ARI Research Note 2014-04

Augmented Reality Mentor for Training Maintenance Procedures: Interim Assessment

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August 2014

United States Army Research Institute
for the Behavioral and Social Sciences

U.S. Army Research Institute
for the Behavioral and Social Sciences

Department of the Army
Deputy Chief of Staff, G1

Authorized and approved for distribution:

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REPORT DOCUMENTATION PAGE

1. REPORT DATE (dd-mm-yy)	2. REPORT TYPE	3. DATES COVERED (from. . . to)
August 2014	Interim	September 2012 – August 2014

4. TITLE AND SUBTITLE	5a. CONTRACT OR GRANT NUMBER
Augmented Reality Mentor for Training Maintenance Procedures: Interim Assessment	W91WAW-12-C-0063
	5b. PROGRAM ELEMENT NUMBER 633007
6. AUTHOR(S) Louise Yarnall, Sara Vasquez, Eryn Heying, Anna Werner	5c. PROJECT NUMBER A792
	5d. TASK NUMBER 398
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SRI International 333 Ravenswood Avenue Menlo Park, CA 94025	5e. WORK UNIT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences 6000 6th Street (Bldg 1464 / Mail Stop 5610) Fort Belvoir, VA 22060-5610	8. PERFORMING ORGANIZATION REPORT NUMBER
	10. MONITOR ACRONYM ARI
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	11. MONITOR REPORT NUMBER Research Note 2014-04

13. SUPPLEMENTARY NOTES
Contracting Officer's Representative and Subject Matter POC: Dr. William R. Bickley

14. ABSTRACT *(Maximum 200 words)*: The Augmented Reality Mentor is a 2-yr advanced development effort seeking to demonstrate the training potential of integrating visual augmented reality (AR) with virtual personal assistant (VPA) technology. The training demonstration venue is basic maintenance training for the Army's Bradley Fighting Vehicle (BFV). This report is a high level assessment of the AR Mentor's potential as of the end of the first year of effort. BFV maintenance students, BFV instructors, and non-BFV mechanics felt that, relative to using the technical manual to guide training, the AR mentor presented less of a mental load. Relative to instructor training, novice maintenance students using AR Mentor showed equivalent levels of errors and help-seeking, and significantly lower levels of instructor intervention. Observations indicated AR Mentor students engaged in greater collaborative problem solving than in other learning conditions. Accuracy of voice recognition and relevance of instruction from the VPA was judged adequate. AR Mentor is a wearable technology; users indicated that at times its form and fit somewhat hindered their movement. The AR Mentor assessment results will inform continued development during the second year of the project.

15. SUBJECT TERMS
Augmented reality, Mentor, Bradley Fighting Vehicle, Military training, Training technology

SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT	20. NUMBER OF PAGES	21. RESPONSIBLE PERSON
16. REPORT	17. ABSTRACT	18. THIS PAGE			
Unclassified	Unclassified	Unclassified	Unlimited Unclassified	54	Dorothy Young 703-545-3478

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AUGMENTED REALITY MENTOR FOR TRAINING MAINTENANCE PROCEDURES: INTERIM ASSESSMENT

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AUGMENTED REALITY MENTOR FOR TRAINING MAINTENANCE PROCEDURES: INTERIM ASSESSMENT

Background

The U.S Army seeks to improve instruction to maintain military readiness. One specific instructional challenge focuses on the training of maintenance personnel for armored vehicles. Armored vehicle technology is complex. There is not enough time in the schoolhouse to teach every maintenance procedure for every piece of equipment. Further, instructors are assigned to their roles in temporary rotations, typically lasting up to 3 years, and most come to their instructional task with limited teaching experience. Given these constraints, the U.S Army seeks technologies to improve the efficiency and effectiveness of instruction and to support on-the-job learning.

Recent research suggests that augmented reality and automated voice technologies offer the potential to achieve improved learning. Together, these technologies have the potential to:

- Improve learning and long-term memory through parallel processing of multiple representations of information (e.g., video and audio) (Mayer & Moreno, 2002).
- Reduce the demands on learners' short-term memory during learning by presenting dynamic representations of multi-step procedures (Chandler 2009; Hegarty et al., 2003; Lowe 1999).
- Improve learners' long-term memory of multi-step procedures by focusing their attention on the boundaries of key sub-steps (Zacks et al., 2007).
- Build learners' understanding of key sub-steps by giving them more control over the review of these steps (Spanjer, Wouters, Van Gog, & Van Merrienboer, 2011).
- Focus learner attention efficiently on the central elements of a complex procedure (Yantis & Jonides, 1984).

Additionally, such technologies have the potential to increase the time in the schoolhouse for higher-order learning. For example, they may reduce the burden on instructors for low-level, redundant teaching activities such as correcting errors in technical manuals and re-explaining basic procedures, thus freeing up the opportunity for instruction around higher-order problem solving. They may also reduce the burden on peer "helpers" who read technical manuals aloud, thus increasing the opportunity for learners to engage in more complex activities, such as collaborative problem solving.

Based on these principles, the Army Research Institute has contracted SRI International to develop and test a prototype technology, the Augmented Reality Mentor (AR Mentor). It is a head-mounted display device through which technicians can receive audio-visual guidance while learning to conduct adjustments on military equipment. The AR Mentor provides guidance via on-demand voice instruction and five types of visual overlays to the work environment: 3D graphic animations to describe tools and how to manipulate them, animated arrows that direct the learners' gaze direction, live-action videos of maintainers conducting adjustment procedures, text-annotated graphic images of complex tools, and diagrammatic images of complex equipment.

The learner may direct the flow of these audio-visual forms of guidance, skipping them and asking them to repeat as needed. The device additionally features a limited capacity to detect when the learner is positioned correctly on military equipment to conduct an adjustment.

The AR Mentor first prototype was developed from September 2012 through October 2013 to support instruction around an advanced adjustment to the Bradley Fighting Vehicle (the "Bradley"). In November 2013, SRI's Education Division designed and conducted in progress performance and usability assessments of AR Mentor. This report summarizes the assessment approach and emerging findings.

The AR Mentor performance assessment focused on a set of proof-of-concept research questions focused on the technology's usability and efficacy for task learning.

1. What are novice Soldier perceptions of the usability of the technology?
2. What quality of task performance do novice Soldiers demonstrate using the technology (as measured by number of errors, frequency of help-seeking, time to complete sub-steps, and time to complete the entire procedure)?
3. What are novice Soldiers' perceptions of their own learning with the technology?
4. What are the perceptions of experienced mechanics of the usability and efficacy of the technology for learning adjustments on unfamiliar military equipment?
5. What are the perceptions of instructors of the usability and efficacy of the technology for teaching how to make adjustments?

Method

To obtain an objective assessment of the novice Soldiers' perceptions of and performance with the AR Mentor prototype, the study compared pairs of novices learning the procedure in three different learning conditions:

- AR Mentor only,
- Instructor/technical manual, and
- Technical manual only.

The instructor/technical manual condition reflected business-as-usual instruction in the schoolhouse as the instructor monitors a student pair using the technical manual to perform the procedure. The technical manual only condition provided a baseline view of learner capacity unaided by instructor guidance. Pilot testing and observations of standard schoolhouse instruction had indicated that instructors use intrusive guidance with Soldiers, meaning they monitor the novices' performance closely and intervene before novices request assistance. This instructional approach can mask the actual points of difficulty the novices encounter in procedural learning, possibly giving them a false sense of competence and a limited opportunity to develop resilience in problem solving (Shechtman et al., 2013).

Additionally, we engaged both Bradley instructors and trained tank mechanics with no Bradley experience in using the AR Mentor to conduct the repair procedure, and then interviewed them about their perceptions of its usability and efficacy.

Participants

We engaged three types of participants: 12 novice Bradley maintainers, three experienced tank maintainers who had little to no experience with Bradleys, and three experienced Bradley instructors. All were recruited in accordance with human subjects regulations and procedures.

The novice Bradley maintainers were selected for their lack of exposure to the procedure. For all but one pair, none of the novices had ever been taught this specific procedure and none had actually performed it before. They were also selected to provide a representative range of learner aptitude based on their scores on subtests of the Armed Services Vocational Aptitude Battery (ASVAB). For Bradley maintainers, the composite tests were the Mechanical Maintenance (MM), which combines the ASVAB subtests of numerical operations, auto and shop information, mechanical comprehension, and electronics information, and the General Technical (GT), which combines the ASVAB subtests of Paragraph Comprehension and Arithmetic Reasoning. As a reference, the Army recommends that maintainers of Bradley Fighting Vehicles have a minimum MM score of 105. Our sample included a range of novices who scored a low of 89 and a high of 134 on the MM. It also included one Soldier for whom English was a second language and one Soldier for whom English was not the primary language spoken at home. Each condition included a pair with higher ASVAB scores and a pair with lower ASVAB scores.

Procedures

We engaged all participants in performing a 34-step adjustment procedure. Pairs of novice Soldiers and experienced maintainers conducted the procedure collaboratively in each learning condition. Instructors were on hand in all three conditions to intervene if students made an error that would impede progress, but they were asked to avoid intervening in the AR Mentor and manual conditions, except for providing guidance as they normally would in the instructor condition.

The instructors conducted the procedure independently with physical help from the research team. In the AR Mentor condition only, both members of a pair had a chance to use the AR Mentor so the research team could collect more data on usability and efficacy. In the other two learning conditions, the pairs went through the procedure only once to provide comparative performance data. We allocated up to 2-3 hours for the performance task and post-procedure interviews. All repairs were conducted on Bradleys in a military schoolhouse and set to the same starting conditions.

Instrumentation

We developed two protocols for all novice Soldiers, an *observational protocol* (Appendix A) and a *learning experience questionnaire* (Appendix B). In addition, for the AR Mentor

condition, we developed the *AR Mentor usability questionnaire* (Appendix C) and an interview protocol that was administered to the Soldiers in that condition only (Appendix D). The observation protocol recorded the following performance data: time to complete three sub-phases of the adjustment, total task completion time, number of errors, and number of instances of help (either sought or intrusively provided). In the instructor condition only, we also tallied the types of instructor guidance provided (procedural, conceptual, self-regulating, safety precaution, technical manual correction). The learning experience questionnaire included a 7-item holistic rating of perceived difficulty of the learning experience using a modified, unweighted version of the NASA Task Load Index (Hart & Staveland 1988) and a researcher-designed 17-item rating of perceived difficulty of each of the steps of the procedure (Nederhof 1985). This instrument employed a third-person difficulty rating strategy to minimize social stigma (e.g., "You need to tell another Soldier which steps are harder…), and then presented pairs of steps from the procedure. The steps varied on procedural or conceptual complexity. These pairs were derived from absolute ratings of each step by both researchers (based on observations of Soldiers doing the task) and an experienced Bradley instructor. The AR Mentor usability questionnaire included 19 Likert-scale items asking for ratings of the ease of using the technology's visual and audio guidance features. The AR Mentor usability interview protocol included three questions seeking more detail about each participant's preferences for audio and visual guidance features and experience of physical comfort using the technology.

Results

This report focuses primarily on the quantitative results from the data collection, and a future report will focus more on qualitative analysis and a closer look at the step-by-step learning efficacy results. For this report, there were two primary analyses we conducted on the data from the novice Soldiers: Comparison of their performance metrics and comparison of their holistic perceptions of learning efficacy among the three conditions. We additionally analyzed the holistic learning efficacy results according to Soldiers' ASVAB scores (MM and GT). This analysis clarified how Soldiers of different verbal, quantitative, and mechanical aptitude varied in their perceptions of the difficulty of learning the task in the three different conditions. For this report, we also analyzed feedback from the AR Mentor novices for their ratings of the overall usability of the technology and the specific usability of the technology's visual and the audio guidance features. We also completed brief initial qualitative summaries of feedback from the experienced mechanics and the instructors about the usability of the AR Mentor. The samples in this study are small, and so the results should be considered exploratory.

We present the novice Soldier results first. This includes the performance metrics comparison, followed by the comparison of holistic perceptions of learning efficacy, and concluding with the AR Mentor usability data.

Performance Metrics Comparison

Counts of performance metrics showed that the AR Mentor condition took slightly longer and involved a few more errors than the instructor condition. Novice Soldiers took longer and made more errors in the manual-only condition. The data on help seeking and total instances of instructor intervention indicate that the AR Mentor required much less guidance from the

instructor (see Table 1). The novices working with the AR Mentor were observed to be engaged in much more independent, collaborative troubleshooting than those in the instructor condition. The trends from the observational data will be presented in a future report.

Table 1.
Comparison of average total trainee error, help-seeking, instructor guidance, and total time for the three learning conditions*

Learning Condition	Total Errors Mean (individual scores)	Total Help Seeking Mean (individual scores)	Total Instructor Guidance Mean (individual scores)	Average Total Time (hour:min:sec)
AR Mentor (n=4)	2.75 (5,2,3,1)	7.50 (15,3,11,1)	2.00 (6,1,1,0)	1:11:00
Instructor + Manual (n=2)	1.50 (1,2)	8.00 (9,7)	46.50 (58,35)	0:55:30
Manual only (n=2)	8.00 (11,5)	25.00 (25,25)	22.50 (26,19)	2:15:00

* To see the full distributions see appendix E

Holistic Perceptions of Learning Efficacy

The NASA Task Load Index results are presented, focusing on the Soldiers' perceptions of the mental and physical demand of learning the procedure, the pace of the learning and related frustration levels. Then, we present an aggregate rating of the Soldiers' perceptions of overall difficulty of learning in each condition. These analyses also explore how students' perceptions of learning vary by their baseline competence, as indicated by their ASVAB scores.

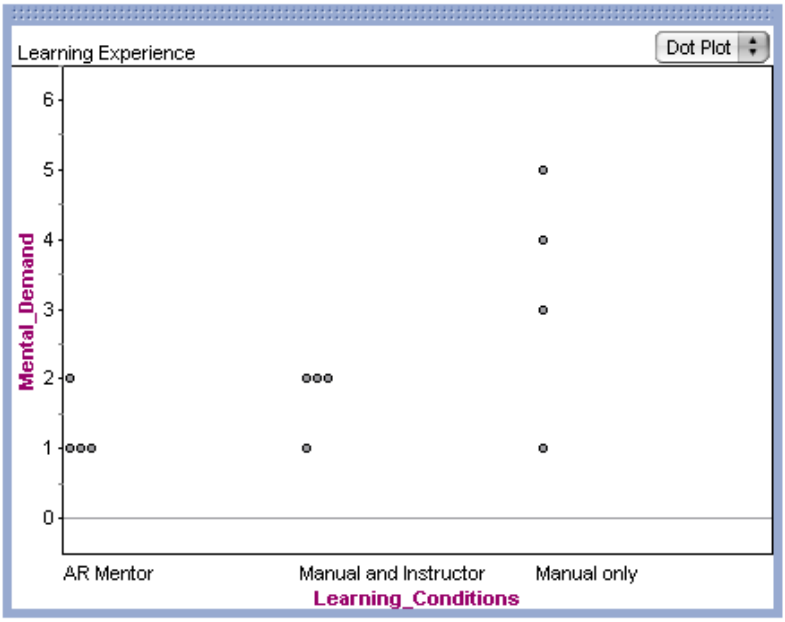
Perceptions of Mental and Physical Demand by Condition

The novice Soldiers reported lower levels of both mental and physical demand in the AR Mentor condition compared to the instructor condition and the manual condition. The table below presents the average rating the students reported on the following two questions on the survey: How *mentally* demanding was learning the adjustment? How *physically* demanding was learning the adjustment? (1-5, Very low to Very high).

Table 2.
Comparison of novice Soldiers' mean perceptions of the mental and physical demand while learning a technical procedure in the three conditions

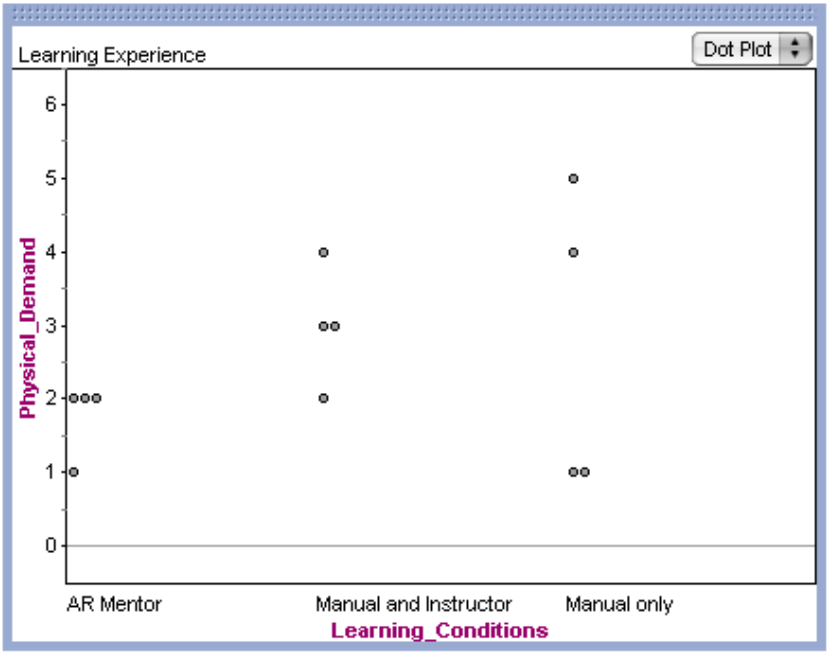
	AR Mentor *n* =4	Manual and Instructor *n* =4	Manual Only *n* =4
Mental demand	1.25	1.75	3.25
Physical demand	1.75	3.00	2.75

To gain insight into these scores, it helps to look at the distribution of results (Figures 1 and 2). The distribution of the ratings in the Manual Only condition is the widest for both forms of demand, mental and physical. Only one student reported low mental demand (1) while all others reported higher scores (3 or greater). The distribution of the physical demand ratings is higher in the Manual Only and Instructor conditions than in the AR Mentor condition.



* Each dot represents a student in each condition.

Figure 1. Distributions of novice Soldiers' perceptions of mental demand in three different learning conditions: AR Mentor, Instructor, and Technical Manual.



* Each dot represents a student in each condition.

Figure 2. Distributions of novice Soldiers' perceptions of physical demand in the three different learning conditions.

Perceptions of Pace of Learning and Frustration

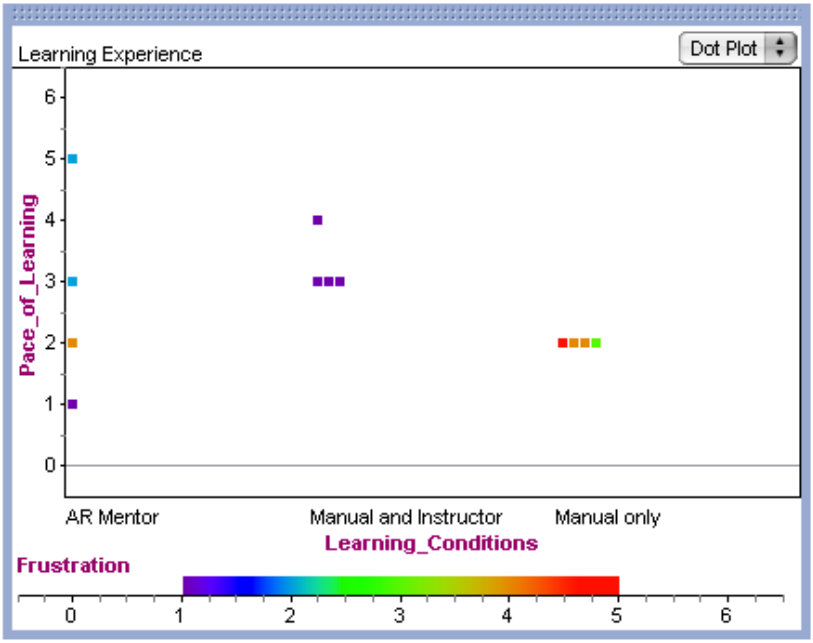
The novice Soldiers reported highest levels of frustration when learning in the manual only condition and lowest in the instructor condition, while they rated the AR Mentor between these two extremes (see Table 3). They reported the pace was slowest in the manual condition, fastest in the instructor condition, and they rated the AR Mentor between these points.

Table 3.
Comparison of novice Soldiers' mean perceptions of the pace of learning and frustration levels while learning a technical procedure in the three different conditions

	AR Mentor	Manual and Instructor	Manual Only
Pace of Learning (1=slow, 5=fast)	2.75	3.25	2.00
Frustration (1=low, 5=high)	2.25	1.00	4.00

We hypothesized that the rating for the pace of learning was tied to some of the other underlying variables, such as their frustration level. Exploring their ratings of the pace of learning with the overlay of the frustration variable shows that students who have experienced

higher level of frustration tended to perceive the pace of learning as slow, while those students (with the exception of one) who reported lower levels of frustration tended to report faster pace of learning experience (see Figure 3).



* Each dot represents a student in each condition.

Figure 3. Comparison of how novice Soldiers' frustration levels relate to their perceptions of the pace of learning by the three different learning conditions.

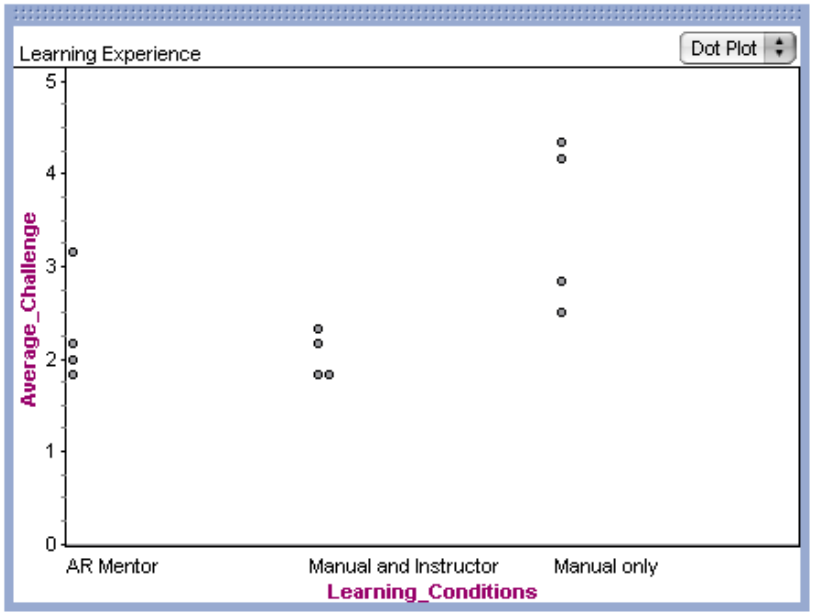
Overall Perception of the Challenge of Learning the Task

All the facets of the NASA Task Load Index (except for perceptions of success) can be linked to an overall measure of perceived challenge of the task (1-5, Very low to Very high). This combines perceptions of mental demand, physical demand, effort, frustration, difficulty of asking questions (reversed scale), and pace of learning (reversed scale). The distribution shows that novice Soldiers perceived learning with the AR Mentor to be comparably challenging to learning with an instructor. Novice Soldiers reported both of these conditions were easier than learning with the manual only (see Table 4).

Table 4.
Comparison of novice Soldiers' mean perceptions of the overall challenge of learning a technical procedure in the three different conditions

	AR Mentor	Manual and Instructor	Manual Only
Average Challenge	2.29	2.04	3.46

We again provide the distribution of results to clarify the nature of these ratings. There is a wider distribution in the manual condition and the AR Mentor condition compared to the instructor condition (see Figure 4).

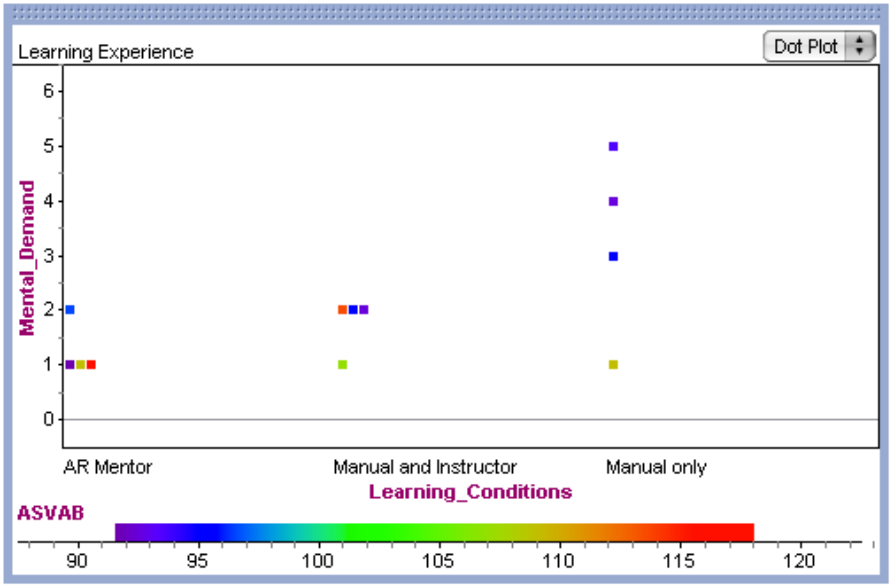


* Each dot represents a student in each condition.

Figure 4. Distributions of novice Soldiers' perceptions of the challenge of learning a procedural task in three different learning conditions: AR Mentor, Instructor, and Technical Manual.

Exploration of Holistic Ratings of Learning Efficacy with Novice Soldiers' ASVAB Scores

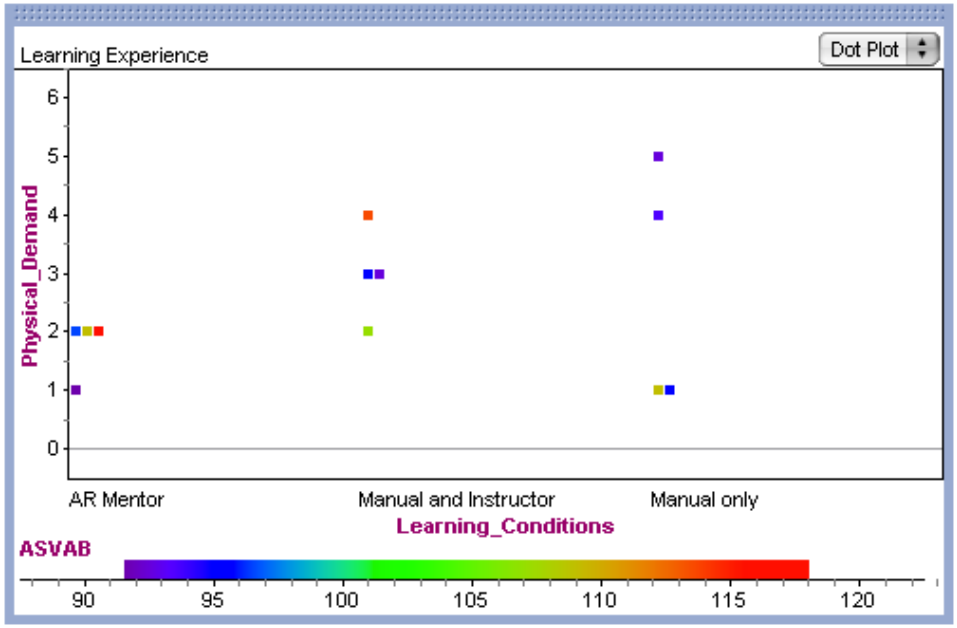
This analysis helped explain some of the wider distributions in novice Soldiers' perceptions of the difficulty of learning in the different learning conditions. As Figure 5 shows, students with a lower ASVAB scores tended to perceive the task as more mentally demanding than those with higher ASVAB scores in all three conditions, but particularly in the manual only condition (see Figure 5).



* Each dot represents a student in each condition.

Figure 5. Distributions of novice Soldiers' perceptions of the mental demand of learning a procedural task in the three different learning conditions according to Soldiers' ASVAB scores.

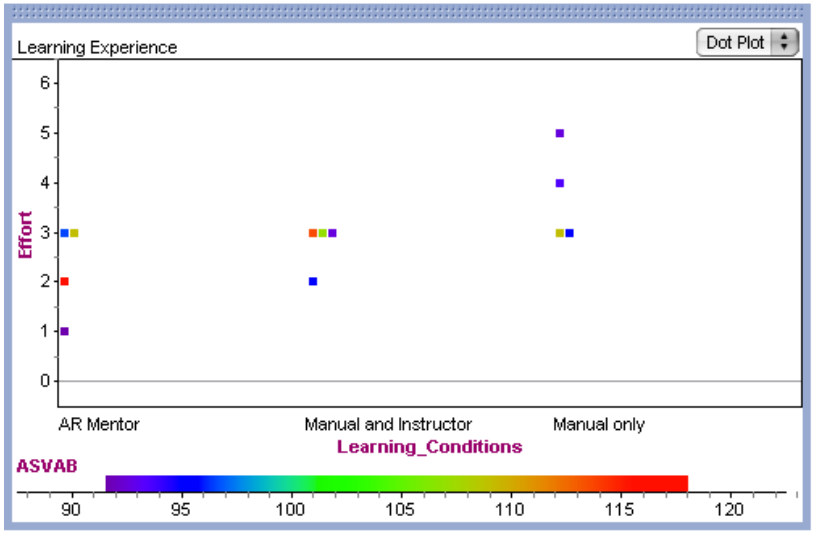
By contrast, novice Soldiers' perceptions of the physical demand of the task did not appear to relate as strongly to their ASVAB scores (see Figure 6).



* Each dot represents a student in each condition.

Figure 6. Distributions of novice Soldiers' perceptions of the physical demand of learning a procedural task in the three different learning conditions according to Soldiers' ASVAB scores.

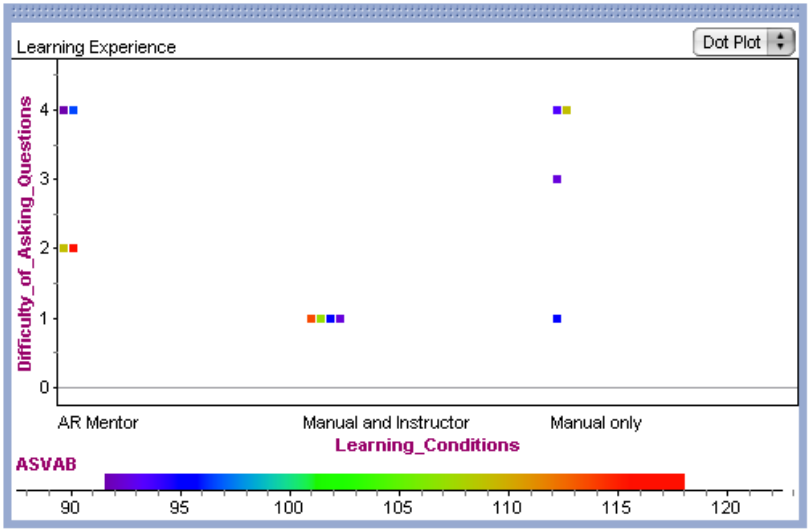
Novice Soldiers' perceptions of the level of effort they devoted to completing the task also did not appear to relate strongly to their ASVAB scores (see Figure 7).



* Each dot represents a student in each condition.

Figure 7. Distributions of novice Soldiers' perceptions of level of effort of learning a procedural task in the three different learning conditions according to Soldiers' ASVAB scores.

Novice Soldiers' perceptions of the difficulty of asking questions while learning the task varied by both the learning condition and their ASVAB scores. Students with low ASVAB scores reported higher difficulty asking questions of the AR Mentor than those with higher ASVAB scores. Such differences were not observed in the Manual and Instructor condition. There was a wider range of perceptions of difficulty asking questions reported in the manual condition (see Figure 8).



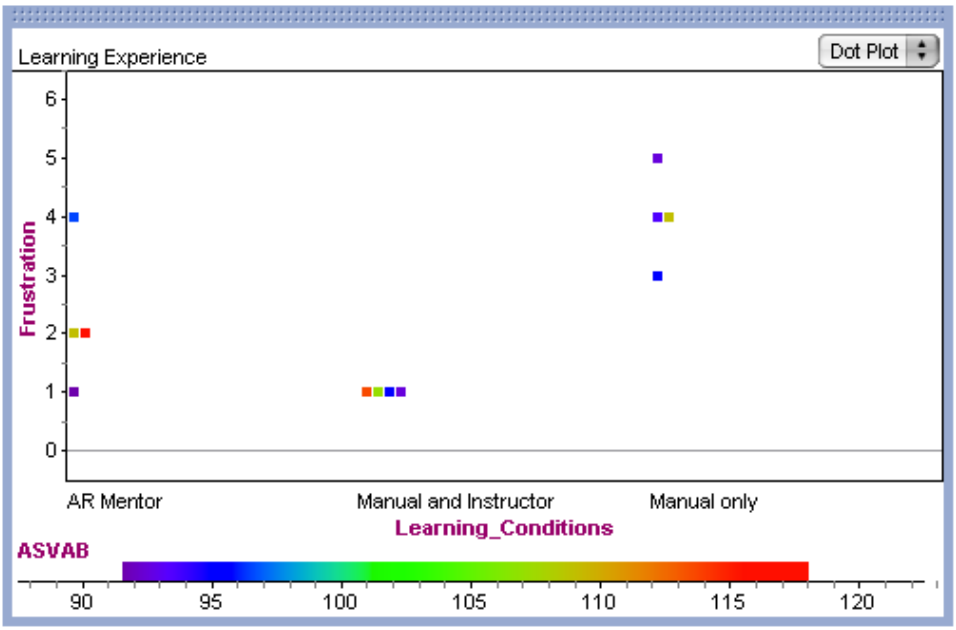
* Each dot represents a student in each condition.

Figure 8. Distributions of novice Soldiers' perceptions of the difficulty of asking questions while learning a procedural task in three different learning conditions AR Mentor, Instructor, and Technical Manual according to Soldiers' ASVAB scores.

Novice Soldiers' reports of their frustration levels with the task also varied by both the learning condition and their ASVAB scores. Students with both high and low ASVAB scores reported relatively low levels of frustration in the instructor condition, but relatively high levels of frustration in the manual condition, with the ASVAB in the middle (see Table 5). The distribution of frustration level is widest in the AR Mentor condition, and low scorers are split between highly frustrated and minimally frustrated, while higher ASVAB scorers are both reporting relatively low levels of frustration (see Figure 9).

Table 5.
Comparison of novice Soldiers' mean perceptions of frustration while learning a technical procedure in three different conditions: AR Mentor, Instructor, and Technical Manual according to Soldiers' ASVAB scores

	AR Mentor	Manual and Instructor	Manual Only
Frustration	2.25	1.00	4.00



* Each dot represents a student in each condition.

Figure 9. Distributions of novice Soldiers' perceptions of frustration while learning a procedural task in three different learning conditions AR Mentor, Instructor, and Technical Manual according to Soldiers' ASVAB scores.

AR Usability Data

We present analyses of the overall ratings of AR Mentor's usability, followed by ratings of the usability of the visual representations and the audio guidance, and the physical comfort aspects of using the technology.

Overall usability. Novice Soldiers gave high ratings to the overall usability for AR Mentor. They reported feeling they and their helpers knew what adjustments they needed to make and that the AR Mentor provided a smooth flow of guidance (see Table 6).

Table 6.
Novice Soldiers' perceptions of overall usability of the AR Mentor

Overall Usability	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Low to High)				Average Rating
How well could you understand what you needed to do to adjust the Bradley?	5	2	4	5	4.00
How consistently did the AR Mentor audio and visual instructions occur when you needed them to occur?	4	4	5	4	4.25
How consistently did you know which steps required you to coordinate with a helper and which required action only by you?	4	3	5	5	4.25
Overall					4.17

Visual representations. The AR Mentor provides visual guidance using five types of visual representations that are overlaid on the work environment: 3D graphic animations to describe tools and how to manipulate them, animated arrows that direct the learners' gaze direction, live-action videos of maintainers conducting adjustment procedures, text-annotated graphic images of complex tools, and diagrammatic images of complex equipment and the Bradley location map.

The novice Soldiers (n=4) gave generally high ratings to the understandability of the AR Mentor's visual representations. Soldiers showed a slight preference for videos of a maintainer conducting a repair. "It'd be almost like having another instructor there since it's showing them exactly what they need to do, the tools they need to have in place, exactly what they need," one instructor said. Ratings of the understandability of these different representations are presented in Table 7.

Table 7.
Novice Soldiers' perceptions of understandability of AR Mentor's visual representations

Visual Representations	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Low to High)				Average Rating
Video demos	5	4	5	5	4.75
Text	4	4	5	5	4.5
Directional arrows	NA	4	4	5	4.33
Diagrams	4	3	5	5	4.25
Bradley map image	4	3	5	5	4.25
3D animations	5	3	5	4	4.25
Overall					4.39

The directional arrows and Bradley map image provide Soldiers with visual pointers to where they should be located when performing sub-steps of the adjustment. Soldiers generally reported being able to find where they should be standing on the Bradley when using the AR Mentor (Table 8).

Table 8.
Novice Soldiers' perceptions of ease of determining where to stand on the Bradley while using the AR Mentor

Orientation	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Low to High)				Average Rating
How easy was it to find where you should be standing on the Bradley?	5	2	5	5	4.25

Automatic Speech Recognition (ASR) & Virtual Personal Assistant (VPA).

The AR Mentor features a realistic male voice that guides the learner through each task. The voice is projected so that the "helper" and instructor can hear what the Soldier wearing the head-mounted rig can hear. The system is programmed to permit the Soldiers to engage in regular conversation and to respond only to direct queries prefaced by the term, "Computer," as in, "Computer, please go to step 10". For each step, the VPA goes through a script describing the procedures. These are chunked at different levels of information complexity, ranging from a single step to roughly five sub-steps. Safety warnings are inserted. The VPA additionally checks with the Soldier for understanding and completion of each step before proceeding to the next step. It is programmed to respond to a range of queries, from simple procedures to open-ended queries focused on the purpose of the task. When the VPA system fails to comprehend a request or question, it says so and asks the Soldier to restate.

The ASR/VPA system has distinct interactive dimensions: Speech recognition, question response, and pace.

The novice Soldiers gave moderately high ratings to the system for speech recognition (see Table 9).

Table 9.
Novice Soldiers' perceptions of quality of AR Mentor's speech recognition

Speech Recognition	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Low to High)				Average Rating
How often did the AR Mentor know when you were speaking?	4	4	3	3	3.50
How well did you understand the AR Mentor's audio instructions?	4	3	4	5	4.00
How often did the AR Mentor respond correctly to what you were saying?	5	3	4	4	4.00
Overall					3.83

Too few Soldiers asked questions of the system to get a sense of its quality (see Table 10).

Table 10.
Novice Soldiers' perceptions of quality of AR Mentor's question response

Question Response	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Low to High)				Average Rating
If you asked the AR Mentor any questions, how relevant and useful were the AR Mentor's answers?	1	n/a	n/a	n/a	1.00
If you asked AR Mentor to go to a step, how well could the AR Mentor go to the step you wanted?	5	n/a	5	n/a	5.00

Novice Soldiers generally expressed impatience with the pace of the voice guidance (see Table 11).

Table 11.
Novice Soldiers' perceptions of quality of AR Mentor's pace of voice guidance

Pace of AR Mentor voice guidance	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	Average Rating
	Scale of 1-5 (Always to Never)				
How often did you want to interrupt the AR Mentor when it was saying it didn't understand you?	2	3	1	2	2.00
How often did you want to speed up the AR Mentor voice when it was speaking?	2	1	2	1	1.50
How often did you want to slow down the AR Mentor voice when it was speaking?	4	5	3	5	4.25
Overall					2.58

Physical Aspects: Comfort. In terms of comfort, Soldiers gave mid-range ratings to the extent to which the AR Mentor restricted their movement and got in the way of their body and head (see Table 12).

Table 12.
Novice Soldiers' perceptions of comfort when using the AR Mentor

Physical movement using AR Mentor	Soldier ID				
	P1.1	P1.2	P2.2	P2.3	
	Scale of 1-5 (Never to Always)				Average Rating
To what extent did the AR Mentor restrict your movement and get in the way of your body and your head?	3	2	3	4	3.00

Summary of Instructor and Experienced Mechanic Perspectives

In interviews conducted after using the AR Mentor to conduct the procedure, both Bradley instructors and experienced tank mechanics reported generally positive experiences with the technology. This section briefly summarizes those responses.

All three Bradley instructors endorsed the use of visual representations to guide the learning of the procedure and characterized the technology as a type of "backup instructor" who could remind students what to do. They liked the VPA's capacity to require students to hear the safety precautions. They all said their students would like using it. They could see the tool as a way to engage more learners in learning, either by freeing up the instructor's time to focus on higher-level aspects of troubleshooting or adding an additional capability to the technology that would permit other students to see on a large screen what the hands-on student was seeing while conducting an adjustment. Two noted the AR Mentor restricted mobility and visibility, but not to the point of preventing the work to proceed. They said they would like to see the technology cover all the content in the technical manual.

All three experienced tank mechanics liked the AR Mentor as a way to walk through a new procedure in the field. "If I can see it, I can do it," as one said, and the technology capitalized on this preference. They said they preferred learning new procedures from such technology to a technical manual, and expressed the belief that they could better recall a procedure after just one pass with the AR Mentor. They expressed reservations about the technology for conducting repairs in tight spaces or bright light. They recommended a tighter, more compact form. They also said the AR Mentor voice was too slow, and they would prefer to control it with a push button. In particular, they did not want to wait to go through every new tool during the initial tool check; rather, they would like to see all the tools and then press an "OK" button. All said the AR Mentor built on their own knowledge of tools and moving around large military armored vehicles effectively. Although the experienced mechanics had either never worked on a Bradley before or conducted an unrelated adjustment once in the distant past, each could conduct the repair in under an hour on the first pass with the AR Mentor.

Conclusions

Overall, all the participants—novice Soldiers, Bradley instructors, and experienced mechanics—gave generally positive ratings to the AR Mentor prototype and concept. Particularly, they like the graphics and video because, consistent with learning theory, these representations required less mental effort than the use of technical manuals to learn new procedures. The data suggest that the technical manuals present a particular challenge to Soldiers entering at the lower ASVAB levels, and those Soldiers perceive the AR Mentor to present information in a less demanding manner. Instructors could immediately see that the time they must devote to redundant aspects of teaching could be greatly reduced by such technology, perhaps freeing them up to engage in higher-level forms of instruction.

At the basic performance level, the AR Mentor produced a complete rehearsal of the full procedure in a slightly longer time than instructor-led training, but it did so in a manner that appeared to afford a higher opportunity for the novices to engage in collaborative troubleshooting than the instructor condition. Given the Army's desire to improve readiness at all levels of its forces, this tradeoff between putting slightly more time into instruction in exchange for a greater chance to develop independent troubleshooting skill may be worthwhile. Further testing is needed to measure how robust the learning results are as compared to current schoolhouse methods.

The technology generally functioned well both for novice Soldiers with little mechanical experience and for experienced mechanics with little familiarity of the specific procedures to adjust the Bradley. Our initial review of the data indicated there were some distinctions in how experienced and inexperience mechanics used the AR Mentor technology. Clearly, the pace of the VPA guidance is something that would need to be adjusted for these two types of learners. For example, it may be useful to require novices to hear every safety precaution and acknowledge every tool during an initial tool check, but experienced mechanics will be impatient with iteration of such obvious basics.

As a prototype, AR Mentor has limitations, which all participants acknowledged. A more compact and robust form would be required to permit mechanics to work in tight spaces. The AR images may not be visible through the monocle in all environments, particularly in areas with high levels of light. Some users found it challenging to adjust to looking at their work through a monocle. Others, particularly low ASVAB learners, showed evidence of discomfort asking questions of the AR Mentor. In fact, not one Soldier posed a conceptual question to the AR Mentor. The one Soldier who tried asking an open-ended question did not receive a productive response. The AR Mentor's Reasoner system, which links visual representations and audio guidance, still falls short of its stated goal to engage learners in such potentially rich question-response activities.

As a first step toward that goal, two issues are that some of the AR Mentor visual representations were not functioning effectively and some of the VPA instructions contained too many steps. If instructional content is ever to be produced at mass scale for such technology, further study is needed to define the design features of visual representations and dialog scripts. Such study needs to focus both on how to design to reduce cognitive load, but, more importantly,

also to understand what visual representations and audio dialogs may serve as a springboard to deeper learning.

The AR Mentor system appears to reduce the load on Soldiers' working memory of Soldiers, as indicated by the reports from all the study participants. However, this study raises questions about whether such technology can do more. In theory, the AR Mentor technology can support improved long-term memory retention and knowledge retrieval. We still need to test whether using AR Mentor does improve retention of procedural knowledge. In addition, a goal for the AR Mentor is to improve understanding of higher-order concepts that may improve troubleshooting skill. In this study, we did not observe any instruction that would be expected to improve conceptual knowledge of mechanical or electrical systems nor did we observe any such improvement. These are the questions to be explored further through design and testing.

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Appendix A: Observation Protocol

OBSERVER: _____ DATE: _____ MAINTAINER ID: _____
MAINTAINER GROUP: _____

AR MENTOR Observation Protocol – AR MENTOR CONDITION
Updated 10/18/2013

Observation/Instrument Instructions

- Record the start time of the activity.
- n the first column of checkboxes labeled **Complete**, indicate with a check mark when the maintainer completes the step.
  - o
    f the maintainer does not perform the step at any point, leave the box empty.
- If the maintainer backtracks on a step or performs a step incorrectly, place an X in the box next to the step in the **Error** column.
- Record the end time of the activity.
- Conduct the post-activity conceptual checks (after each phase).
- Answer the post-observation debrief questions (note: there are two sets of questions, one for the AR-Mentor condition and one for the instructor condition).

Conceptual Check:

At the end of the three evaluation phases (setup, continuity, reassembly), ask the maintainer the questions listed and indicate if he/she answered correctly or incorrectly in the space provided.

Help Seeking Behavior.

Place an "X" in the column marked **Help Seeking Behavior** for any observed instances of help seeking behavior. We operationalize help seeking as:

- ☐ Asking helper for assistance
- ☐ Verbally expressing puzzlement or confusion AND receiving a helper response
- ☐ Showing evidence of an active effort to resolve a problem

It is not:

- ☐ Verbally expressing frustration
- ☐ Observing that one is puzzled without a helper response or active effort to resolve problem

Please note whether problem was resolved.

- ☐ It is not asking what or when about the next step.

Instructor Guidance.

Note all instances of instructor feedback / guidance, categorizing instructor guidance in the following ways:

- ☐ (P) Procedural: Related to how a task is understood or performed
- ☐ (C) Conceptual: Provides information specific to underlying tasks or relating and extending tasks (i.e., encourages deep understanding)
- ☐ (SR) Self-regulating: Encourages self-regulation or reflection on one's understanding and behavior
- ☐ (SP) Safety precaution: Warns the student about safety
- ☐ (TM) Technical Manual referral: Instructor corrects the technical manual

Post Observation BFV Quantitative Performance Measures:

For the Post Observation Analysis section, tally the total time, number of errors, instances of help-seeking behavior, and the instances and types of instructor guidance.

Time for Technical Manual Review/Translation into Action:

With the pre-selected steps identified, record the start time (when the helper reads the technical manual step), end time 1 (when the maintainer begins implementation) and end time 2 (when the maintainer ends implementation).

Evaluation Phase 1: Set Up

Start time: _____

Complete	Error / Backtrack	Step	Help-seeking Behavior
		1. Puts Traverse Drive select lever into manual position	
	☐	2. Puts Gun Elevation Drive into power and positions at 0 mils or higher	
	☐	3. Puts TOW Elevation Drive into manual position	
		4. Manually traverses Turret to 4750 mils	
		5, Raises Cargo Hatch	
	☐	6. Zeroes Turret Drive Level on TAS Mounting Plate to center on 0° (clean mounting plate, loosen thumbscrew, place turret drive level on TAS mounting plate, rotate knob on turret drive level until 0° level bubble centers, and tighten thumbscrew). • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	
		7. Manually raises TOW launcher to 90° firing position (uses speeder wrench or alternative to move TOW Elevation Drive out of saddle)	
	☐	8. Zeroes Turret Drive Level UNDER TOW launcher (maintainer places Turret Drive Level on non-magnetic baseplate UNDER TOW launcher, manually raises or lowers TOW launcher as helper watches for 90° bubble to center)	

Complete	Error / Backtrack	Step	Help-seeking Behavior
		9. Zeroes Turret Drive Level on SIDE of TOW launcher to ensure 0° bubble centers (loosen thumbscrew, position turret drive level on side of TOW launcher, rotate knob on turret drive level until 1.2° level bubble centers, and tighten thumbscrew). • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	
	☐	(Safety precaution) Props up TOW launcher with jack stand	
		10. Removes shield from housing (including 4 screws with socket adapter)	
		11. Removes plug 2W306P2 from jack 2A204J2 to permit gearbox cover removal	
	☐	12. Removes gearbox cover including 4 screws, lock washers, washers, and cover (gasket not removed in training condition)	

End time: _____

Post Observation Analysis (BFV Quantitative Performance Measures):

Error Tally: _____
Help-seeking Tally: _____
Instructor Guidance Tally (all types): _____; Procedural _____; Conceptual: _____; Self-regulating: _____; Safety precaution: _____; Technical manual: _____
Total Time: _____ mins.

Conceptual Checks:

Question	Answer	Correct/Incorrect
Steps 2-3. "Can you have the GED and TED both in power or both in manual simultaneously? Why or why not?"	Answer: Yes you may have both in power. No you may not have both in manual because the shaft that lifts the launcher will break.	
Step 6. Why is it important to ensure that the initial zeroing of the bubble level on the TAS mounting plate is exact? "	Answer: If the bubble level is not properly zeroed, the entire adjustment process is at risk of being ineffective (because the TAS mounting plate will not be appropriately leveled to the rest of the vehicle).	
Step 8. "Why do you put the bubble level on the front of the launcher and not on the base plate?"	Answer: Because the base plate is not magnetic.	

Evaluation Phase 2: Continuity Testing

Start time: _____

Complete	Error / Backtrack	Step	Help-seeking Behavior
		13. Installs adapter CA1430 on connector P2 of cable CX308	
	☐	14. Installs adapter CA1430 on jack 2A204J2 at base of gearbox .	
	☐	15. Backs off adjustment screw on plate until power is lost to TOW launcher upper position switch	
	☐	16. Connects multimeter probes to pin holes B & C on the P1 connector of Cable CX308 and connects multi-meter leads to the probes • Start time (Helper reads step): _____	

Complete	Error / Backtrack	Step	Help-seeking Behavior
		• End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	

	☐	17-18. Manually lowers TOW launcher halfway to stowed position using release knob, and then raises TOW launcher until helper says 0° bubble on Turret Drive Level is centered on SIDE of TOW launcher	
		19. Tighten adjustment screw on plate until electrical continuity is signaled by continuous sound from multi-meter • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	

Complete	Error / Backtrack	Step	Help-seeking Behavior
		20-23. Manually lowers TOW launcher halfway to stowed position and then manually raise TOW launcher, having helper make sure 0° bubble on Turret Drive Level is centered again. Verify continuity exists. If not, repeat steps 18-21. • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	
		[Optional] If continuity not signaled, maintainer engages in troubleshooting: check leads on multi-meter, check cable, repeat raising/lowering of TOW launcher, tightening of adjustment screws	

End time: _____

Post Observation Analysis (BFV Quantitative Performance Measures):
Error Tally: _____
Help-seeking Tally: _____
Instructor Guidance Tally (all types): _____; Procedural _____; Conceptual: _____; Self-regulating: _____; Safety precaution: _____; Technical manual: _____
Total Time: _____ mins.

Continuity Conceptual Checks:

Question	Answer	Correct/Incorrect
Step 15. "Please explain what happens to the upper limit switch when you loosen the adjustment screw."	Answer: It breaks the contact between two metal plates, interrupting the electrical current to the upper limit switch. It is OK to say that it takes the ground away too.	
Step 17. "Why do you lower the TOW launcher halfway to stowed position and then raise it back up?"	Answer: It is lowered because this is when the upper limit switch should be "off." / To break continuity. It is then raised because this is the angle at which the launcher switch's continuity should be restored to permit the indicator light to go on.	
Steps 20-21. "Why do you repeat the TOW lifting and leveling process?"	Answer: To ensure the adjustment remains fixed even with movement of the TOW launcher / To double-check continuity.	

Evaluation Phase 3: Reassembly

Start time: _____

Complete	Error / Backtrack	Step	Help-seeking Behavior
		24. Once continuity is re-established, disconnects multimeter probes from pin holes B& C on connector P1 of cable CX308.	
		25. Removes adapter CA1430 from Jack 2A204J2. • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	
		26. Removes adapter CA1430 from connector P2 of cable CX308	
		27. Installs cover on gearbox by installing gasket, cover, 4 screws and washers (no grease in training condition). • Start time (Helper reads step): _____ • End time 1 (Maintainer starts implementation): _____ • End time 2 (Maintainer completes full implementation): _____	
		28. Install Plug 2W306P2 on Jack 2A204J2.	
		29. Install shield on housing with four screws. Torque to HALF of 54-59 ft-lb using torque wrench (training condition).	
		30. Close cargo hatch.	

Complete	Error / Backtrack	Step	Help-seeking Behavior
		31. Manually lower TOW launcher to stowed position using release knob.	
		32. Manually traverse turret back to 6400 mils	
		33. Verify no faults (that TOW lift upper position indicator light is on when lifting TOW launcher back into 90° firing position).	

End time: _____

Reassembly Post Observation Analysis (BFV Quantitative Performance Measures):
Error Tally: _____
Help-seeking Tally: _____
Instructor Guidance Tally (all types): _____; Procedural _____; Conceptual: _____; Self-regulating: _____; Safety precaution: _____; Technical manual: _____
Total Time: _____ mins.

Reassembly Conceptual Checks:

Question	Answer	Correct/Incorrect
Step 33. "Why is it important to verify no faults?"	Answer: To ensure that the indicator light works	
All steps. “In what circumstances will the upper limit switch adjustment be required?”	Answer: When the upper limit switch is malfunctioning (or the tow lift indicator light shows an error).	

Post-observation AR Mentor technical questions

We will use this to cross-check students' reports in the attitude and usability survey.

AR Mentor Condition	Please note below any observed difficulties with AR Mentor
1. AR Mentor speech recognition	
a. How often did the AR Mentor misunderstand the Soldier's speech?	
i. If the AR Mentor misunderstood the Soldier's speech, what was the nature of the misunderstanding?	
2. Accuracy of the AR Mentor's instructions	
a. Were there any points at which the AR Mentor's programmed instructions appeared to be incorrect or inaccurate?	
3. Soldier errors	
a. Did the Soldier exhibit signs that they did not know what step was next?	
i. If yes, how did they identify the next step?	
b. Did the Soldier appear to be able to locate where they should be standing on the Bradley?	
c. Did the Soldier appear to be looking at the correct part on the Bradley?	
d. Did the solider appear to understand the images and directions on the screen?	

4. Soldier frustration	
a. Did the Soldier exhibit signs of frustration, boredom, or discontent?	
b. Did the Soldier exhibit signs of physical discomfort (e.g., problems with the vest, maintaining 3 points of contact)?	
c. Did the Soldier try to interrupt the AR Mentor at any point?	
5. Helper tasks	
a. Did the helper appear to know where to stand and what tasks to do?	
i. If not, when did these instances occur?	

Appendix B: Learning Experience Questionnaire

AR Mentor Learning Experience Questionnaire

The questions below ask you about your training experience learning to adjust the TOW launcher upper limit switch of the Bradley Fighting Vehicle.

Please select the response that appropriately finishes the following statements about learning to adjust the upper limit switch of the Bradley Fighting Vehicle*:*

1. How *mentally* demanding was learning the adjustment?

Very low	1	2	3	4	5	Very high

2. How *physically* demanding was learning the adjustment?

Very low	1	2	3	4	5	Very high

3. How was the pace of learning the adjustment?

Very slow	1	2	3	4	5	Very fast

4. How successful were you in doing what you were asked to do?

Failure	1	2	3	4	5	Perfect

5. How hard did you have to work to accomplish your level of performance?

Very low	1	2	3	4	5	Very high

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

Very low	1	2	3	4	5	Very high

7. How difficult was the process of asking questions while learning the adjustment?

Very difficult	1	2	3	4	5	Very easy

8. Please briefly describe what did or did not work well for you while learning the adjustment procedure.

9. Imagine you are teaching a fellow maintainer to adjust the TOW launcher upper limit switch. Think about what you have learned while conducting the adjustment. Below you will see pairs of statements reflecting the knowledge or skills you need to do the adjustment. Please review each pair and select the ONE statement that you believe will represent the knowledge or skill that will be more difficult for the maintainer to learn.

	Knowledge or skills needed to do the adjustment	**More Difficult**
a.	making sure that you have the correct cable adapters for the multimeter setup (TC5) OR making sure that the multimeter probes are correctly and continuously connected through testing and verification (	☐ ☐
b.	manually raising and lowering the TOW launcher to adjust it for leveling with the Turret Drive level (TC1/3) OR elevating the gun (TS4)	☐ ☐
c.	knowing which steps involved verifying the problem (TS5) OR knowing which steps involved ensuring equipment conditions were met	☐ ☐
d.	positioning the Turret Drive Level on TOP of the TAS mounting plate(TS4/5) OR positioning the Turret Drive Level on SIDE of TOW launcher	☐ ☐
e.	elevating the gun (TS4) OR manually traversing the turretTS2/1)	☐ ☐

	Knowledge or skills needed to do the adjustment	More Difficult
f.	manually raising and lowering the TOW launcher to adjust it for leveling with the Turret Drive Level (TC1/3) OR removing and replacing the metal shield (TS1/4)	☐ ☐
g.	knowing which steps involved finding the part that caused the problem (TS5)(TS5) OR knowing which steps involved replacing or adjusting the part (TS5)(TS5)	☐ ☐
h.	making sure that the multi-meter probes are correctly and continuously connected through testing and verification (TC5) OR positioning the Turret Drive Level on SIDE of TOW launcher (TS4)	☐ ☐
i.	knowing which steps involved checking to ensure the problem no longer exists (TS5)(TS5) OR knowing which steps involved replacing or adjusting the part (TS5)(TS5)	☐ ☐
j.	knowing the circumstances in which this adjustment will be required (P4/5) OR understanding purpose and use of each tool (P4/5)	☐ ☐
k.	knowing the risks of imprecise technical settings (P4/5) OR understanding the risks of having the TOW Elevation Drive (TED) and Gun Elevation Drive (GED) simultaneously in power position (P3/4)	☐ ☐
l.	knowing why you repeat the TOW lifting and leveling process (P1/4) OR knowing why is it important to verify no faults (P1/5)	☐ ☐
m.	knowing why the Turret Drive Level is placed on the short side of the launcher rather than the long side when setting level (P2/3) OR knowing why you repeat the TOW lifting and leveling process (P1/4)	☐ ☐
n.	understanding the risks of having the TOW Elevation Drive (TED) and Gun Elevation Drive (GED) simultaneously in power position (CP3/4) OR knowing why is it important to verify no faults P1/5)	☐ ☐

	Knowledge or skills needed to do the adjustment	More Difficult
o.	understanding the electrical circuitry of the upper limit switch of the Bradley Fighting Vehicle (C1/5) OR understanding how loosening the adjustment screw breaks the continuity of the upper limit switch (C2/1)	☐ ☐
p.	knowing why you lower the TOW launcher halfway to stowed position and raise it back up (C2/4) OR understanding the electrical circuitry of the upper limit switch of the Bradley Fighting Vehicle C1/5)	☐ ☐
q.	understanding how loosening the adjustment screw breaks the continuity of the upper limit switch (C2/1) OR knowing why you lower the TOW launcher halfway to stowed position and raise it back up C2/4)	☐ ☐

Thank you! This is the end of our first questionnaire. Please let the interviewer know that you have completed it. Please wait a moment while they review the questionnaire, and follow-up with any questions. Afterwards, they will give you the next questionnaire to complete. Your feedback will be very helpful going forward.

For interviewer: At this point ask any follow-up questions based on your review of the survey.

Appendix C: Usability Questionnaire

AR Mentor Usability Questionnaire

Please rate your experience using the AR Mentor to learn the adjustment procedure on a scale of 1 to 5.

1. How easy was it to find where you should be standing on the Bradley?

Never could find	1	2	3	4	5	Always could find

2. How well could you understand your location from the Bradley map image?

Poorly	1	2	3	4	5	Perfectly

3. How well could you follow the directional arrows?

Poorly	1	2	3	4	5	Perfectly

4. How well could you understand what you needed to do to adjust the Bradley?

Not at all	1	2	3	4	5	Perfectly

5. How well could you understand what to do from the 3D animations?

Poorly	1	2	3	4	5	Perfectly

6. How well could you understand what to do from the video demos?

Poorly	1	2	3	4	5	Perfectly

7. How well could you understand what to do from the diagrams?

Poorly	1	2	3	4	5	Perfectly

8. How easily could you read the AR Mentor's text?

Couldn't read any	1	2	3	4	5	Could read all

9. How well did you understand the AR Mentor's audio instructions?

Never understood	1	2	3	4	5	Always understood

10. How often did the AR Mentor know when you were speaking?

Never	1	2	3	4	5	Always

11. How often did the AR Mentor respond correctly to what you were saying?

Never	1	2	3	4	5	Always

12. How often did you want to interrupt the AR Mentor when it was saying it didn't understand you?

Never	1	2	3	4	5	Always

13. How often did you want to speed up the AR Mentor voice when it was speaking?

Never	1	2	3	4	5	Always

14. How often did you want to slow down the AR Mentor voice when it was speaking?

Never	1	2	3	4	5	Always

15. Did you ask the AR Mentor to go to a specific step? Circle one: Yes No

15a. If yes, how well could the AR Mentor go to the step you wanted?

Poorly	1	2	3	4	5	Perfectly

16. Did you ask the AR Mentor any questions? Circle one: Yes No

16a. If yes, how relevant and useful were the AR Mentor's answers?

Not at all	1	2	3	4	5	Completely

17. To what extent did the AR Mentor restrict your movement and get in the way of your body and your head?

Always restricted	1	2	3	4	5	Always moved easily

18. How consistently did you know which steps required you to coordinate with a helper and which required action only by you?

Never knew	1	2	3	4	5	Always knew

19. How consistently did the AR Mentor audio and visual instructions occur when you needed them to occur?

Never	1	2	3	4	5	Always

Thank you! This is the end of our second questionnaire. Please let the interviewer know that you have completed it, and they will be asking you a few follow-up questions. Your feedback will be very helpful going forward.

Appendix D: AR Mentor Usability Interview Protocol

AR Mentor Usability Interview

Thank you for completing the Usability questionnaire. Now I'm going to ask you just a few questions about using AR Mentor during the adjustment.

1. What type of media in AR Mentor did you use the most: Audio or visual (animations, diagrams, video demos, text)? Please discuss the reasons for your choice.

2. Please describe your sense of the comfort or discomfort while wearing the AR Mentor.

3. Please listen to the list of problems and note whether you experienced any of these and, if so, please describe how much of a problem they presented while learning about the adjustment:

   - ☐ Being delayed
   - ☐ Missing a step
   - ☐ Doing the wrong step
   - ☐ Not knowing next steps
   - ☐ Being confused about task
   - ☐ Experiencing nausea
   - ☐ Experiencing split vision
   - ☐ Feeling cautious and tentative while moving around the Bradley
   - ☐ Catching your clothes, arms, legs on cables or cords
   - ☐ Having difficulty getting in and out of the turret
   - ☐ Other (Please describe)

Wrap up:
"That is it for today. Thank you for taking the time to use the AR Mentor, and answer our questions. Your feedback will help our team to improve the design and usability of the AR Mentor."

Appendix E: Full Distribution of Data Across Conditions For Errors, Help Seeking, Instructor Guidance and Total Time

				Instructor Guidance						
MID	Condition	**Total Errors**	**Total Help Seeking**	**Procedural**	**Conceptual**	**Self Regulating**	**Safety**	**Tech Manual**	**Total Guidance**	**Total Time**
P1.1	AR Mentor	5	15	4	0	0	0	1	6	1:52:00
P1.2	AR Mentor	2	3	1	0	0	0	0	1	1:04:00
P2.2	AR Mentor	3	11	1	0	0	0	0	1	1:02:00
P2.3	AR Mentor	1	1	0	0	0	0	0	0	0:46:00
Mean		2.75	7.50	1.50	0.00	0.00	0.00	0.25	2.00	1:11:00
Total		11.00	30.00	6.00	0.00	0.00	0.00	1.00	8.00	4:44:00
P3.2	Instructor	1	9	37	1	17	5	1	58	0:55:00
P4.1	Instructor	2	7	23	0	9	1	0	35	0:56:00
Mean		1.5	8	30	0.5	13	3	0.5	46.5	0:55:30
Total		3.00	16.00	60.00	1.00	26.00	6.00	1.00	93.00	1:51:00
P5.1	Tech Manual	11	25	15	0	6	5	2	26	2:30:00
P6.2	Tech Manual	5	25	14	0	1	2	0	19	2:00:00
Mean		8.00	25.00	14.50	0.00	3.50	3.50	1.00	22.50	2:15:00
Total		16.00	50.00	29.00	0.00	7.00	7.00	2.00	45.00	4:30:00

Appendix F. Instructor Interview Protocol

AR Mentor Practice and Interview Protocol – Bradley Instructor

Instructions:

Our team would like to draw upon your expertise teaching mechanics to adjust the Bradley to help us improve on the design and usability of new training technology called Augmented Reality Mentor or AR Mentor. I will be asking you to conduct an adjustment on the Bradley so you can have the experience that a trainee would with the AR Mentor, and then I will interview you. The adjustment may take between 40-50 minutes to complete. The interview will take about 20-25 minutes.

The SRI team will take 5 minutes to train you in how to use the AR Mentor. [Use the training script to familiarize the instructor with the features of the AR Mentor.]

You will be conducting the upper limit switch TOW launcher adjustment on the Bradley with the assistance of the AR Mentor. Is this an adjustment you have taught? (Circle answer below)

Yes No

As you go through the adjustment, the SRI team will assist you should you have problems with this new technology. I will observe you as you conduct the adjustment and make notes of your reactions to the technology. (*During the adjustment, please observe and note reactions and questions)*

Instructor has now completed the adjustment:

Now that you have completed the adjustment, I'd like to ask you some questions about your experience. I will be taking notes and audio recording our interview. Please answer as honestly as possible, as your feedback is very important.

Questions:

Referring to your observation notes, ask the instructor about any salient reactions, positive and/or negative (e.g., frequent positive comments, frequent interaction problems, etc.)

1. As I observed you working, it appeared that you liked/disliked [name the AR Mentor features that were subjects of positive/negative reactions]. Is this correct? As an instructor, what struck you about these features? How do you think your students would react to these features? [go through each observed feature listed one at a time] Follow up: What was your impression of how the adjustment process flowed using the AR Mentor?

2. Please describe your sense of comfort or discomfort while wearing the AR Mentor. Do you think your students' comfort level would be adequate with the AR Mentor?

3. Based on your experience, how might your work as an instructor change if your students had access to the AR-Mentor? (Follow up: Do you think students will remember the procedure and steps better using the AR Mentor than the TM?)

4. Were there any features of the AR Mentor that you thought would benefit your students? (*Follow-up prompts: ask about 3D animations, videos, diagrams, text, voice-overs*)

5. Were there any features of the AR-Mentor that you thought your students might find inconvenient or that might require special training? (*Follow up prompts: Ask about eye-gaze tracking arrow, 3D animations, videos, diagrams, text, voice-overs)*

6. Was there any way that the instructions in the AR Mentor could have been improved? Was there any information or instruction lacking that could confuse students*? (Follow-up: Probe for should information be focused on new skills to this task, such as Turret Drive Level, and should information on older skills be de-emphasized, such as multimeter connections, turret rotation?)*

7. Do you think that all the AR Mentor instructional visualizations (diagrams, 3D animations, videos) were appropriate tools for teaching the tasks? *(Follow-up: if the instructor didn't think all were appropriate, probe for which ones were not appropriate and why. Probe for: Is the visualization necessary to support learning or not? Are there some places where visualization is needed and not present?)*

8. As you used the AR Mentor, did you have some ideas about ways you might be able to use the AR Mentor or its visualizations and instructions in your own teaching or demonstrations? (*Follow up questions: Probe for how to support the students using the AR Mentor, how to correct student performance, how to grade student performance, and how to explain aspects of the adjustment)*

9. Did you learn anything from using the AR Mentor that you would incorporate into your own teaching of the adjustment?

Wrap-up:

That is the end of our interview, thank you for taking the time to use the AR Mentor, and answer our questions. Your feedback will be very helpful going forward.

Appendix G: Mechanic Interview Protocol

AR Mentor Practice and Interview Protocol – Experienced Mechanic

Instructions:

Our team would like to draw upon your expertise as a mechanic to help us improve on the design and usability of new training technology called Augmented Reality Mentor or AR Mentor. I will be asking you to conduct an adjustment on the Bradley so you can have the experience that an experienced mechanic would have learning a new adjustment with the AR Mentor, and then I will interview you. The adjustment may take between 40-50 minutes to complete. The interview will take about 20-25 minutes.

The SRI team will take 5 minutes to train you in how to use the AR Mentor. [Use the training script to familiarize the instructor with the features of the AR Mentor.]

You will be conducting the upper limit switch TOW launcher adjustment on the Bradley with the assistance of the AR Mentor. Is this an adjustment you have ever done? (Circle answer below)

Yes No

As you go through the adjustment, the SRI team will assist you should you have problems with this new technology. I will observe you as you conduct the adjustment and make notes of your reactions to the technology. (*During the adjustment, please observe and note reactions and questions).*

Mechanic has now completed the adjustment:

Now that you have completed the adjustment, I'd like to ask you some questions about your experience. I will be taking notes and audio recording our interview. Please answer as honestly as possible, as your feedback is very important.

Questions:

Referring to your observation notes, ask the mechanic about any salient reactions, positive and/or negative (e.g., frequent positive comments, frequent interaction problems, etc.)

1. As I observed you working, it appeared that you liked/disliked [name the AR Mentor features that were subjects of positive/negative reactions]. Is this correct?

    a. As an experienced mechanic, what struck you about these features? How do you think other experienced mechanics would react to these features as they learn a new adjustment in the field? [Go through each observed feature listed one at a time]
    b. Follow up: What was your impression of how the adjustment process flowed using the AR Mentor?

2. Please describe your sense of comfort or discomfort while wearing the AR Mentor. Do you think other mechanics would find the AR Mentor comfortable to use in the field?

3. As an experienced mechanic, describe the prior knowledge you used to complete the task in this unfamiliar situation.

4. Did the AR Mentor help you overcome your unfamiliarity with the Bradley and ultimately complete the adjustment? Would some preparation or overall orientation to the Bradley have been helpful in facilitating the completion of the adjustment? *(Follow-up: Probe for what information, preparation, or orientation would have been helpful.)*

5. Based on your past experience in the field, do you think you might be able to use the AR-Mentor to learn how to perform new adjustments?

6. Were there any features of the AR Mentor that would particularly benefit mechanics working out in the field? (*Follow-up: Probe for 3D animations, videos, diagrams, text, voice-overs*)

7. Were there any features of the AR-Mentor that you thought mechanics in the field might find inconvenient or that might require special training? (*Follow-up: Probe for eye-gaze tracking arrow, 3D animations, videos, diagrams, text, voice-overs)*

8. How could the instructions given by AR Mentor have been improved for an experienced mechanic? Was there any information or instruction lacking? Was there too much information and not enough flexibility, such as skipping steps or going to only certain steps? *(Follow-up: Probe for which skills seemed particularly new to the experienced mechanic and which seemed to be more familiar, e.g., multimeter connections, turret rotation)*

9. Do you think that all the AR Mentor instructional visualizations (diagrams, 3D animations, videos) were appropriate tools for learning the tasks? *(Follow-up: If the mechanic didn't think all were appropriate, probe for which ones were not appropriate and why. Also probe for: Is the visualization necessary to support learning or not? Are there some places where visualization is needed and not present?)*

10. Do you think that doing the adjustment with the AR Mentor aided you in remembering the steps and the overall procedure? Do you feel that learning was sufficiently effective so that you would not need to use the AR Mentor the next time you conduct this adjustment?

    a. Would it have been more efficient to use a technical manual to learn the new adjustment, instead of using the AR Mentor? In the future when doing the adjustment, would you use the AR Mentor or the TM?

11. Are there advantages or disadvantages to using the AR Mentor to perform the adjustment, as opposed to a technical manual?

12. What advantages, if any, do you see in using the AR Mentor in in the field over using only a TM and guidance from another experienced mechanic?

13. Would you recommend using AR Mentor for repairs or adjustments to other mechanics in your field? Please explain why or why not.

Wrap-up:

That is the end of our interview, thank you for taking the time to use the AR Mentor, and answer our questions. Your feedback will be very helpful going forward.