Journal of Deaf Studies and Deaf Education Advance Access published August 23, 2016

Journal of Deaf Studies and Deaf Education, 2016, 1–13

doi:10.1093/deafed/enw050
Empirical Manuscript

EMPIRICAL MANUSCRIPT

Adapting Experiential Learning to Develop Problem-Solving Skills in Deaf and Hard-of-Hearing Engineering Students

Matthew M. Marshall[1], Andres L. Carrano[2], and Wendy A. Dannels[1]

[1]Rochester Institute of Technology and [2]Auburn University

Correspondence should be sent to Matthew M. Marshall, Kate Gleason College of Engineering, Rochester Institute of Technology, 77 Lomb Memorial Drive, Rochester, NY 14623 (e-mail: mmmeie@rit.edu).

Abstract

Individuals who are deaf and hard-of-hearing (DHH) are underrepresented in science, technology, engineering, and mathematics (STEM) professions, and this may be due in part to their level of preparation in the development and retention of mathematical and problem-solving skills. An approach was developed that incorporates experiential learning and best practices of STEM instruction to give first-year DHH students enrolled in a postsecondary STEM program the opportunity to develop problem-solving skills in real-world scenarios. Using an industrial engineering laboratory that provides manufacturing and warehousing environments, students were immersed in real-world scenarios in which they worked on teams to address prescribed problems encountered during the activities. The highly structured, Plan-Do-Check-Act approach commonly used in industry was adapted for the DHH student participants to document and communicate the problem-solving steps. Students who experienced the intervention realized a 14.6% improvement in problem-solving proficiency compared with a control group, and this gain was retained at 6 and 12 months, post-intervention.

Individuals who are deaf and hard-of-hearing (DHH) are underrepresented within the science, technology, engineering, and mathematics (STEM) professional fields. The percentage of DHH individuals employed in a STEM field (15.5%) is only slightly lower than the percentage of hearing individuals employed in STEM fields (17.9%), with DHH individuals tending to be employed in positions that involve manual labor and a lower pay grade, whereas hearing workers are more often employed in higher paying positions that require higher levels of education (Punch, Creed, & Hyde, 2004; Walter, 2010). Consequently, DHH people employed in STEM fields are not as likely as hearing people to start on a career path that leads to professional advancement in their careers and major contributions to their field.

One reason for the underrepresentation of DHH people in STEM professions may be found within postsecondary education trends. Although DHH students who pursue postsecondary degrees often choose to pursue STEM majors, they typically do not complete the minimum baccalaureate degree that is needed for a career as a STEM professional (e.g., an engineer or a scientist). According to the U.S. Census Bureau (2008), only 23.0% of DHH students complete a postsecondary degree of any kind (vs. 38.3% of hearing students), and of these graduates, only 34.6% obtain a baccalaureate degree (vs. 47.5% of hearing students). Although the percentage of DHH students in 2-year associate degree programs who pursue STEM majors (50.9%) is larger than the percentage of hearing students (39.5%), the career options for graduates with an associate degree naturally offer less pay and lower opportunity for advancement than the career options available to graduates with baccalaureate degrees (Walter, 2010). The large number of DHH students who pursue a STEM major is a strong indication that many DHH students have interest in STEM professions, but the low percentage of DHH STEM professionals is consistent with the low completion rates for DHH students enrolled in STEM baccalaureate programs.

Received November 9, 2015; revisions received July 11, 2016; accepted July 12, 2016

Success in pursuing STEM baccalaureate degrees and subsequent careers requires proficiency in mathematics and problem-solving, which are the areas in which DHH students have been shown to struggle. If DHH students begin postsecondary STEM programs with insufficient mathematical and problem-solving preparation, it is not surprising that these students are often not successful in completing a STEM baccalaureate degree. STEM fields are inherently quantitative and require students to develop the mathematical proficiency necessary to support the demands of the profession. Research findings have consistently found that DHH students of all ages, on average, lag behind their hearing peers with respect to mathematical proficiency upon completion of high school (e.g., Marschark & Spencer, 2009; Pagliaro & Kritzer, 2013; Qi & Mitchell, 2012; Traxler, 2000). Researchers have identified that on account of the varied experiences with which DHH students access the world and develop “numeracy,” the progression of learning mathematical concepts is different than the typical progression of learning experienced by hearing students (Pagliaro, 2015). Pagliaro and Kritzer (2013) identified that the gap between hearing and DHH students in mathematics knowledge may begin even before formal education starts. By the time they reach the age for postsecondary school, only 50% of DHH students have mathematics proficiency at a sixth-grade level (Pagliaro, 2010; Traxler, 2000), with 39.9% of high school students who are DHH demonstrating aptitude for mathematical calculation in the lower quartile (average percentile for DHH students is 38.4%) as compared to the general population of the same age (Walter, 2010).

Despite the discrepancy in mathematics performance between DHH students and hearing students, researchers have demonstrated that simple interventions can bridge this performance gap in young children. Nunes et al. (2009) evaluated multiplicative reasoning among young children and though DHH children initially underperformed in comparison with hearing children, an intervention that addressed how the children constructed representation of the problem significantly improved the performance of the DHH students. Similar results were observed by the same research group when using a simple intervention to evaluate young DHH students’ understanding of inverse relations (Nunes et al., 2008). Therefore, the observed mathematical performance discrepancy between DHH students and hearing students does not appear to be the result of competence. With careful consideration of what is understood about how DHH student learn, instruction may be designed to narrow or completely bridge the gap in performance. Intervention can even be introduced in the preschool years to ensure DHH students keep pace with their hearing peers in mathematics development. Kritzer and Pagliaro (2013) developed a series of workshops and online modules to help parents of DHH preschool children take a more active role in their children’s development by incorporating simple exercises into daily routines to raise children’s awareness of simple mathematics concepts.

Along with operational mathematical proficiency, students in STEM programs need to develop the skills necessary to apply mathematics to solve the types of problems that STEM professionals encounter. Unfortunately, research has also demonstrated that DHH students tend to struggle with fundamental problem-solving. The term “problem-solving” has different meanings based on context, but in the research of DHH student learning, the largest body of research exists in evaluating performance in solving story problems that require the student to understand a story-based scenario and apply mathematical concepts to answer a question. Similar to the findings with mathematical procedures, DHH students, on average, lack the preparation expected of students entering postsecondary school. Nearly 50% of DHH students perform at a fifth-grade level or lower in solving applied problems (Pagliaro, 2010; Traxler, 2000), and according to the Second National Transition Longitudinal Study (Walter, 2010), 53.7% of high school students who are DHH demonstrate aptitude for solving applied problems in the lower quartile as compared to the general population of the same age (average percentile for DHH students is 25.1%).

Although the problems solved in STEM fields are obviously more complex than arithmetic story problems, proficiency in solving story problems provides a foundation on which to develop the higher order critical thinking that is used to solve real-world problems. Students who enter a STEM field need to develop the critical thinking skills necessary to solve the many open-ended, real-world problems that professionals in engineering and science face. It is this type of applied problem-solving that is emphasized in postsecondary STEM programs. Research on the performance of DHH students in solving problems other than story problems is limited, but the research that is available suggests that the gap between hearing and DHH students observed in mathematics and basic problem-solving may also exist. Marschark and Everhart (1999) examined problem-solving strategies of DHH and hearing students and found that DHH students were less efficient than their hearing peers in solving a “Twenty Questions” task. Luckner and McNeill (1994) used a “Tower of Hanoi” puzzle to evaluate performance differences between DHH and hearing students and found that hearing students outperformed DHH students at all age levels, but the gap narrowed for students over the age of 13. Although neither of the problem-solving tasks examined in these studies is well-representative of the types of problems STEM professionals encounter in the real world, the studies suggest that the challenges DHH students encounter in solving arithmetic story problems extend to problems that are more abstract.

In contrast to the typically well-structured problems that students work on in textbooks and solve in the classroom, all students may be challenged in adapting to the open-endedness of real-world problems. However, the situation may be worse for DHH students, as some researchers have demonstrated and suggested that when engaged in problem-solving, DHH students struggle to understand the interaction among concepts or variables that are related (Marschark & Everhart, 1999; Marschark, Convertino, & Larock, 2006; Molander, Pedersen, & Norell, 2001; Pagliaro, 2010). Obviously, this “connecting of the dots” skill is critical when solving open-ended, context-dependent problems that are unfamiliar.

Related to the familiarity of problems, DHH students may also be at a disadvantage due to the gap in content knowledge they often bring to the classroom (Luckner, 2010; Marschark, Sapere, Convertino, & Pelz, 2008). Just as the mathematics gap between hearing and DHH students described previously is not due to DHH students being less intelligent than hearing students, the gap in content knowledge does not reflect a disparity in intelligence. Hearing students benefit from frequent incidental learning, both inside and outside the classroom, that occurs as the result of informal interaction with their peers. DHH students are frequently marginalized in these situations (Hopper, 2011), which places them at an obvious disadvantage in acquiring content knowledge through the incidental learning that hearing people acquire on a daily basis. Because people draw from past experience to formulate hypotheses and develop analogous solutions to unfamiliar problems, reduced content knowledge limits the extent to which an individual can leverage past experiences to aid in problem-solving. Finally, the well-documented lag that many postsecondary DHH students demonstrate with the reading and comprehension of written text (e.g., Marschark et al., 2009; Traxler, 2000) limits the extent to which DHH students are able to effectively use written information to augment their inexperience and "catch up" to their hearing peers to effectively solve a problem.

Although research has provided some insight in understanding how the educational needs and the cognitive development of DHH students differ from those of hearing students, translating this body of research into effective and innovative pedagogy has presented a significant challenge to researchers and educators alike. Technological innovation continues to offer potential interventions to improve pedagogy and specialized communications, but the absence of convincing, evidence-based research, as defined by Horner et al. (2005), limits the extent to which research may confidently be transferred to practice. Beal-Alvarez and Cannon (2014) conducted a review and critical analysis of the research base related to the integration of technology use in educating DHH students. The study concluded that no single intervention met the criteria established by Horner et al. (2005) for "evidence-based" practice.

Despite this lack of evidence-based support, researchers and practitioners have established "best practices" based on personal experience or empirical evidence that falls short of meeting the evidence-based criteria (Beal-Alvarez & Cannon, 2014). This collection of best practices offers a starting point for the development of innovative pedagogy for DHH students. The objective of this work is to leverage effective STEM pedagogy, in general, with some best practices for educating DHH students to develop and evaluate an experiential-based approach to teaching to DHH students the problem-solving skills needed to address the types of problems that STEM professionals face. The approach is based on three distinct pillars: (a) experiential learning through active and collaborative learning; (b) various best practices for teaching mathematics and science to DHH students; and (c) the Plan-Do-Check-Act (PDCA) problem-solving method utilized in industry.

Experiential Learning

The experiential approach in this effort is rooted in the related approaches of active learning and cooperative learning. Essentially, active learning is a learn-by-doing approach that introduces student activity into the classroom and is associated with one of the highest percentages of knowledge retention (Prince, 2004). Cooperative learning, where students interact and learn from one another, has been shown to also result in higher information retention, improved teamwork, better development of interpersonal skills, better attitude toward subject matter, and lower levels of anxiety (Felder & Brent, 2007; Prince, 2004). Johnson, Johnson, and Smith (1998a) found that one of the reasons for the higher retention achieved in active and cooperative learning approaches is due to cognitive rehearsal, in which students learn best when they teach the subject to themselves. Felder, Felder, and Dietz (1998) conducted a longitudinal study in which cooperative learning students outperformed a traditionally taught group on a number of measures, including retention and graduation rates. Carrano, Kuhl, and Marshall (2008) combined active and collaborative learning in an engineering laboratory environment with significant role-playing style. Students indicated an increased level of interest and content retention, and 100% of the participants preferred this approach over a lecture-based format.

Formal assessment of the effectiveness of active learning among DHH students appears to be limited to only two studies. Lang, Stinson, Kavanagh, Liu, and Basile (1999) evaluated the learning styles of DHH postsecondary students and found that the "participative" learning style had a significant positive correlation with academic achievement. Similarly, Quinsland (1986) demonstrated that DHH college students engaged in a role-playing style of learning retained factual knowledge more completely than students who experienced a traditional lecture. Unfortunately, the positive effects of active learning of DHH students are stifled by the reality that participation of DHH students in active learning in higher education settings is a significant challenge (Lang, 2002). Nevertheless, Easterbrooks and Scheetz (2004) have recommended collaborative learning as a means of enriching the critical thinking skills of DHH students.

Best Practices for STEM Instruction to DHH Students

Easterbrooks and Stephenson (2006) conducted a thorough review of the most highly cited practices in literary and mathematics/science instruction of DHH students and analyzed the extent to which research supports these practices. Consistent with the findings of Beal-Alvarez and Cannon (2014), significant research support was found to be lacking for most of the practices cited. Although strong research support for these individual practices is lacking, the collection of these practices represents an appropriate starting point for designing an intervention specially adapted for DHH students, even in the absence of strong, evidence-based support. The 10 practices from Easterbrooks and Stephenson (2006) incorporated into this intervention are briefly described below:

1. *The teacher as skilled communicator*—the teacher must be able to communicate in the language used by DHH students.
2. *Instruction through primary language*—learning is best achieved when using the students' native language.
3. *Teacher as content specialist*—the teacher should possess training, experience, and certification in content-area knowledge.
4. *Active learning*—DHH students who engage in experiential learning perform better than those taught using a lecture format.
5. *Visual organizers*—most DHH students benefit from the visual presentation of information, so visual tools should be used to support instruction.
6. *Authentic, problems-based instruction*—STEM should be taught using collaborative, case-based, real-world problems to improve comprehension of abstract problems.
7. *Use of technology*—technology can be used to enhance communication and visual components of instruction.
8. *Specialized content vocabulary*—specialized vocabulary should be presented (e.g., signed or captioned) consistently and in a manner that is standardized.
9. *Critical thinking*—step-by-step strategies limit how students can apply information to other experiences; need to focus on problem-solving process.
10. *Mediating textbooks*—instructors need to bridge the gap between reading level and written content because of high variability in reading level of DHH students.

A benefit of using the experiential, laboratory-based approach is that it provides the ideal opportunity to incorporate the *active learning* and *authentic, problems-based instruction* practices that are a challenge to incorporate into traditional, lecture-based instruction.

Plan-Do-Check-Act

The problem-solving methodology employed in this work is based on PDCA, an approach that has been widely adopted by industry and popularized by Toyota. PDCA is a legacy from quality guru W. Edwards Deming decades ago and is conducted in well-prescribed steps (Sobek & Smalley, 2008). Engrained in the approach is a way to report results from the PDCA process that is known as the "A3 report." The components of the PDCA approach and A3 report are presented below:

PDCA Step-by-Step:

1. Identify the Problem [Plan]
2. Document the Current State [Plan]
3. Set a Target or Goal [Plan]
4. Determine the Root Cause [Plan]
5. Develop a Countermeasure Plan [Plan]
6. Implement Plan [Do]
7. Confirm Results [Check]
8. Standardize/Control [Act]

Generally speaking, an A3 report is simply an 11 × 17-inch sheet of paper that documents all components of the PDCA process, thus effectively capturing the problem-solving journey in a concise manner. Because space is at a premium, and every step of the problem-solving process must be captured, the A3 report strongly encourages the use of visual aids, charts, and other pictorial information for efficient communication. Also, since it provides a structured way of reporting on problems and countermeasures, through repetitive use, it encourages discipline in problem-solving (Sobek & Smalley, 2008). Finally, of particular relevance to DHH students, the A3 report is a highly effective communication tool that transcends the barrier of languages: at Toyota, Japanese-only speaking personnel often, and effectively, communicate with English-only speaking personnel via highly visual A3 reports. The format is standardized in a way that, once familiar, is very easy to follow. Essentially, the A3 report encompasses the *visual organizers* and *critical thinking* best practices described by Easterbrooks and Stephenson (2006) in that it provides a visual representation of the problem-solving process.

Intervention Description

The approach developed immerses DHH students in an experiential, hands-on environment where they conduct problem-solving exercises in a systematic and iterative manner. Three modules were developed in which problem-solving activities are progressively and iteratively presented to the students who then use the PDCA approach and A3 report to document their problem-solving process. These modules incorporate written case studies and hands-on problem-solving activities conducted in an industrial engineering laboratory. This laboratory is highly flexible and modular and allows students to design, implement, and execute various systems by performing as assembly line and warehouse operators in work scenarios. The laboratory setting allows students to perform problem-solving within a context by observing, collecting, and analyzing the root causes as well as implementing the countermeasure improvements. Students progress through the modules in a spiral instructional approach, reiterating the same concepts with different delivery modes and in different environments, while deepening the degree of implementation. Although the fidelity of the intervention was not formally assessed, the intervention was administered by the same instructor to all students who experienced the intervention. Figure 1 presents an overview of the three modules, followed by a detailed description of each module.

Module 1

The first module exposes students to the theory and fundamentals of the PDCA approach in a traditional, lecture-based setting and utilizes a case study to prepare students for implementing PDCA in subsequent, experiential modules. Students learn, step by step, the PDCA method and A3 report by reviewing and understanding how to work through a case study involving an automotive supplier. This module focuses on the *Plan* portion (Steps 1–5) of PDCA and ends with students debriefing on their A3 report to the rest of the class as would be followed in industry, and the instructor provides feedback on how the report could be improved. All the instructional materials in this module (lecture, examples of A3 reports, and cases) were adapted for effective delivery to DHH students by providing them access to short videos that are both English subtitled and signed using American Sign Language (ASL). These videos provide definitions of key technical terms and offer alternative modes of accessing the case study other than written text.

Module 2

The second module exposes the students to problem-solving within the context of warehousing and order-fulfillment scenarios and uses the production systems lab. During this module, students work on an order-picking rack area where parts are located in designated bins. The students work in teams of two to five members to fill several prescribed orders for a "shift duration" of approximately 5 min. The worker must fill orders as quickly as possible in order to maximize the number of orders that are shipped on a given day. One team member serves as the worker, whereas the other team members observe and collect performance data. Once the shift is completed, two questions are posed to students to prompt problem-solving: Can the current system handle a twofold increase in order fulfillment? If not, what could be done to ensure that the demand is met? Some problems are then identified and presented using the A3 report framework. Some of the anticipated focus areas yield problems in the area of human factors and ergonomics, direct cost of the operation, bin and stock keeping unit allocation, and standard

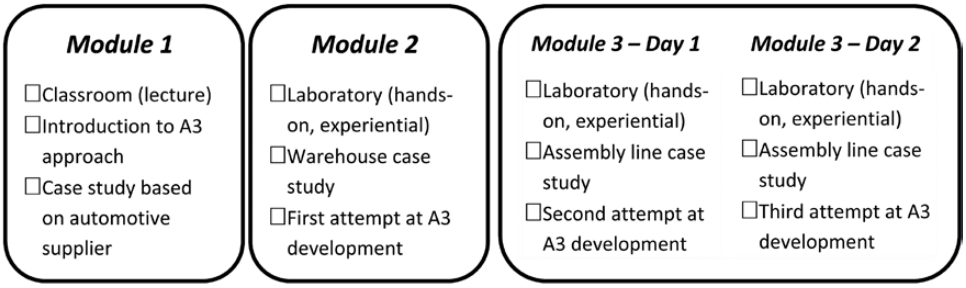

Figure 1 Summary of the modules used for improving problem-solving.

work design. In this module, the students focus again on working through the *Plan* portion (Steps 1–5) of PDCA. However, this time, the emphasis is placed on documenting the current situation (Step 2) and analyzing the root causes (Step 4) via direct investigation. This crucial process, also known in Japanese as *Genchi Gembutsu* (or "*go to the source and see*"), is an integral part of the PDCA approach. It requires that the teams gather data at the location where the issues are originated while brainstorming in a structured way using tools like fishbone diagrams, decision trees, or the "5 Why's" approach. This module ends with the team debriefing to the class on their A3 report, from problem definition up to proposed countermeasure plan, effectively covering Steps 1–5 in the problem-solving approach. Afterward, teams go through the same activity one more time while implementing the proposed set of countermeasures (implement plan, Step 6) to confirm the result (Step 7). If the result is a success, as it usually is, then the standardize/control concept (Step 8) is briefly discussed in class.

Module 3

During the third module, students are exposed to problem-solving within the context of assembly production lines. This is accomplished over two sessions that are each 2 hr in duration. In the first session, students are introduced to a radiator fan automotive assembly of low complexity (i.e., approximately 10 parts). Once they become familiar with the assembly, the students are asked to perform assembly tasks in a four-station manual assembly line, the design of which has been preestablished by the instructor. The students then perform at the line in various capacities for one "shift duration" of 8 min. The data collection includes time studies of cycle time, operator utilization, throughput rate, and work in process at various stations. After the shift ends, students gather in teams of four to six and conduct quick problem-solving around a specific problem in the line. Focus areas may include throughput and cycle time issues, line balancing, and operator utilization. The student teams progress quickly through Steps 1–5 and focus on Steps 6 (Do), 7 (Check), and 8 (Act) for a complete A3 report. The improvements (countermeasure plan) are then implemented, and the line is run again for a similar period of time. The same metrics are collected, and the benchmark against the improvement target is established during the debriefing at the end of the session. The first session ends with the students being challenged to make additional improvements in line performance. The students then have 7 days to independently perform this extended problem-solving while trying out different ideas. They have access to the lab to investigate and try out modifications during this period, and they again need to document this process within an A3 format.

The second session of the third module begins with the student presentations of their problem-solving approach (A3 report), the corresponding improvements, and expected performance. The team then sets up the line with the countermeasures and performs for another shift of equal length. The process is repeated one more time when they have to perform one final round of quick problem-solving, followed by the corresponding A3 report and debriefing. By the end of this module, the students have performed five problem-solving cycles, in three different settings (automotive supplier, warehousing, and assembly) and have documented this journey in five different A3 reports. This iterative approach reinforces the concepts and engrains the problem-solving process (Sobek & Smalley, 2008).

Adaptation for Best Practices

Table 1 presents a summary of the best practices described by Easterbrooks and Stephenson (2006) and the extent to which each practice has been incorporated into the intervention. Some of these practices were more thoroughly incorporated into the intervention than others, but at least some attempt was made to reflect each practice in the intervention. Further description of these adaptations follows.

As presented in Table 1, technology plays a key role in successfully adapting classroom content to DHH students. For this intervention, technology was used to support video content that used both English subtitles and ASL interpretation to convey case studies and vocabulary relevant to the various components of this intervention. In particular, the following were developed and produced:

- A series of four 10-min videos (both captioned and signed in ASL by the main instructor) to present the text-based case studies used for assessment.
- Sixty-four, 5–10 s video clips each providing a definition of key vocabulary words related to the case studies and laboratory activities. These were captioned in English and also signed in ASL. In some cases, pictures or diagrams were included to clarify vocabulary.
- Twenty-eight video clips supporting the step-by-step introduction of the PDCA approach to problem-solving covered in Module 1.
- Approximately thirty 5–10 s videos explaining various laboratory terms and safety procedures necessary for modules 2 and 3.

All specialized vocabulary definitions were developed by engineering faculty from Rochester Institute of Technology and National Technical Institute for the Deaf (NTID) involved in this project and were signed in ASL by an experienced instructor. The video segments were recorded and produced by a professional recording studio experienced in producing adapted materials for DHH students. These materials were easily accessible and available on demand while students performed laboratory activities and problem-solving discussions. These videos reside in the servers that support the courses, so the students are able to access them on demand through the course management platforms. Also, a Microsoft OneNote® template was designed to interactively guide the students through the problem-solving approach and the A3 report. This template guides the students through each step of the problem-solving process as they fill in the appropriate sections of the A3 report and provides examples of how to complete each step of the A3 report using embedded videos and links to the aforementioned content. This template was installed on Microsoft Surface Tablets that were made available to the students throughout the experience and, in particular, during lab exercises. Figure 2 presents a screenshot of the OneNote application used by the students. In addition to the captioned and signed video content, the students also had access to the information through reading material. This approach allows the student the opportunity to access the information in several different ways, thus increasing the likelihood that their preferred mode is always available.

Methods

The data collection used to evaluate the intervention was conducted over three academic years (fall 2011–spring 2014) and is comprised of three cohorts, one from each academic year. A series of case studies was developed and administered

Table 1 Best practices and their adaptation used to develop intervention

Practices	Description and Adaptation
(1) The teacher as a skilled communicator	Instructor must be able to impart instruction in native language. • Native ASL communicator as instructor • Materials also provided in spoken and captioned English
(2) Instruction through primary language.	More than one language is involved in instruction of DHH students. Learning is best achieved when using students' native language. • Native ASL communicator as instructor • Materials also provided in spoken and captioned English
(3) Teacher as content specialist	The teacher should possess specific training, expertise, and certification in content–area knowledge of the subject being taught. • Instructor is experienced in teaching DHH students and has extensive industrial experience in using A3 process.
(4) Active learning	Students who engage in experiential learning achieve greater understanding and comprehension and are more cognitively engaged. • Laboratory (hands-on)-based instruction • Industry-based, contextual exercises with role playing. • A3 problem-solving requires synthesis and analysis
(5) Visual organizers	Teachers should enhance concept mastery through the use of visual organizers such as graphs, charts, and visual maps. • Lab-based instruction and A3 process are highly visual • Text-based materials presented on captioned /signed video
(6) Authentic, problem-based instruction	Instructor should incorporate collaborative, case-based, real-world, problems. • Majority of instruction in industry-like laboratory environment • Use of real-world case studies • Multiple opportunities for group discussion • Follow-up implementation of improvements
(7) Use of technology	Technology enhances communication and visual component of instruction. • Tablets are used while students are engaged in lab activities to provide interactive and immediate information access • Production of captioned, ASL-signed content videos to augment written text and provide ASL interpretation of key technical terms
(8) Specialized content vocabulary	Specialized vocabulary must be developed and consistently interpreted with signs and finger-spelling. • A video-based technical glossary in both captioned English and ASL available online and through Tablet (e.g., definition of "bottleneck") • Contextual pre-activity exposure of specific vocabulary
(9) Critical thinking	Provide step-by-step problem-solving strategies but also go beyond that to promote higher order critical thinking. • A3 presents a highly prescriptive and structured process • Modules initially provide iterative drill-and-practice of A3 process, followed by students practicing independently • Experimentation requires critical thinking skills as students make observations, formulate hypotheses, collect data, and implement data-driven solutions
(10) Mediating textbooks	Reading levels in DHH students is highly variable. Instructors need to bridge this gap between reading level and written language demands. • Reading materials were supplemented with ASL and English-captioned videos of case studies. • Definitions of technical terms were provided using ASL and English-captioned videos

Note. Best practices are adapted from Easterbrooks and Stephenson (2006). ASL = American Sign Language; DHH = deaf and hard-of-hearing.

pre- and postintervention for each cohort and were evaluated and scored by a team of faculty using a custom rubric. The participants, case studies, time line, rubric, and evaluation methods are described in this section.

Participants

The intervention was developed primarily for first-year DHH students in the Engineering Studies program at the NTID, a two-and-a-half year associate degree program. All students who participated in the study were first-year students in this degree program. A control group was evaluated in the 2011–2012 academic year, prior to developing and implementing the intervention, and the intervention groups were evaluated in the 2012–2013 and 2013–2014 academic years. Although the intervention was delivered through several different first-year courses, the experience was identical for all students who were exposed to the intervention, and these two groups were combined into a single "intervention" group. The control group ("control") consisted of 34 students, and the intervention group (intervention) consisted of a total of 40 students (17 from 2012–2013 and 23 from 2013–2014). No participants in the control group later became a participant in the intervention group.

Case Studies

Four case studies were either adapted from existing material or developed specially for this research by the investigators.

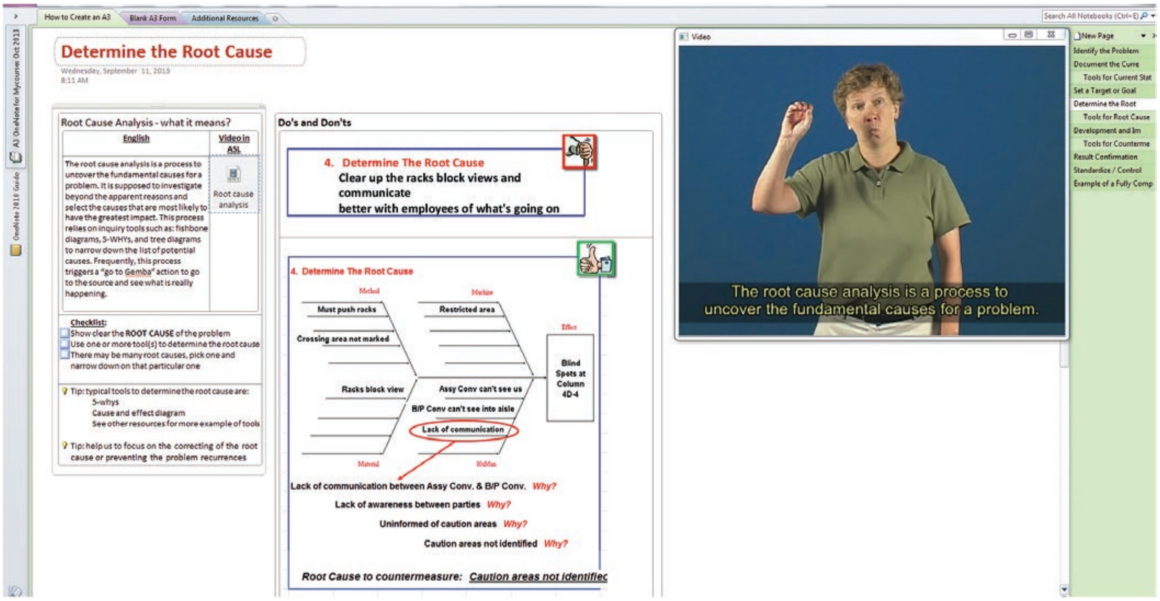

Figure 2 Screenshot of Microsoft OneNote application developed to guide students through the problem-solving sequence.

Each of the four cases presents a situation where several, open-ended problems were described, and enough information was provided to develop a root–cause analysis. For all cases, one of the several problems and root causes could be identified. The case studies were designed to be about two pages long with both text and graphical information and are modeled after a format used by Sobek and Smalley (2008) to support the teaching of problem-solving using the A3 report. The context of the first case is health care and was adapted from existing literature (Sobek & Smalley, 2008). The second case focuses on the operation of a microbrewery and was developed specifically for this intervention. The third case is an adaptation of training materials from Toyota and deals with problems related to household utility expenses. The last case addresses pizza delivery logistics and was developed specifically for this intervention by the investigators. For each case study, students were placed in groups of two or three and provided the case information. Students were asked to provide a written response to identify the problem, summarize the current situation, identify the root causes, propose interventions and improvements, and document all aspects of their problem-solving approach. Teams were given as much time as needed to complete the report, which was typically 15–30 min. Students in the intervention group had access to both the case reading materials and the video content that used English subtitles and ASL to translate the narrative and define vocabulary of the case studies.

Time line

The four cases were used to assess each student's performance on problem-solving skills. The first case (health care) was always used as a preintervention ("PRE") instrument and was administered during the first 3 weeks of the academic term prior to when the intervention was conducted. The intervention took place between Weeks 4 and 8 of the term. The second case (microbrewery) was always administered as a postintervention ("POST") assessment between Weeks 9 and 15 of the same academic term. The third and fourth cases were administered as follow-up instruments ("FOLLOW1" and "FOLLOW2") at approximately 6 and 12 months, respectively, after the intervention. Every student completed the PRE and POST assessments, but due to attrition and other factors, not all students participated in the FOLLOW1 and FOLLOW2 assessments. Participation and attrition numbers are presented with the results. The same evaluation schedule was followed for the control group even though these students did not experience the intervention.

Rubric

A custom rubric to score the student work was developed by three engineering faculty. Six criteria were developed to assess the student's ability to: (a) define the problem, (b) document the current state, (c) identify a metric and set a target, (d) identify root causes, (e) develop solutions and action plans, and (f) communicate technical information. Each criterion was clearly defined and score levels of "beginner" (score = 1), "developmental" (score = 2), "accomplished" (score = 3), and "exemplary" (score = 4) and their corresponding performance attributes for each category were specified, similar to the approach developed by Mertler (2001). Thus, a student work could receive a maximum rubric score of 24 points. Half-point scoring was used for situations in which a criterion was judged to be in between rubric levels.

Evaluation Methods

Student case study responses were evaluated using the assessment rubric by a team of three faculty familiar with the cases and the problem-solving approach, and this team scored the student work for each case study. All identifying information was removed from the student work and a randomized, blind evaluation was conducted. Reviewers were aware neither of the students' identities nor whether the students were part of the control or intervention groups. For each student work, the faculty individually evaluated each of the categories in the rubric and then discussed the ratings until consensus was reached for each rubric category. Consensus was defined as having all analysts score within one-half point from each other and for each criterion. Upon arriving at consensus, the final score was taken to be the average of the individual evaluators. Typically, the time to review a case study response, discuss individual scores, and arrive at consensus was approximately 10 min for each case study. The rubric was not formally evaluated with respect to its reliability. However, the same individuals were used to evaluate all the student work and use of the rubric required discussion to achieve group consensus on every case study that was evaluated. A total of 133 case studies were evaluated over the course of this 3-year study.

Analysis

Consensus rubric scores for each individual student were provided to a team of external evaluators for data analysis. For each student, an overall problem-solving score was determined by summing the score of each criterion in the rubric, for a maximum possible score of 24. Repeated measures analyses of variance (ANOVAs) for Group × Test were used to determine whether statistically significant differences exist among experimental variables for both the overall score and the scoring from each individual rubric element. The Group factor has two levels, corresponding to the control and intervention cohorts, and the Test factor has four levels, corresponding to the four assessment points at which problem-solving case studies were administered (PRE, POST, FOLLOW1, and FOLLOW2). Tukey analysis of means was used to determine which experimental levels were statistically different from one another.

Results

Mean values (and standard deviation) of the overall score for all combinations of experimental variables are presented in Table 2. Because of student attrition, a common problem in this degree program, the sample size of students available for the two follow-up assessments was much smaller than the original cohort. To maximize the statistical power of the data, the short-term impact and long-term impact of the intervention were analyzed separately. This allowed for the use of a larger data set for comparison of PRE to POST.

Short-Term Impact of Intervention

A total of 74 students participated in both the PRE and POST assessment (34 control and 40 intervention). ANOVA was used to evaluate differences in overall problem-solving performance between students who experienced the intervention and students who did not. Figure 3 presents a summary of the mean (and standard deviation) PRE and POST evaluation scores for the students who participated in both evaluations. A statistically significant Group × Test interaction effect was observed, $F(1, 72) = 9.86$, $p = .002$. A Tukey analysis of means revealed that although no statistically significant change occurred in PRE to POST for the control group, the POST score increased by 14.6% for the intervention group. The Tukey analysis showed that this increase was statistically significant. It should also be noted that no statistically significant difference in PRE score was observed between the control and intervention groups.

Long-Term Impact of Intervention

Throughout the 3-year project, some students transferred programs, left the university entirely, or were otherwise unavailable for follow-up evaluation. As a result, only 32 students of the 74 completed all four evaluations (PRE, POST, FOLLOW1, and FOLLOW2), with 14 of these from the control group and 18 from the intervention group. Figure 4 presents a summary of the scores for each of the four evaluations performed in this study (PRE, POST, FOLLOW1, and FOLLOW2) for the 32 students who completed all four evaluations. Mean values are separated by control and intervention cohorts (n = 14 and n = 18, respectively). A statistically significant Group × Test interaction effect was observed, $F(3, 90) = 2.75$, $p = .047$. Tukey analysis of means revealed that the intervention cohort maintained a significantly higher level of performance throughout the period of evaluation following the pretest. The intervention group produced scores that were 25.4%, 19.9%, and 37.0% higher than the scores produced by the control group for POST, FOLLOW1, and FOLLOW2, respectively. All of these differences were statistically significant based on the Tukey analysis.

Figure 5 presents a more detailed breakdown of students' performance with respect to the individual criteria evaluated with the rubric. The first five correspond to a subset of the elements that are embedded in the PDCA process and A3 report—problem definition, identifying current state, setting a target metric, root–cause analysis, and development of solutions. The final criterion is holistic and refers to the ability of the students to communicate technical information. Data presented are for the subjects who completed both PRE and POST (n = 34 and n = 40 for control and intervention groups, respectively). In Figure 5, the bars represent the average criterion score for PRE, whereas the dashes represent the score for POST. Asterisks denote where PRE and

Table 2 Mean and standard deviation for overall assessment scores of control and intervention groups.

	Control	Intervention
Subjects completing both PRE and POST		
	Control (n = 34)	Intervention (n = 40)
PRE	9.85 (1.65)	10.66 (1.50)
POST	9.76 (1.97)	12.22 (2.02)
Subjects completing PRE, POST, FOLLOW1, and FOLLOW2		
	Control (n = 14)	Intervention (n = 18)
PRE	10.16 (1.01)	11.31 (1.38)
POST	10.16 (1.84)	12.74 (1.95)
FOLLOW1	10.56 (2.57)	12.66 (2.44)
FOLLOW2	9.45 (1.72)	12.95 (2.16)

Note: PRE = pretest; POST = posttest; FOLLOW1 = 6 months after posttest; FOLLOW2 = 1 year after posttest.

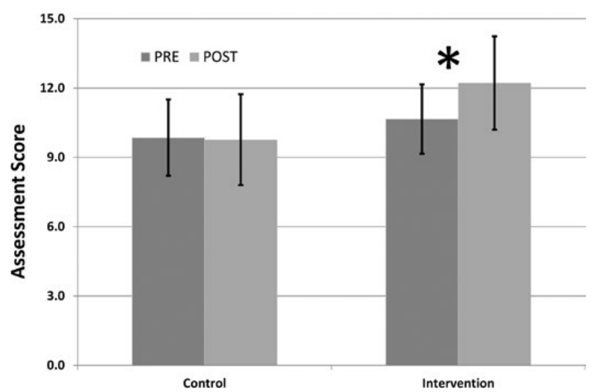

Figure 3 Comparison of mean PRE and POST assessment scores for the control and intervention groups. Error bars represent 1 *SD*. Asterisk denotes a statistically significant difference between PRE and POST scores, as determined by post hoc Tukey comparison (p < .05). PRE = pretest; POST = posttest.

POST differences were statistically significant. For the control group, no statistically significant improvements were observed between PRE and POST for any criterion. However, significant improvements were observed for the intervention group for four of the six criteria. This comparison is useful in interpreting which aspects of the problem-solving process appear to benefit the most from the intervention.

Discussion

Exposure to the intervention developed in this project was associated with improvement in demonstrated problem-solving performance among DHH students. Students who experienced the intervention realized a statistically significant, 14.6% improvement in assessed problem-solving skills (POST) relative to their baseline (PRE) assessment. Students from a similar cohort who did not experience the intervention did not realize the same gain. Furthermore, this improvement was sustained over time, as students maintained this performance at 6 and 12 months after experiencing the intervention (Figure 4). A comparable performance in the follow-up evaluations was not observed for the control group, so the improved performance of the intervention group is not likely the result of student maturation alone. The apparent lasting effect of the intervention is encouraging because improved problem-solving skills should benefit these students as they encounter new problem-solving situations in other courses within their STEM curricula.

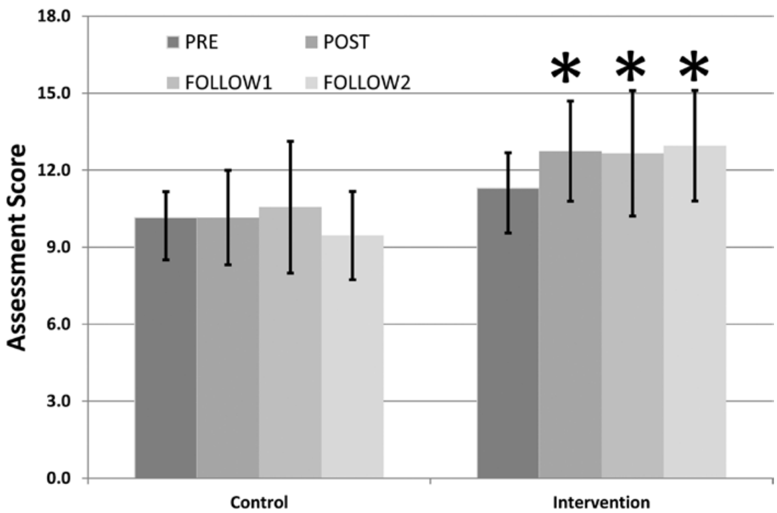

Figure 4 Comparison of mean PRE, POST, and FOLLOW-UP assessment scores for the control and intervention groups. Error bars represent 1 SD. Asterisks denote a statistically significant difference between control and intervention groups, as determined by post hoc Tukey comparison ($p < .05$). PRE = pretest; POST = posttest; FOLLOW1 = 6 months after posttest; FOLLOW2 = 1 year after posttest.

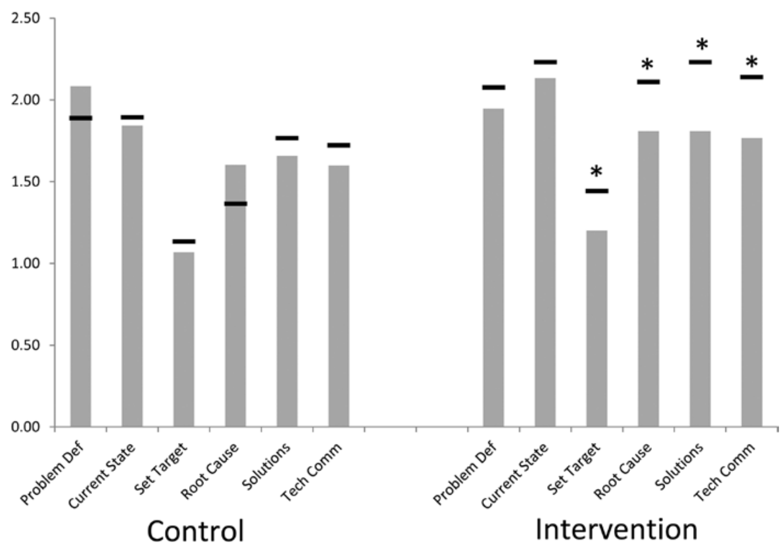

Figure 5 Comparison of assessment scores by criterion for control and intervention groups. Bars and dashes represent mean values for PRE and POST assessment scores, respectively. Asterisks denote statistically significant differences between PRE and POST scores, as determined by post hoc Tukey comparison ($p < .05$).

The rubric used in this study was developed to assess the basic steps of the problem-solving process, as described by the A3 framework. These steps include defining the problem, describing the current state of the system, defining and setting a target metric, determining the problem's root cause, and identifying a feasible solution. In addition to these five steps, the rubric evaluated the quality of technical communication demonstrated by the students. The results presented in Figures 3 and 4 collapse the data across all criteria, but additional insight may be gained from evaluating the individual rubric elements. As presented in Figure 5, the improvement that students achieved was not uniform across all aspects of the problem-solving process. In particular, students who experienced the intervention did not realize a statistically significant improvement in the *problem definition* and *current state description* steps. Relative to the other steps, these two were the highest at the baseline (PRE) assessment, so there was less potential improvement to be realized. In addition, though a statistically significant improvement was realized for *setting a target*, its level of performance at POST was still much lower than all the other criteria. Thus, although students performed better overall in problem-solving, opportunities remain to improve all aspects of the problem-solving process.

The intervention combined supported pedagogical practices for STEM education with adaptations identified as best practices for teaching DHH students. One key aspect of this approach that has been well-documented in the literature is collaborative and cooperative learning. Throughout the assembly line and warehouse experiential laboratory activities as well as during the case studies used to evaluate problem-solving, students were engaged in collaborative sequences (Haller, Gallagher, Weldon, & Felder, 2000) in which small groups of students worked together with no clear role differentiation (e.g., pupil vs. teacher roles). In a review of over 90 years of research, Johnson et al. (1998a) found that cooperation improved learning outcomes relative to individuals across the board. Similar results were found in an updated study by the same authors (Johnson, Johnson, & Smith, 1998b) that reviewed 168 studies between 1924 and 1997 as well as a study by Springer, Stanne, and Donovan (1999) that reviewed 37 studies of students in STEM programs. This body of research supports the findings of this study in which the students may have benefited from the collaborative aspect of the intervention, though it is not possible to determine the extent to which collaboration alone contributed to student learning.

This intervention also employed active learning, a well-established approach that promotes student engagement by introducing student activity into traditional lecturing (Prince, 2004). Instead of presenting students with an abstract problem in the classroom, devoid of context, students were introduced to the laboratory problems by serving as "workers" within the authentic assembly line and warehousing scenarios. After gaining familiarity with these settings and a basic understanding of the variables driving performance, students were then presented with the problem that became the focus of the laboratory experience, giving them a context for the problem. Because DHH students have demonstrated a gap in content knowledge relative to hearing peers (Hopper, 2011; Luckner, 2010; Marschark et al., 2008), providing context for what may otherwise be an abstract and unfamiliar scenario (production line or warehouse) may be particularly beneficial even beyond the benefits of active learning that others have reported for hearing students. Several research studies (e.g., Hake, 1998; Redish, Saul, & Steinberg, 2000) have found significant differences in pretest and posttest student performance in a variety of STEM fields when using active learning techniques. When substantial use of interactive-engagement methods was implemented, Redish et al. (2000) found that test scores measuring conceptual understanding were twice as high in those classes promoting engagement and that the improved learning gains are due to the nature of the active engagement and not the extra time spent on any given topic. By nature of the experiential learning that was central to this project, students were actively immersed in the environment where they were executing problem-solving.

The experiential learning aspect of the intervention has been effective for STEM education in general, but the aspect of this approach that targeted DHH students was to incorporate as much as possible, the best practices described by Easterbrooks and Stephenson (2006) and summarized in Table 1. These best practices include active and experiential learning. A;though evidence-based support of these individual best practices is lacking, this project provides empirical support of the benefit of collectively employing these practices. The practices include providing accessibility options in ASL, captioned English, and spoken English. These accommodations also provided on-demand support as students worked on problem-solving both in the experiential lab activities and in the case studies used to evaluate the students' problem-solving skills. If students have questions about the definition of a technical term or are uncertain about the next step of the A3 problem-solving approach, they have ready access to video clips that convey the desired information in multiple formats (written/spoken English or ASL). Utilization of the video clips varied and was formally evaluated only for the case study used for pre-assessment (PRE). When working on this case study, 29% of students used no videos (i.e., only read the written case study); 38% only viewed the video presentation of the case study without accessing any specialized vocabulary video clips; 21% watched the case study and reviewed one or more vocabulary video clips; and 11% read the case study and reviewed one or more vocabulary video clips. Although the student usage of the video clips was evaluated, a related limitation of the study is that the fidelity of the intervention was not formally evaluated, so it is not possible to know that the intervention was administered in exactly the same way it was intended across the several different courses in which it was used. However, the intervention was delivered by the same instructor and she attempted to minimize any variation in delivery.

The motivation for developing this intervention was to address the immediate and ongoing needs of the students enrolled in STEM postsecondary programs. Although the results provide an optimistic outcome for the intervention, the analysis unfortunately cannot partition the individual contribution of the various aspects of the intervention. The results suggest that students benefited from the intervention as a whole, yet there is no way to determine the extent to which any of the individual components of the intervention (i.e., active and collaborative learning, inclusion of best practices, or PDCA approach) are responsible for the positive results. Furthermore, these three components are not mutually exclusive because Easterbrooks and Stephenson (2006) name directly (active learning) or allude to (authenticate problem-based instruction and critical thinking) other aspects of the intervention. In describing the best practices, Easterbrooks and Stephenson (2006) present for each practice the limited empirical evidence that supports each of the individual practices. Despite not being able to attribute the improvements observed in student problem-solving to specific aspects of the intervention, this study provides some evidence of the positive impact that may result from integrating the collection of best practices.

The results of this project naturally raise questions about whether and how the intervention may be adapted to other learning environments and other types of students. The intervention activities took place in a production systems laboratory, which is a unique facility in that it provides students with an experience that closely resembles the types of activities that engineers in production systems encounter in practice. It also allows for the physical experimentation that forms the basis of experiential learning. This provided the students both a context and a process for developing and practicing the PDCA approach. A potential perceived limitation of this approach is the reliance on the specialized laboratory that provides students the experience of working in a setting that closely resembles industrial settings. Although the laboratory component certainly enhances the experience of the students who have participated in the intervention, availability of a comparable facility should not be seen as a requirement for implementing the intervention. The key aspect of the laboratory is that it provides an authentic, problem-based experience, which is a principle emphasized in the Easterbrooks and Stephenson (2006) best practices (Table 1). Tabletop simulations may easily be employed (and may be equally effective) while using Legos or other simpler products to simulate the types of systems that students experienced in this intervention, even if the authenticity of the experience is slightly lower (Hernandez, 2015; Whitman, Steck, Koert, & Paarmann, 2007). Several implementations with Legos and paper airplanes have been shown to be very effective for experiential learning. Alternatively, some virtual simulations are available (e.g., the beer game, the Fresh Connection, and Littlefield Technologies) that can enhance the experience by maintaining some of the collaborative elements without significant investment in materials or equipment.

It is important to emphasize that the students who participated in this project were almost entirely students who chose to enter a STEM field of study. This presents at least two limitations that should be considered. First, though mathematics proficiency was not evaluated, it is reasonable to assume that the participating students were motivated and perhaps better prepared for developing the problem-solving skills that were the focus of this intervention. As a result, the positive results observed likely occurred under the best possible set of circumstances to observe improvements. Second, the intervention was developed specifically for these postsecondary students, which raises a question about whether the intervention or a modified version of it may be adapted to a younger group of students who may not have a strong STEM orientation like the students in this study. The experiential activities used in this project have been used as community outreach programs with students as young as fifth grade. Although the PDCA approach and A3 report have not been introduced to these younger students as part of the activity, it would not be difficult to adapt the terminology and structure of PDCA to an age-appropriate level. Most likely, for high school students, the approach may be implemented without modification.

Additional Limitations

Along with the limitations already described, other limitations need to be considered in evaluating the contribution of this work. First, the design of the intervention utilized only the best practices summarized by Easterbrooks and Stephenson (2006). This is not meant to imply that the Easterbrooks and Stephenson list comprises all possible best practices. Instead, this set of practices provided a convenient resource on which to base the intervention that was developed. Likewise, this list encompasses a wide variety of pedagogical principles, and this intervention was developed to incorporate as many of these as possible, but a claim cannot be made that the collective list or any individual best practice was implemented to the fullest extent possible. The extent to which any single practice was incorporated is a subjective judgment and is not easily measured, but this project was an attempt to develop a single intervention that leveraged each practice to at least some degree.

The students who participated in this project were all first-year DHH students enrolled in the Engineering Studies program at NTID. It was assumed that because of this, there would be little difference between students in the control group and students who participated in the intervention group. Although there was not a significant difference between groups with respect to pretest, problem-solving performance, it is not possible to conclude that the two groups were the same with respect to other important factors such as mathematics level, reading level, or preferred language since these were not evaluated or collected from the participants. This information would have also allowed comparisons to be made to determine whether the impact of the intervention was influenced by individual factors. Also, related to reading level and preferred language, all participants were required to provide a written response for the problem-solving evaluation used to assess the intervention. Although students were free to use diagrams and graphics as part of their response, some written English was required to fully respond, and this may have prevented some DHH students from fully expressing what they know (Qi & Mitchell, 2012).

Finally, though a control group of DHH students was used, it would have been useful to have another control group of first-year hearing students to contrast with the observed findings. This would have provided some insight as to whether DHH and hearing students differ with respect to the baseline level of problem-solving and whether experiencing the intervention results in comparable gains for hearing students. Because the A3 report and PDCA approach have been employed by the researchers in upper level engineering courses with hearing students, there is anecdotal evidence that students benefit, but this has not been formally assessed. This is something that will be analyzed in the future because the researchers have access to first-year students enrolled in engineering programs.

Conclusion

This study presents the development and evaluation of an intervention to improve problem-solving skills of DHH students by combining best practices identified for DHH students and STEM education in general. The findings provide evidence that the approach is effective in improving the problem-solving skills of DHH students enrolled in their first year of a STEM postsecondary program. A major contribution of this work is the finding that, despite a lack of evidence-based support in the literature for the individual best practices described in Easterbrooks and Stephenson (2006), the combination of practices has a positive impact on student outcomes as measured using performance on problem-solving case studies. Although the intervention used a specialized engineering laboratory to present real-world problems to students, the approach may easily be adapted without need for specialized facilities or equipment.

Conflicts of Interest

No conflicts of interest were reported.

Funding

This work was supported by the National Science Foundation (DUE-1141076). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Beal-Alvarez, J., & Cannon, J. E. (2014). Technology intervention research with deaf and hard-of-hearing learners: Levels of evidence. *American Annals of the Deaf*, 158, 486–505. doi:10.1353/aad.2014.0002

Carrano, A. L., Kuhl, M. E., & Marshall, M. M. (2008). Integration of an experiential assembly systems engineering laboratory module. *International Journal of Engineering Education*, 24, 1012–1017. Retrieved from: http://www.ijee.ie/latestissues/Vol24-5/s17_ijee2044.pdf

Easterbrooks, S. R., & Scheetz, N. A. (2004). Applying critical thinking skills to character education and values clarification with students who are deaf or hard of hearing. *American Annals of the Deaf*, 149, 255–263. doi:10.1353/aad.2004.0024

Easterbrooks, S. R., & Stephenson, B. (2006). An examination of twenty literacy, science, and mathematics practices used to educate students who are deaf or hard of hearing. *American Annals of the Deaf*, 151, 385–397. doi:10.1353/aad.2006.0043

Felder, R. M. & Brent, R. (2007). Cooperative learning. In Mabrouk, P.A. (Ed.), *Active Learning: Models from the analytical sciences* (pp. 34–53). doi:10.1021/bk-2007-0970.ch004

Felder, R. M., Felder, G. N., & Dietz, E. J. (1998). A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally taught students. *Journal of Engineering Education*, 87, 469–480. doi:10.1002/j.2168–9830.1998.tb00381.x

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66, 64–74. doi:10.1119/1.18809

Haller, C. J., Gallagher, V. J., Weldon, T. L., & Felder, R. M. (2000). Dynamics of peer education in cooperative learning workgroups. *Journal of Engineering Education*, 89, 285–293. doi:10.1002/j.2168–9830.2000.tb00527.x

Hernandez, P. (2015). What if you had been in charge? Exploring historical case studies through experiential learning and tabletop exercises. *Developments in Business Simulation and Experiential Learning*, 42, 253–257. Retrieved from https://journals.tdl.org/absel/index.php/absel/article/ view/2963.

Hopper, M. J. (2011). *Positioned as bystanders: Deaf students' experiences and perceptions of informal learning phenomena*. (Doctoral dissertation). University of Rochester, Rochester, NY. Retrieved from http://gradworks.umi.com/34/58/3458642.html

Horner, R. H., Carr, E. G., Halle, J., McGee, G., Odom, S., & Wolery, M. (2005). The use of single-subject research to identify evidence-based practice in special education. *Exceptional Children*, 71, 165–179. doi:10.1177/001440290507100203

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998a). *Active learning: Cooperation in the college classroom*. Edina, MN: Interaction Book Company.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998b). Cooperative education returns to college: What evidence is there that it works? *Change*, 30, 26–35. doi:10.1080/00091389809602629

Kritzer, K. L., & Pagliaro, C. M. (2013). An intervention for early mathematical success: outcomes from the hybrid version of the Building Math Readiness Parents as Partners (MRPP) project. *Journal of Deaf Studies and Deaf Education*, 18, 30–46. doi:10.1093/deafed/ens033

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. doi:10.1093/deafed/7.4.267

Lang, H. G., Stinson, M. S., Kavanagh, F., Liu, Y., & Basile, M. L. (1999). Learning styles of deaf college students and instructors' teaching emphases. *Journal of Deaf Studies and Deaf Education*, 4, 16–27. doi:10.1093/deafed/4.1.16

Luckner, J. (2010). Preparing teachers of students who are deaf or hard-of-hearing. In Marschark & Spencer (Eds.), *Oxford handbook of deaf studies, language, and education* (Vol. 1, pp. 41–56). New York, NY: Oxford University Press.

Luckner, J. L., & McNeill, J. H. (1994). Performance of a group of deaf and hard-of-hearing students and a comparison group of hearing students on a series of problem-solving tasks. *American Annals of the Deaf*, 139, 371–377. doi:10.1353/aad.2012.0290

Marschark, M., & Everhart, V. S. (1999). Problem-solving by deaf and hearing students: Twenty questions. *Deafness and Education International*, 1, 65–82. doi:10.1179/146431599790561370

Marschark, M., Convertino, C., & Larock, D. (2006). Optimizing academic performance of deaf students: access, opportunities, and outcomes. In D. F. Moores & D. S. Martin (Eds.), *Deaf learners: New developments in curriculum and instruction* (pp. 179–200). Washington, DC: Gallaudet University Press.

Marschark, M., Sapere, P., Convertino, C., & Pelz, J. (2008). Learning via direct and mediated instruction by deaf students. *Journal of Deaf Studies and Deaf Education*, 13, 546–561. doi:10.1093/deafed/enn014

Marschark, M., Sapere, P., Convertino, C. M., Mayer, C., Wauters, L., & Sarchet, T. (2009). Are deaf students' reading challenges really about reading? *American Annals of the Deaf*, 154, 357–370. doi:10.1353/aad.0.0111

Marschark, M., & Spencer, P. (2009). *Evidence of best practice models and outcomes in the education of deaf and hard-of-hearing children: An international review*. Trim, Ireland: National Council for Special Education. Retrieved from http://www.nabmse.org/wp/wp-content/uploads/downloads/2012 /07/1_NCSE_Deaf.pdf

Mertler, C. A. (2001). Designing scoring rubrics for your classroom. *Practical Assessment, Research & Evaluation*, 7, 1–10. Retrieved from http://tinyurl.com/zasmruc

Molander, B. O., Pedersen, S., & Norell, K. (2001). Deaf pupils' reasoning about scientific phenomena: school science as a framework for understanding or as fragments of factual knowledge. *Journal of Deaf Studies and Deaf Education*, 6, 200–211. doi:10.1093/deafed/6.3.200

Nunes, T., Bryant, P., Burman, D., Bell, D., Evans, D., & Hallett, D. (2009). Deaf children's informal knowledge of multiplicative reasoning. *Journal of Deaf Studies and Deaf Education*, 14, 260–277. doi:10.1093/deafed/enn040

Nunes, T., Bryant, P., Burman, D., Bell, D., Evans, D., Hallett, D., & Montgomery, L. (2008). Deaf children's understanding of inverse relations. In M. Marschark & P. C. Hauser (Eds.), *Deaf cognition: Foundations and outcomes* (pp. 201–225). New York, NY: Oxford University Press. doi:10.1080/10986060802583980

Pagliaro, C. M. (2010). Mathematics instruction and learning of deaf and hard-of-hearing students: what do we know? Where do we go? In M. Marschark & P. C. Spencer (Eds.), *Oxford handbook of deaf studies, language, and education*, (Vol. 1, pp. 156–

171). New York, NY: Oxford University Press. doi:10.1093/oxfordhb/9780195390032.013.0011

Pagliaro, C. M. (2015). Developing numeracy in individuals who are deaf/hard of hearing. In H. Knoors & M. Marschark (Eds.), *Educating deaf students: Creating a global evidence base*. New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780190215194.003.0008

Pagliaro, C. M., & Kritzer, K. L. (2013). The Math Gap: A description of the mathematics performance of preschool-aged deaf/hard-of-hearing children. *Journal of Deaf Studies and Deaf Education*, 18, 139–160. doi:10.1093/deafed/ens070

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93, 223–231. doi:10.1002/j.2168–9830.2004.tb00809.x

Punch, R., Creed, P. A., & Hyde, M. (2004). Issues in the school-to-work transition of hard of hearing adolescents. *American Annals of the Deaf*, 149, 28–38. doi:10.1353/aad.2004.0015

Qi, S., & Mitchell, R. E. (2012). Large-scale academic achievement testing of deaf and hard-of-hearing students: past, present, and future. *Journal of Deaf Studies and Deaf Education*, 17, 1–18. doi:10.1093/deafed/enr028

Quinsland, L. K. (1986). *Experiential learning vs. lecture learning with postsecondary hearing-impaired learners: A study of the potential need for change to occur in instructional methodology*. (Unpublished doctoral dissertation). Walden University, Minneapolis, MN.

Redish, E., Saul, J., & Steinberg, R. (2000). On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics*, 65, 45. doi:10.1119/1.18498

Sobek, D. K. & Smalley, A. (2008). *Understanding A3 thinking: A critical component of Toyota's PDCA management system*. New York, NY: Taylor and Francis.

Springer, L., Stanne, M., & Donovan, S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. *Review of Educational Research*, 69, 21–52. doi:10.3102/00346543069001021

Traxler, C. B. (2000). The Stanford Achievement Test: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, 5, 337–348. doi:10.1093/deafed/5.4.337

U.S. Census Bureau. (2008). American community survey. Retrieved from http://www.census.gov/acs/www

Walter, G. G. (2010). *Deaf and hard-of-hearing students in transition: Demographics with an emphasis on STEM education*. Rochester, NY: Rochester Institute of Technology.

Whitman, L., Steck, J., Koert, D., & Paarmann, L. (2007). A class for undergraduate technical literacy using Lego Mindstorms. Retrieved from http://tinyurl.com/hzdwhl7