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## Benefits and Challenges of Multidisciplinary Project Teams: "Lessons Learned" for Researchers and Practitioners

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*Adopting a multidisciplinary research approach would enable test and evaluation professionals to more effectively investigate the complex human performance problems faced in today's technologically advanced operational domains. To illustrate the utility of this approach, we present “lessons learned” based on our experiences as a multi-agency, multidisciplinary team collaborating on an Army research project involving a dynamic military command and control simulation. Our goal with these lessons learned is to provide guidance to researchers and practitioners alike concerning the benefits and challenges of such collaboration. Our project team's diverse members, drawn from both industry and government organizations, offer their multiple perspectives on these issues. The final sections then summarize the challenges and benefits of multidisciplinary research.*

**Key words:** Collaboration; command and control; experiments; human performance; multidisciplinary research; simulation.

**M**ultidisciplinary research involves a coordinated effort that brings together several disciplines to provide complementary contributions in the service of a common goal (Fiore and Salas 2007). Multidisciplinary project teams offer multiple perspectives and a broad range of expertise for generating unique and creative solutions to solve real-world problems. We propose that test and evaluation professionals would benefit from adopting a multidisciplinary research approach to investigate the complex human performance problems faced in today's technologically advanced operational domains. We illustrate this approach by presenting “lessons learned” based on our experiences as a multi-agency, multidisciplinary team collaborating on a U.S. Army research

project involving a dynamic military command and control simulation. We begin with a brief overview of the experiment and then discuss each lesson learned in turn. The discussion reflects the multiple perspectives of our project team's diverse members, drawn from both industry and government organizations. Commentary is also provided from the project manager's perspective. We conclude with a summary of the challenges and benefits of multidisciplinary research.

### Experiment overview

As part of a U.S. Army-sponsored project, an experiment was conducted at the Aberdeen Test Center (ATC) in Aberdeen Proving Ground, Maryland. Six Soldier, Operator, Maintainer, Tester, and Evaluator (SOMTE) soldiers were assigned to one of two

three-person crews (vehicle commander, driver, and gunner) of a Mounted Combat System (MCS) vehicle. Crews completed eight 75-minute simulated military missions, maneuvering their MCS vehicles through desert and urban environments while controlling unmanned ground and aerial systems. For complete details on the objectives, methods, and results for this experiment, see Bolstad et al. (2009) and Mitchell et al. (2009).

### **Experiment research objectives**

For our project team's industry representatives (SA Technologies, Pearson Knowledge Technologies, Perceptive Research, and Parallel Consulting), the primary research objective was to collect data in future command and control scenarios to develop the Automated Communications Analysis of Situation Awareness (ACASA) system, which unobtrusively assesses situation awareness based on analysis of team communications. The goal was to link measures of situation awareness to correlated measures derived from communications among team members. To facilitate discussion, these project team members are referred to as the "ACASA researchers."

For our project team's government representatives (Army Research Laboratory Human Research and Engineering Directorate [ARL-HRED]), the primary goal was to verify existing ARL-HRED task analysis and workload predictions associated with an Improved Performance Research Integration Tool (IMPRINT) analysis of the MCS. To facilitate discussion, these project team members are referred to as the "ARL-HRED analysts." The ATC representative on our project team served as the experiment coordinator, handled participant recruitment, and supervised the programming and running of the simulation and collection of the physiological and task performance data.

### **Data collection measures**

To address these research objectives, our project team utilized different measures and techniques. ACASA researchers collected objective situation awareness data using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley 1995) and recorded digital audio files of voice communications, both within and across teams, using BBN-Talk. ARL-HRED analysts used a modified version of the Instantaneous Self-Assessment of Workload (ISA) (Kirwan et al. 1997) questionnaire to assess participants' self-reported estimates of their perceived workload during the missions. The workload data were supplemented with experimenter observations. ATC researchers set up the electroencephalogram (EEG) recordings to collect

physiological workload data. Task performance data were collected automatically by the simulation and recorded in log files.

### **Lessons learned**

Here, we discuss several important lessons learned gleaned from our multidisciplinary collaboration in conducting this experiment. These lessons learned are aimed at providing guidance to researchers and practitioners alike concerning the benefits and challenges of such collaboration. Insights are presented from all perspectives of our project team regarding the process of planning and executing an experiment involving multiple stakeholders with distinct research objectives.

### **Meeting distinct research objectives**

In multidisciplinary research, researchers must understand their own research objectives as well as how these are related to the other project team members' objectives. Our project team's research objectives for this experiment were similar in that we were all interested in assessing human performance during completion of complex cognitive tasks. However, our objectives differed in terms of the specific aspects of cognition and performance investigated by each team member (e.g., situation awareness, mental workload). Our project team members had multiple data modalities, with different requirements, from multiple independent researchers. Further, each planned analysis for each data modality required different "minimums" of data to be collected for a valid and reliable analysis. One researcher's experimental design would likely not provide enough data (or enough of the right kind of data) for the other researchers involved.

Ensuring that our project team's distinct research objectives were met required careful planning of the experiment, involving all stakeholders. We created a comprehensive test plan detailing how all the researchers' measures would be implemented in the experiment. This allowed us to visualize how our data collection would fit within the experiment and to coordinate our data collection activities, so we did not interfere with each other. The experiment was designed well enough ahead of time to allow our project team members to generally work within their own stovepipes when collecting data within their specialties. Our project team's investment in planning and designing the experiment paid considerable dividends during the execution of the experiment and subsequent data analysis.

Our multidisciplinary project team's different research objectives were aligned in terms of the need for a small-scale experiment involving a realistic task and manageable variability of events. Using realistic

scenarios with representative participants (soldiers) provided context validity to the results. Although we had limited control over scenario design and simulation configuration, enough flexibility was available to enable the project team to meet their research objectives. For example, to verify their workload analysis, ARL-HRED analysts needed to ensure that scenarios developed by ATC researchers represented missions analogous to missions in the IMPRINT MCS analysis. The similarity of missions was important to make it more likely that soldiers participating in this experiment would perform the same set of tasks as the soldiers in the ARL-HRED IMPRINT analysis. Collecting data from a similar set of tasks, in turn, would permit ARL-HRED analysts to compare workload data and performance measures collected during the experiment to the IMPRINT-predicted workload data for the same tasks.

*Lesson learned #1.* Upfront collaborative design of an experiment allows each researcher to effectively work independently within his/her area of expertise during the actual data collection of the experiment. Thus, in multidisciplinary research, team members should begin working together early during the experiment's planning and design stages and then work independently, where appropriate, during the execution stage (rather than the reverse!).

### **Resolving conflicting data collection requirements**

Meeting our project team's distinct research objectives involved careful consideration of how to efficiently incorporate the different measures and apparatus into the overall experimental design. For example, collecting team communication data during a distributed team simulation requires instrumentation technology for each participant (e.g., headphones, multichannel digital recording software). It can be challenging to instrument each participant to reliably collect the required data while not being overly intrusive to the point of affecting participants' performance during the experiment, which would interfere with other project team members' research objectives.

Similarly, each group within our project team had specific requirements to optimize their organization's data collection techniques. While continuous measures (e.g., EEG recordings) were easy to coordinate during the experiment, collection of non-continuous measures (e.g., the SAGAT) had to be more carefully planned in advance. For example, the SAGAT used by ACASA researchers required pausing the simulation and interrupting task performance. These pauses, in turn, created challenges for ARL-HRED analysts who would have

preferred to collect continuous workload data during the mission. This required a trade-off in the experimental design, prioritizing collecting situation awareness data over collecting continuous workload data.

Collecting team communication data was also a priority in this experiment. Accordingly, the simulation scenarios were specifically designed to elicit frequent voice communications among participants. However, this created another challenge for ARL-HRED analysts in that sending and responding to voice communications became the most frequent tasks performed by participants, both alone and in combination with other tasks. This frequency of communications may have biased results regarding which tasks contributed to the highest workload during the experiment. If ARL-HRED analysts had collected data in their own independent study, this bias may not have occurred.

*Lesson learned #2.* Conducting multidisciplinary research requires careful consideration of conflicting data collection requirements with the goal of minimizing interference across the different measures and judicious prioritization of research objectives when necessary.

### **Leveraging data collection efforts**

Another important consideration for conducting multidisciplinary research involves leveraging the data collected by other project team members to meet one's own research objectives. Support for the utility of such synergistic collaborations was demonstrated in this experiment. For example, to create predictive statistical models of situation awareness, ACASA researchers had to integrate several sources of experimental data from multiple researchers, including transcriptions of the digital audio recordings, SAGAT scores, multichannel digital EEG logs, and additional data logged by the simulation. While these streams were collected by experts in different disciplines, it was possible to integrate these into a useful dataset for analysis because of our project team's early collaborative planning.

Furthermore, by comparing the physiological data collected by ATC researchers with the ISA self-report ratings collected by ARL-HRED analysts, we could establish an association between these two different types of workload measures. Similarly, by comparing this workload data with the situation awareness data collected by ACASA researchers, we could also possibly identify a relationship between different workload levels and performance. ARL-HRED analysts could also use the team communication data collected by ACASA researchers to calculate frequency and duration of messages for input into subsequent IMPRINT analyses of manned ground vehicles.

*Lesson learned #3.* One of the major benefits of multidisciplinary research is that team members have access to a broader range of data at no (or only minimal) additional cost.

### **Resolving technical issues**

Technical issues are almost always encountered in empirical research, particularly in studies involving simulations. The larger the experiment, the greater is the potential for unanticipated technical problems to occur. Our project team was distributed, multiple technologies were involved to instrument and collect data, and those installing and configuring the technology were removed from those who would be analyzing the data. Indeed, our project team members did not all meet in person until everyone assembled together on the days scheduled to conduct the actual experiment. Additionally, our project team worked under resource and time constraints owing to project deadlines and other commitments, leaving limited time available to conduct practice runs of the experiment test plan to test the systems and measures. Not surprisingly, our project team encountered its share of technical issues during the execution stage.

One of the more significant technical problems involved synchronizing the simulation "clock" time with the different measures (e.g., SAGAT, digital audio recordings, EEG recordings, observations). Synchronization of data collection to the simulation clock times was critical for aligning and comparing results across the different measures administered during the experiment. Although our project team had agreed upon having a central reference clock, so that all researchers could synchronize their individual data collection efforts, how those clock times were recorded within the individual data streams differed. Unfortunately, this issue could not be completely avoided because of the different technologies used to run the simulation and collect each type of data. This resulted in some challenges in resolving different interpretations of the central clock when analyzing multiple data streams together. Nonetheless, through careful comparison across data files and follow-up discussions, our project team was able to sufficiently resolve this issue to facilitate data analysis. In particular, our project team benefited from the manual recording by ARL-HRED analysts of the simulation clock time whenever the simulation was started and stopped. Their detailed records facilitated scoring the SAGAT data using the simulation log files.

*Lesson learned #4.* Establish from the outset a standardized central reference time that can be used by all researchers for tagging and analyzing data.

Another concern for any research endeavor is to minimize the occurrence of missing or incomplete data. In some cases, this is unavoidable, such as with unexpected equipment malfunctions or simulation delays. However, other instances of missing data can be avoided with proper planning. For example, in addition to SAGAT, ACASA researchers had planned to collect additional situation awareness data by having a Subject Matter Expert (SME) present real-time queries to participants. Unfortunately, this SME had also been assigned to serve as the company commander during the experiment and was responsible for briefing the participants on their missions and operations orders as well as monitoring their activities. The workload associated with performing this important role prevented him from being able to administer the real-time queries and record participants' responses on a consistent basis. Because of a lack of sufficient data, analysis of the real-time queries could not be conducted.

*Lesson learned #5.* Review assignments to minimize conflicts; individuals assigned to critical roles in the experiment should not be tasked with also collecting data and vice versa. Whenever possible, designate a trained experimenter to regularly verify that data are being collected as scheduled and to inform researchers when any problems are detected.

Another incident that occurred during the experiment highlights the importance of coordinating with others outside of the project team. During one of the missions, a computer acting as a central data collection point was accidentally taken offline by a regularly scheduled maintenance operation. The personnel in charge of this operation were simply performing their regular duties to effectively maintain the organization's technologies. However, because they were unaware of the experiment and the criticality of keeping this computer online, this communication failure resulted in a potential vulnerability in our data collection efforts. While the results were not catastrophic overall, the event did require resetting the simulation run.

*Lesson learned #6.* Beyond the project team's research stakeholders, a multidisciplinary team can also benefit from including representation of operational stakeholders. This helps ensure explicit communication of data collection requirements and constraints with members of the broader organization who may either directly or indirectly affect the project team's data collection efforts.

On a more general level, our multidisciplinary project team members have different training, backgrounds, experiences, and traditions. Similarly, each discipline has communal conventions for how data are collected, what formats are preferred, and how data are

labeled, organized, and analyzed. A multidisciplinary project team must communicate these practices and preferences to others who may be analyzing their data. What may seem implicit, obvious, or expected data collection practices within one research discipline may not be so when another discipline is analyzing that same data. To illustrate, one of the technical challenges noted by ARL-HRED analysts was their lack of adequate understanding of the relationship between the physiological measures recorded by ATC researchers and a workload algorithm embedded in the software associated with these measures. ARL-HRED analysts observed the measures and algorithm fluctuating throughout the experiment. However, because they did not understand the relationship between the measures and workload, they could not annotate this observed relationship in their observation data of participants' performance.

*Lesson learned #7.* A more thorough understanding by all project team members of the different instrumentation, software, and techniques used in the experiment may mitigate the occurrence of technical problems during multidisciplinary research activities. It can also provide synergistic benefits to the team as a whole.

### **Resolving administrative issues**

Multidisciplinary research also creates potential administrative issues. To minimize the occurrence of such problems, our project team held regular meetings to design the experiment, create a common test plan, and coordinate our various research activities. Creating a common test plan helped to foster a broader perspective on the experiment. Still, some administrative issues had to be addressed both before and during the experiment.

Our project team was distributed across the country in different time zones, requiring a greater level of coordination to schedule regular meetings among researchers. Additionally, much of the simulation software design and hardware/software instrumentation was handled by contracted resources onsite. This required training the contractors on the technology to be employed along with documenting and communicating requirements. Since ACASA researchers were unable to access the experiment site prior to the study, this arrangement worked out well.

A notable administrative constraint associated with the experiment resulted from differences in funding mechanisms. Ideally, when several organizations participate in a joint experiment, funding for all parties involved should be provided prior to planning. Unfortunately, ACASA researchers experienced delays at

times in receiving contract funding. As a result, ARL-HRED analysts experienced delays in receiving the inputs they needed from the other organizations. Nonetheless, our project team was able to reduce costs overall by collaborating with other researchers on this multi-agency experiment. For example, ATC researchers had access to soldiers whose mission is to support ATC testing. Thus, working with ATC researchers shortened the process for obtaining soldiers to serve as participants, and one of these soldiers also helped develop the mission scenarios.

Another administrative issue resulted from differences in the publication approval processes of the participating organizations. Thus, each organization prepared and published its own separate reports and manuscripts, with reference, as appropriate to the other project team's publications. Still, all data collected during the experiment were shared among all project team members, and we have been coordinating across our different organizations to prepare joint publications that provide a more comprehensive report of the experiment's findings.

*Lesson learned #8.* Multidisciplinary research requires consideration of the administrative capabilities and constraints of all key stakeholders, including, but not limited to, geographical distribution, funding mechanisms, and organization-specific policies and resources. Careful planning and regular communications among project team members can help avoid or minimize the effects of many of these issues.

### **Managing multidisciplinary projects**

Managing and providing oversight on a multidisciplinary research project involving multiple stakeholders with distinct research objectives presents unique challenges to the project manager. Arguably, the greatest of these is *prioritization*. The project manager has to weigh the benefits of each of the research aims with the specific test requirements imposed by the researcher. As part of the prioritization process, the project manager is the "middle-man" between the different disparate groups. Communicating the project's end goal with each of the researchers and de-conflicting their different requirements takes up much of the project manager's time during the planning process. However, the end result of this prioritization and de-confliction process is an overall experiment test plan with consent from all project team members.

These challenges notwithstanding, a multidisciplinary research approach offers distinct advantages compared with collecting data in a simpler study focused on a specific research question. Researchers conducting stovepipe research rarely venture outside of their own

lanes. However, when working with other researchers toward a common goal, they can critically think through their own processes and techniques and judge them against other research techniques. Multidisciplinary project team members also have access to data they usually would not collect. This additional data may spur them to adapt their techniques to include new sources of data in future research or refine their theories based on conclusions drawn from this previously unexplored data. At a broader level, with multiple researchers from several disciplines all working toward achieving the same goal, their combined output will examine the problem from every side and provide a robust answer not typically found in a stovepipe one-discipline approach. Thus, the added input from other disciplines furthers the conclusions derived from the research, and multiple groups are all able to converge and support a unified comprehensive solution to the problem.

### **Challenges in multidisciplinary research**

The primary challenge in conducting multidisciplinary research is meeting the constraints of different stakeholders with different agendas. Although our project team actively worked together to develop a comprehensive experiment test plan that addressed each researcher's data collection requirements, in execution, trade-offs had to be made when attempting to coordinate overlapping implementation of multiple measures. Thus, a potential disadvantage of multidisciplinary research is that conflicting data collection requirements may hinder the project team's ability to meet all their members' different research objectives.

Mitigating this issue requires establishing a systematic process by which the project team can objectively agree to a primary goal while still permitting stakeholders to determine their specific research objectives and carefully prioritize their data collection requirements for meeting this goal. Multidisciplinary project teams would also benefit from assuming there are "hidden" requirements and subtle interdependencies that can only be discovered and addressed through early exchanges among team members. Thus, upfront collaboration on planning and experimental design is crucial for successful multidisciplinary research. With experience, multidisciplinary project teams can improve their ability to make the right decisions on necessary trade-offs, balancing research objectives with available resources.

### **Benefits of multidisciplinary research**

In many cases, the advantages of multidisciplinary research generally outweigh its inherent challenges and costs. Still, the decision on whether or not this is the optimal approach primarily depends on the research

question being investigated, with more complex research questions benefiting the most from participation of team members with a wider range of resources and different areas of expertise. Setting up and executing even a small-scale simulation experiment is cumbersome, time-consuming, and expensive. By dividing up this task, our project team was able to significantly reduce the amount of time needed to plan and execute the experiment. Pooling resources also resulted in significant cost savings as none of the organizations possessed the resources to conduct such a complex experiment on their own.

Multidisciplinary research also enables the project team to capitalize on a broader range of expertise, drawing from several disciplines. By working together, we were able to draw upon our members' unique yet complementary areas of expertise to address the numerous challenges we faced during planning and execution of the experiment and, thereby, achieve a greater return on our investment. Working independently, a single organization would have had to invest a significant amount of time and expense to develop and implement all the technologies and measures required.

Multidisciplinary research can also be beneficial from a theoretical perspective. Unexpected yet fascinating results and greater theoretical insights can emerge when researchers are empathetic to and knowledgeable of the interests and objectives of other stakeholders. Thus, rather than viewing requirements of other team members as potential constraints, it is worthwhile to leverage these different perspectives to achieve greater theoretically significant outcomes arising from the synergistic activities of multidisciplinary research. It will certainly not happen every time, but this is no reason not to leave the door open to something new, unique, and potentially important to the scientific community. Many great scientific theories and discoveries have come from precisely these kinds of robust interactions. An independent researcher conducting his or her own separate experiment would never have these valuable opportunities afforded by multidisciplinary research.

### **Conclusion**

Science is about problems and possibilities; that is, solving problems and realizing possibilities (Fiore and Salas 2007). In today's technologically sophisticated organizations, human operators must contend with a wider range of problems and possibilities marked by ever increasing complexity. Solving these complex problems and realizing the possibilities of technological advances requires coordinated collaborative scientific endeavors that cut across multiple disciplines. Our goal with this paper was to illustrate how a multidisciplinary



research approach holds significant promise for yielding greater scientific advances in understanding and improving human performance than could be accomplished by a researcher working within a single discipline. We hope our lessons learned will encourage researchers and practitioners alike to consider a multidisciplinary approach for their future research endeavors, so they, too, can achieve a greater return on their investment. □

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