenced test. The pretest assessment was followed by two weeks of instruction. After completion of instruction, a posttest assessment was administered using a parallel version of the criterion-referenced chemistry knowledge test.

Results. Treatment and control students did not differ at pretest on knowledge of chemistry ($t(43) = 0.38$, $p = 0.71$) with the treatment students recording a mean of 3.29 ($SD = 3.12$) and controls registering a mean of 2.96 ($SD = 2.65$). To examine the efficacy of the web-based chemistry curriculum, a two-way factorial analysis of covariance was conducted with experimental condition and school-level (middle school and high school) as main effects. The pre-test measure was the covariate used to adjust for any pretest differences across condition. At post test the treatment students had a mean of 14.90 (SD = 6.09) on the knowledge test, while the control students had a posttest mean of 4.25 ($SD = 3.43$). The ANCOVA indicated that there was a significant main effect for condition and that school-level and the two-way interaction were not significant. Consequently, these terms were dropped from the model and a one-way ANCOVA by condition was conducted. This analysis indicated that treatments subjects' performed significantly better than controls ($F(1,42) = 54.3$, $p < 0.001$) after controlling for initial differences at the pretest. The effect size of the Internet-based curriculum was exceptionally large (*Cohen's* $f = 1.12$), accounting for 56% of the variance (R^2) in test scores.

On a student satisfaction questionnaire, 68% of the treatment students indicated that the lessons were at the appropriate level of difficulty. Eighty-seven percent indicated that learning the content with the web-based curriculum was more enjoyable than learning it from a teacher and 87% indicated that they thought they could learn more in this manner.

Discussion

The results of the three studies conducted at the Oregon Center for Applied Science indicate that the interactive multimedia and web-based curriculum materials yielded significantly greater knowledge gains for deaf students as compared to traditional classroom experiences. For the Earth Science study, greater pre-to-post improvements were found for treatment subjects on both a 50-item criterion-referenced Earth Science Test (Woodward, 1994) and on the Comprehensive Test of Basic Skills, although statistical significance was not attained for the latter.

The Physical Science study demonstrated that an interactive multimedia program using Direct Instruction principles (see *Theory of Instruction* by Engelmann and Carnine, 1982) and appropriate population-specific enhancements to teach deaf students is significantly more effective than standard teacher-led curricula. The clinical trial with the web-based Chemistry curriculum also resulted in greatly enhanced knowledge in the treatment group compared to the standard instruction group. The treatment effects were non-trivial (i.e., very large, *Cohen's* $f = 1.12$), suggesting that this approach to science education may lead to significant improvements in student knowledge gains.

The results of all three studies provide strong support for a multimedia instructional approach. Well-designed, proven-efficacious science instructional programs for hearing students can be successfully adapted for use with deaf students by interspersing text and ASL explanations with content animation and by providing additional practice on vocabulary and content graphic organizers. Original materials can also be developed with these emphases. The materials can be effectively presented via the web or through more traditional classroom delivery.

These studies, in addition to the multimedia study by Dowaliby and Lang (1999), show a possible synergistic effect whereby the use of a combination of various forms of adjunct instructional aids may have a positive impact on learning distinct from the contributions of the individual components. Further research may help us understand the relative contributions of graphic organizers, adjunct questions, ASL explanations, and other forms of visual support to text comprehension. Research is also needed to determine the optimal amount of text to place on a computer screen when students are known to have reading difficulties. Multiple visual demands, such as when a computer screen includes simultaneous use of captions, graphics, and signing, may also impact learning by students who are deaf. Research may lead to improved methods of presenting science content to enhance the learning in deaf students, which will benefit *all* students.

Note

1. The term "deaf" will be used in this paper to refer to both deaf and hard-of-hearing students.

References

Barman, C.R. & Stockton, J.D. (2002). An evaluation of Project SOAR-High: A web-based science program for deaf students. *American Annals of the Deaf* 147: 5–10.

Carnine, D.W., Engelmann, S., Hofmeister, A. & Kelly, B. (1987). Videodisc instruction in fractions. *Focus on Learning Problems in Mathematics* 9: 31–52.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral sciences*. Hillsdale, NJ: Erlbaum & Associates.

Coombs, N. (1989). Using CMC to overcome physical disabilities. In R. Mason & A. Kaye, eds, *Mindweave: Communication, Computers, and Distance Education*. New York: Pergamon Press.

Craig, P.A. & Ting, S. (June, 2001). Web-based curriculum development for chemistry and biochemistry using IdeaTools. Paper presented at the Instructional Technology and Education of the Deaf Symposium. National Technical Institute for the Deaf, Rochester, NY.

Daniele, V.A., Aidala, C., Parrish, R., Robinson, V., Carr, J. & Spiecker, P. (2001). Distance learning pilot: Physics and mathematics. Paper presented at the Instructional Technology and Education of the Deaf Symposium. National Technical Institute for the Deaf, Rochester, NY.

Dowaliby, F.J. & Lang, H.G. (1999). Adjunct aids in instructional prose: A multimedia study with deaf college students. *Journal of Deaf Studies and Deaf Education* 4: 270–282.

Duderstadt, J.J. (1998). Transforming the university to serve the digital age. *Cause/Effect* 20: 21–32.

Duncan, T.E., Duncan, S.C., Hops, H. & Stoolmiller, M. (1995). Analyzing longitudinal substance use data via generalized estimating equation methodology. *Multivariate Behavioral Research* 30: 317–339.

Ellsworth, M. & Huckleberry, T. (2001). Strategies assessing technology online. Paper presented at the Instructional Technology and Education of the Deaf Symposium. National Technical Institute for the Deaf, Rochester, NY.

Ely, D. (June, 2001). Facts and fallacies about the future of technology in education of the deaf. Paper presented at the Instructional Technology and Education of the Deaf Symposium. National Technical Institute for the Deaf, Rochester, NY.

Engelmann, S. & Carnine, D. (1982). *Theory of Instruction*. Eugene, OR: ADI Press.

Foster, S., Long, G. & Snell, K. (1999). Inclusive instruction and learning for deaf students in postsecondary education. *Journal of Deaf Studies and Deaf Education* 4: 225–235.

Grasha, A.F. (1996). *Teaching with Style: A Practical Guide to Enhancing Leaning by Understanding Teaching and Learning Styles*. Pittsburgh: Alliance Publishers.

Grossen, B. & Carnine, D. (1990). Diagramming a logical strategy: Effects on different problem types and transfer. *Learning Disabilities Quarterly* 13: 168–182.

Hanafin, M.J. & Peck, K.L. (1988). *The Design, Development, and Evaluation of Instructional Software*. New York: Macmillan Publishing.

Harcourt/Brace (1995). *Stanford Achievement Test – 1995*. San Antonio: Harcourt/Brace.

Hertzog, M., Stinson, M.S. & Keiffer, R. (1989). Effects of caption modification and instructor intervention on comprehension of a technical film. *Educational Technology Research and Development* 37: 59–68.

Holt, J. (1994). Classroom attributes and achievement test scores for deaf and hard of hearing students. *American Annals of the Deaf* 139: 430–437.

Jackson, D.W., Paul, P.V. & Smith, J.C. (1997). Prior knowledge and reading comprehension ability of deaf and hard-of-hearing adolescents. *Journal of Deaf Studies and Deaf Education* 2: 172–184.

Jelinek Lewis, M.S. & Jackson, D.W. (2000). Preparing to watch TV: A training module for accessing captions for students who are deaf. *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomics Society*, USA, 2, 113–116.

Jelinek Lewis, M.S. & Jackson, D.W. (2001). Television literacy: Comprehension of program content using closed-captions for the deaf. *Journal of Deaf Studies and Deaf Education* 6: 43–53.

Kameenui, E., Carnine, D., Darch, C. & Stein, M. (1986). Two approaches to the development phase of mathematics instruction. *The Elementary School Journal* 86: 633–650.

Kameenui, E. & Carnine, D., eds (1998). *Effective Teaching Strategies that Accommodate Diverse Learners*. Upper Saddle River, NJ: Prentice-Hall, Inc.

Kennedy, M. (June, 2001). A study of current models of online learning for deaf learners. Paper presented at the Instructional Technology and Education of the Deaf Symposium. National Technical Institute for the Deaf, Rochester, NY.

Lang, H.G. (2000). *A Phone of Our Own*. Washington, DC: Gallaudet University Press.

Lang, H.G. (2002). Higher education for deaf students: Research priorities in the new millennium. *Journal of Deaf Studies and Deaf Education* 7: 267–280.

Lang, H.G., Stinson, M.S., Kavanagh, F., Liu, Y. & Basile, M. (1999). Learning styles of deaf college students and instructors' teaching emphases. *Journal of Deaf Studies and Deaf Education* 4: 16–27.

Lang, H.G., Babb, I., Scheifele, P., Brown, S., LaPorta-Hupper, M., Monte, D., Johnson, P.R. & Zheng, D. (2002). Classroom of the Sea. *NTID Research Bulletin*, Winter.

Mallory, J.R. & Lang, H.G. (2002, March). Video streamed and multimedia instructional tools that benefit a deaf, distance learning audience. Presentation at the Society for Information Technology & Teacher Education International Conference, Nashville, Tennessee.

Marschark, M., Lang, H.G. & Albertini, J.A. (2002). *Educating Deaf Students: From Research to Practice*. New York: Oxford University Press.

McKee, B.G. & Scherer, M.J. (1992). *A Formative Evaluation of Two Gallaudet University/Rochester Institute of Technology Courses Offered via Teleconferencing*. Rochester, NY: National Technical Institute for the Deaf.

McIntosh, A. (1995). Conceptual teaching + Semantic mapping = Discovering connections. *Perspectives in Education and Deafness* 14: 11–17.

McIntosh, R., Sulzen, L., Reeder, K. & Kidd, D. (1994). Making science accessible to deaf students: The need for science literacy and conceptual teaching. *American Annals of the Deaf* 139: 480–485.

Meath-Lang, B., Caccamise, F. & Albertini, J. (1982). Deaf students' views on English language learning: Educational and sociolinguistic implications. In H. Hoemann & R. Wilbur, eds, *Social aspects of deafness*, Volume 5, pp. 295–329. Washington, DC: Gallaudet University.

Moore, L. & Carnine, D. (1989). Evaluating curriculum design in the context of active teaching. *Remedial and Special Education* 10: 28–37.

Muthukrishna, A., Carnine, D., Grossen, B. & Miller, S. (1993). Children's alternative frameworks: Should they be directly addressed in science instruction? *Journal of Research in Science Teaching* 30: 233–248.

Niedelman, M. (1991). Problem solving and transfer. *Journal of Learning Disabilities* 24: 322–329.

Rogers, S.M. (1990). Distance learning: Educational applications of the NREN. *Educom Review* A5(2): 25–29.

Scherer, M.J. & McKee, B.G. (1993). *The views of adult deaf learners and institutions serving deaf learners regarding distance learning cooperative arrangements with NTID/RIT: The results of two surveys*. Rochester, NY: Rochester Institute of Technology.

Sims, E.M. (2000). *Final Report for SBIR Phase II Project. Signing Avatars*. Orlando, FL: Seamless Solutions, Inc.

Woodward, J. (1994). Effects of curriculum discourse style on eighth graders' recall and problem-solving in earth science. *The Elementary School Journal* 94: 299–314.

Woodward, J. & Noell, J.W. (1991). Science instruction at the secondary level: Implications for students with learning disabilities. *Journal of Learning Disabilities* 24: 277–284.

Zeger, S.L. & Liang, K.Y. (1986). Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 42: 121–130.