ARL-TN-0875 ● FEB 2018

US Army Research Laboratory

The Augmented REality Sandtable (ARES) Research Strategy

by Christopher J Garneau, Michael W Boyce, Paul L Shorter, Nathan L Vey, and Charles R Amburn

NOTICES

Disclaimers

ARL-TN-0875 ● FEB 2018

US Army Research Laboratory

The Augmented REality Sandtable (ARES) Research Strategy

by Christopher J Garneau, Michael W Boyce, Paul L Shorter, Nathan L Vey, and Charles R Amburn
Human Research and Engineering Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
February 2018	Technical Note	February 2015–November 2017

4. TITLE AND SUBTITLE	
The Augmented REality Sandtable (ARES) Research Strategy	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Christopher J Garneau, Michael W Boyce, Paul L Shorter, Nathan L Vey, and Charles R Amburn	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
US Army Research Laboratory Human Research and Engineering Directorate ATTN: RDRL-HRA-AA Aberdeen Proving Ground, MD 21005-5068	ARL-TN-0875
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Augmented REality Sandtable (ARES) is a research and development testbed with the aim of determining the improvements in battlespace visualization and decision-making that aid in providing a common operating picture at the point of need and best meet user requirements. As a testbed for research, ARES is primarily concerned with human factors research in the areas of information visualization, multimodal interaction, and human performance assessment. The purpose of this technical note is to discuss completed, ongoing, and planned research and provide an overall strategy for future work.

15. SUBJECT TERMS

Augmented REality Sandtable, battlespace visualization, simulation and training, information visualization, multimodal interaction, human performance assessment

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Christopher J Garneau
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER (Include area code)**
Unclassified	Unclassified	Unclassified	UU	34	(410) 278-5814

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

INTENTIONALLY LEFT BLANK.

1. Introduction

The Augmented REality Sandtable (ARES) is a research and development testbed with the aim to improve battlespace visualization in order to provide a user-defined common operating picture at the point of need. As a physical platform, ARES consists of several modalities, including but not limited to the following:

- A traditional sand table filled with play sand and supplemented with commercial off-the-shelf components that allow the user to view and interact with visual representations of an area of operations (AO) and related data.
- A mobile software application that provides an overview of the AO with geospatial terrain data and additional layers of data for interaction and analysis.
- An application that displays terrain and other data in the AO via mixed-reality headsets (e.g., Microsoft HoloLens or HTC Vive).

In addition to the various modalities, government-owned ARES software provides geospatial terrain information and map images, tracks the sand topography, and allows users to build or edit tactical mission plans. The software serves the data to client applications that then provide the data to users via one of the modalities. Figure 1 shows how the modalities work together in one ecosystem.

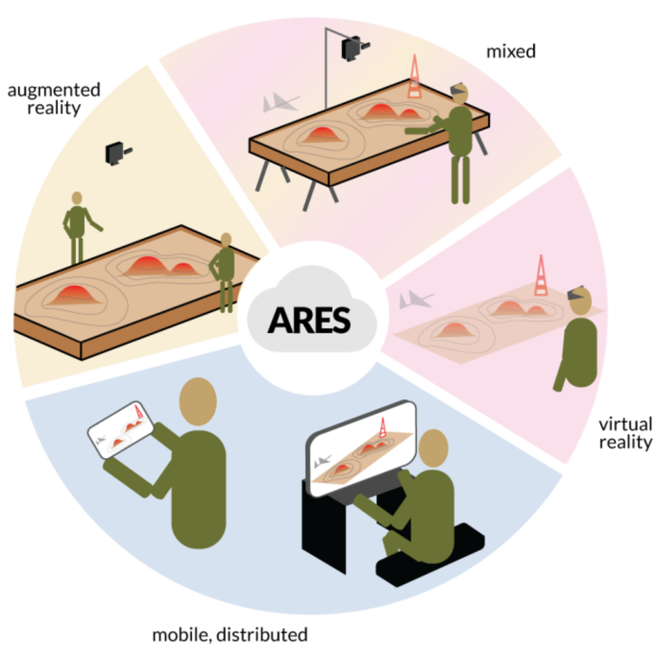

Fig. 1 ARES platform concept showing multiple modalities

As a testbed for research, ARES is primarily concerned with human factors research in the areas of information visualization, multimodal interaction, and human performance assessment. The purpose of this technical note is to discuss completed, ongoing, and planned research and provide an overall strategy for future research. In this context, "research" refers to activities conducted to gain insight into basic or applied areas of inquiry related to ARES, as differentiated from the "research and development" required to expand the capabilities, supported analyses, or features of the ARES platform.

A US Army Research Laboratory (ARL) special report was prepared in 2015 that includes a description of the ARES platform, relevance to the Army, similar efforts to date, existing and planned future capabilities, and discussion of many key leader engagements (Amburn et al. 2015). While the 2015 ARES report included passing mention of research and evaluation activities, the present technical note instead delves deeper into the research activities. This document should not be viewed as a comprehensive agenda of work to be completed but is instead analogous to the work of an urban planner. In that domain, deliverables might include conceptual drawings showing generic blocks with intended buildings or usages, but actual construction might substantially differ both in form and purpose. Similarly, our plan is intended to summarize the work performed to date, project the regions within which research will be developed, and establish the predominant and supplementary research questions that support future activities. However, this plan is subject to change with changing requirements, new technological developments, or interest and/or funding for research with new use cases.

2. Research Questions and Areas for ARES Research

Fundamentally, the predominant research question underlying all ARES research activities is the following: What improvements in battlespace visualization and decision-making aid in providing a common operating picture at the point of need and best meet user requirements? The ARES platform brings together development in several areas to provide improvements to traditional means of battlespace visualization, including: interactive displays; tangible user interfaces; and augmented, virtual, and mixed reality. Each of these topics contributes to one of the research areas under investigation to provide advancements that help answer the predominant research question above. These advancements may take the form of improvements to the ARES interface and interaction among modalities, development of other interface device(s), or generalizable research that answers important questions of interest, ultimately yielding new tools for Soldiers that contribute to Army readiness. This section addresses the predominant research question, lanes of research, and an overall strategy for achieving research goals.

2.1 ARES Motivation and Mission

An augmented reality sand table has the potential to enhance spatial awareness, improve visualization of the battlespace, increase engagement, enable distributed collaboration, and save time when authoring 3-D terrains and scenarios (Amburn et al. 2015). Research for the ARES platform supports many of the following Army Warfighting Challenges (ACIC 2017):

- AWFC #1: Develop Situational Understanding
- AWFC #5: Counter Weapons of Mass Destruction
- AWFC #6: Conduct Homeland Operations
- AWFC #8: Enhance Realistic Training
- AWFC #9: Improve Soldier, Leader, and Team Performance
- AWFC #14: Ensure Interoperability and Operate in Joint, Inter-organizational, Multi-national (JIM) Environment
- AWFC #15: Conduct Joint Combined Arms Maneuver
- AWFC #17/18: Employ Cross-Domain Fires
- AWFC #19: Exercise Mission Command

Research for the ARES platform may also support the following ARL Key Campaign Initiatives (KCIs), as identified in ARL's Technical Implementation Plan 2016–2020 (ARL 2016):

Information Sciences Campaign

- KCI-IS-2: Taming the Flash-Floods of Networked Battlefield Information
- KCI-IS-3: Acting Intelligently in a Dynamic Battlefield of Information, Agents, and Humans
- KCI-IS-4: Sensing and Information Fusion for Advanced Indications and Warnings

Human Sciences Campaign

- KCI-HS-1: Robust Human and Machine Hybridization
- KCI-HS-2: Multi-faceted Assessment of Soldier Variability
- KCI-HS-3: Training Effectiveness Research

ARES is certainly not the first augmented reality sand table; the 2015 ARES report tabulated 25 efforts related to visualizing spatial data on virtual or sand table interfaces stretching back 20 years. The overwhelmingly positive reaction to ARES and the existence of various other virtual/augmented reality sand table research and development efforts bear testament to the great interest that exists in improving traditional means of visualizing and interacting with geospatial data relevant to the battlespace.

It is also important to emphasize that the ARES research program is not limited to specific modalities (e.g., sand table). For instance, research might consider whether an augmented reality projection on a wall with an interactive natural user interface enables new or different visualization, analysis, and decision-making capabilities. To address this consideration—and many others in this domain—it is helpful to consider each part of the predominant research question for the ARES program. The following subsections address the 3 constituent components: improved battlespace visualization and decision making, common operating picture defined by user requirements, and point of need.

2.1.1 Improved Battlespace Visualization and Decision Making

Advancements in geospatial terrain visualization offer direct application to the ARES platform. Many Geospatial Information System software suites offer the ability to import terrain information and build graphical layers on top of the base layer. However, these computer-based applications do not inherently offer a true 3-D representation of the data as they are depicted on a 2-D computer monitor. Novel systems have begun to bring this data into 3-D space and combine it with intuitive user interfaces. For instance, Mitasova et al. (2012) discuss various techniques for constructing interactive 3-D multisurface visualizations with application to tangible environments; Fuhrmann et al. (2009) investigated the use of geospatial holograms for wayfinding and route planning for use by Special Weapons and Tactics (SWAT) teams. Providing additional layers of information and analyses on top of the geospatial data enhances the ability of decision makers to make more informed decisions. For instance, additional visualization capabilities might enable better perception of the terrain and dynamic presence of units and the employed tactics. It is essential to conduct research on the human factors of such improvements to investigate their effect on the performance of decision makers and optimize the presentation.

2.1.2 Common Operating Picture Defined by User Requirements

A key characteristic of the ARES platform is the customizability and interactivity of the geospatial visualization. In other words, the platform enables decision makers to select the information that is relevant to them to create a picture of the battlespace that supports decisions they have to make. Other literature refers to this as a User-Defined Common Operating Picture (UDOP). Mulgund and Landsman (2007) describe the UDOP operational concept and a prototype implementation; Hiniker et al. (2007) discuss plans to assess an interface designed with UDOP principles. Research should seek to better understand the types of information relevant to certain classes of users, mechanisms for customizing the interface, and how best to integrate the various data to present an enhanced common operating picture.

2.1.3 Point of Need

The point of need refers to the venue—both environment and setting—where decisions must be made or training needs to be conducted. An ideal decision support tool easily adapts to varying points of need, whether in a classroom or operational setting, or in a conference room or outdoor environment. The ARES sand table interface extends to both classroom and operational settings but is limited to controlled indoor environments; the mobile and mixed reality interfaces offer greater portability but do not have a tangible component. Areas of research to consider are how the platform can be extended to other environments, how various modalities may interact to better address adaptability/scalability to the point of need, and what the implications are for the overall value to the decision-maker.

The following sections discuss each of the research areas that characterize ARES research activities.

2.2 Information Visualization Research Area

The critical question in information visualization is how best to transform data into something that people can understand for optimal decision-making (Ware 2012). ARES is fundamentally a system for visualizing a battlespace and providing tools that enable better decisions to be made. The information visualization research area investigates questions in this domain. In a military context, information visualization has been described as the cohesion of information characteristics and human cognitive processes that are embodied and situated by 2 requirements. The first is battle command, which entails decision-making and visualizing the current and future state of operations. The second is situational awareness, which entails the ability to identify, process, and comprehend the critical elements of information about what is happening (Ntuen 2009).

Information visualization elevates the comprehension of information by fostering rapid correlation and perceived associations (Livnat et al. 2005). The design of the information visualization platform must support the decision-making process, identifying and characterizing problems, and determining appropriate responses. In the context of research for the ARES platform, the area of greatest interest is the nexus of mixed reality and data visualization to ensure that optimization of information visualization techniques for battle command and situational awareness are incorporated. This inherently involves large datasets (e.g., geospatially distributed model outputs).

Research conducted in this area has explored information visualization in specific contexts (e.g., battlespace visualization), the use of multiple views to visually convey information (Baldonado et al. 2000), and situational awareness for decision-making. In addition, other research has attempted to support information visualization research and development by creating a taxonomy to codify human perceptual and cognitive capabilities and limitations, independent of domain, thereby providing a means to empirically assess and compare research outcomes (Pfitzner et al. 2001). Colleagues at ARL are also conducting research in information visualization that may be relevant to the ARES platform (e.g., Chen 2005; Chen et al. 2014; Hansberger 2015); any future efforts in similar topics should first consult these or other ARL researchers to gain insight on lessons learned or points for collaboration.

Research questions of interest may include the following:

- Can a defined taxonomy help delineate various factors in battlespace visualization that will serve to assist in evaluating and assessing the effectiveness of ARES?
- How would using various information visualization techniques in a distributed environment affect team performance?
- How do various information visualization implementations affect performance on tasks related to battlespace visualization and what types of tasks or scenarios are best suited to the various implementations?
- How might various information visualization techniques help users visualize interactions with intelligent agents in the battlespace and improve human–agent teaming?
- Do users benefit from controlling the amount and type of information presented to them on ARES?

- Do various components of the ARES platform enhance users' situational awareness, and to what extent?
- What are the limits of visual perception that are necessary to allow users to perceive terrain features (e.g., should a hill be 3 inches or 12 inches to provide maximum situational awareness)?
- Do the same information visualization techniques apply across the ARES modalities (i.e., sand table, mobile tablet, and mixed reality headset)?
- Do some users learn better with using a real 3-D display than with virtual 3-D or 2-D/printed maps?

Information visualization research should be formulated in the context of how it relates to battle command doctrine, situational awareness, and developing a taxonomy in which to work.

2.3 Multimodal Interaction Research Area

A goal of the ARES program—reflected in the predominant research question—is to provide decision makers with battlespace visualization tools at the point of need. ARES accomplishes this via the use of virtual, augmented, or mixed reality in multiple modalities (Fig. 1). The multimodal interaction research area is concerned with how various modalities moderate the experience and affect user performance. Until very recently, ARES has relied primarily on a single visual-tactile interface (i.e., the sand table); future research should consider the interaction among multiple interfaces that may also include other new modalities (e.g., gestures, auditory cues, voice commands).

Multimodal interfaces may be characterized as systems that respond to inputs in more than one modality or communication channel—for instance, speech, gesture, writing, touch, etc. (Jaimes and Sebe 2007). As a broad area of research, multimodal interaction seeks to research and develop technologies, methods, and interfaces that make full use of human capabilities to interface with a system. Turk (2014) provides a good review of relevant literature in this area. Multimodal integration is an area ripe for exploration—better understanding individual modalities, how and when to integrate multiple channels in models, and exploring the full range of modality combinations are all research challenges.

Many examples in the literature have explored different modes of interacting with information using nonconventional displays that are directly applicable to the modalities employed by the ARES platform, including 1) interactive tabletops (e.g., Annett et al. 2011; Alnusayri 2015), 2) tangible user interfaces (e.g., Ishii 2008;

Maquil 2016), and 3) augmented reality and holograms (e.g., Fuhrmann et al. 2009). For these types of interfaces, an important consideration is that users appropriately tailor displays to the task at hand and select an appropriate level of detail for their interaction—factors that should be assessed empirically (Hegarty et al. 2012). Large-format interfaces—for instance, interactive tabletops (Maldonado 2014) or projector-based augmented reality (Marner et al. 2014)—often facilitate collaboration. Tangible user interfaces may facilitate inquiry but may not lead to more thorough interaction or deeper questions about the content (Ma et al. 2015), though when used for learning may yield greater learning gain (Schneider et al. 2011). Voice command and auditory feedback—perhaps in the form of a natural language interface—present another avenue for interaction in the ARES ecosystem that should also be explored in future research. As with the information visualization research area, there are at least a few colleagues at ARL who are also conducting research in various types of (and combinations of) interfaces that may be relevant to the ARES platform (e.g., Elliott et al. 2009; Myles and Kalb 2015). Researchers working on future efforts in similar areas should remain vigilant for lessons learned or points of collaboration.

Some sample research questions of interest to the ARES program in this research area include the following:

- What are the benefits and drawbacks to the user of various types of interfaces (e.g., sand table, mobile tablet, and mixed reality headsets)?
- Does the use case affect user performance for the various modalities?
- How might each interface and its mode of interaction affect users' ability to visualize and fuse information coming from a multitude of sensors and data sources to efficiently make decisions?
- Can users interact with ARES without the use of peripheral devices (i.e., using gestures) and what benefit does this type of interaction provide?
- Do some users perform better using a tangible user interface?
- Does touching or shaping the sand matter?
- What do the findings portend for other systems that may benefit from tactile feedback?
- How does user and team performance using a distributed multiple-modality system compare with a distributed single-modality system?

Generally, research questions in this area should be formulated to characterize 1) factors moderating the experience between a user and an interface, 2) the quality of analysis or overall performance of a user as a function of a chosen modality, and/or 3) individual and/or team performance given a system with multiple modalities and/or multiple users.

2.4 Human Performance Assessment Research Area

The predominant research question for ARES specifies that tools developed by the platform to enhance decision-making attempt to best meet its users' requirements. Thus, there exists the need to accurately model human performance for any new modalities or information visualization techniques employed by the platform. Correctly understanding human performance can assist in explaining human variability (Szalma 2009) and sources of human error, and provide predictions for task outcomes and the behaviors preceding them. Successful performance on a task requires a certain degree of precision. Humans are susceptible to internal and external factors that cause them to be imprecise. Examples of these factors include aptitude, existing knowledge, stress, and time pressure (DOE 2009).

The human performance assessment research area facilitates alignment of system parameters and capabilities with human preferences and abilities while operating in complex environments. This allows for the customization of interfaces that yield optimal performance.

The literature suggests many different approaches for modeling human performance. The effective analysis of human performance requires sufficient granularity in the level of detail associated with each human interaction. Quantitative and qualitative methods must capture this detail to ensure scientific validity. Of specific emphasis to ARES is the relationship between the human and the system.

Human performance assessment tends to fall under 3 specific areas: 1) perception and attention allocation, 2) command and control, and 3) cognition and memory (Byrne and Pew 2009). Within attention and perception are human factors fundamentals such as signal detection theory (i.e., does a stimulus provide enough information to distinguish a target amongst distractors?), visual search, and multitasking (Laughery et al. 2012). Command and control relies on the ability to select information in an efficient and effective manner (e.g., the Hick–Hyman law for choice response time [Hick 1952; Hyman 1953] and the observe, orient, decide, and act [OODA] loop to model associated actions [Gooley and McKneely 2012]). Cognition and memory consists of the understanding of acquiring skills and expertise (i.e., cognitive skill acquisition), the interpretation and aggregation of presented information (i.e., situation awareness), and decision-making as it is related to ARES users (e.g., military decision-making process) (Lickteig et al. 1998).

Potential human performance assessment research questions relevant to the ARES program include the following:

- Can augmented reality capabilities increase performance on tasks related to battlespace visualization?
- To what extent does augmented reality increase performance metrics (e.g., accuracy, time on task, situational awareness) and what types of tasks or scenarios most benefit from its use?
- Can the ARES platform effectively instruct students through one-to-one or one-to-many methods (e.g., virtual avatars, intelligent tutors, video teleconferences)?
- Do certain users' spatial abilities make a difference?
- Are there differences in the amount of information users retain across various modalities (e.g., PowerPoint, topographical map, traditional sand table, various ARES modalities)?
- What are the generalizable performance predictors across tasks as users are interacting with ARES?
- How do individual difference factors such as self-efficacy, motivation, and personality mediate or moderate performance outcomes?
- How do the metrics associated with individual human performance assessment transfer to collaborative learning or team performance assessment associated with ARES interaction?
- What standardized human performance metrics can individual researchers using ARES technologies measure to ensure the ability to compare across experiments?
- How is human error represented within ARES technology interaction (i.e., active errors compared to latent errors and slips compared to mistakes)?

Research efforts in human performance assessment will also need to focus on addressing both the strengths and weaknesses of assessment. Strengths include specificity, clarity, and objectivity, while weaknesses include generalizability, validity, and confounding variables (Byrne and Pew 2009; Creswell 2014). The management of these potential dimensions will rely on a combination of designing to Soldier requirements while ensuring soundness of empirical rigor.

2.5 Strategy for Establishing the Platform and Achieving Basic Research Goals

The 3 research areas all share a common thread: how best to enable the human user to view and interact with content/information so that they can better understand the information; communicate with peers, supervisors, and subordinates; and make better and faster decisions. A challenge in crafting any research strategy for a new product or platform is appropriately scoping the research, demonstrating the value of the platform while simultaneously performing basic and applied research that is relevant beyond the platform. To resolve pressing immediate questions, an effective strategy might first ask, "Is this worth doing?", "Do users like and respond better to this interface or technique?", and "Is performance better than what already exists?" Once the value of the platform is established, follow-up research should ask more focused, basic research questions of interest to the greater scientific community that also yield insight to improve the platform and, in our case, provide value to the Army.

Figure 2 summarizes the overall research strategy, showing the modalities, research areas, and research outcomes. The goal of the ARES research program is to balance the practical need for demonstrating the value of the platform and its enhancements while also conducting basic research and continuously expanding the boundary of the applications and technologies considered within the platform. Ultimately, the ARES platform should keep the enhancement of Army readiness as its ultimate goal.

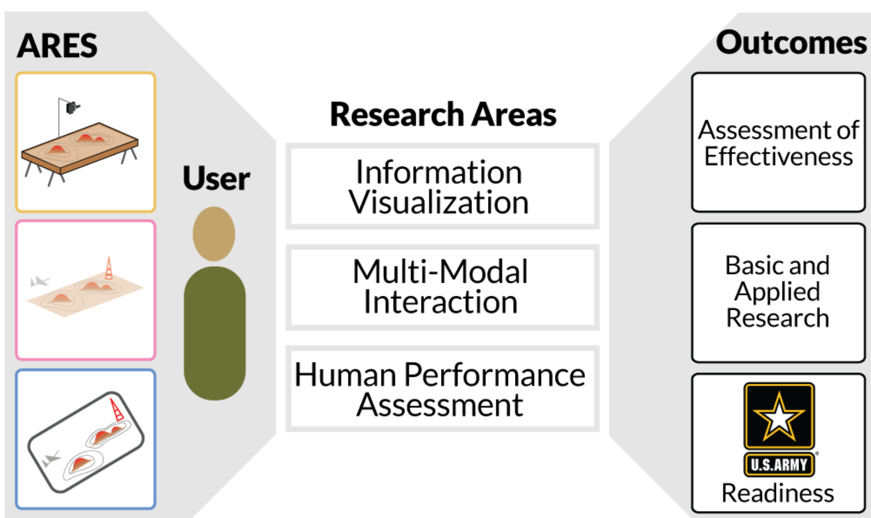

Fig. 2 ARES research strategy

3. Completed, Ongoing, and Planned ARES Research

Several research efforts for the ARES platform have already been completed and published, are ongoing, or are planned as of the end of fiscal year (FY) 2017 (the time of writing for this technical note). Table 1 lists these efforts and breaks them down by research area and time frame. The subsequent paragraphs describe the principal investigator(s), start/completion dates, and an abstract/executive summary for each effort. Note that actively planned work is included in the "Planned" category, but not conceptual future work. Generally, the criteria used to determine the planned research included here are the following: 1) the purpose of the study is known and some objectives have been established that relate to one or more ARES research questions, 2) the means of achieving the objectives have been considered, and 3) the researchers who will perform the work have been identified (or a contract is in place that could support the research). Also note that almost all of the research crosses all 3 research areas, but the table only indicates each study's primary area of inquiry.

Table 1 Completed, ongoing, and planned (short-term) ARES studies, organized by research area

Research areas	Completed	Ongoing	Planned
Information Visualization	N/A	4. Chem-Bio Model Visualization	7. Terrain Correlation Guidance
Multi-Modal Interaction	N/A	5. Cognitive Impact of Tangible AR	8. Floor Projection
Human Performance Assessment	1. Impact on Learning 2. Tactics (Pilot) 3. Tactics II	6. Time and Accuracy	9. Impact on Learning II: Expansion to AR/VR 10. Land Navigation 11. Distributed Collaboration

3.1 Completed Studies

3.1.1 Study 1: Impact on Learning

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Kelly Hale (Design Interactive, Inc.)

Completion Date: Q1 FY16

Abstract/Executive Summary:

The goal of this study was to empirically examine spatial knowledge acquisition and understanding using traditional media (2-D paper, topographic map), a 3-D terrain rendering on a PC, and the Augmented REality Sandtable (ARES). The main objective of the study was to determine the impact of the various media on spatial knowledge acquisition and spatial reasoning skills. Results from the study indicate that ARES supported improved landmark identification and distance estimation as compared to the traditional alternatives; users also provided high ratings of perceived utility for the ARES platform. The study participants included 43 students from the University of Central Florida's (UCF) Reserve Officers' Training Corps (ROTC) and 7 Reserve personnel from the US Army's 143rd Sustainment Command in Orlando, Florida.

Publications:

- Schmidt-Daly TN, Riley JM, Hale KS, Yacht D, Hart J. Augmented REality Sandtable's (ARES) impact on learning. Adelphi (MD): Army Research Laboratory (US); 2016. Report No.: ARL-CR-0803.

3.1.2 Study 2: Tactics (Pilot)

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Michael Boyce (ARL)

Completion Date: Q2 FY16

Abstract/Executive Summary:

This research project integrated the Generalized Intelligent Framework for Tutoring (GIFT) and the Augmented REality Sandtable (ARES) for the assessment of military tactics. An experiment involving 19 students from the University of Central Florida's (UCF) Reserve Officers' Training Corps (ROTC) assessed performance, physiological, and experiential data in a between-subjects design. The conditions consisted of a 2-D map displayed on either a flat or contoured surface (sand table), both of which leveraged the projection technology of ARES. Results of the study did not indicate significant differences between time on task, accuracy, or electrodermal activity, but a larger sample size is needed to verify findings. Preference between conditions was more prevalent in support of ARES; however, individuals that preferred the flat condition discussed issues with the ARES condition being more difficult to precisely measure, consistent with the findings in the literature.

Publications:

- Boyce MW, Reyes RJ, Cruz DE, Amburn CR, Goldberg B, Moss JD, Sottilare RA. Effect of topography on learning military tactics – integration of Generalized Intelligent Framework for Tutoring (GIFT) and Augmented REality Sandtable (ARES). Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2016. Report No.: ARL-TR-7792.

- Boyce MW, Goldberg B, Moss JD. Electrodermal activity analysis for training of military tactics. Proceedings of the Human Factors and Ergonomics Society Annual Meeting; 2016; Sage, CA. Los Angeles (CA): SAGE Publications. vol. 60; No. 1; p. 1339–1343.

- Boyce MW. From concept to publication – a successful application of using GIFT from the ground up. Generalized Intelligent Framework for Tutoring (GIFT) Users Symposium (GIFTSym4); 2016 Jan. p. 125.

- Boyce MW, Cruz D, Sottilare R. Interpretative phenomenological analysis for military tactics instruction. In: Kantola J, Barath T, Nazir S, Andre T, editors. Advances in human factors, business management, training and education. Springer International Publishing; 2017. vol. 498; p. 623–634.

3.1.3 Study 3: Tactics II

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Michael Boyce (ARL)

Completion Date: Q2 FY17

Abstract/Executive Summary:

This was a follow-on effort to Study 2. Experimentation assessed how displaying information onto different surfaces can influence the performance and engagement of cadets in answering questions on military tactics. The study used 2 experimental conditions: flat 2-D projection vs. the Augmented REality Sandtable (ARES). Objective performance measures included time on task and accuracy while self-report surveys and electrodermal activity measured engagement. There were 62 cadets recruited through the United States Military Academy (USMA). Data collection is complete and analysis is underway as of Q4 FY17.

Publications:

- Boyce MW, Rowan CP, Moss JD, Amburn CR, Shorter PL, Garneau CJ, Sottilare RA. The impact of surface projection on military tactics comprehension. Military Psychology. Forthcoming 2017.

3.2 Ongoing Studies

3.2.1 Study 4: Chem-Bio Model Visualization

Primary Research Area: Information Visualization

Principal Investigator: Dr Jennifer Murphy (Quantum Improvements Consulting)

Start Date: Q2 FY18

Abstract/Executive Summary:

This Defense Threat Reduction Agency (DTRA)-funded study uses new Augmented REality Sandtable (ARES) visualizations of chemical and biological agent propagations across user shaped terrains on the physical sand table. By employing these new visualizations for use in the Army's Chemical, Biological, Radiological, and Nuclear School's Captains Career Course, the purpose of this study is to better understand how interaction with ARES may result in deeper representations and understanding of terrain and weather effects on plume propagations. It is hypothesized that interacting with the new visualizations on ARES will enable students to produce better-quality deliverables in less time, with higher scores on knowledge assessment, and better information retention over time. Additional hypotheses will assess cognitive demand, attitude, and technology acceptance for students using the ARES visualization and traditional learning materials.

3.2.2 Study 5: Cognitive Impact of Tangible AR

Primary Research Area: Multi-Modal Interaction

Principal Investigators: Dr Michael Boyce (ARL), Dr Aaron Gardony (NSRDEC)

Start Date: Q4 FY17

Abstract/Executive Summary:

This study examines how the physical ability to touch and manipulate sand influences cognitive processes that critically underlie mission planning and mission success, as compared to passively observing the same action. It employs a systematic empirical investigation, emphasizing quantitative metrics. Specifically, the influence of tangibility afforded by the Augmented REality Sandtable (ARES) on the development of spatial mental representations of complex 3-D terrain is investigated. Data collection trials in this study entail 96 participants grouped in dyads and then instructed to either build terrain features on the ARES or to observe another participant as they build the terrain features. Assessment on their knowledge of the terrain, as well as their ability to recall the terrain they built in the presence of distractors, will take place after performing their respective tasks. The primary independent variable is whether the participant is an observer or a builder, while the dependent variables consist of terrain knowledge (both conceptual and verification of terrain) as well as spatial memory performance.

3.2.3 Study 6: Time and Accuracy

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Kelly Hale (Design Interactive, Inc.)

Start Date: Q4 FY17

Abstract/Executive Summary:

The objective of this study is to evaluate the effectiveness and efficiency of sand table terrain model construction using the Augmented REality Sandtable (ARES) compared to traditional sand table methods, and to gather perceptions and objective data on the usability of the ARES software, technology, and interface design. The study participants were Soldiers from the Army's 3rd Infantry Division. The apparatus used was the 7- × 4-ft physical sand table, ARES software, and associated mobile tablet for the experimental condition (using ARES), whereas the control condition (traditional sand table) used a replica of the 7- × 4-ft sand box and an associated terrain building kit. Materials included an informed consent, a demographics questionnaire, a written land navigation test to evaluate construction aptitude, data recording forms to capture sand table construction performance, and questionnaires that measure perceived usability and capture feedback on tool utility.

3.3 Planned Studies

3.3.1 Study 7: Terrain Correlation Guidance

Primary Research Area: Information Visualization

Principal Investigator: Dr Stephen Serge (University of Central Florida Institute for Simulation & Training)

Anticipated Start Date: Q1 FY18

Abstract/Executive Summary:

User interaction with the Augmented REality Sandtable (ARES) involves direct user manipulation of the sand to conform to specific terrain features projected onto the sand. Currently, the table is capable of providing a "rough guide" to users in order to adjust the elevation of the sand. This helps users set up a table that reflects the terrain features of the particular map area in order to provide a deeper level of realism and accuracy. One of the main goals of creating this representation of the Area of Operation (AO) is to instill in the users a sense of familiarity with the AO prior to running any operations. The initial push of this research effort focuses on quickly compiling and developing a research-supported approach toward the development of a new integrated guided terrain build feature within the ARES software. Depending on outcomes, additional research goals may be added in a second phase of research.

3.3.2 Study 8: Floor Projection

Primary Research Area: Multi-Modal Interaction

Principal Investigator: Dr Gregory Welch (University of Central Florida Institute for Simulation & Training)

Anticipated Start Date: Q1 FY18

Abstract/Executive Summary:

The goal of the proposed work is for the development of a large-area floor projection to extend the visible range and interaction capabilities of the Augmented REality Sandtable (ARES). Several research questions will be addressed in the formulation of the study plan as follows: 1) What are the appropriate human factors tools and techniques (as measured by cost and ease of use) to create intuitive and usable interaction with large-scale projection? 2) What is the impact on cognition (i.e., load, processing, and awareness) of large-scale projection as compared to smaller form factor interfaces? 3) How can information be displayed to facilitate distributed collaboration across geographically dispersed teams as well as to large groups of individuals viewing the display? 4) When presented with multiple ways to view information across platforms and form factors, what is the process for interaction as a user is switching between views? 5) How can the technology infrastructure be used to increase the scalability and generalizability to support variable system configurations based on environmental constraints?

3.3.3 Study 9: Impact on Learning II: Expansion to AR/VR

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Kelly Hale (Design Interactive, Inc.)

Anticipated Start Date: Q1 FY18

Abstract/Executive Summary:

The goal of the proposed work is to conduct an evaluation of the Augmented REality Sandtable (ARES) (as viewed through an AR peripheral such as the Microsoft Hololens) and compare results to data collected in Study 1. The proposed study will be run as a between-subjects investigation to evaluate differences between multimedia displays of sand tables on spatial knowledge and decision-making tasks.

3.3.4 Study 10: Land Navigation

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Ben Goldberg (ARL)

Anticipated Start Date: Q2 FY18

Abstract/Executive Summary:

The purpose of this study is to use the Augmented REality Sandtable (ARES) as a use case with the Generalized Intelligent Framework for Tutoring (GIFT) for a land navigation task. Participants will be asked to plan a route and place map symbology in the correct locations on the map. Participants will be cadets from the United States Marine Academy. Real-time user performance assessments and feedback from GIFT will be provided to participants. Study metrics will include objective and subjective measures of learning and performance (e.g., workload, engagement, usability) while interacting with the various ARES modalities (and also perhaps traditional/2-D alternatives).

3.3.5 Study 11: Distributed Collaboration

Primary Research Area: Human Performance Assessment

Principal Investigator: Dr Gregory Welch (Tentative; University of Central Florida Institute for Simulation & Training)

Anticipated Start Date: Q3 FY18

Abstract/Executive Summary:

The purpose of this study is to research methods to improve distributed collaboration scenarios with multiple users interacting with the Augmented REality Sandtable (ARES) systems in geographically distributed locations. With new mixed reality tools being implemented and evaluated across the Department of Defense, we want to know how well users understand, discuss, and collaborate on complex battlespaces (e.g., kinetic, cyber, and social) using mixed reality. Two testbeds, already in place at 2 remote locations for use by Reserve Officers' Training Corps (ROTC) students, will use a server to share scenario visualization and edit with video teleconference capabilities to support communications. Human performance metrics (e.g., workload, engagement, usability) will be evaluated, along with measures of effectiveness of communication and post-knowledge of the resultant plan.

3.4 Summary

Together, these 11 completed, ongoing, or planned studies represent efforts that seek to establish the effectiveness of the ARES platform, expand to new applications and points of need, and explore new technologies and capabilities while performing research that answers questions of greater scientific interest in information visualization, multimodal interaction, and human performance assessment.

4. Conclusion

The ARES platform provides an opportunity to bring together multiple technologies for user interaction—including virtual and augmented reality, a tangible interface, and other distributed modalities—to improve battlespace visualization and decision-making to provide a common operating picture at the point of need. The purpose of this technical note is to situate completed, ongoing, planned, and future work into the overall topology of research for the ARES platform. Future work in the various research areas will answer questions of broad scientific interest and will establish ARES as a platform for exciting developments.

5. References

[ACIC] Army Capabilities Integration Center. Army warfighting challenges. Ft Eustis (VA): Army Capabilities Integration Center; 2017 [accessed on 2017 Oct 2]. http://www.arcic.army.mil/Initiatives/ArmyWarfightingChallenges.

Alnusayri MA. Proximity table: exploring tabletop interfaces that respond to body position and motion [dissertation]. [Halifax, Nova Scotia, Canada]: Dalhousie University; 2015.

Amburn C, Vey N, Boyce M, Mize J. The Augmented REality Sandtable (ARES). Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2015. Report No.: ARL-SR-0340.

Annett M, Grossman T, Wigdor D, Fitzmaurice G. Medusa: a proximity-aware multi-touch tabletop. Proceedings of the 24th annual ACM symposium on user interface software and technology; 2011. p. 337–346.

[ARL] Army Research Laboratory (US). U.S. Army Research Laboratory Technical Implementation Plan 2016–2020. Adelphi (MD): Army Research Laboratory (US); 2016 [accessed 2017 Nov 21]. https://www.arl.army.mil/www/pages/172/docs/Technical_Implementation_Plan_v2_FINAL.pdf.

Baldonado MW, Woodruff A, Kuchinsky A. Guidelines for using multiple views in information visualization. Proceedings of Advanced Visual Interfaces (AVI 2000); 2000. New York (NY): ACM Press; c2000. p. 110–119.

Byrne MD, Pew RW. A history and primer of human performance modeling. Rev Hum Fact Ergon. 2009;5(1):225–263.

Chen C. Top 10 unsolved information visualization problems. IEEE Computer Society. 2005;25(4):12–16.

Chen JYC, Procci K, Boyce M, Wright J, Garcia A, Barnes M. Situation awareness-based agent transparency. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2014. Report No.: ARL-TR-6905.

Creswell JW. Research design: qualitative, quantitative, and mixed methods approaches. 4th ed. Thousand Oaks (CA): Sage Publications; 2014.

[DOE] US Department of Energy. Human performance improvement handbook volume 1: concepts and principles. Washington (DC): Department of Energy (US); 2009. Handbook No.: DOE-HDBK-1028-2009.

Elliott LR, Coovert MD, Prewett M, Walvord AG, Saboe K, Johnson R. A review and meta analysis of vibrotactile and visual information displays. Adelphi (MD): Army Research Laboratory (US); 2009. Report No.: ARL-TR-4955.

Fuhrmann S, Komogortsev O, Tamir D. Investigating hologram-based route planning. Trans GIS. 2009;13(s1):177–196.

Gooley JG, McKneely JA. Command and control systems engineering: integrating rapid prototyping and cognitive engineering. Johns Hopkins APL Technical Digest. 2012;31(1):31–42.

Hansberger J. Development of the next generation of adaptive interfaces. Adelphi (MD): Army Research Laboratory (MD); 2015. Report No.: ARL-TR-7251.

Hegarty M, Smallman HS, Stull AT. Choosing and using geospatial displays: effects of design on performance and metacognition. Journal of Experimental Psychology: Applied. 2012;18(1):1.

Hick WE. On the rate of gain of information. Q J Exp Psychol A. 1952;4(1):11–26.

Hiniker P, et al. Operational replanning with user defined operational picture: warfighting experiment & operational assessment plan. 12th International Command and Control Research & Technology Symposium (ICCRTS): Adapting C2 to the 21st Century; 2007. Paper I-131.

Hyman R. Stimulus information as a determinant of reaction time. JESP. 1953;45(3):188.

Ishii H. Tangible bits: beyond pixels. Proceedings of the 2nd International Conference on Tangible and Embedded Interaction; 2008. p. xv–xxv.

Jaimes A, Sebe N. Multimodal human–computer interaction: a survey. CVIU. 2007;108(1):116–134.

Laughery KR Jr, Plott B, Matessa M, Archer S, Lebiere C. Modeling human performance in complex systems. In: Salvendy G, editor. Hoboken (NJ): John Wiley and Sons; 2012. Handbook of human factors and ergonomics. 4th ed.

Lickteig CW, Sterling BS, Elliott GS, Burns JE, Langenderfer JE. Assessing battle command information requirements and the military decision making process in a concept experimentation program. Alexandria (VA): Army Research Institute for the Behavioral and Social Sciences; 1998.

Livnat Y, Agutter J, Moon S, Foresti S. Visual correlation for situational awareness. IEEE Symposium on Information Visualization; 2005 Oct 23–25; Minneapolis (MN). INFOVIS 2005; c2005. p. 95–102.

DOI: 10.1109/INFVIS.2005.1532134.

Ma J, Sindorf L, Liao I, Frazier J. Using a tangible versus a multi-touch graphical user interface to support data exploration at a museum exhibit. Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction; 2015 Jan 15–19; Stanford, CA. New York (NY); c2015. p. 33–40.

Maldonado RM. Analysing, visualising and supporting collaborative learning using interactive tabletops [dissertation]. [Sydney (Austrailia)]: The University of Sydney; 2014.

Maquil V. Towards understanding the design space of tangible user interfaces for collaborative urban planning. Interacting with Computers. 2016;28(3):iwv005.

Marner MR, Smith RT, Walsh JA, Thomas BH. Spatial user interfaces for large-scale projector-based augmented reality. CGA. 2014;34(6):74–82.

Mitasova H, Harmon RS, Weaver KJ, Lyons NJ, Overton MF. Scientific visualization of landscapes and landforms. Geomorphology. 2012;137(1):122–137.

Mulgund S, Landsman S. User defined operational pictures for tailored situation awareness. 12th International Command and Control Research & Technology Symposium (ICCRTS): Adapting C2 to the 21st Century; 2007.

Myles K, Kalb J. An evaluation of signal annoyance for a head-mounted tactile display. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2015. Report No.: ARL-TR-7239.

Ntuen CA. Theory and evaluation of battlefield visualization in context. Army Center for Human-Centric Command & Control Decision Making; 2009 June 15–17; Washington, DC. ICCRTS; c2009. http://www.dodccrp.org/events/14th_iccrts_2009/presentations/137.pdf

Pfitzner D, Hobbs V, Powers D. A unified taxonomic framework for information visualization. 2nd Australian Institute of Computer Ethics Conference (AICE2000); 2001; Canberra (Australia): Australian Computer Society, Inc.; c2001.

Schneider B, Jermann P, Zufferey G, Dillenbourg P. Benefits of a tangible interface for collaborative learning and interaction. IEEE Trans Learn Technol. 2011;4(3):222–232.

Szalma JL. Individual differences in human–technology interaction: incorporating variation in human characteristics into human factors and ergonomics research and design. Theor Issues Ergon Sci. 2009;10(5):381–397.

Turk M. Multimodal interaction: a review. Pattern Recognit Lett. 2014;36:189–195.

Ware C. Information visualization: perception for design. 3rd ed. Waltham (MA): Morgan Kaufmann, Elsevier; 2012.

List of Symbols, Abbreviations, and Acronyms

2-D	2-dimensional
3-D	3-dimensional
AO	area of operations
ARL	US Army Research Laboratory
ARES	Augmented REality Sandtable
DTRA	Defense Threat Reduction Agency
FY	fiscal year
GIFT	Generalized Intelligent Framework for Tutoring
KCI	Key Campaign Initiatives
NSRDEC	US Army Natick Soldier Research, Development and Engineering Center
OODA	observe, orient, decide, and act
PC	personal computer
ROTC	Reserve Officers' Training Corps
SWAT	Special Weapons and Tactics
UCF	University of Central Florida
UDOP	User-Defined Common Operating Picture
USMA	United States Military Academy

1 (PDF) DEFENSE TECHNICAL
INFORMATION CTR
DTIC OCA

2 (PDF) DIR ARL
IMAL HRA
RECORDS MGMT
RDRL DCL
TECH LIB

1 (PDF) GOVT PRINTG OFC
A MALHOTRA

1 (PDF) ARL
RDRL HRB B
T DAVIS
BLDG 5400 RM C242
REDSTONE ARSENAL AL
35898-7290

8 (PDF) ARL
SFC PAUL RAY SMITH1
CENTER
RDRL HRO COL H BUHL
RDRL HRF J CHEN
RDRL HRA I MARTINEZ
RDRL HRR R SOTTILARE
RDRL HRA C A RODRIGUEZ
RDRL HRA B G GOODWIN
RDRL HRA A C METEVIER
RDRL HRA D B PETTIT
12423 RESEARCH PARKWAY
ORLANDO FL 32826

1 (PDF) USA ARMY G1
DAPE HSI B KNAPP
300 ARMY PENTAGON
RM 2C489
WASHINGTON DC 20310-0300

1 (PDF) USAF 711 HPW
711 HPW/RH K GEISS
2698 G ST BLDG 190
WRIGHT PATTERSON AFB OH
45433-7604

1 (PDF) USN ONR
ONR CODE 341 J TANGNEY
875 N RANDOLPH STREET
BLDG 87
ARLINGTON VA 22203-1986

1 (PDF) USA NSRDEC
RDNS D D TAMILIO
10 GENERAL GREENE AVE
NATICK MA 01760-2642

1 (PDF) OSD OUSD ATL
HPT&B B PETRO
4800 MARK CENTER DRIVE
SUITE 17E08
ALEXANDRIA VA 22350

ABERDEEN PROVING GROUND

16 (PDF) ARL
RDRL HR
J LOCKETT
P FRANASZCZUK
K MCDOWELL
K OIE
RDRL HRA A
C R AMBURN
N L VEY
RDRL HRA AA
C J GARNEAU
P L SHORTER
RDRL HRA B
M W BOYCE
RDRL HRB
D HEADLEY
RDRL HRB C
J GRYNOVICKI
RDRL HRB D
C PAULILLO
RDRL HRF A
A DECOSTANZA
RDRL HRF B
A EVANS
RDRL HRF C
J GASTON
RDRL HRF D
A MARATHE

INTENTIONALLY LEFT BLANK.