Extended Reality for Enhanced Training and Knowledge Capture

Brandon T. Klein
Sandia National Laboratories
Albuquerque, NM
btklein@sandia.gov

Nadine E. Miner
Sandia National Laboratories
Albuquerque, NM
neminer@sandia.gov

ABSTRACT

Training is a key application area for Extended Reality (XR). XR training can provide instantaneous feedback, safe what-if scenario exposure and intermittent testing to minimize re-training and maximize retention. These are important aspects of training at Sandia National Laboratories (Sandia's) Z Machine (Z). Z is the world's most powerful and efficient laboratory radiation source for conducting research in high-energy density science. Over time, Z has increased in shot complexity and usage demand. Operators must be ready to efficiently setup hundreds of experiment configurations at a daily cadence. Furthermore, as the Bureau of Labor and Statistics show, the U.S. workforce is aging, so capturing the knowledge of experienced staff is a key concern (Bureau of Labor and Statistics, 2017). Sandia XR researchers and Z teams are developing XR methods and capabilities to enhance training and knowledge capture required to operate this world-class facility. We draw from current learning science research to motivate the design of an XR training framework based on four stages of teaching: Learn, Apply, Evaluate, and Synthesize. The XR training framework implements three self-selectable training phases: Demonstrate, Teach, Evaluate. The XR training can be applied to the Synthesize stage when the trained knowledge is used in a real-world operational environment. This paper describes the XR capabilities being developed for Z at Sandia and the qualitative results obtained to date. Moving forward, we are developing full-scale cognitive experiments to quantify the anticipated benefits of using XR for training: reduced training time, increased retention, and reduced errors.

ABOUT THE AUTHORS

Brandon T. Klein is a Principal Member of Technical Staff at Sandia National Laboratories. His professional experience diversely includes cloud computing, high-performance computing, autonomic computing, DevOps, containerization, enterprise architecture, cybersecurity, systems engineering, financial markets, spatial and planetary sciences, and high energy density physics. His professional accreditations include: CISM®, TOGAF® 9 Certified, ITIL® Intermediate, AWS Certified Solutions Architect Professional. His academic background includes undergraduate and graduate degrees from the University of New Mexico (UNM) in Finance and Economics; Information Assurance and Management Information Systems, respectively. His passion resides at the functional intersection of metaphysics and computer science.

Nadine E. Miner, PhD is a Principal Member of Technical Staff at Sandia National Laboratories. She is a member of Sandia's Software Simulation and Analysis department and is the software lead for Sandia's Advanced XR Software Simulation team. She has served Sandia for more than 22 years in diverse research areas such as virtual and augmented reality, machine learning, neural networks, software development, and systems engineering. She holds a B.S. in Computer Engineering from the University of New Mexico (UNM), an M.S. in Electrical Engineering from the California Institute of Technology, and Ph.D. in Computer Engineering with Specialization in Virtual Reality from UNM.

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INTRODUCTION

Traditional methods for scaled training of a workforce include the use of instructional manuals, videos, or power points. Another long-standing and effective method of training is apprenticeship, training alongside an expert. Each of these methods have their pros and cons. The first methods are: not interactive; have limited visual cues; do not provide the user with hands-on practice; are expensive to produce; and difficult to keep current. Training with an expert is the most expensive method, but it gives trainees valuable hands-on practice and direct feedback directly from the expert. Expert training: is time and resource constrained; cannot be easily captured for later review/refresh; and is difficult to parallelize and perform at scale. As such, there is an opportunity for Extended Reality (XR) Training to provide an improved training experience over traditional methods. It can provide trainees with hands-on, interactive, experiential training, and feedback can be incorporated as well. XR methods can be an effective way to capture knowledge and provide the captured information to trainees in a flexible, dynamic, visual way. XR training can be scaled and given to multiple participants in parallel and in different locations. Participants can practice what-if and high-consequence scenarios, and repeated/cyclical training is readily available. Furthermore, the XR training can be overlaid onto real-world environments so the training can become an operational assistant. XR training promises to increase retention through repetition and knowledge-testing, along with the reduction of errors through end-to-end operational assistance.

The National Research Council (NRC), among others, sponsored extensive research on the Science of Learning (Bransford et al., 2004). Although the research focused on improving our K-12 education system, much can be extracted from this research to guide the principles for structuring learning experiences that enable people to learn new material and apply it in new environments. Additionally, said research shows Active Learning experiences, where people can control their own learning and recognize when they need more information, leads to greater understanding. Well-designed XR learning experiences enable users to do just that: to move at their own pace, to view additional information as needed, and to gain an understanding of the information rather than just memorization. Our goal with XR training aims to create experiences, emphasized around learning with understanding, that enable people to not only remember and repeat information, but to recall and use information in varying contexts.

For structuring the XR training framework, our selected teaching paradigm originated from the academic research of Bloom's Taxonomy and the six levels of objectives (Bloom et al., 1956; Anderson, 2001), distilled into four levels of objectives: Learn, Apply, Evaluate, and Synthesize (Figure 1). The XR training framework we developed implements three self-selectable training phases: Demonstrate (this corresponds to Learn), Teach (this corresponds to Apply), Evaluate (this corresponds to Evaluate). In the Learn stage, knowledge is acquired by allowing trainees to view scenario animations and see demonstrations of the required information sequencing. This stage provides trainees with a passive learning experience. In the Apply stage, trainees gain information comprehension when they are taught the sequence of information through a step-by-step walk-through of the scenario. Trainees apply the step-by-step instructions to physical parts that they manipulate as the instructions are sequenced. This provides trainees with an active learning experience. Testing is encompassed in the Evaluate stage and is important because it incorporates self-assessment. The final learning stage we consider is Synthesize where trainees synthesize the knowledge gained during the XR training by practicing the assembly sequences independently or with the XR training as an operational assistant.

In this paper, we first motivate the reasoning behind using XR for training. Then we describe the XR training framework developed and the use of the system through the teaching stages of Learn, Apply, Evaluate, and Synthesize. Finally, we discuss the importance of testing and verification to quantify the benefits of using XR for training which is the next phase of the work.

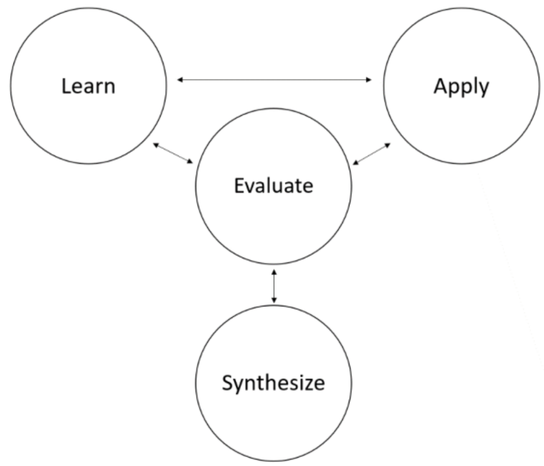

Figure 1. Learn, Apply, Evaluate, Synthesize

MOTIVATION FOR XR AT Z

Over time, the Sandia Z Machine (Z) has increased in shot complexity and usage demand. We are investigating how to increase operational efficiency without adding additional complexity while ensuring Z operations are safe and secure with the new solutions. Since Z is a mission-critical collaborative systems-of-systems (SoS) (Schaffner, 2017), the mitigation and elimination of constraints in the SoS will have nonlinear cascading effects. Operators must be ready to efficiently setup hundreds of experiment configurations on a daily cadence. We are investigating the use and integration of XR technology at Z to determine if it would aid in reducing operational and configuration complexity or improve administration over the configuration and operational complexity of the facility.

The workforce training at Z is nontrivial and requires a vast breadth of critical, tacit knowledge that resides within a small number of individuals, and sometimes within only one individual. Workforce training is heavily constrained by the time-sequence availability of subject-matter-experts (SMEs) or team leads in addition to the copious amount of tacit knowledge at Z. Each day at Z has a new scientific experiment underway and the workforce must be trained to successfully execute the experiment safely and securely. Due to the unique construct of Z, certain training scenarios allow only one individual to be trained at a time by the on-site SME. Although training manuals are in place, the nuances required for some experimental setups are only known to the SME, further constraining the limited resource. Thus, current workforce training processes at Z are sequentially linear in a nonlinear environment, producing operational difficulties.

For these reasons, we are investigating the use and effectiveness of XR technology for training at Z. We have developed an in-house, general-purpose framework that allows us to easily encode sequential training scenarios. The framework provides incorporation of supplemental information trainees can activate if needed, such as videos and manual pages. In this way, the XR technology captures and encodes the traditional and expert-training methods currently employed to alleviate the constraint of SME requirements. The XR training framework is deployed on Microsoft HoloLens® augmented reality (AR) headsets which permits parallel training of multiple participants. During the Evaluate (test) phase, after all the training sequences are completed, SMEs have the capability to observe, in real-time, the performance of trainees as well as review evaluation results. The Evaluate phase is designed to better prepare trainees for production operations. We do not foresee the ability to eliminate the SMEs presence completely; however, the burden and single point constraint is significantly reduced by employing XR training technology.

XR APPLIED TO STAGES OF LEARNING

In this section, we describe the XR training framework and application in relation to the training and knowledge capture at Z. A framework is employed to present a coherent and consistent training environment to trainees, no matter the training scenario. The interaction is designed to be intuitive to provide self-paced learning and exploration. Figure 2 shows the initial splash screen and Training Scenario Selection menu first presented to trainees.

Initial Splash Screen XR Training for Z | Training Scenario Selection

Figure 2. XR Training at Z: Start-up Sequence

Learn – Demonstrate Virtual Training

The Learn stage of our teaching paradigm focuses on passive learning by providing trainees the appropriate mediums to interface and become familiar with the processes, activities, and associative nomenclature in an enhanced manner not seen before at Z. Passive learning provides a structured learning environment where students are exposed to large amounts of information in a short period of time; where important concepts and content can be presented in a linear, organized manner. The passive learning structure is an important aspect of a training framework because passive-first learning can improve subsequent active-learning of abstract tasks (MacDonald and Frank, 2016).

Virtual training is very helpful; however, electronic documentation conveys with words and figures, electronic video shows only from the gamut of the lens, and web applications have functionality limitations. Additional interactive mediums are beneficial for learning. Simulated interactive models and processes accessible via an array of electronic devices enhance operational training and knowledge capture. Thus, we envision employing a variety of devices such as smart phones, tablets, and desktop computers, in addition to extended reality devices to fully capture the complex information required for Z experiment setups.

Providing enhanced virtual training enables trainees to learn digitally, from anywhere, to understand appropriate objects, procedures, and associative nomenclature; without having to learn under stressful, and time compressed conditions. Trainees are no longer bound to physical facilities nor specific dates and times to learn a unique experimental procedure setup. Instead, trainees are provided the ability to understand assemblies, subassemblies, procedures, and nomenclature through interactive exploration of the systems or SoS via Computer-aided Design (CAD) representations.

The desired virtual training of the Learn stage is an interactive digital library. The interactive digital library information is dynamically presented to trainees via an electronic device. The interactive, step-by-step demonstration of the Learn stage of the training is presented to trainees through an immersive head-mounted display (HMD), in our case the Microsoft HoloLens. With the codified dynamic library, the capability to streamline updates and relevant information is incorporated with DevOps Continuous Improvement/Continuous Delivery (CI/CD) pipelines; to provide trainees real-time up-to-date models along with processes validated and vetted by the appropriate SMEs.

Figure 3 is an example of the dynamic digital library embedded in the Demonstrate phase of the XR training framework. In the example, trainees are shown a demonstration of the assembly and disassembly sequence for a Z facility diagnostic named CRITR (Sinars et al., 2011). When trainees ask for help (via a voice command or gesture), the system provides them with the optional commands for the Demonstrate phase which are shown in the figure.

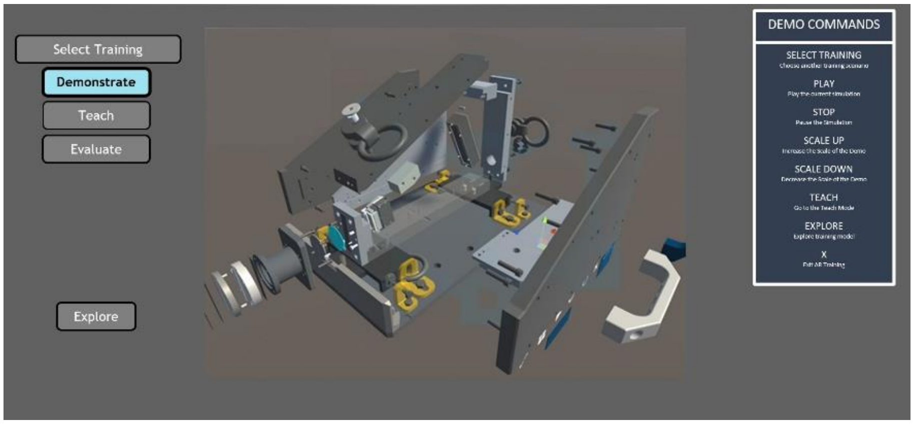

Figure 3. Learn Stage Demonstrates the Assembly and Disassembly Sequence of the 'CRITR' Assembly

Apply – Teach the Training Scenario

During the Apply stage, active learning is employed where trainees are taught steps of the selected training scenario then actually perform the steps. A key development element for XR training focused on ensuring the trainees were able to observe the training steps while physically performing the steps with the actual hardware, or convincing replicas of the hardware. The previous example demonstrates how AR HMDs, such as the Microsoft HoloLens, provide enhanced training since the real-world can be manipulated with graphical information overlaid in a consistent, uniform manner.

In this stage, simulated steps of the training processes were created, and the trainees sequentially performs each step on the actual hardware. The trainees can iterate and reiterate over the training sequences as desired. Also, trainees can elect to deviate and explore the associated models, at their own pace, alleviating the SME training constraint. Digitizing processes with simulation enable trainees to fail fast in a safe and secure manner without endangering lives or risk damaging expensive hardware, contrasted to the current on-the-spot live training. Trainees can quickly replay processes from many different perspectives enabling continual improvement cycles; and approach executing the processes holistically.

Figure 4 shows the implementation of the Apply stage where trainees are taught the sequence of steps required to accomplish the selected training scenario. Trainees are given instructions visually via text and animation of each step. Auditory feedback provides additional confirmation of the required operation. For scenarios that have multiple steps, trainees access successive steps with the CONTINUE command (voice or gesture). Help for the Teach mode provides trainees the ability to: repeat instructions, go back a step, go to the next step, or access additional information. Additionally, the simulated training environment and models can be overlaid on real-world parts or 3D printed parts.

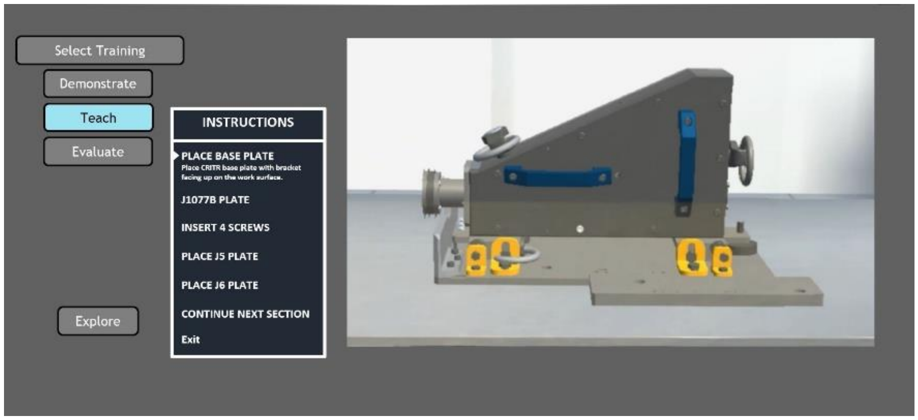

Figure 4. Apply Phase Teaches the Scenario Steps

Simulated processes allow preparatory functionality for teams preparing to engage with the processes; teams could prepare ahead of the go-live day in which unique processes are engaged. XR technologies allow trainees to work through simulated training modules that incorporate multiple processes and models along the training sequence (simulation modules within simulation modules).

Simulation features like modules and multi-user are desired, which allow trainees to partake concurrently in a multi-user fashion, which further increases the learning experience. Providing additional mediums may help trainees apply knowledge interfaced in the previous Learn stage; eliminating the need for physical presence in live operational environments or the SME. Ergo, learning takes place from a concurrent polynomial time perspective instead of the present serial linear methodology and information is presented in a consistent, uniform manner. The consistent, uniform workforce training offers monumental effects around the creation of a collective consciousness for the workforce.

Evaluate – Test Reinforcement Learning

The Evaluate stage tests trainee knowledge. This stage aligns with "metacognition"—Metacognition refers to a person's ability to predict their performance. Research shows metacognition increases the degree that learning transfer is achieved (Palinscar and Brown, 1984). Research also shows knowledge retrieval practice and intermittent training can improve retention; thus testing is an effective way to cement the knowledge during human learning (Roediger and Butler, 2011). Repeated and intermittent testing is even more effective to strengthen the learning process and reinforce the learned concepts.

During this stage, trainees will be exposed to various tests regarding: memory retrieval and retention, ability to assemble or complete processes correctly, and total time for completion. In the XR training framework, the Evaluate phase currently implements as a simple mechanism to test the speed at performing the current sequential training scenario. Trainees can repeat the timed evaluation until desired proficiency is obtained. The current type of timed evaluation by no means fully implements this phase; much more can be done to evaluate the performance of a task. Ideally, the Evaluate phase would have object recognition embedded so correct execution of the training sequence can be automatically validated. However, full 3D object recognition requires powerful computer vision and machine learning algorithms that are not yet available for general purpose applications.

Synthesize - Real-life Training

Once trainees have passed the Evaluate stage, the Synthesize stage places trainees in live production environments ready to synthesize what they learned and applied from the previous stages. At this point, SMEs can oversee trainees for real-life training with live on-the-spot reinforced training. XR technology also provides a “Remote Assist” capability such that SMEs can watch trainees perform operations remotely, in real-time, and answer questions or provide feedback in, real-time, to the trainees; alleviating the need for physical presence. Such examples of real-world use-cases leveraging the remote assistance via XR technology are within medical and surgical applications (Pratt et al., 2018). Figure 5 depicts an operational environment typical of Z at Sandia National Laboratories.

Figure 5. Synthesize Stage - Workers at Sandia's Z Facility test for energy irregularities

Trainees, at the completion of the Synthesize stage, should be proficiently studied in the processes so they can teach the processes back to SMEs and oversee other trainees. When trainees can oversee colleagues, the teaching paradigm reaches full cycle and the workforce is able to scale quickly, with uniformity and consistency due to a structured teaching architecture.

ASSESSING XR FOR TRAINING AT Z

Intuitively, the use of XR for training at Z appears to provide significant benefit with little downside. However, it is not enough to make a costly business decision by intuition alone. The purpose of questioning the viability of XR at Z ensures technology does not drive the reason behind integration, but that technology provides a solution or supplement to help meet a business need. What is the purpose and what are we trying to do? Another significant reason to question the use of technology is related to the reality of the Diffusion of Innovations theory (Rogers, 1962) for technology or also known as the Technology Adoption Lifecycle, defined by Geoffrey Moore (Moore, 1991).

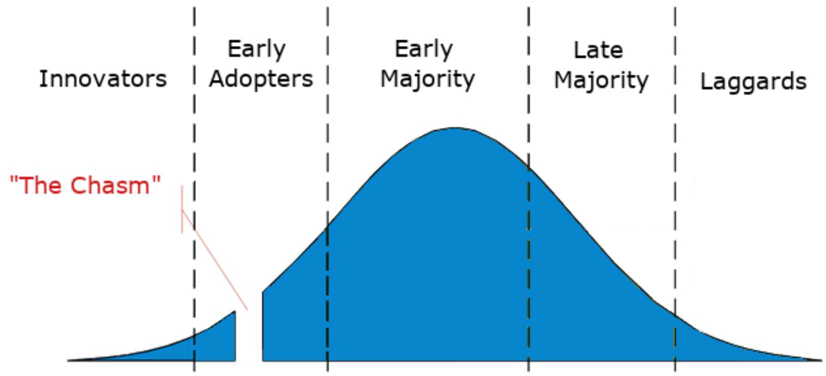

Figure 6. Technology Adoption Lifecycle. Adapted from Craig Chelius [CC (https://creativecommons.org/licenses/by/3.0)] by Shane Bramley and Brandon Klein

Understanding the why and how for XR at Z becomes an important undertaking with respect to adopting the technology. We may understand the designated technology provides all the appropriate benefits, the value-add is obvious and quantifiable for the business. However, the cultural adoption of the technology becomes the biggest obstacle due to "The Chasm" (Figure 6), also defined by Geoffrey Moore. The Chasm originally focused on how to bridge the gap between innovators of the technology with persons who understand the technology and want to adopt using it. From a business perspective, the adoption problem aligns with directing and managing change in an organization from a People, Process, Technology framework, first captured and discussed by Harold Leavitt in 1962 and subsequently evolved via academia and industry (Leavitt 1964).

In order to adopt and use XR (Technology) at Z, the designated technology must successfully demonstrate it provides significant value-add to the business via improvement of a process or processes (Process); and this improvement must be abundant enough, both qualitatively and quantitatively, the culture (People) desires the technology adoption. If we assess a technology with high optimism because it is associated with the latest and greatest buzzword, but do not apply pragmatism, then we are a nothing more than a dreamer. Conversely, if we assess a technology with substantial pessimism because it is associated with the latest and greatest buzzword, but do not apply pragmatism, then we are a nothing more than a cynic. Thus, when assessing technology, it is prudent to pragmatically consider the people, process(es), and technology of the intended environment, holistically, to help bridge the adoption of the technology and ensure the solution is aligned to meet appropriate objectives from all perspectives.

XR is not an emerging technology, focused research regarding the efficacy and efficiency continually enhance the domain. A recent example of such research came from the EDUCAUSE/HP "Campus of the Future" project, where eleven colleges and universities explored the potential of XR and 3D scanning/printing technologies to enhance teaching, learning, and research. The project discovered said technologies allowed trainees to partake in active and experimental learning while immersed in real-life, multisensory, multi-user experiences. The project also recognized XR and 3D scanning printing technologies take time for the benefits to be realized as well as, since the initial cost to develop simulated environments can be expensive (Pomerantz, 2018).

CONCLUSION & FUTURE WORK

In this paper we covered how research and development of XR technologies are underway to provide operational efficiency for Z from a principally based teaching perspective through enhanced training methodologies to efficiently scale the workforce. We pragmatically explored how the XR training framework appropriately implemented the teaching paradigm of Learn, Apply, Evaluate, and Synthesize. The teaching paradigm enabled us to categorize and develop appropriate XR capabilities to enhance training use-cases for Z.

We selected a designated training use-case to enhance, via the XR training framework, and tailored the development around the proposed teaching paradigm. We demonstrated how an enhanced XR training framework would functionally align to the teaching paradigm: the Learn stage with the Demonstrate phase; the Apply stage with the Teach phase; the Evaluate stage with the Evaluate phase. We also demonstrated how an enhanced XR training solution would functionally align with the Synthesize stage by providing reinforced learning to trainees through preliminary simulated exposure.

We obtained valuable quantitative results from the XR training solutions which provided important findings regarding the usefulness of XR training at Z. We developed several pilot XR training scenarios over the past two years that provided valuable qualitative findings. First, the process of modeling and simulating traditional paper-manual assembly/disassembly procedures revealed omissions and process steps requiring clarification. Upon consultation with experts, we discovered documentation discontinuity, especially for atypical occurrences. Next, due to attrition of personnel, we found encoding processes and capturing expert knowledge was more critical than ever. Furthermore, we found XR training provided the advantage of an interactive, visual, and auditory experience over traditional training methods; trainees were able to see and interact with simulations of models and complex procedures. XR training provides trainees with safe exposure to what-if scenarios and on-the-spot refresh for infrequent setups.

Future work will include formalized case studies around the XR training framework designed to test the efficacy of training at Z. The lack of quantitative metrics around the XR training framework is the impetus for the case studies. We want to uncover if the XR training framework will quantitatively improve training efficiency compared to existing training methods at Z. If the case studies reveal the XR training framework quantitatively improved training efficiency, then further research and development in XR capabilities at Z is warranted.

ACKNOWLEDGEMENTS

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