Mobile eXtended Reality (XR) Training: Executing a Productive Training Effectiveness Evaluation

Betsy Guzmán Laxton, Rebecca Kwasinski, JoAnn Archer
Design Interactive, Inc.
Orlando, FL
Betsy.Laxton@designinteractive.net , JoAnn.Archer@designinteractive.net
Rebecca.Kwasinski@designinteractive.net

ABSTRACT

Mobile eXtended Reality (XR) offers realistic, low-cost immersive training that is accessible anytime and anywhere bringing learners to proficiency faster and promoting skill retention. Leveraging mobile XR technology provides continuous practice through accessible training for all expertise levels, even in diverse and resource-limited environments such as combat scenarios.

Creating an effective mobile XR application requires integrating training requirements and system refinement for optimal user experience. Ensuring high usability before collecting Training Effectiveness Evaluation (TEE) data is crucial to avoid confounding performance metrics with usability issues. Validated measures, combined with qualitative data, are necessary to understand scores and further develop the system to maximize cognitive, psychomotor, and affective effectiveness.

This paper presents a case study on evaluating and refining a mobile XR system for Tactical Combat Casualty Care (TCCC) training using iterative usability testing and preliminary training effectiveness evaluation (PTEE) methods. The mobile XR training system identified four critical areas for improvement: 1) Virtual coherence of 3D virtual models and assets, 2) Familiarization with Mobile XR interactions, 3) Improve hands-on portion of skills and assessment practice lessons formulation, and 4) Lesson progression. The evaluation also highlighted the need for the system to be adaptable for consolidation training, refresher training, and pretraining. By executing on these results, the TEE design was updated to address flexible training needs and subsequent user testing showed high usability ratings. The analysis proved that high usability and effective mobile XR training can enhance the TCCC learning process and support scalable, cost-effective training while improving learner readiness and confidence.

ABOUT THE AUTHORS

Betsy Guzmán Laxton is a Research Associate at Design Interactive, Inc. with an industrial engineering and sociology background. She has 5 years of experience conducting Human Factors research with a focus on eXtended Reality (XR) and over 10 years of project management experience in the medical practice field focused on creating efficient work systems. Her combined expertise contributes to the development and usability of XR training applications for an improved user experience.

JoAnn Archer is the Deputy Director of Research, Development, Test, and Evaluation, and the eXtended Reality (XR) Solutions Portfolio Manager at Design Interactive. With over 17 years of experience in systems engineering and program management within high-tech environments, she brings a strategic and visionary approach to innovation. She has successfully led numerous Department of Defense (DoD), government, and commercially funded projects, ensuring the development and deployment of cutting-edge XR and AI-driven immersive training, operational, and sustainment solutions. Her work is grounded in applied research and data analytics, driving the creation of adaptive technologies that remain at the forefront of innovation.

Rebecca Kwasinski is a Research Lead for the XR Solutions portfolio at DI with over 8 years of expertise in research, data collection, data processing, and data analyses. Before joining DI, Rebecca Kwasinski worked as a research fellow in the Optical Imaging Laboratory at Florida International University, where she worked to with near-infrared imaging of lower extremity ulcers to provide a quantitative assessment of the wound healing process. Rebecca also worked as a Project Engineer for ECRI where she worked to develop and execute test protocols to evaluate a wide variety of medical technologies. Her current work at Design Interactive has focused on leading projects to create XR training and operational content.

Mobile eXtended Reality (XR) Training: Executing a Productive Training Effectiveness Evaluation

Betsy Guzmán Laxton, JoAnn Archer, Rebecca Kwasinski
Design Interactive, Inc.
Orlando, FL
Betsy.Laxton@designinteractive.net, JoAnn.Archer@designinteractive.net, Rebecca.Kwasinski@designinteractive.net

INTRODUCTION

Across both defense and commercial sectors, there is a persistent demand to improve training processes and performance outcomes. As operational environments grow more complex and resource-constrained, the modeling and simulation (M&S) industry continues to seek innovative technologies that enhance the efficiency, accessibility, and effectiveness of training. Among these, mobile eXtended Reality (XR) is emerging as a promising solution, offering immersive, on-demand training capabilities that extend beyond traditional classroom or simulation center constraints. With the ubiquity of mobile devices and the reduced cost of mobile XR systems, this modality offers scalable, low-cost opportunities to accelerate learner proficiency and promote sustained skill retention.

Mobile XR has the potential to transform how training is delivered and maintained, particularly for high-consequence domains such as Tactical Combat Casualty Care (TCCC). Its effectiveness is dependent on more than just technological deployment or content translation to an XR interface. Effectiveness depends on the instructional design and evaluation across the cognitive (e.g., knowledge and lesson clarity), psychomotor (e.g., procedural skills and execution), and affective (e.g., attitude/confidence and motivation) domains of learning. Compared with head-worn displays (HWDs), mobile devices introduce unique challenges in spatial rendering, interaction, and display of 3D content which can impact immersion and task performance. These challenges underscore the need for a structured, evidence-based approach to both design and assessment.

Unlike evaluations that focus solely on outcome-based performance metrics, a comprehensive training effectiveness evaluation (TEE) examines how users learn, apply and adapt skills under realistic conditions. These components reflect how well users acquire targeted knowledge, develop procedural skills, and demonstrate shifts in decision-making or behavior—each essential for operational readiness. Cohn et al. ((2017) emphasized that evaluations limited to final performance outcomes often overlook the deeper learning mechanisms contributing to success. By implementing a life-cycle approach, developers and instructors iteratively refine training systems based on feedback and performance data to better understand how a system supports learning over time, not just immediate task completion.

Usability is a critical, and often underemphasized, factor in this process. In XR environments, usability encompasses interface clarity, intuitive interaction, and ease of navigation—all of which shape how trainees engage with content. If a system is difficult to use or poorly designed, learner performance may reflect confusion or frustration rather than true skill deficits, skewing evaluation results. Early usability testing can reveal whether XR interaction techniques support or hinder learning, especially in high-consequence domains like TCCC. Identifying and addressing these barriers helps ensure the system promotes—not impedes—effective training and skill transfer.

These considerations are not unique to high consequence domains within the military. Commercial sectors such as emergency response, industrial safety, and technical maintenance face similar challenges in delivering accessible, effective training under operational constraints. By embedding usability testing early in the design cycle and integrating those findings into system refinement, developers can ensure XR platforms deliver meaningful, measurable outcomes across industries.

This paper presents a preliminary evaluation of a mobile XR training system, identifying key areas for improvement and demonstrating that design updates based on these findings significantly enhance usability, adaptability, and training effectiveness. Rather than deferring evaluation until the training system was complete, this effort integrated usability and a Preliminary Training Effectiveness Evaluation (PTEE) iteratively to ensure the system's functionality aligned with intended learning outcomes across cognitive, psychomotor, and affective domains—an approach applicable to both defense and commercial training applications. The resulting data informed the system refinements across (1) virtual coherence of 3D virtual models and assets, (2) need for mobile XR familiarization among novice users, (3) hands-on portion of skills and assessment practice lessons, and (4) clear lesson progression. By grounding the evaluation within cognitive, psychomotor, and affective learning domains, this research highlights how mobile XR training can be designed, implemented, and continuously improved to meet the evolving needs of military medical training and inform broader applications.

BACKGROUND

TCCC Training Use Case

Training for high-stakes environments, such as combat casualty care, demands tools that promote rapid proficiency, knowledge retention, and adaptability to adjust to dynamic scenarios. Over the past decade, XR—which encompasses virtual, augmented, and mixed reality—has become increasingly prominent in training applications across both commercial and defense sectors. XR-based training has demonstrated success in improving spatial awareness, procedural skill acquisition, and decision-making under pressure, particularly when paired with well-designed instructional strategies (Stanney et al., 2022). These technologies are especially promising when applied to domains such as TCCC, where learners must demonstrate mastery of life-saving procedures under stress and within time constraints.

TCCC training, as established by the Defense Health Agency's Joint Trauma System, focuses on equipping personnel with evidence-based trauma care practices suitable for prehospital battlefield conditions. Traditional delivery formats—such as classroom instruction or manikin-based simulations—are often constrained by resource availability, instructor bandwidth, and logistical challenges. A mobile XR application addresses many of these limitations by enabling learners to engage in self-paced, immersive training from virtually any location. This expands access to both initial instruction and critical refresher training, allowing skills to be sustained over time and under diverse operational constraints.

Mobile XR Testbed

The mobile XR application used for the case study is AUGMED® Mobile, an advanced medical XR training application that is currently in development by the DoD to address critical gaps in TCCC training. This application represents an adaptive, modular, immersive, and extensible XR training system designed for both new learners and those refreshing their knowledge of the TCCC curriculum. The key aim of this system is to implement contextualization and embodied learning within an XR environment to accelerate trainee proficiency across all learning skills (cognitive, psychomotor, and affective domains). By doing so, the system aims to enhance comprehension, improve skill retention, and reduce the overall time required to achieve competency compared to traditional training methods. Leveraging the capabilities of XR technology, the system bridges the gap between traditional classroom-based instruction to hands-on skills training. It delivers spatialized instructional content and realistic, context-rich training cues to create highly engaging and effective learning experiences.

However, a crucial first step to developing XR training solutions that leverage principles of contextualization and embodied cognition to enhance training is to evaluate usability of novel contextualized design elements and embodied interactions afforded by XR. If the embodied interaction techniques featured in the system are too cumbersome for trainees to intuitively use, then transfer of training is likely to be diminished. Careful examination of these features can highlight positive and negative experiences in XR, possible improvements to overall usability, and future directions for evaluating the application of contextualization and embodied cognition principles into the design of XR training solutions for TCCC.

Currently, the mobile XR application used for the case study consists of 14 lessons covering the MARCH (Massive Hemorrhage, Airway, Respiration, Circulation, Head Injury/Hypothermia) continuum. Lessons were developed based on adaptation strategies designed and developed for XR consumption (Stanney et al., 2022) and are structured by lesson types that progressively build upon one another. Symptom and Injury lessons reinforce recognition of signs and symptoms through scaffolded learning. Tools and Treatment lessons detail procedural steps, tool usage, and proper application. Skills Practice lessons reviews tools and steps, followed by hands-on training. Scenario lessons guide trainees in applying skills in real-world contexts. Assessment Practice lessons offer virtual, feedback-driven training using manikins or role players to prepare for formal evaluation. A total of seven activities and assessments were developed for pedagogically driven contextualization and embodied cognition: Discovery, Locate and Select, Matching, Multiple Choice, Action Plan, Timed Activity and Navigation. Each activity has been carefully crafted to afford a variety of contextually rich and embodied formative assessments within a room-scale 3D training experience when used in the mobile XR form factor.

Prior to the PTEE, the system and its content underwent usability testing at four user testing touchpoints with data collected at MacDill AFB and Lackland AFB. In addition, there were two expert heuristic evaluations of the mobile XR training system. These evaluations ensured the system was usable to the end user, resulting in usability scores ranging from average to excellent (Laxton & Archer, 2024). The application used for the case study was deployed to several device types including iPhone 14, iPhone 14 Pro, iPad Air, and iPad.

MODIFICATIONS BASED ON PTEE FINDINGS

The data collected for the PTEE incorporated both structured and unstructured questions, enabling the generation of comparative usability scores alongside qualitative user feedback. The System Usability Scale (SUS), a widely recognized industry standard for evaluating usability (Brooke, 1986), was used to assess the mobile XR training application used for the case study. In addition to the SUS, a custom system feature questionnaire was administered, where participants rated specific features of the application using a Likert scale ranging from *Strongly Disagree* to *Strongly Agree*. To gain deeper insights into user perceptions, open-ended questions were included to capture detailed feedback explaining the rationale behind participants' ratings. This evaluation was conducted within the context of a TCCC Combat Lifesaver class. The findings underscore the importance of evaluating the system in its intended operational context to accurately assess usability and performance. The quantitative results indicated the system was of average usability overall and that the system features were better than average. The qualitative data supported the findings with responses that indicated that there were areas of improvement. Analysis of the data collected during the PTEE indicated there were four critical areas for system refinement and implementation that were addressed and subsequently evaluated during the study discussed in this paper: (1) virtual coherence of 3D virtual models and assets (psychomotor), (2) need for mobile XR familiarization among novice users (affective), (3) improve hands on portion of skills and assessment practice lessons (cognitive and psychomotor), and (4) clear lesson progression (cognitive).

Visual Coherence

Mobile XR training systems rely on the integration of 3D assets and environments to deliver immersive and effective learning experiences. Findings from the PTEE revealed a recurring issue: users consistently observed a mismatch between the virtual casualty model and the manikin. This misalignment was problematic during the landmarking process, where users spent considerable time attempting to achieve exact alignment resulting in increased frustration and low scores regarding placing the virtual model. This visual mismatch negatively impacted usability and detracted from the overall sense of immersion. It also interfered with psychomotor skill development, as users did not transfer visual cues to spatial locations onto the manikin easily, affecting their procedural mastery in TCCC.

The first improvement implemented was to adjust the virtual model to be the same dimensions as the manikins used for testing. This allowed the virtual model to better align with the manikin, creating a more seamless visual. In parallel, visual assets within the application were refined to enhance realism and instructional clarity. For example, bleeding and breathing effects were updated to appear more lifelike, and animations were enhanced to better illustrate procedural steps and expected outcomes. All lessons were systematically reviewed to identify and update visual elements requiring improvement, further elevating the overall training experience.

To address the alignment issues, micro-control adjustments were introduced to the landmarking process, allowing users to fine-tune the placement of the virtual model. However, user feedback indicated that this added control did not significantly improve satisfaction, as precise alignment remained difficult to achieve such that users kept adjusting and readjusting the virtual casualty. To streamline the process, a QR code-based landmarking system was introduced. This solution allowed trainees to simply scan the code, automatically positioning the virtual model over the manikin with minimal effort and no additional adjusting. The intent of this approach was to significantly reduce the setup time and improve consistency since the virtual model was immediately placed in the scene, over the manikin.

Familiarization with Mobile XR Interactions

The trainee feedback from the PTEE emphasized the need for familiarization and guidance when using the mobile XR system. This was further supported by low scores on features related to the ease of interacting with 3D assets and understanding how to interact with the XR activities. The System Usability Score (SUS) score for the statement "*I needed to learn a lot of things before I could get going with AUGMED® Mobile*" was below average. The evaluation highlighted that trainees were not fully comfortable with the interaction mechanics of the mobile XR environment. The training sessions included multiple lessons delivered in rapid succession, leaving little time for reflection or reinforcement. As a result, trainees often felt uncertain about how to navigate the system and engage confidently with training content.

To address this, an initial solution involved the development of a Quick Start Guide embedded within the lesson structure. This guide included animations and step-by-step instructions to demonstrate how users should perform specific interactions.

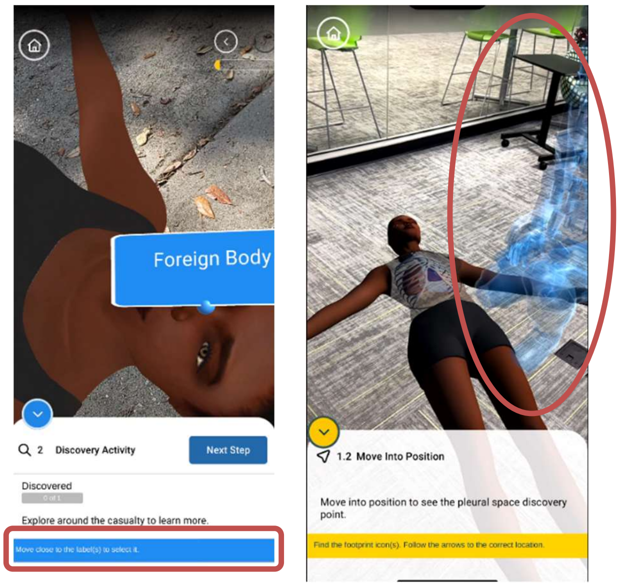

Figure 1 System Instructions Display with Every Activity (left) and Avatar Demonstrates Where to Kneel (right)

To enhance the onboarding experience, the system was updated to include concise, context-specific instructions displayed each time an activity appears, as illustrated in Figure 1 (left). Additionally, an avatar (circled in Figure 1, right) provides visual guidance, directing the trainee to the appropriate location for inspecting the virtual casualty and identifying key visual cues.

Improving Skills and Assessment Practice Lessons

As part of the mobile XR training system used for the case study, assessment practice lessons reflect trainee proficiency for both psychomotor and cognitive skills. However, open-ended responses from the PTEE indicated that trainees wanted more opportunities to practice skills and retry activities where they may have initially responded incorrectly prior to the assessment practice lessons. During the PTEE, when trainees selected their preferred lesson to complete, the SUS scores were higher, indicating that self-paced learning enhances usability. In response, the skills practice lessons which are meant to be completed before assessment practice lessons, were redesigned to incorporate faded scaffolding, as shown in Table 1, providing users with increasing levels of autonomy as they progressed through training.

Table 1. Faded Scaffolding Levels Applied in the Skills Practice Lessons

Scaffolding Level	Purpose	Timer/Cadence	Guidance	User Progression	Try Again
Most Scaffolded	Practice skill steps at user's pace	Not timed /No cadence	Audio/Visual	User controls advancement to next step	Yes

Less Scaffolded	Practice skill steps at a slow, guided pace	Timed/ Slow cadence	Audio/Visual	User practices skill step after system prompts at slower than target pace	Yes

Table 1 includes references to integrated audio guidance to support trainees during the hands-on skills practice lessons. These lessons were updated to provide step-by-step audio and visual instructions, allowing trainees to progress at their own pace and maintain control over the tempo of the activity. To help trainees stay focused on the task, several options were considered to ensure a hands-free experience—such as having a buddy hold the phone, employing a tripod, or using a hands-free phone holder—thereby preserving the immersive quality of the training. In-house user testing indicated that the hands-free holder provided the most immersive experience.

After completing skills practice lesson, trainees progressed to the assessment practice lessons, where they demonstrated hands-on proficiency through timed activities. To enhance greater immersion and support comprehension of visual and audio cues, on-screen elements depict the injury first on the virtual model and then on the manikin, providing context for the task. These visuals were paired with the same step-by-step guidance used in the skills practice lesson, reinforcing recognition and appropriate treatment of the specific injury.

Early-stage lessons were modified to include greater structured support, enabling users to engage in continuous, hands-on practice that builds both procedural knowledge and psychomotor skill proficiency. The immersive experience was further enhanced through the integration of auditory cues and the recommendation to use a hands-free phone holder, allowing users to follow visual and audio prompts while performing physical tasks.

To support learning and retention, the feedback for all activities were updated throughout to provide more guidance through the process and to reinforce learning. Assessment practice lessons were also updated to allow users to retry activities if their initial response was incorrect. Additionally, an After Action Review (AAR) feature was introduced, enabling users to review their performance data and revisit results as a personalized study guide at any time after completing a lesson.

Lesson Progression

Another key finding from the PTEE was the need for a more consistent and transparent progression structure across all MARCH-related lessons. The SUS scores from the PTEE indicated lower usability when the trainees were advanced to the higher proficiency lessons without first completing the foundational content. To address this, the lesson blueprint was used to systematically evaluate each module and identify gaps in instructional flow. Each MARCH area was intended to follow the structured progression: Symptoms and Injuries, Tools and Treatment, Scenario, Skills Practice, to Assessment practice. New lessons have been developed to fill the identified gaps and ensure a coherent path that supports skill acquisition and retention.

Additionally, each lesson was updated to include an introductory sentence at the beginning of each lesson that clearly outlines the lesson's objectives and expectations. This guidance enables users to determine whether the lesson aligns with their current training needs and, if not, redirect themselves to a more appropriate module. This self-directed structure promotes affective engagement by giving learners control over their path and reinforces cognitive development by sequencing content in a way that builds foundational knowledge before assessment. The updates were specifically designed to ensure that users enter assessment practice lessons only after achieving sufficient confidence and familiarity with the preceding content.

STUDY DESIGN

To evaluate the impact of the revised content and system enhancements, user testing was conducted using the updated respiration management lessons. Based on findings from the PTEE, which indicated that trainees lacked sufficient time for internalizing key concepts, this round of testing focused on a targeted subset of lessons. The selected lessons were designed to span the full instructional progression-from foundation knowledge to assessment practice-allowing trainees to build confidence and familiarity with the system at their own pace. This approach aimed to reinforce a clear sense of progression in proficiency while addressing previously identified usability challenges.

The respiration suite of lessons served as a pilot to validate both instructional improvements and system functionality in a realistic training environment based on the four type of modifications discussed. Testing occurred during a Combat Lifesaver (CLS) course at MacDill AFB the week of Nov. 18, 2024. The number of participants was constrained by the number of trainees registered for the class. The study involved a small (n=8) participant sample, appropriate for formative evaluation in applied settings. The goal was to generate actionable insights to inform future iterations.

Prior to engaging with the mobile XR training system, trainees completed classroom-based instruction on respiration management. On the first day of testing, the trainees completed informed consent forms and demographic questionnaires before completing the following lessons on the mobile XR training platform:

- Respiration Symptoms and Injuries
- Chest Seal Tools and Treatment
- Chest Seal Skill Practice

Lessons were completed in this order to follow the lesson progression blueprint that focuses on building foundational knowledge before completing assessment lessons. The first two lessons were completed using the manual landmarking and no manikin such that trainees only had to fit the virtual manikin to the space available. For the third lesson, Chest Seal Skills Practice, the trainees used a hands-free phone holder to maintain the immersion, supported by visual and audio cues while practicing the hands-on skills. Additionally, since the hands-on skills required the use of a manikin, the QR code-based landmarking system was used to quickly get the trainees started on the lesson.

Trainees were instructed to repeat a lesson until they achieve a final score of 80% or higher before advancing to the next lesson in the progression. This requirement increased trainee confidence in the knowledge and skills learned during each lesson while building familiarity with the mobile XR training application.

Following the completion of the Chest Seal Tools and Treatment and Chest Seal Skills Practice lessons, the trainees completed the system usability survey (SUS) and system feature survey. These tools were used to gather feedback on both didactic content (e.g., Symptoms and Injuries, Tools and Treatment) and hands-on activities (e.g., Skills Practice). This comparison enabled the research team to assess user perceptions of instructional clarity versus hands-on engagement within the mobile XR training platform. There was also a short survey at the end with open-ended questions. This approach allowed researchers to distinguish between outcomes across the cognitive domain (clarity of knowledge delivery), the psychomotor domain (skill execution) and the affective domain (engagement and user confidence).

On the second day of testing, trainees were offered the opportunity to revisit any of the previous lessons before completing the Respiration Assessment Practice 1 lesson. The trainees again used a hands-free phone holder and the QR code-based landmarking to facilitate the hands-on skills required in the assessment practice lesson. After completing the Respiration Assessment Practice lesson, trainees repeated the SUS and system feature survey and participated in exit interviews. These interviews included the same open ended questions as day 1 except that the data were gathered by the researcher rather than written out by the trainee. This data captured qualitative insights into the user's experience.

RESULTS AND ANALYSIS

Demographic Information

A total of eight trainees (four male, four female) participated in the user testing activities. The majority of participants reported limited prior experience with Tactical Combat Casualty Care (TCCC), with an average rating of 1.9 (SD = 1.1) on a 6-point scale ranging from 0 ("Not at All") to 5 ("A Lot"). Similarly, participants indicated minimal familiarity with augmented reality (AR) technology, with a mean score of 1.5 (SD = 1.3) on the same scale.

Respiration Symptoms and Injuries, and Chest Seal Tools and Treatment Lessons

As shown in Figure 2, the average SUS score was 89.1 ± 9.1 (95% CI [81.49, 96.71]), indicating high user satisfaction. Users generally agreed or strongly agreed that the application was well-integrated, easy to use, and instilled confidence. Negative feedback was minimal, with only a small proportion finding the system cumbersome or unnecessarily complex.

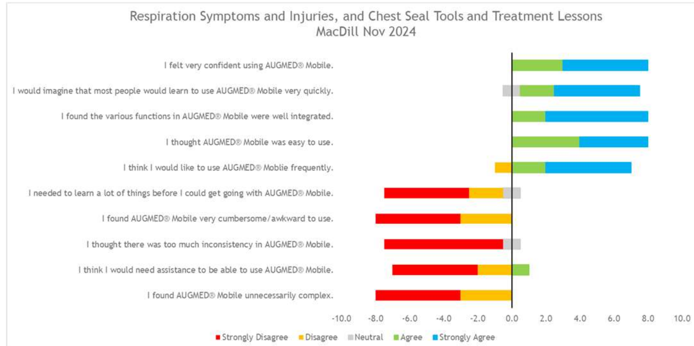

Figure 2 SUS Scores for Respiration Symptoms and Injuries, and Chest Seal Tools and Treatment lessons

Figure 3 presents user ratings for specific system features, yielding an average score of 4.6 ± 0.34 (95% CI [4.32, 4.88]) on a 5-point scale. Trainees strongly agreed that the lessons were clear and that instructions were easy to hear and follow. High ratings were also observed for the ability to progress through lessons smoothly and receiving immediate, helpful feedback.

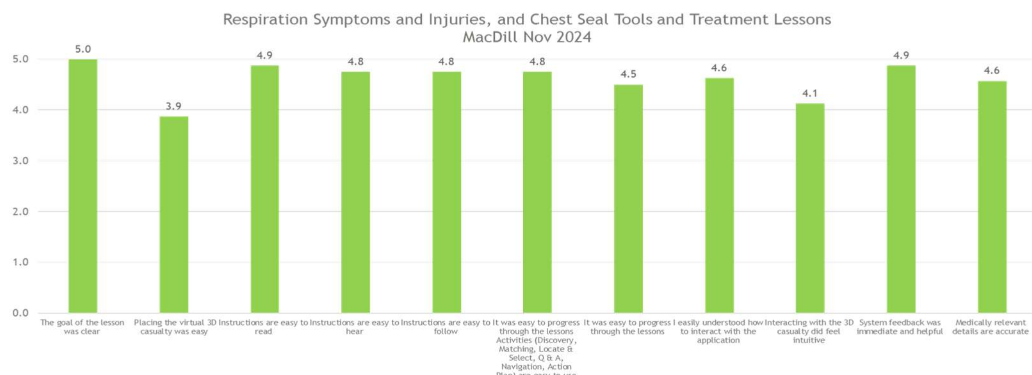

Figure 3 System Feature scores for Respiration Symptoms and Injuries and Chest Seal Skills Practice lesson

Chest Seal Skills Practice and Respiration Assessment Practice 1 Lessons

The Chest Seal Skills Practice session served as the trainees' first hands-on experience using the mobile XR-based training platform. This session was met with high levels of user satisfaction, as evidenced by a SUS score of 88.8 ± 8.6 (95% CI [81.61, 95.99]) (Figure 4). Trainees reported feeling confident using the system, finding it well-integrated, and believing that others could quickly learn to use it.

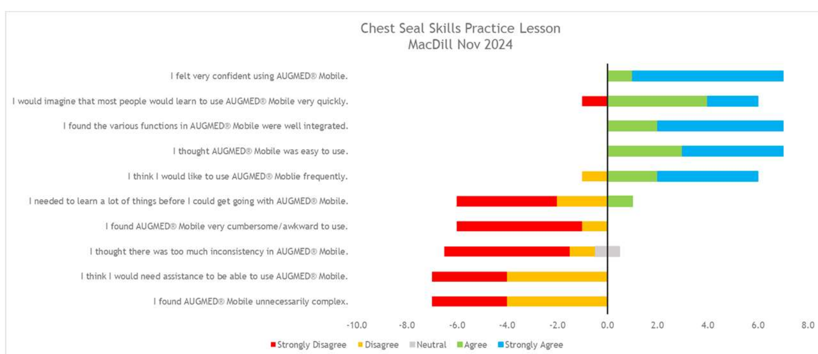

Figure 4 SUS scores for Chest Seal Skills Practice lesson

The Chest Seal Skills Practice lesson received favorable ratings across system features, with an average score of 4.6 ± 0.40 (95% CI [4.27, 4.93]) out of 5 (Figure 5). Users appreciated the clear lesson objectives, straightforward instructions, and the ease of placing the virtual 3D casualty. They found it simple to progress through the lesson

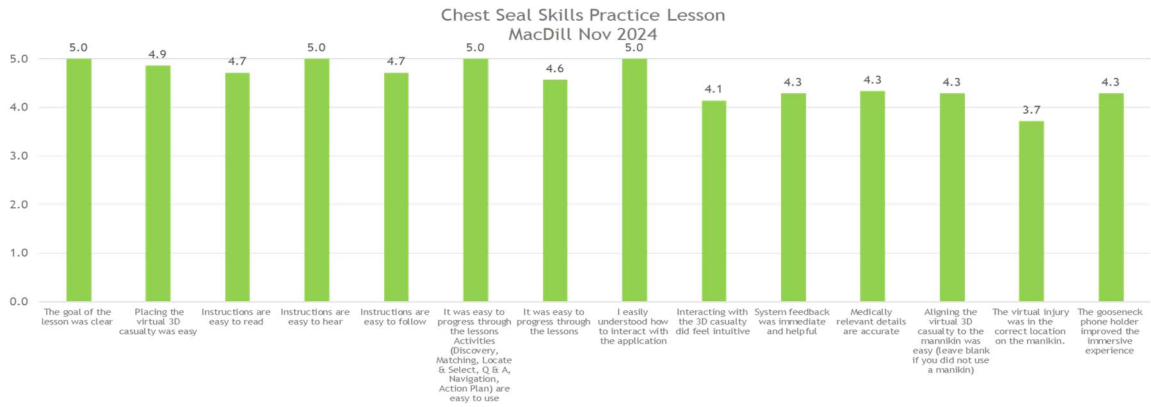

Figure 5 System Features scores for Chest Seal Skills Practice lesson

activities and effectively interact with the application. Additionally, the use of a gooseneck phone holder enhanced the immersive experience and contributed positively to the system's overall effectiveness.

The Respiration Assessment Practice 1 session was the participants' second hands-on and first scenario-based interaction using the XR platform. The session's SUS score was 80.6 ± 14.4 (95% CI [68.56, 92.64]) (Figure 6), indicating above-average usability. Users expressed confidence in using mobile XR training application and found it well-integrated and easy to learn, though some reported initial complexity and inconsistencies.

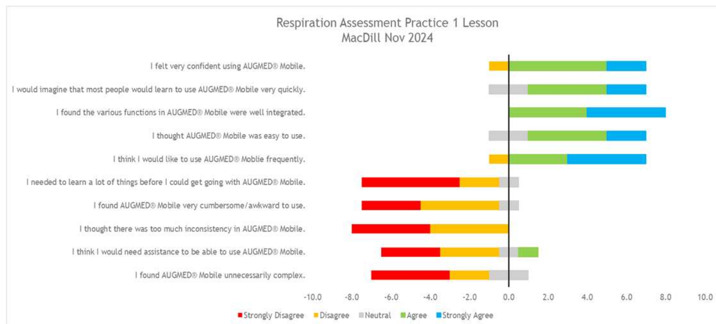

Figure 6 SUS scores for Respiration Assessment Practice 1 lesson

System feature ratings averaged 4.3 ± 0.38 (95% CI [3.98, 4.62]) (Figure 7), with the high scores for lesson clarity (4.9), ease of instructions (4.5-4.6), and immediate feedback (4.6). Lower scores were noted for intuitiveness in

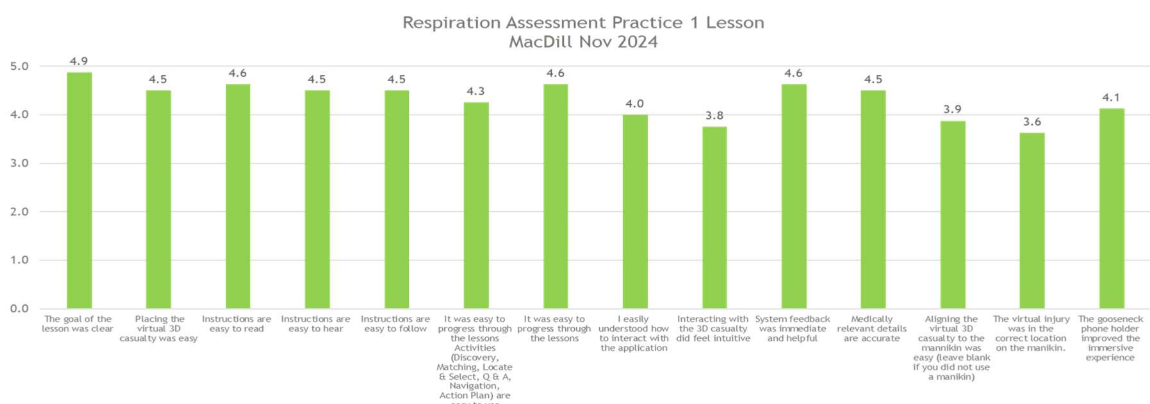

Figure 7 System Feature scores for Respiration Assessment Practice 1 lesson

interacting with the 3D casualty (3.8) and alignment of the virtual injury on the manikin (3.6). Overall, the results affirm the platform's overall usability and effectiveness in enhancing tactical trauma training across all lesson types.

Qualitative Responses

In the open-ended responses, 86% of users (6 out of 7) reported that the system supported their preparation for the Tactical Trauma Assessment, indicating strong confidence in its instructional value. Additionally, the lesson review feature received unanimous praise (5 out of 5), suggesting it effectively reinforced key learning objectives and contributed to learner confidence.

DISCUSSION

As the data show, refinements to the mobile XR training system resulted in noticeable usability improvements. As low-cost, immersive training technologies continue to emerge, these data show that is essential to rigorously evaluate these platforms to determine their effectiveness in enhancing performance. A critical first step in this process is resolving usability issues, ensuring that performance data collected during a TEE is not confounded by user interface or interaction challenges. The mobile XR platform used for this study, AUGMED® Mobile, was developed through an iterative design process and underwent frequent user testing. By incorporating user feedback from usability testing and conducting a PTEE, actionable feedback resulted significant improvements were made to the system's usability. The four areas identified as part of the PTEE all contributed to the higher usability and overall satisfaction of the trainees using the system.

Visual Coherence

Maintaining alignment between virtual and physical elements is critical for immersion and psychomotor skill development in XR environments. The transition from manual to QR code-based landmarking resulted in high scores for the alignment of the virtual casualty model with the physical manikin as indicated by a system feature score of 4.9 (SD=0.4) for the Chest Seal Skills Practice lesson and a score of 4.5 (SD=0.8) for the Respiration Assessment Practice 1 lesson as compared with the system feature score of 3.9 (SD=0.8) for the two lessons that used the manual landmarking. This enhancement reduced setup time, minimized user frustration, and the realism of the training experience for hands on skills (skill practice and assessment practice lessons). These changes were reflected in higher user ratings for model placement and overall lesson clarity, reinforcing the importance of seamless visual integration in mobile XR platforms.

Familiarization with Mobile XR Interactions

Initial PTEE results revealed that trainees struggled with understanding how to interact with 3D assets and navigate the XR environment. To address this, onboarding content was embedded throughout the lessons. These additions helped trainees quickly acclimate to the system, as evidenced by the excellent SUS scores (all in the 80s-range) and positive feedback on system intuitiveness. The consistent scores across the "Interacting with the 3D content felt intuitive," had similar means across the lessons: 4.1 (SD=1.0) for the Respiration Symptoms and Injuries and the Chest Seal Tools and Treatment lessons, 4.1 (SD=0.9) for the Chest Seal Skills Practice lesson and 3.8 (SD=1.2) for the Respiration Assessment Practice 1 lesson. This supports the broader finding that early and embedded guidance is essential for reducing cognitive load and increasing user confidence in mobile XR training.

Assessment Practice Formulation

Trainees expressed a desire for more opportunities to practice and retry activities, particularly when initial attempts were unsuccessful. In response, the system incorporated faded scaffolding and retry options within skills practice lessons, allowing users to gradually build autonomy. The scores for the system features "I easily understood how to interact with the application," and "System feedback was immediate and helpful," were all 4.0 or greater for all the lessons. The addition of an After Action Review (AAR) feature further supported time to internalize knowledge and skills acquired and promote retention. These enhancements led to high satisfaction scores and strong agreement that the system supported preparation for formal assessments as supported by the qualitative data, indicating that structured, self-paced practice is a key driver of both skill acquisition and learner confidence.

Lesson Progression

The original lesson structure had an unclear progression, which impacted user understanding of training flow. By applying a lesson blueprint and conducting a gap analysis, the development team ensured that each MARCH module followed a logical sequence—from foundational knowledge to assessment practice. The near-perfect scores for the system feature, "The goal of the lesson was clear," with average scores of 5.0 for the Respiration Symptoms and Injuries and Chest Seal Tools and Treatment lessons, 5.0 for the Chest Seal Skills Practice lesson and 4.9 (SD=0.4) for the Respiration Assessment Practice 1 lesson. Lessons were updated to include clear objectives and entry points, enabling users to self-direct their learning based on readiness. The high scores reported for the system feature, "It was easy to progress through the lessons," were an average of 4.5 (SD=0.5) for the Respiration Symptoms and Injuries and Chest Seal Tools and Treatment lessons, 4.6 (SD=0.5) for the Chest Seal Skills Practice lesson, and 4.6 (SD=0.5) for the Respiration Assessment Practice 1 lesson. This structured progression supported affective engagement and ensured that trainees entered assessment lessons with sufficient preparation, as reflected in high system feature ratings and positive qualitative feedback.

Taken together, these findings affirm that a structured, iterative approach can produce a mobile XR training system that is both usable and instructionally effective. Improvements across the four identified areas directly contributed to enhanced performance in all three learning domains:

- **Cognitive**: Clear instructional design and lesson sequencing supported knowledge acquisition.
- **Psychomotor**: Hands-on practice with realistic cues enabled procedural execution.
- **Affective**: Embedded guidance and learner autonomy increased confidence and engagement.

While the sample size was limited (n=8), the consistency of positive feedback across both quantitative and qualitative measures suggests that the revised mobile XR training system is well-positioned to support scalable, effective training in high-consequence environments like TCCC. Future work should expand testing to a broader user base, increase the sample size, and explore long-term retention and transfer of skills.

CONCLUSION

The PTEE using the mobile XR training platform confirms the value of integrating usability and learning assessments early in the development process of immersive training systems. By identifying and addressing four core usability challenges—virtual model alignment, user familiarization, assessment lesson formulation, and lesson progression—the development team ensured that the training experience promoted meaningful learning rather than being hindered by interface barriers.

This approach enabled focused engagement across the cognitive, psychomotor, and affective dimensions of learning. Trainees demonstrated strong knowledge acquisition (cognitive), improved procedural execution (psychomotor), and increased confidence and engagement (affective), as reflected in both quantitative usability scores (SUS: 89.1 ± 9.1) and positive qualitative feedback. Future efforts will expand testing to larger and more diverse cohorts, and include longitudinal evaluation of skill retention and transferability across operational domains.

Importantly, this lifecycle evaluation process—anchored in usability, instructional design, and iterative feedback—demonstrates a replicable model for both defense and commercial training systems. In high-consequence environments such as TCCC, this ensures that performance metrics reflect actual learning outcomes. For commercial applications, such as medical, industrial, or maintenance training, the same principles can be applied to accelerate onboarding, improve retention, and enhance workforce readiness.

Ultimately, mobile XR training systems that are designed and refined using a comprehensive TEE framework offer a return on investment by delivering scalable, low-cost training that supports continuous skill development and operational performance across industries.

REFERENCES

Brooke, J. (1986). System usability scale (SUS): A quick-and-dirty method of system evaluation user information. *Digital Equipment Co. Ltd*, 43.

Cohn, J. V., Stanney, K. M., Milham, L. M., Jones, D. L., Hale, K. S., Darken, R. P., & Sullivan, J. A. (2017). Training Evaluation of Virtual Environments. In E. Baker, J. Dickieson, W. Wulfeck, & H. F. O'Neil (Eds.), *Assessment of Problem Solving Using Simulations* (1st ed., pp. 81–105). Routledge.

Laxton, B. G., & Archer, J. (2024). Improving usability for mobile eXtended Reality (XR): A case study using Tactical Combat Casualty Care training and readiness to measure training effectiveness. *Proceedings of the Interservice/Industry Training, Simulation and Education Conference*, I/ITSEC 2024, Paper 24288.

Stanney, K. M., Archer, J., Skinner, A., Horner, C., Hughes, C., Brawand, N. P., Martin, E., Sanchez, S., Moralez, L., Fidopiastis, C. M., & Perez, R. S. (2022). Performance gains from adaptive eXtended Reality training fueled by artificial intelligence. *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, *19*(2), 195–218.