Integration of experiential learning to develop problem solving skills in deaf and hard of hearing STEM students

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Abstract

A pervasive assumption about educating students who are deaf or hard-of-hearing (DHH) is that overcoming the communication barrier between instructor and student is sufficient to effectively educate these students. However, a critical challenge that DHH students face in pursuing STEM degrees is developing problem-solving skills and by extension, understanding the interaction among concepts or variables that are interrelated. To address these challenges, an approach was developed that combines interactive, experiential learning activities with the A3-based approach to problem-solving commonly used in industry. Utilizing a state-of-the-art production systems laboratory, DHH students act as workers in manufacturing and warehousing scenarios and work in teams to solve problems they encounter first-hand. By being part of the system, students quickly develop the content knowledge needed to address problems introduced as part of the lab activity. This paper presents the preliminary results of a three-year study on the effectiveness of this approach. Preliminary results indicate that the first group of students who experienced the intervention realized significant improvement in problem-solving skills and maintained this performance at a six- and twelve-month follow-up. Data collection and analysis are still ongoing for the second intervention group.

Introduction

Challenges in educating deaf and hard-of-hearing (DHH) students exist in all areas of education, but of particular concern to STEM fields is the difficulty DHH students experience in developing the critical skill of problem solving, which requires the integration of information to iteratively generate hypotheses and solutions around the traditional scientific method. The struggles that many DHH students face in mathematics as well as general problem-solving skills are well-documented and limit the potential for DHH students to be successful while pursuing careers in STEM.1-3

Several important findings in DHH research have provided some insight as to why DHH students lag behind their hearing peers in the development of problem-solving skills. First, DHH students, on average, do not possess the same level of conceptual knowledge as their hearing peers.4-6 As a result, when faced with a problem involving an unfamiliar system or environment, DHH students may not easily relate past experience to the problem at-hand. Though the causes for this remain in debate, limited knowledge base significantly restricts the tools and experiences that a student may use to understand a complex system. Approaches involving the use of analogous solutions to solve problems cannot be utilized when a student does not possess a rich bank of experience from which to draw. Due in part to inexperience and a relative deficiency of conceptual knowledge in comparison to hearing students, DHH students often struggle to comprehend the interaction among concepts or variables that are related.1,2,5 Another study showed that DHH students do not receive immediate access to the surrounding information (known as informal and incidental learning) and consequently lagged behind hearing peers in the
process of acquiring information. Obviously, these characteristics and circumstances present a significant obstacle to the development of effective problem solving skills.

While research has provided some insight in explaining how the educational needs of DHH students differ from hearing students, translating this body of research into effective and innovative teaching strategies has presented a significant challenge to researchers and educators, alike. The objective of this work was to develop and evaluate a novel, experiential-based approach to teaching problem-solving skills to DHH students in STEM fields. The approach developed in this work is based on three distinct pillars: (i) experiential learning through active and collaborative learning in laboratory environments; (ii) the best practices for teaching math and science to DHH students; and (iii) the PDCA problem solving method.

(i) Experiential Learning: The experiential approach in this effort is rooted in proven learning methods including active learning and collaborative learning. Active learning, in which students perform activities beyond listening to a lecture and taking notes, has been effective in learning and applying course material. Essentially, active learning is a learn-by-doing approach that results in one of the highest percentages of knowledge retention. 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 towards subject matter, and lower levels of anxiety. Johnson, Johnson, and Smith, found that one of the reasons for the higher retention achieved in cooperative learning approaches is due to cognitive rehearsal, in which students learn best when they teach the subject to themselves. Felder, Felder, and Dietz conducted a longitudinal study in which cooperative learning students outperformed a traditionally taught group on a number of measures, including retention and graduation rates. Johnson et al synthesized research on the effectiveness of collaborative learning and found that, compared to traditional, independent learning, collaboration improved nearly all measured learning outcomes. Since DHH students possess wide-ranging levels of academic preparedness, upbringing, reading comprehension and communication modes and skills, it is hypothesized that a learn-by-doing approach where students interact with one another would be beneficial for DHH students.

(ii) Best STEM Practices: Easterbrooks and Stephenson conducted a review of best practices for teaching DHH students math and science topics. Each of these practices is founded in what researchers have discovered about how DHH students learn effectively in STEM classrooms, and are briefly described below.

1. The teacher as skilled communicator – teacher must be able to communicate in 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 – 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 are “visual learners,” 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) 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** – because of high variability in reading level of DHH students, instructors need to bridge the gap between reading level and written content.

It is difficult for traditional, mainstream classroom approaches (e.g., lectures) to utilize more than a few of these at any time. A benefit of the experiential, laboratory-based approach is that it enables the use of more of these principles than can be incorporated into a typical classroom setting.

**PDCA Method**: The problem solving methodology employed in this work was Plan-Do-Check-Act (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. The components of an A3 problem solving report are:

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. Implementation a Plan [Do]
7. Result Confirmation [Check]
8. Standardize / Control [Act]

Engrained in the approach is a way to report results from the PDCA process that is becoming well known as the “A3 report”. Generally speaking, an A3 is simply an 11 x 17-inch sheet of paper that represents the entire amount of space available to document all components of the PDCA process. Because space is at a premium, and every step of the problem solving process must be captured, it strongly encourages the use of visual aids, charts and other pictorial information for communication. Also, it provides a structured way of reporting on problems and countermeasures that encourages a disciplined way of solving problems. Finally, it 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 A3s. The format is standardized in a way that, once familiar, is very easy to follow. For the many reasons listed above, this thinking and problem solving tool had the potential to be very effective in instructing DHH students.

In this work, an approach is presented that utilizes an experiential learning environment to introduce and rehearse the PDCA method of problem-solving. The approach also leverages the best practices described above to maximize the benefit and accessibility to DHH students.
should result in high levels of achievement and improvement in demonstrated problem solving proficiency.

**Intervention Description**

The approach developed in this work sought to immerse DHH students in a context-rich environment where they would conduct problem solving exercises in a systematic and iterative manner. This was accomplished by designing a series of three modules where problem solving is progressively and iteratively presented to the students. These modules were supported by case studies and hands-on problem solving-related activities that were designed to be conducted in a production systems laboratory and for two different industrial problem areas. 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. A layout of the modules, where every session represents approximately two hours of contact, is presented in Figure 1.

![Figure 1: Layout of modules](image)

**Description of the modules and sessions:** During these modules, the students participate in hands-on experiences in a laboratory facility. This laboratory contains several industrial-grade assembly lines and a warehouse area. This facility is highly flexible and modular and allows students to design, implement and execute various systems by performing as line/warehouse operators. The types of activities that can be setup are numerous and always involve industry-supplied parts (such as automotive components), tooling and equipment. Some of the activities are based on assembly lines while others are based on warehousing and order fulfillment operations. In addition, the laboratory setting allows students to perform problem solving by going to the real source (gemba) (e.g. assembly line or warehouse area) and by observing, collecting, and analyzing the root causes as well as implementing the countermeasures. Typically, these activities at the source cannot be experienced in traditional classroom settings, thus preventing the students from completing the problem solving cycle.

- **Module 1 (session A):** The first module exposes students to the theory and fundamentals of the PDCA approach in a traditional classroom setting (lecture). Students learn the A3 method by reviewing and understanding how to work through an automotive supplier-based case study. This module ends with students debriefing on their assigned A3 report to the rest of the class. All the instructional materials in this module (lecture and
examples of A3 reports) are enhanced and adapted for effective delivery to DHH students by providing them access to short videos that are both English-captioned and ASL-signed.

- **Module 2 (session B):** The second module exposes the students to problem solving within the context of warehousing and order fulfillment activities. During this module, students work on a picking rack area where parts are located in the appropriate bins and the operator is directed by pick-to-light technology. The students work in teams of 2-5 members to build several orders for a “shift duration” of approximately 5-minutes. The objective of the worker is to fill orders as quickly as possible in order to maximize the number of orders that are shipped on a given day. Once the activity is completed, two questions are given to students: can the current system handle the demand of the peak season? If not, what could be done to ensure that the demand is met? Some problems are identified and presented within the A3 framework. Some of the anticipated focus areas yield problems in the area of human factors and ergonomics, direct cost of the operation, bin and SKU allocation, statistical activity profiling, and standard work design. In this second module, the students focus again on working through the Plan portion (steps 1-5). However, this time the emphasis is placed on documenting the current situation (step 2) and analyzing the root causes (step 4) via direct investigation at the workstation. This crucial process, also known as *Genchi Gembutsu* (or “go and see”), is an integral part of the PDCA problem solving. It requires that the teams gather data at the source of the problem while brainstorming in a structured way such as using tools like fishbone diagrams, decision trees or the 5 Why’s. This module ends with the team debriefing to the rest of the class on their A3 document from problem definition up to their proposed countermeasure plan. Then the teams go through the activity again per their proposed countermeasure known as implementation plan (step 6) to confirm the result (step 7). If the result is a success, then the standardize/control concept (step 8) is briefly discussed.

- **Module 3 (session C):** During the third module, students are exposed to problem solving within the context of assembly production lines. This is accomplished over two two-hour sessions. In the first session, students are introduced to a component of medium complexity (e.g. 10-20 parts - an ABS brake module or a radiator fan assembly). Once they become familiar with the component, they are asked to perform assembly tasks in a four-station manual assembly line, the design of which has been pre-established. The students then perform at the line in various capacities, for one “shift duration” of approximately eight minutes. After the shift ends, students gather in teams of 4-6 and conduct quick problem solving around a specific problem in the line. Focus areas include: throughput and cycle time issues, line balancing, and operator utilization. The student teams conduct a quick problem solving, progressing quickly through steps 1-5, and focusing on steps 6 (Do), 7 (Check) and 8 (Act) for a complete A3. The improvements (countermeasure plan) are then implemented, and the line is run again for a similar period of time. The same metrics are collected again, and the benchmark against the improvement target is performed during the debriefing at the end of the session. The first session (session C) ends with the students being tasked with improving again the performance of the line. The students have seven days to perform this extended problem
solving. They have access to the lab to investigate and try out modifications during this period. They again need to document this process within an A3 format.

- **Module 3 (session D):** The second session of the third module (session D) begins with the student presentations of their problem solving approach (A3 report), the corresponding improvements as well as expected performance. The team then sets up the line with the countermeasures and performs for another shift. The process is repeated one more time when they have to perform one final round of quick problem solving, followed by the corresponding A3 presentation and debriefing.

By the end of the third 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 formats.

### Adaptation for Best Practices

The adaptation of the modules and content for effective delivery to DHH students is rooted in the work by Easterbrooks and Stephenson which inventoried practices used to educate DHH students in science, math, and literacy. Table 1 presents these best practices and how they have been addressed in this approach.

<table>
<thead>
<tr>
<th>PRACTICES</th>
<th>ADAPTATION</th>
</tr>
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<tbody>
<tr>
<td>(1) The teacher as a skilled communicator</td>
<td>Instructor must be able to impart instruction in native language.</td>
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<tr>
<td></td>
<td>• Native ASL communicator as instructor</td>
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<td>(2) Instruction through primary language.</td>
<td>More than one language is involved in instruction of DHH students. Learning best achieved when using students native language.</td>
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<tr>
<td></td>
<td>• Instruction in ASL before competence is assessed in English</td>
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<td></td>
<td>• ASL and finger spelling as main language of instruction</td>
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<tr>
<td>(4) Active learning</td>
<td>Students who engage in experiential learning achieve greater understanding and comprehension and are more cognitively engaged.</td>
</tr>
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<td></td>
<td>• Laboratory (hands-on) based instruction</td>
</tr>
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<td></td>
<td>• A3 problem solving requires synthesis and analysis</td>
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<td>(5) Visual organizers</td>
<td>DHH students are visual learners and learn best when visual tools support the instruction of all content.</td>
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<tr>
<td></td>
<td>• Lab-based instruction and A3 process are highly visual</td>
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<td></td>
<td>• Text-based materials presented on captioned /signed video</td>
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<tr>
<td>(6) Authentic, problem-based instruction</td>
<td>Instructor should incorporate collaborative, case-based, real-world, problems.</td>
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<td></td>
<td>• Majority of instruction in industry-like laboratory environment</td>
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<td></td>
<td>• Use of real world case studies</td>
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<td></td>
<td>• Multiple opportunities for group discussion</td>
</tr>
<tr>
<td>(7) Use of technology</td>
<td>Technology can be used to enhance communication and visual components of instruction.</td>
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<tr>
<td></td>
<td>• Tablet to provide interactive, real time information access without interrupting line-of-sight with signing instructor</td>
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<tr>
<td></td>
<td>• Production of fully captioned /signed content videos</td>
</tr>
<tr>
<td>(8) Specialized content vocabulary</td>
<td>Specialized vocabulary must be developed and consistently interpreted with signs and finger spelling.</td>
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<tr>
<td></td>
<td>• A video-based glossary in both captioned English and ASL available through tablet (e.g. definition of “bottleneck”)</td>
</tr>
<tr>
<td></td>
<td>• Pre-teaching of specific vocabulary</td>
</tr>
</tbody>
</table>
Critical thinking

Provide step-by-step problem solving strategies but also go beyond that to promote higher order critical thinking.

- A3 as a highly prescriptive process
- Begin with drill-and-practice, but extend independent work
- Experimentation requires critical thinking skills

Mediating textbooks

Reading levels in DHH students is highly variable. Instructors need to bridge this gap between reading level and written language demands.

- Scaffolding techniques for access of information (lower level reading materials, ASL-signed or captioned video, etc.)
- Case studies and text materials captured in video

Table 1: Module adaptation framework

As indicated in the table, technology provides an opportunity for successfully adapting classroom content to DHH students. The focus of the first phase of this intervention was to develop videos that used both English captioning and ASL interpretation to convey case studies and vocabulary relevant to the various components of this intervention. First, we developed a series of four 10-minutes videos (both captioned and signed by the main instructor) to present text-based materials (e.g. case study) to the students. Along with four case studies, short video clips providing definition of sixty-four vocabulary words (related to the case study and laboratory activities) were captioned and provided in ASL. Also, an additional twenty-eight video clips were produced to discuss problem-solving and laboratory terms. These videos reside in the servers that support the courses, so the students are able to access them on demand. In addition to these captioned and signed videos, the students have access to the information through reading material. This scaffolding approach allows the student the opportunity to access the information in several different ways.

Data Collection and Assessment

Data collection and assessment has been completed for two cohorts of DHH students (and is in progress for another cohort) over three years of course offering to assess the effectiveness of the intervention. Several instruments were administered pre- and post-intervention for each cohort and were evaluated and scored by a team of faculty using a custom rubric. The population, instruments, timeline, rubric and evaluation methods are described in this section.

Population: The target audience for this intervention is first-year DHH students in the Engineering Studies program at NTID, which is a two and a half year associate’s degree program. A control group was evaluated in the 2011-2012 academic year, prior to implementing the intervention, and the intervention group was evaluated in the 2012-2013 academic year. Though the intervention was delivered in several different courses, the experience was the same for all students who received the intervention. The control group consisted of 34 students, and the intervention group consisted of 17 students.

Instruments: Four case studies were either adapted from existing material or completely developed for this research. Each of the four cases presented a situation where several problems were described and enough information was provided to develop a root-cause analysis. The format length was designed to be about two pages long with text and graphical information. The context of the first case is healthcare and was adapted from existing literature.14 The second case
focuses on the operation of a microbrewery. The third case is an adaptation of training materials from Toyota and deals with problems related to household utilities. The last case addresses pizza delivery logistics. For each case, students were grouped into two or three members and provided the case information. Students were required to: identify the problem, summarize the current situation, identify the root causes, and propose interventions/improvements. Enough time was provided to all teams to allow for completion of the report. Students in the intervention group had access to the video content which used English captions and ASL to translate the narrative and vocabulary of the case studies.

**Timeline:** The four cases were used to assess student’s gain on problem solving skills. The first case (healthcare) was always used as a pre-intervention (PRE) instrument and was administered during the first three weeks of the academic term prior to where the intervention was conducted. The intervention typically took place during weeks 4-8 of the term. The second case (microbrewery) was always administered as a post-intervention (POST) assessment around weeks 9-15. The third and fourth cases were administered as follow-up instruments (FOLLOW1 and FOLLOW2) at six and twelve months, respectively, after the intervention.

**Rubric:** A custom rubric to score the A3 reports was developed. Six criteria were developed to assess the student’s ability to: (i) define the problem, (ii) document the current state, (iii) identify a metric and set a target, (iv) identify root causes, (v) develop solutions and action plans, and (vi) 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 were specified.

**Evaluation methods:** The evaluation was performed by a team of three faculty who scored the A3 reports for each case study. All the A3 reports from the control and intervention groups were randomized for blind evaluation. The faculty individually evaluated each of the categories in the rubric and then discussed the ratings until consensus was reached, which was defined as having all analysts within one-half point for each criterion. Both the individual and consensus scores per rubric category were reported to the external evaluating center for analysis. This process was repeated for each of the four cases.

**Analysis:** Because some students either transferred programs, left the university entirely, or were otherwise unavailable for follow-up evaluation, a total of only 23 students completed all four evaluations (PRE, POST, FOLLOW1, and FOLLOW2), with 14 of these from the control group and 9 from the intervention group. However, a total of 51 students participated in both the PRE and POST tests (34 in Control group and 17 in Intervention group), so data from these students were used to evaluate the short-term effect of the intervention. Since both the control and intervention groups consisted of first-year students enrolled in the Engineering Studies program, it was expected that the groups would produce similar performance for the PRE assessment. However, this was not the case, as the PRE results for the intervention group were significantly better than for the control group (t(30) = -2.44, p = 0.021). Therefore, in order to adjust for differences in the baseline PRE scores between the control and intervention groups, Analysis of Covariance (ANCOVA) was employed using the PRE evaluation scores as a covariate.

Two separate analyses were performed to evaluate the short-term and the sustained effects of the intervention. First, a one-way ANCOVA was performed to evaluate the short-term effect using data from the 51 students who completed both PRE and POST evaluations. The independent
variable, Group, was evaluated at two levels, control and intervention. The dependent variable was the POST evaluation score, and the PRE evaluation score was used as the covariate. Second, a two-way ANCOVA was performed to evaluate the longer-term effects of the intervention using data from the 23 students who completed all four tests (PRE, POST, FOLLOW1, and FOLLOW2). The independent variables were Group, which again consisted of the control and intervention cohorts and Test, which consisted of three levels, POST, FOLLOW1, and FOLLOW2, where FOLLOW1 and FOLLOW2 were follow-up exams administered at six-months and one-year after the POST evaluation. The dependent variable was the score for each evaluation, and the PRE evaluation score was again used as the covariate.

**Results**

Figure 2 presents a summary of the raw PRE and POST evaluation scores for the 51 students who participated in both the PRE and POST evaluations. Mean values are separated by control and intervention cohorts (n=34 and n=17, respectively). Without adjusting for differences in PRE score, the intervention group achieved POST scores that were 25.1% higher than the control group. The covariate, PRE score, was significantly related to POST score ($F(1,48) = 12.87, p = 0.001$), but a significant effect of Group remained after controlling for the effect of PRE score ($F(1,48) = 11.98, p = 0.001$). Based on a covariate PRE score of 10.27, adjusted POST means for control and intervention are 9.97 and 11.79, respectively. Therefore, adjusting for PRE score differences, the intervention group achieved POST scores that were 18.2% higher than the control group.

![Problem-Solving Assessment Evaluation](image)

**Figure 2.** Comparison of raw mean PRE and POST assessment scores for the control and intervention groups.

Figure 3 presents a summary of the scores for each of the four evaluations performed in this study (PRE, POST, FOLLOW1, and FOLLOW2) for the 23 students who completed all four evaluations. Mean values are separated by control and intervention cohorts (n=14 and n=9, respectively). The covariate, PRE score, was significantly related to future test scores ($F(1,62) = 8.32, p = 0.005$), but even after adjusting for differences in PRE assessment performance, a statistically significant effect was observed for the Group main effect ($F(1,62) = 13.72, p = 0.000$), indicating that the intervention group scores were significantly higher across all Test...
levels. The Test main effect was not statistically significant (F(2,62) = 0.21, p = 0.813), which suggests that for both the control and intervention groups, the POST, FOLLOW1, and FOLLOW2 performance remained effectively level. In addition, the Group*Test interaction effect was not statistically significant (F(2,62) = 1.64, p = 0.202), which indicates that the Group effect was consistent across all tests.

![Figure 3. Comparison of raw mean PRE, POST, and FOLLOW-UP assessment scores for the control and intervention groups.](image)

**Discussion**

The results of the student assessments provide a strong indication that the approach we have implemented is resulting in a positive effect on the development of problem-solving skills among the DHH students who experienced the intervention. Furthermore, this improvement was sustained at six-months and one-year following the intervention. As indicated in Figure 3, comparable performance in the follow-up evaluations was not observed for the control group, so the elevated levels for the intervention group are not likely the result of simple maturation. The lasting effect of the intervention is promising because improved problem-solving skills will benefit these students as they encounter other problem-solving opportunities in other courses within their curricula.

As indicated in Figures 2 and 3, the PRE assessment scores were higher for the intervention group than they were for the control group, which is not a result we expected since both groups were first year students from the same Engineering Studies program at NTID. However, this difference may be the unintended result of providing students in the intervention group with access to video clips that presented the case studies and associated vocabulary in both ASL and English subtitles. Though these videos did not provide additional information beyond what was presented in the written case studies, students did have the opportunity to receive the information in a mode that is more conducive to their learning preference. A limitation of this experimental design is that allowing students in the intervention group access to this material prevents the assessment of a true PRE assessment baseline. It may well be the case that the higher PRE scores observed for the intervention group are due to improved accessibility of the case study information.
material and not due to a stronger cohort of students in the intervention group. Regardless, the
use of the PRE assessment scores as a covariate adjusted for this higher baseline of PRE
assessment scores in the intervention group, so the gains in problem-solving performance are
meaningful.

The intervention activities took place in the Toyota 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. Though the laboratory
certainly enhances the experience of the students who have participated in the intervention,
development of a comparable laboratory should not be seen as a requirement to implement the
intervention we developed. 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
best practices (Table 1). Table-top simulations may easily be employed using Legos or other
simpler products to simulate the types of systems that we exposed students to in this intervention
even if the authenticity of the experience is slightly lower.\textsuperscript{15}

Despite the promising results observed with the existing intervention, we know that there is still
opportunity to improve the intervention as we continue implementing it in our courses. Over the
past year, we have made improvements to the intervention and have implemented these
improvements to a new group of students. Specifically, we developed a tablet-based OneNote
notebook that guides students through the process of completing an A3 evaluation. The
notebook contains text, diagrams, and video clips of ASL interpretation that define critical terms
related to problem-solving and the use of the A3 approach. We are in the process of evaluating
this intervention group using the same approach described in this paper to determine if the
improved intervention results in even greater gains in problem-solving skills.

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