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TITLE: Development of an Integrated Team Training Design and Assessment Architecture to Support Adaptability in Health Care Teams

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14. ABSTRACT

Purpose and Scope: It is the purpose of this project to optimize adaptability and mitigate teamwork-related threats to patient safety by addressing key methodological and conceptual gaps in healthcare simulation-based team training. The investigators are developing the necessary conceptual framework and team performance assessment mechanisms to support training systems that improve adaptability and performance in trauma teams.

Aim 1a. Develop a team training design architecture to support simulation-based training/assessment systems capable of developing adaptive expertise in healthcare teams

Aim 1b. Develop evidence-based guidelines and recommendations for the development of embedded, adaptive feedback and performance assessments

Aim 2. Develop and refine a predictive model of trauma team performance and outcomes for use in an adaptive guidance system

Major Findings: The investigators performed a four-step process to develop a unified team training design architecture and supporting conceptual framework. They identified key training design principles and recommendations for the development and implementation of embedded, adaptive feedback and performance assessment. The investigators designed a prototype of a Bayesian Belief Network (BBN)-based model of trauma team performance and outcomes. The investigators went through several model iterations and settled on one model for final testing. After testing and validation, the model was finalized.

Impact: The provision of emergency care in a combat situation mandates well-developed adaptive expertise, making this work relevant to military healthcare. Our work provides a roadmap and mechanism for future work in a multitude of healthcare teams and settings.

15. SUBJECT TERMS

Military healthcare team; Trauma teams; Team training; Teamwork; Adaptive performance; Leadership; Simulation; Modeling; Bayesian belief networks (BBN)

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INTRODUCTION

Team adaptability is necessary for effective team performance and is especially critical for trauma teams, whose members must anticipate change and rapidly coordinate effective responses. Teams that are not highly adaptive will function in a reactive mode that is fraught with potential safety and error risks. Rigorously designed computer-based simulation systems have the potential to support active learning experiences and improve adaptability and performance in individuals and teams. However, without the proper supporting design elements, these simulations are ineffective and inefficient training tools. Our research addressed this knowledge gap by providing the necessary conceptual framework and assessment mechanism to support the design and implementation of highly effective simulation-based team training with embedded, adaptive guidance. First, the project developed a unified training design architecture capable of supporting simulation-based team training with embedded performance assessment and adaptive guidance. The resulting design architecture and underlying conceptual work provides a clear plan and guidelines for the development and implementation of highly effective simulation-based training with embedded, adaptive guidance that optimizes team adaptability and team performance. Second, the project developed a functional prototype of a predictive trauma team performance assessment tool that can support the provision of embedded, adaptive guidance during simulation-based team training. This predictive assessment system is based upon Bayesian belief networks (BBNs), which are statistical models that allow predictive modeling of complex systems. They are able to incorporate real-time observations (performance measures, individual characteristics, team characteristics) to inform future outcomes and intelligently guide learners toward more effective behavior. Given these characteristics, BBNs are uniquely suited for use in the development of simulations with real-time, adaptive guidance.

KEYWORDS:
Healthcare teams
Trauma
Trauma teams
Team training
Teamwork
Adaptability
Adaptive performance
Leadership
Simulation
Modeling
Bayesian belief networks (BBN)

ACCOMPLISHMENTS – AIM 1

Aim 1a. Develop a team training design architecture to support simulation-based training /assessment systems capable of developing adaptive expertise in healthcare teams

Aim 1b. Develop evidence-based guidelines and recommendations for the development of embedded, adaptive feedback and performance assessments

What were the major goals of the project?

The primary outcome of Aim 1a was a conceptually and methodologically sound training design architecture that supports the development and integration of team training and automated assessment technologies in simulation environments. The primary outcome of Aim 1b was a set of best practice guidelines and recommendations for the design and incorporation of adaptive, embedded feedback (guidance) into simulation-based team training. The tasks, timeline, and status of each step associated with Aims 1a and 1b are summarized in the table below.

Aims 1a and 1b Tasks	Timeline (Months)	Status
Task 1: Project Start-up		
Establish subcontracts to enable purchasing.	0 – 3	**Completed**
Local/Site IRB application submissions	0 – 3	All IRB submissions have been completed and the project has been awarded exempt status by each institution. **100% COMPLETED**
Assembly of subject matter expert panel	0 – 3	Subject matter experts have been invited and the panel now contains experts from emergency medicine, simulation, trauma surgery, and nursing. Individuals were chosen for their expertise and to ensure geographical representation. **100% COMPLETED**
Human Research Protection Office IRB	3	The HRPO has granted exempt status. **100% COMPLETED**
Milestone(s) Achieved: 1. Project infrastructure in place 2. Local/Site IRB and HRPO Approval	6	**100% COMPLETED**
Task 2: Identify constructs of interest		
Literature search strategy	0 – 3	Search strategy within healthcare literature, trauma performance literature, trauma outcomes literature, and team science has been defined. **100% COMPLETED**
Review of identified manuscripts and literature	0 – 6	The review of relevant literature (healthcare and team science) to inform the conceptual model and framework of adaptive performance has been completed. **100% COMPLETED**
Milestone(s) Achieved: 1. Identification of individual and team performance constructs for the conceptual framework and training architecture	6	We identified relevant individual and team constructs and designed a draft framework. **100% COMPLETED**
Task 3: Determine relevant variables and relationships		
Develop nomological net among constructs identified in Task 2	3 – 9	We have identified key relationships between processes and variables critical for team adaptability. **100% COMPLETED**
Subject matter expert review of variables and relationships	6 – 9	Trauma care and military experts reviewed the components of our adaptability model. Modifications included the addition of cognitive adaptability and diagnostic process as a key component of trauma team adaptive capacity. **100% COMPLETED**
Milestone(s) Achieved: 1. Identification of relationships between individual and team performance constructs for the conceptual framework and training architecture	9	**100% COMPLETED**

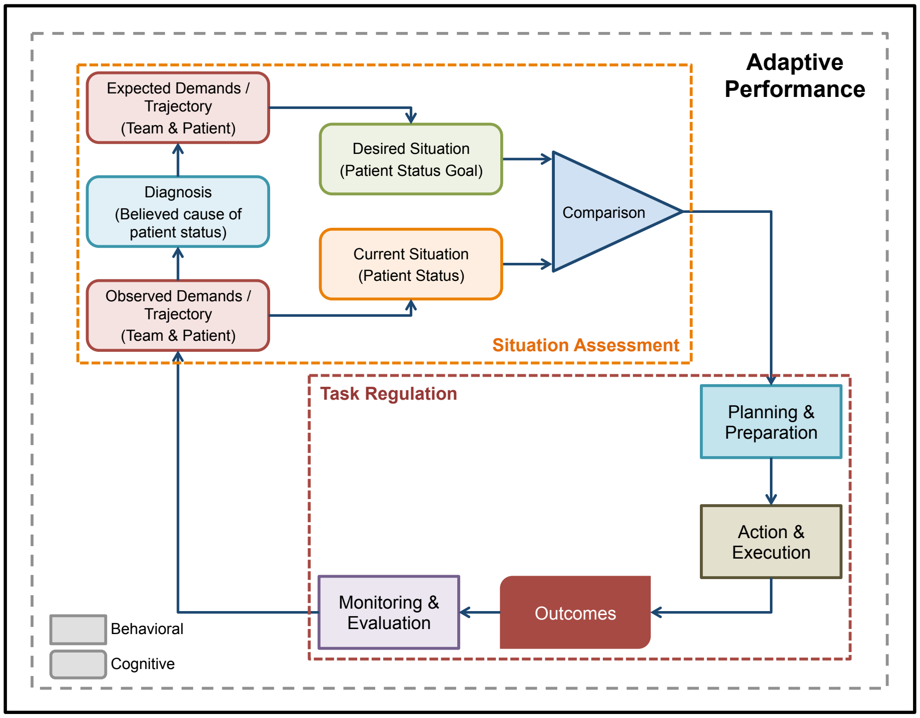
Task 4: Identify appropriate level of constructs and variables		
Identification of appropriate levels for constructs, relationships, and outcomes identified in Task 3	6 – 9	Literature reviews and subject matter expert opinion was used to choose and adapt a model of individual, team, and system-level measurement necessary to guide the development and implementation of effective team training. **100% COMPLETED**
Milestone(s) Achieved: 1. Multilevel framework of healthcare team training performance	9	We identified relevant individual and team constructs and designed a draft framework. We continued to revisit this framework throughout model testing occurs. As model testing is complete, this milestone is complete. **100% COMPLETED**
Task 5: Identify appropriate outcome measures and mechanisms		
Construct framework for provision of adaptive guidance during simulation-based team training	6 – 9	Relevant feedback mechanisms and designs have been identified and a draft framework has been designed. We anticipate revised the feedback mechanisms and design based upon Aim 2. **100% COMPLETED**
Subject matter expert review of feedback framework	9 – 12	Our military, external team science, and external emergency medicine subject matter experts reviewed the structure of our feedback framework to ensure the framework is compatible with current military training efforts and reflective of current team science recommendations. **100% COMPLETED**
Milestone(s) Achieved: 1. Integrated team training design architecture 2. Evidence-based guidelines and recommendations for the provision of embedded, adaptive guidance	12	**100% COMPLETED** See Attachments 1 – 3.
Task 5a: Cross reference feedback principles and team training architecture with TeamSTEPPS terminology (ADDITIONAL TASK ADDED TO ADDRESS IPR)		
Review current terminology and link both feedback principles and training architecture with TeamSTEPPS principles and trainer materials	18	This work was not initially proposed but was added in response to the IPR comments. We completed this work and provide these materials in Attachments 1 – 3. **100% COMPLETED**
Review current terminology and ensure Crawl-Walk-Run terminology is incorporated and clearly highlighted for instructors.	18	This work was not initially proposed but was added in response to the IPR comments. We completed this work and provide these materials in Attachments 1 – 3. **100% COMPLETED**

What was accomplished under these goals?
The work for Aim 1 is completed, with updated documents and reports, including conceptual models and frameworks provided in Attachments 1-3. Below we discuss each product and how it can direct training design and implementation.

Data Collection: A robust literature review is critical to the development of a comprehensive health care team training design architecture. We conducted an extensive literature review, both within healthcare and team science literature to identify key components of team performance adaptability. We focused specifically on identifying the individual and team processes that drive adaptive behaviors, as well as possible metrics that would indicate adaptability at individual and team levels. We then convened a multidisciplinary group of nurses and physicians from both civilian and military health care settings to provide expertise and insight into how these adaptive behaviors translate to the health care setting, and how they might develop over different levels of expertise. Finally, we observed both simulated and actual trauma team performance to augment our data and further our understanding of how adaptive performance unfolds during highly complex clinical activities. This information was then used to inform the identification of **key conceptual models** described below.

Defining Adaptive Performance in Trauma Teams: We used the literature review and subject matter expert review described above to identify all individual and team-performance concepts and constructs that are relevant to training, assessing, and supporting adaptive trauma team performance. Our initial adaptive performance model did not reflect the need for trauma teams to rapidly incorporate new diagnostic information into the team's plans and processes. Subject matter experts raised an issue that cognitive processes were not adequately represented. We therefore reviewed the diagnostic error literature, diagnostic decision-making literature, and team learning research to augment our model. The result is listed in Figure 1.

Figure 1.



This model reflects the cognitive and behavioral process components of trauma team performance. First, cognition is represented by the team's efforts to make sense of the situation (Situation Assessment). Briefly, the team must use existing data/observations to identify the patient- and team-related tasks and demands. This information is then used to develop a differential diagnosis. Based on this/these diagnoses, the team has expectations regarding how the patient will respond to treatments and how his/her condition will evolve over time. The team continuously compares this "expected" state to the "observed" state of the patient. This comparison informs the team and helps regulate the team processes that regulate task performance. If the team notes a mismatch between expected patient improvement and current patient condition, this should prompt the team to review their plan, make adjustments, and execute the modified plan. The results of these new actions should be monitored and evaluated. The observations made during evaluation become the information that the team uses to reassess the situation, reconsider the differential diagnosis(es), and the adaptive cycle continues. In a rapidly evolving trauma resuscitation, this cycle repeats continuously to ensure the team is adapting to the unstable patient/team/environment.

Identifying appropriate training targets: Training should be purposeful and should target appropriate cognitive, behavioral, and affective/motivational processes in a stepwise fashion. Training mechanisms should support both skill implementation in the clinical environment as well as transfer to novel situations. We identified a staged approach to training that targets appropriate skills necessary to develop adaptive capacity. We include both individual and team-based processes as well as training mechanisms. The framework below (Figure 2) provides an outline for this approach.

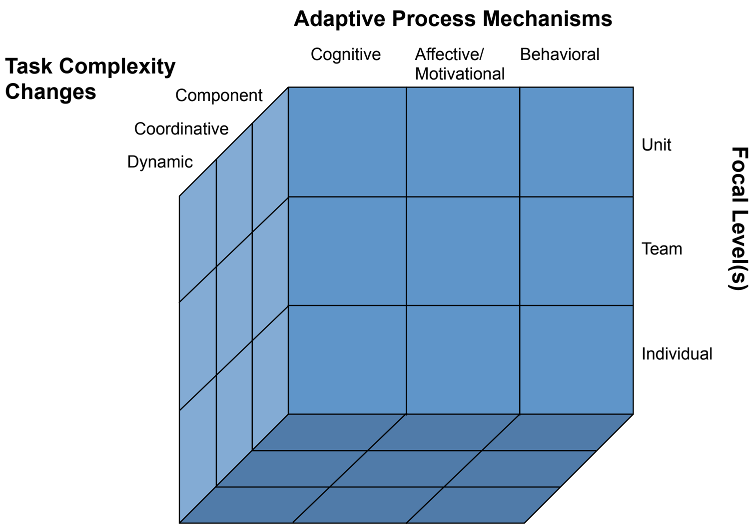
Figure 2. Training targets and training techniques

Basic **Knowledge and Skill Complexity** *Advanced* →

	Instructional Goal			
	Declarative Knowledge/Skill	**Procedural Knowledge/Skill**	**Strategic Knowledge/Skill**	**Adaptive Knowledge/ Skill**
Targeted Knowledge/Skill	Facts, concepts, rules; Definitions, meaning (*What?*)	Task principles; Rule application (*How?*)	Task contingencies; selective application (*Where, when, why?*)	Generalization of task rules, principles, contingencies (*What now, what next?*)
Exemplar Task-based KSAs	Risk factors for ACS	ACLS algorithms ATLS algorithms	Treating undifferentiated shock	Contingency planning based on patient response to treatment
Exemplar Team-based KSAs	Team processes Shared cognition Leadership functions	Communication protocol Feedback/debriefing Conflict management	Resource management Consensus-building Problem definition	Situation awareness Task regulation Affect regulation
Instructional Delivery Technique	Memorization Static practice Consistent Automaticity	←	→	Experimentation Dynamic practice Variable mapping Controlled processing

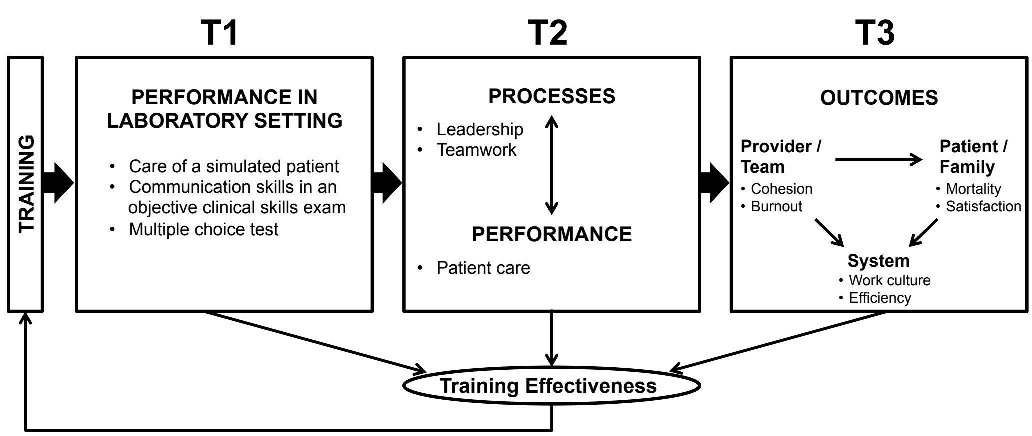
Identifying appropriate level of constructs and variables: A thorough understanding of individual and team performance within complex environments necessitates a multilevel approach to theory-building and outcomes research. Organization-level phenomena emerge through the behavior, perceptions, affect, and interactions of individuals and team. Likewise, individuals and teams are directly influenced by the culture, norms, and structure of the organization. Ignoring the multilevel nature of a construct, intervention, or relationship may result in oversimplification of outcomes and failure to recognize important measurement targets. We developed a multilevel conceptual architecture of adaptation that considers (1) the types of events teams must adapt to (i.e., what type of change is occurring), (2) the types of processes teams use to adapt, and (3) at what level these processes occur. This taxonomy (Figure 3) can help guide the selection of appropriate training targets and can help educators target correct task complexity, appropriate processes (cognitive/behavioral/affective), and direct training and measurement at the correct level (individual, team, unit). Such specificity is important, as being purposeful when designing training will ensure that individuals, teams, and units are prepared for the specific types of adaptation necessary for their work. This level of specificity in training is often overlooked and is not part of current training guidelines. In Attachment 1 we describe training principles related to (1) level of training and (2) specific processes targeted by training. In Attachment 2 we then describe three different task requirements for adaptability and specifically identify training principles associated with each type of task complexity.

Figure 3. Model of task complexity, processes, and level(s) of analysis



Identifying appropriate outcome measures and mechanisms: We noted that training evaluation systems should consider both proximal and distal outcomes. Proximal outcomes include both learning and performance-based outcomes and can include basic declarative knowledge as well as more complex strategic knowledge and performance. Distal outcomes that are trainee-focused include the transfer of learned skills to the work (clinical) environment as well as the application of learned skills to novel situations, i.e., adaptability. High-level distal outcomes include patient, system, and organization-level outcomes. Our literature review focused on the identification of pertinent proximal and distal outcomes. We considered our own systematic reviews as well as other health care team reviews to determine the current state of team assessment. We extended this knowledge by investigating the team science, safety science, and human factors literature. Because our work focuses on developing adaptive expertise, considerable efforts were made to identify outcome measures that reflect adaptive capacity. Subject matter expert review was utilized to help identify where non-health care team assessments can be translated into appropriate health care team training evaluation targets. In Figure 4 we propose a translational simulation-based research model that considers appropriate outcome measures and relationships for individual and team-level adaptability.

Figure 4. Multilevel outcome model for training evaluation



Recommendations for the provision of adaptive feedback: For the purposes of this work, we considered (1) performance measures used for the provision of feedback and (2) training evaluation/outcome metrics used to measure training impact, separately. The provision of feedback is a major focus of this study, with the goal of developing an assessment system capable of supporting embedded, adaptive guidance. We therefore directed our efforts towards developing a conceptual framework to support the content, structure, and provision of adaptive guidance during trauma team simulations. This work relied heavily on the training, education, and debriefing literatures. In Attachment 3 we list feedback principles, scientific rationale, and, where appropriate, exemplars for simulation-based training.

Cross reference feedback principles and team training architecture with TeamSTEPPS terminology: The investigators attended the 2016 IPR held in Fort Detrick, MD. There, they presented preliminary work and received constructive feedback both in person and via written review. Since the IPR, the investigators addressed each point made by the panel and specific comments made by COL. Hopkins-Chadwick during a phone meeting. We added an additional item to our task list (Task 5a) that we feel clarifies our work and improve usability by military units. This task has since been completed and Attachments 1-3 reflect these modifications. We also attach the variables that will be considered for Aim 2 as requested by the 2016 IPR and COL. Hopkins-Chadwick (Attachment 4).

What opportunities for training and professional development has the project provided?
Summarized under Aim 2 below.

How were the results disseminated to communities of interest?
Summarized under Aim 2 below.

What do you plan to do during the next reporting period to accomplish the goals?
Nothing to Report

ACCOMPLISHMENTS – AIM 2

Aim 2. Develop and refine a predictive model of trauma team performance and outcomes for use in an adaptive guidance/feedback system

What were the major goals of the project?
The primary outcome from Aim 2 is a predictive trauma team performance assessment tool that generalizes to teams of varying expertise levels and across civilian and military contexts and is capable of supporting embedded, adaptive guidance during simulation-based team training. Our approach examined the use of Bayesian Belief Networks (BBNs) to support the provision of adaptive, embedded guidance that facilitates development of adaptive expertise and trauma team performance. We utilized existing simulation-based trauma team performance data to construct a BBN that models the relationships between key individual and team characteristics, behavioral outcomes, and patient care events in a previously well-defined and validated simulated scenario. The model leverages the probabilistic interdependencies among these variables to enable educators and/or learners to assess the likelihood of critical team/patient outcomes in the simulated environment. We then incorporated the design architecture conceptual foundations developed in Aims 1a&b to guide the transformation of predictive model data into an adaptive guidance tool. The tasks, timeline, and status of each step associated with Aim 2 are summarized in the table below.

SPECIFIC AIM 2	Timeline (Months)	Status
Task 6: Collection of prospective simulation data		
Subject recruitment	4 – 6	**Completed, 100% completed**
Execute trauma resuscitation simulations	4 – 6	We have completed the simulations necessary for the study; however, we wished to maximize the inclusion of military personnel and therefore continued to enroll military providers through September 2017. This extended enrollment and is one reason we requested a NCE. No additional funds were required to complete this work. **100% Completed**
Train and calibrate raters	6	Rater training has been designed to code new simulations. Existing trauma videos have been coded, with excellent inter-rater reliability. **100% Completed**
Code videos of simulated resuscitations using patient care and teamwork measures	6 – 12	Simulation video processing slightly delayed the initiation of coding; coding is now complete. To ensure timely completion, we hired additional video processors and purchased additional storage to allow more rapid, efficient video processing.

		100% Completed
Transform data into appropriate categorical structure for BBN	9 – 12	We completed initial transformation of existing data into a categorical structure. This was required to execute BBN modeling and required the input of clinical experts. Based on this data transformation, an initial structure for the BBN was constructed using the transformed data (see also Task 8). Choices about data discretization and model structure offer different advantages that the research team continually evaluates, so this process was iterative through Tasks 7 and 8. A second version of the BBN has now been developed based on behavioral clusters identified from existing simulation-based resuscitation performance data. This prototype BBN has been entered into the Netica software for further analysis. **100% Completed**
Milestone(s) Achieved: 1. Team data set of teamwork and patient care performance during trauma resuscitation simulation	12	**100% COMPLETE**
Task 7: Identify and define variables (nodes) for inclusion in team assessment model		
Examination of conceptual frameworks and literature review from Aims 1a and 1b	9 – 12	We have finalized the review of feedback principles to make final decisions regarding when the BBN will be designed to provide information to learners and instructors and in what format the feedback should be delivered. This subtask was delayed by approximately 1 month and is now completed. **100% Completed**
Evaluation of existing experimental dataset to identify and extract variables of interest	9 – 12	We have completed review of all existing datasets. This process resulted in identification of ~150 usable variables for which data is available. We developed protocols for evaluating inclusion/selection of items as variables in the BBN. An initial protocol was used to guide the development of the first prototype BBN (see also Tasks 6, 8), and an additional protocol has been developed to guide the development of a second version of the BBN. This task is on time and completed for the initial BBN and revised BBN. **100% Completed**
Milestone(s) Achieved: 1. Identification of observable measures and latent constructs to be incorporated into the BBN	12	**100% COMPLETED**
Task 8: Design the structure for the prototype BBN team assessment system		
Identify appropriate and parsimonious candidates for the causal structure among the variables	12 – 15	We developed and evaluated multiple possible organizational structures for BBNs. We provided an initial draft of these in the annual report submitted 11/2016 and an updated draft on 06/30/2017. The research team since identified and evaluated three alternative structures of the BBN based on utility of application. The most recent BBN structure (described further below) has been applied to model all events during a trauma simulation. **100% Completed**
Subject matter expert review of variable relationships	12 – 15	To facilitate a thorough and comprehensive SME review, the research team decided to hold the review after the final prototype of the model was completed. As a result, this subtask was accomplished during Q10 as part of finalizing the prototype prior to testing. During Q9, the investigators prepared a document and explanation that would facilitate accurate data gathering from SMEs. **100% Completed**
Milestone(s) Achieved:	15	**100% COMPLETED**

1. Identification of multiple candidate BBNs for the observed variables		
Task 9: Generate initial probability tables for BBN team assessment system		
Transform data into appropriate categorical structure	12 – 15	Based on the proposed BBN structure developed in Task 8, we transformed the dataset into categorical structures that logically developed based upon the clinical content and the BBN prototype structure. Choices about how to discretize certain data and/or whether existing simulations should be recoded to facilitate the model completion were evaluated as the final BBN prototype was completed. This work is completed. **100% Completed**
Explore different learning algorithms	15 – 18	With dataset largely finalized, we imported data into the BBN and evaluated available learning algorithms for construing the necessary conditional probability tables. Results from this step did not reveal substantial differences across the learning algorithms, and thus work will proceed using the most expedient algorithm. **100% Completed**
Assess BBN fit	15 – 18	We have evaluated the sufficiency of the data available to inform the revised BBN prototype. This step revealed a number of variables that were initially included in the BBN that are now candidates for removal given they lack variance in our existing datasets and are thus cannot be used to make predictions/distinctions about teams. Additionally, the revised structure of the BBN now includes latent variables for which there are no data and will require alternative methods for quantifying. These are discussed in the step below, and the results of this step will be used to reevaluate BBN fit/functioning as needed. **100% Completed**
Generate conditional dependencies for latent BBN variables	15 – 18	The revised BBN includes latent variables that identify characteristic patterns/profiles of observed behavior. These profiles can be used to describe and predict the likely behaviors of teams with respect to core team adaptability constructs (information gathering, communication, acting, etc.). To create these profiles, we solicited SME ratings using a swing weighting methodology to allow expert opinion to define the desirability of particular behavioral patterns. A survey task for collecting SME ratings was completed and vetted for usability/interpretation by the research team. The survey was sent out to be completed to SMEs. Data from 6 SMEs was collected, which is sufficient for purposes of generating weights. The data were integrated into the BBN. **100% Completed**
(NEW SUBTASK) Integrate additional data sources to inform meaning of latent BBN variables		To supplement the SME data input for quantifying the meaning of the latent team adaptability variables in the BBN, we incorporated pre-existing team performance and team process data. This step did not require additional data collection **100% Completed**
(NEW SUBTASK) Recode existing videos to provide additional data to provide additional nodes and data for the BBN	24 – 30	This subtask was added based upon early drafts of the BBN. We identified additional items that would support the BBN development and make our process more adaptable to other trauma care events. **100% Completed**
Milestone(s) Achieved: 1. Functional prototype BBN team assessment system	18	**100% COMPLETED**

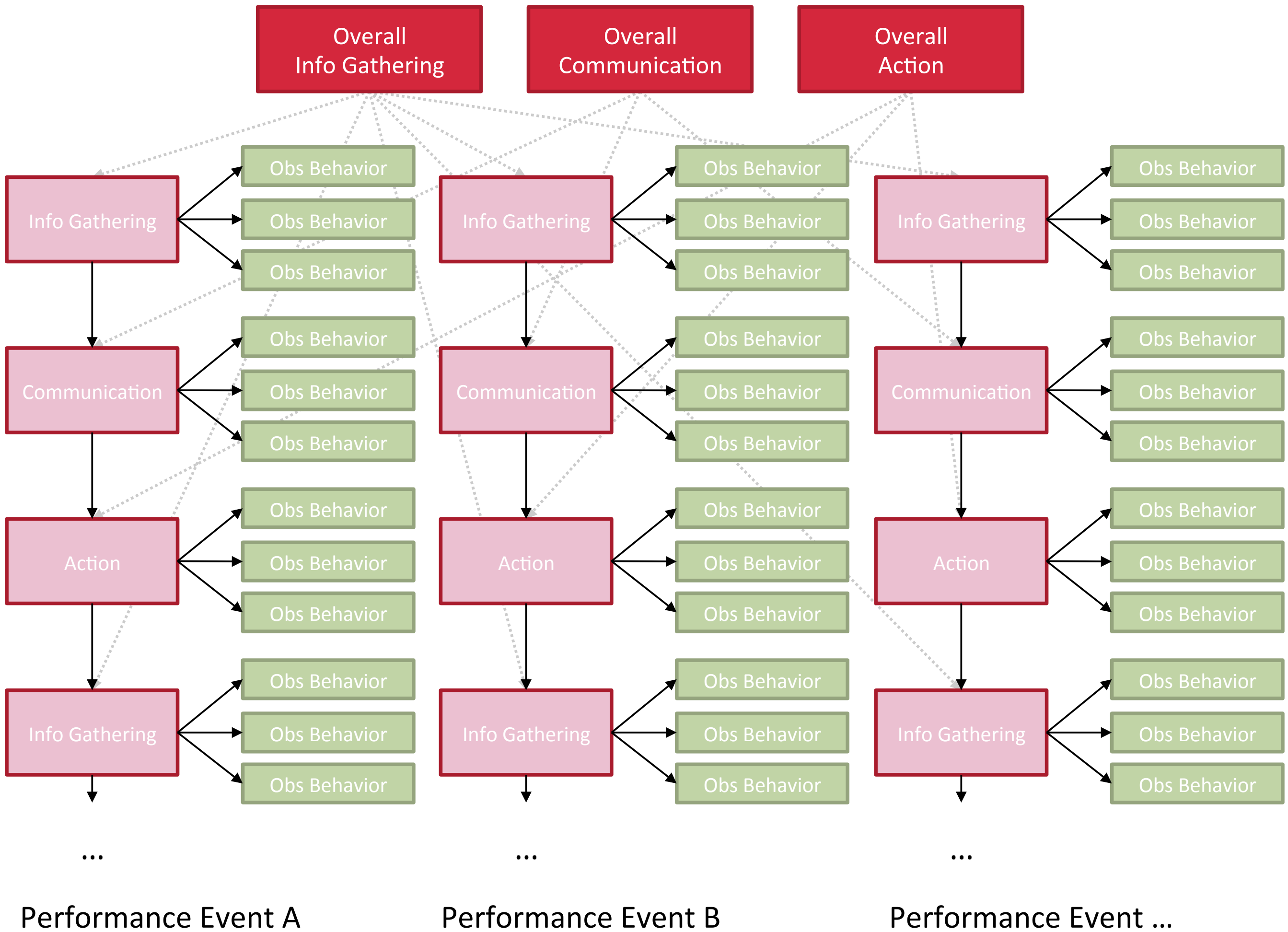
Task 10: BBN team assessment system calibration		
Transform prospective data into appropriate categorical structure for BBN	12 – 15	This process was performed as part of the data analysis from prospective data collection. **100% Completed**
Use prospectively collected data to calibrate BBN	18 – 21	This work was completed at the end of the NCE (PY3) year. Calibration is complete and this task was not delayed once data was available. **100% Completed**
Use subject matter experts and empirical data from the literature review in Aim 1a to adapt the BBN as needed	18 – 21	This work followed the prospective data collection and was performed within the team and with investigators with team science expertise. **100% Completed**
Milestone(s) Achieved: 1. Functional, generalizable prototype BBN trauma team assessment system	21	**100% COMPLETED**
Task 11: Report writing and dissemination		
Submit abstracts to the 2018 Military Health System Research Symposium and the 2019 International Meeting for Simulation in Healthcare	20 – 24	2 abstracts were presented at the 2018 MHSRS, one for each set of Aims. **100% COMPLETED**
Prepare final report and manuscripts	21 – 24	2 manuscripts have been drafted with planned submission within the next month.
Milestone(s) Achieved: 1. Dissemination of methodological approach and empiric findings	24	**In progress, 75% completed**

What was accomplished under these goals?

Trauma Simulations and Performance Coding: The purpose of conducting trauma team simulations was to provide baseline data for the design of the BBN. These simulations were used, along with existing simulation data, to inform the structure of the BBN. Actual trauma resuscitation performance data for both civilian and military trauma team leaders was also considered during BBN development.

BBN Structure: We explored several candidate approaches to BBN design. The overall structure determined to be most informative for the purposes of the project is summarized in Figure 5. Briefly, the adaptive performance model presented in Figure 1 was used to identify three core activities relevant to team adaptation: (1) information gathering (encompassing situation assessment activities relevant to formulating/revising diagnoses and establishing goals and team regulation activities related to monitoring and evaluating team actions/progress); (2) communication (encompassing team regulation activities relevant to planning, preparing, and coordinating team behavior); and (3) action (encompassing team regulation activities relevant to making decisions and carrying out task activities). Observable actions reflecting these core activities can then be identified and associated with these concepts (described below, BBN variables). Lastly, this process can be iterated and the core concepts linked across multiple performance events to permit one to make predictions about a team's overall adaptive capacity. This affords the potential to identify and subsequently provide corrective/reflective feedback around core activities of team adaptation (e.g., situation assessment, planning, action, monitoring) based on observations of a specific performance event that generalizes to potential future events. Such feedback encourages individuals and teams to engage in contingency planning, actively evaluate their performance, and make real-time adjustments as needed (i.e., adapt).

Figure 5. Overall BBN approach



To demonstrate proof of concept and evaluate utility, a full version of the BBN for this structure was built using a reduced number of variables (Attachment 4) and data from an existing dataset. This version of the model spans multiple events (intubation, circulatory support, orthopedic stabilization) from our broader trauma simulation; Figure 6a and 6b provides an example of the model for the intubation event. Goals for the model were to minimize model complexity (i.e., number of modeled relationships); directly map variables/relationships represented in the BBN to the adaptability framework developed in Aim 1; incorporate prediction of medical task performance activities into the model; and provide a straightforward means for incorporating feedback guidance on the basis of model predictions.

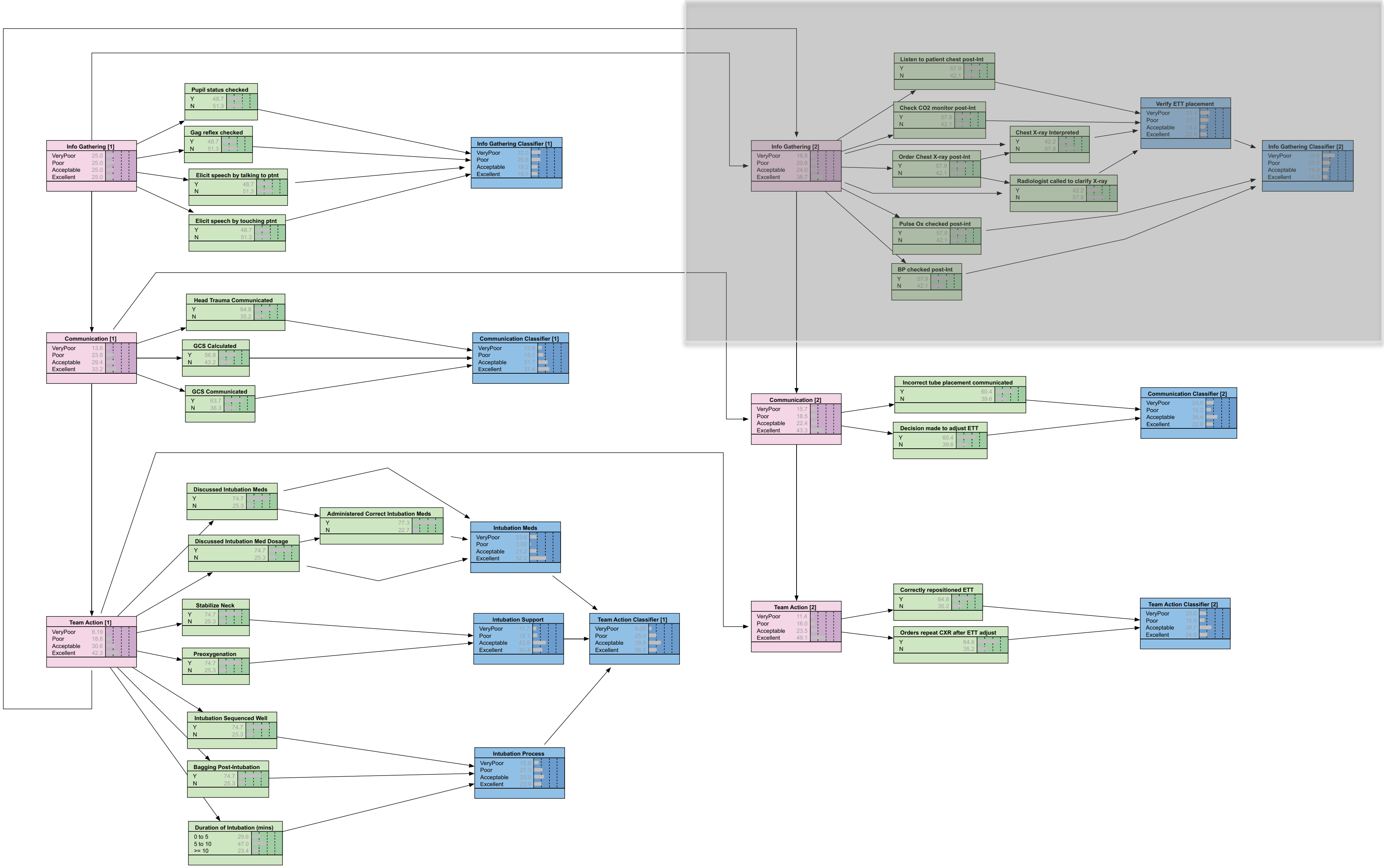
BBN Variables: We reviewed existing datasets for candidate variables appropriate for inclusion in the BBN. This required evaluating over 100 process variables and 80 performance variables. Variables are considered appropriate if there is variability amongst subjects, and if variables correlate with overall performance and process as a whole. A preliminary list of variables was selected and underwent subject matter expert review to determine the appropriateness of variables. We also used subject matter expert input to determine if certain variables should be grouped into composite indicators for inclusion in the BBN. This potentially simplifies BBN input during testing and refinement. Subject matter expert input was collected to help inform some of the meaning of latent team adaptability variables in the BBN. This information was incorporated into the BBN and the model was tested with pre-existing data (see below). Prospective data collection is near completion and relevant data will be included as deemed appropriate by the investigators and subject matter experts.

Generation of Initial Probability Tables for BBN Team Assessment System: The computational "engine" and predictive validity of a BBN relies on the presence of well-informed conditional probability tables (CPTs). A

CPT exists for every node in a BBN and reflects the probability that a particular state for a particular node will be observed given the state of all its parent nodes (e.g., *p*(*Chest Compression Quality* = High | *Assign a Team Leader* = No), etc.). In this sense, CPTs represent the degree of interdependency (i.e., correlation) that exists between variables that share a directed arc. To compute the CPTs for the candidate networks, the investigators utilized their existing dataset to "train" a set of initial conditional probabilities for the modeled variables. This process required several steps. First, data were transformed into an appropriate categorical structure that can be interpreted by a BBN. Next, different learning algorithms were explored (i.e., counting, expectation-maximization, gradient descent) in an attempt to produce the "maximum likelihood BBN," or the set of CPTs that is most likely given the observed data. The fit of the algorithms were assessed using standard model evaluation techniques (e.g., confusion matrix, times surprised, etc.); additionally, these metrics were used to compare candidate BBNs to identify the best fitting model. Finally, in instances where data was unavailable or insufficient to generate a suitable CPT, existing empirical literature (i.e., meta-analyses) and/or subject matter experts generated the nature of the conditional dependence. The result of this step was the best fitting, functional prototype BBN team assessment system based on existing data.

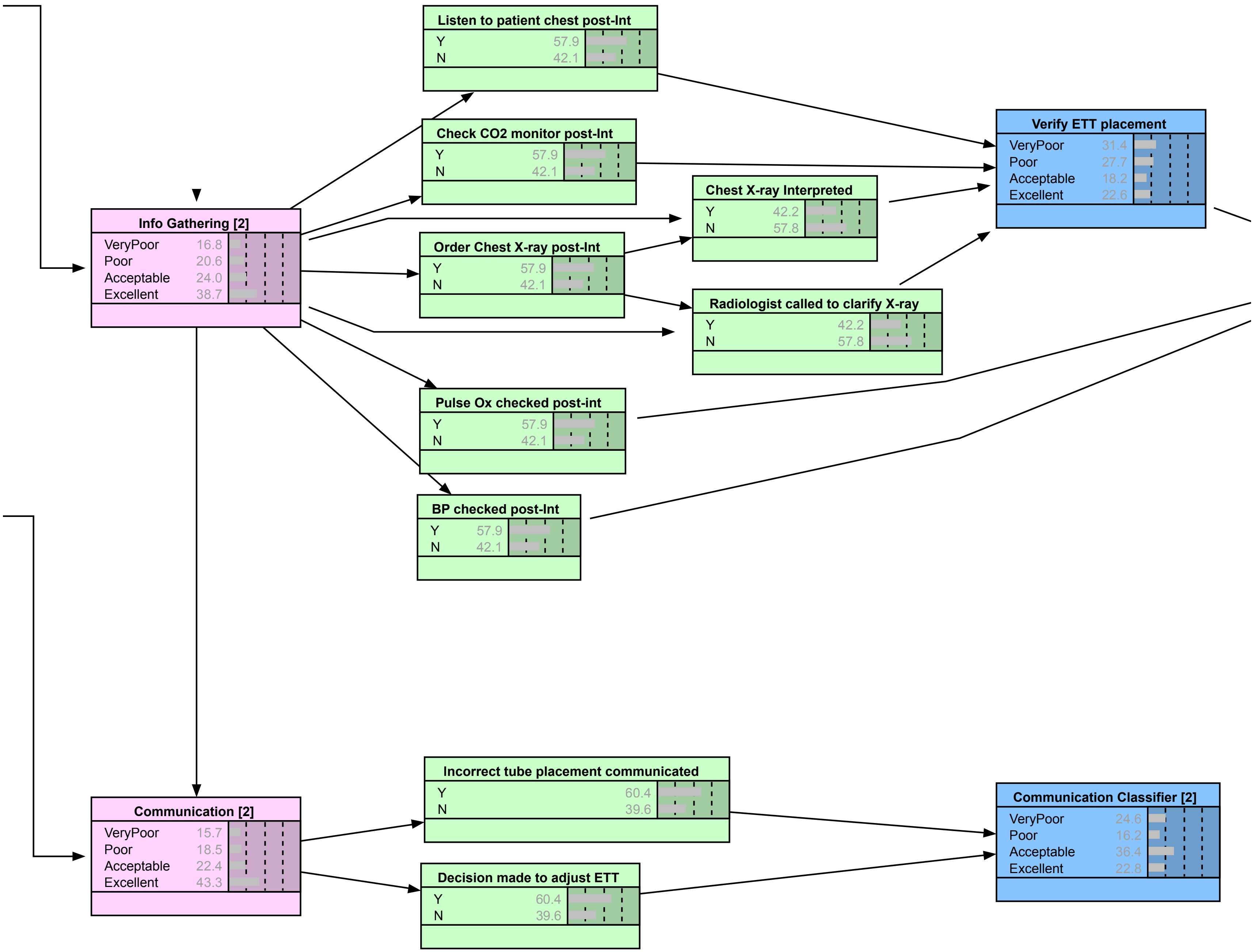
Incorporating Effectiveness Judgments Into BBN Assessment System: The initial version of the BBN included latent variables (i.e., variables for which no data exist but can be estimated) that reflect patterns/profiles of team behavior indicative of core team adaptability constructs (information gathering, communication, decision-making/action). However, an interpretation of each pattern was not known; that is, the BBN was capable of identifying characteristic patterns of behavior a team seems to be following, but could not indicate whether that pattern is desirable/effective vs. undesirable/ineffective. To accomplish this task, we utilized a swing weighting methodology that allowed expert opinion to define the desirability of particular behavioral patterns. This procedure required SMEs to rate the desirability/effectiveness of particular behavioral patterns and uses that information to empirically derive a rank-ordering among the latent patterns in the BBN. The survey rating task for gathering SME ratings was finalized and data collected from 6 SMEs. This sample size was sufficient for purposes of model development and we have thus concluded SME data collection. We cleaned the data for analysis and integrated the weights into the BBN. The final BBN model is included in Attachment 5.

Figure 6a. Sample of BBN structure applied to single performance event (intubation)



*Area in grey expanded in Figure 6b

Figure 6b. Information gathering and communication subcomponents of a single performance event (intubation)



What opportunities for training and professional development has the project provided?
Subjects enrolled in the study received simulation-based trauma team training and assessments. While the provision of training is not a major focus of this project, trainees were able to practice trauma management skills as well as leadership skills under difficult conditions requiring significant individual and team adaptation.

The project supported a graduate student (Benjamin Levine) for three years. During that time, the student worked closely with the PIs on all aspects of the project. The student developed content expertise in the domains of adaptive performance, training design, and performance feedback through conducting/synthesizing the literature review performed for Aim 1 of the project. Additionally, he was trained and worked on the development and validation activities for the BBN for Aim 2 of the project. As part of this work, the student learned how to construct a BBN, best practices for using this methodology, and how to design validation protocols for examining their predictive capabilities. The funding and training provided by the grant also provided this student with the opportunity to attend and participate in multiple conferences as well as the in-progress review meetings. These activities provided an opportunity to learn about and gain practice preparing, translating, and presenting advanced scientific concepts to a professional audience.

The project also provided support for a junior/pre-tenure PI (Dr. James Grand) for three years. In addition to furthering his substantive and methodological expertise, Dr. Grand worked closely with and was advised by the senior PI (Fernandez) on critical aspects of grant and project management, including grant writing, budget preparation, and reporting. Dr. Grand also gained experience preparing and delivering the annual in-progress review presentations to the program officers at Fort Detrick as well as presenting at multiple professional conferences both in his profession (organizational psychology) and emergency medicine. Collectively, these activities greatly benefited Dr. Grand's professional development and experience securing and conducting sponsored research.

How were the results disseminated to communities of interest?
We presented work from Aims 1a, 1b (Attachment 5) and Aim 2 (Attachment 6) at the 2018 Military Health System Research Symposium in Orlando, FL. Regarding Aims 1a and 1b we are preparing two manuscripts, one describing our frameworks, training principles, and concepts related to adaptability (see draft, Attachment 8) and a second related to the provision of adaptive feedback. Adaptive feedback is a relatively new concept within medical simulation and one that needs to be considered within the growing literature around debriefing and the provision of performance-related information. There is a special issue of *Simulation in Healthcare* that will focus on debriefing. We feel this is an excellent target for this work and thus are delaying submission for that special issue.

The Aim 2 focused manuscript is in preparation. A detailed outline is provided in Attachment 9. We plan to submit this methods paper to *Organizational Research Methods* or *Psychological Methods*. A manuscript describing application of BBNs to simulation will be submitted to *Simulation in Healthcare*.

What do you plan to do during the next reporting period to accomplish the goals?
Nothing to Report

IMPACT

What was the impact on the development of the principal discipline(s) of the project?

Previous Knowledge Gap Current healthcare team training and performance frameworks are incomplete and generic in content and focus; they do not fully consider critical training antecedents (individual, team, environmental factors), training design elements, or appropriate outcome metrics for developing highly effective, adaptive teams.

Immediate Impact **We now provide the fundamental knowledge, frameworks, and architectural design to support the future development of an interactive team performance training system that can assess the downstream effects of the individual's, as well as the team's, behaviors and medical decisions on patient safety outcomes.** The framework and design architecture developed through this work clearly defines how critical design elements influence individual and team learning, performance, and adaptive capabilities. This work will provide military and civilian healthcare providers and educators with clear guidelines for the development of training that builds adaptive capacity. Specifically, we provide developmentally appropriate training targets for individuals and teams. We identify what training content and delivery method is most appropriate for developing adaptive behaviors around certain types of tasks. We recognize that frontline medics adapt to different situations than physicians in specialty clinics and our guidelines account for these differences. We aim to provide a clear, easily applied method to help educators and trainers make decisions regarding training development and implementation. Our work will facilitate the development of longitudinal curricula across multiple specialties and disciplines by providing clear training targets for individuals and teams at all levels of performance.

Previous Knowledge Gap Existing assessment tools cannot provide the type of feedback, i.e., adaptive guidance, critical to the development of adaptive expertise within effective healthcare teams.

Immediate Impact **The guidelines and principles for adaptive feedback introduce a new and important concept to healthcare.** The provision of "feedback" and "debriefing" in experiential training has been identified as critical to learning. However, the role for adaptive feedback in the development of highly adaptive teams has not been described. Our work fills this knowledge gap. We will disseminate our review of the topic along with specific recommendations for implementation within simulation-based training. Along with the BBN assessment prototype developed in Aim 2, this information provides the foundation for the development of simulation-based training with automated, adaptive feedback.

We describe a predictive performance assessment mechanism capable of supporting the provision of adaptive guidance during simulation-based team training. developed a predictive model of trauma team performance. This work uses Bayesian Belief Networks to translate measures of team performance and patient care into a model that considers team behavioral patterns and makes suggestions about changes in behavior that will encourage adaptability and optimize future performance. **Our work represents a crucial step in the development of interactive medical simulation systems with automated assessment capabilities.** Without this work, assessments cannot provide the future-oriented, adaptive guidance needed to optimize training effectiveness and the development of adaptive expertise critical for civilian and military healthcare teams.

Long-Term Impact **Our long-term goal is to improve patient safety and reduce medical errors by developing training and assessment systems based on rigorously validated and evidence-based models of team effectiveness.** A robust body of team training and assessment research complements the completed research study. We will present a framework for high level training development as well as the components (scenario, measures, predictive model) necessary to move forward with the development of an integrated, automated simulation system. Additionally, the conceptual work we propose in Aims 1a and 1b clearly delineates important proximal and distal outcome targets for learners. We are uniquely positioned to conduct future work evaluating how embedded, adaptive guidance affects team performance and improves patient safety and outcomes.

Military Impact **The provision of emergency care in a combat situation mandates extreme proficiency in adaptability, making this work highly relevant to military healthcare.** Our approach is generalizable across both military and civilian applications. The focus on adaptive expertise specifically targets the austere environments encountered by tactical medics and forward units. Training that targets adaptability will contribute to both individual and team effectiveness in situations beyond those experienced in simulated environments. The outcomes from this project will **benefit the general public** by providing highly effective training mechanisms to target healthcare team adaptability and minimize adverse events. Our work is synergistic with existing training programs (e.g., TeamSTEPPS) and adaptable to other healthcare teams and settings. Additionally, the proposed work will decrease costs associated with developing suboptimal, less effective training systems.

What was the impact on other disciplines?

Our work has impact beyond healthcare. We highlight the challenges associated with training and evaluating performance in complex environments. This information is useful in human factors and organizational psychology, where teamwork has often been considered a static construct, rather than a dynamic entity where teams learn, adapt, and react to continuous changes in the task, environment, and team. Our framework highlights how important it is to consider characteristics of the task(s) necessitating adaptation when developing training programs. This work provides a foundation to build more comprehensive training that goes beyond TeamSTEPPS-type training to impact complex teams performing in highly dynamic, potentially dangerous situations. Additionally, the application of BBNs as an analytical framework has primarily been restricted to problem domains within engineering and ecology. The use of these techniques for modeling individual and team behavior as well as for guiding the delivery of feedback is both novel and highly generalizable.

With respect to healthcare applications, the application of BBNs we have pursued to model team performance can be extended to all disciplines within healthcare, including forward military units, ambulatory care centers, and long-term rehabilitation units. The use of adaptive guidance can be incorporated into automated, online training as well as mannequin-based simulation curricula.

What was the impact on technology transfer?

Our work necessitates partnership with commercial technology to advance to the next stage, namely incorporating the BBN-driven algorithm into a computer simulated platform to support embedded feedback. If agreeable to the CDMRP, we will seek to continue this work by identifying a strong industry partner and providing a test bed for the integrated components.

What was the impact on society beyond science and technology?

Failure to adapt to rapidly changing conditions is a primary cause of medical error. In military settings, such failures can also lead to significant harm to providers. Our work has a significant impact on patient safety, decreasing soldier morbidity and mortality, and on patient satisfaction. Simulation is a key modality leveraged by the military to advance expertise and ensure that soldiers receive the highest level of clinical care. Significant human and technological resources are dedicated to developing and implementing rigorously tested, high-quality simulation-based curricula. Clear guidelines and a training framework focused on developing adaptive capacity did not exist. We fill this gap and, in doing so, provide an important mechanism to support the development and implementation of highly effective individual and team-level healthcare training. While the proposed work involved conceptual and theoretical design, the necessary next steps will provide an integrated computer-based simulation training platform that can be disseminated world-wide to provide distributed training across multiple healthcare providers throughout the civilian and military systems.

CHANGES/PROBLEMS

Changes in approach and reasons for change

None

Actual or anticipated problems or delays and actions or plans to resolve them

PI Relocation: The PI, Rosemarie Fernandez relocated to the University of Florida- Jacksonville at the beginning of January 2018. This move did not change the scope of the work to be completed nor result in any changes to the budget. However, there were delays in establishing a subcontract at the University of Florida, thus work was delayed. At the recommendation of the Department of Defense, we applied for a second NCE through 3/2019 which was recently awarded. We completed all work during the NCE year.

Simulation coding delay: Coding of simulated and trauma team performance was delayed due to delays in establishing the subcontract at the University of Florida. To augment simulation coding, we added a co-investigator (A. Crichlow) to the research team as well as project coordinator Joseph Shuluk. We were able to do this while staying within the proposed budget. This work was completed within the NCE year.

Dissemination: We had hoped to have all manuscripts submitted prior to the completion of the grant. We presented our work at the 2018 Military Health System Research Symposium and provide manuscript drafts in our Attachments.

Changes that had a significant impact on expenditures

None

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

None

PRODUCTS

Publications, conference papers, and presentations

1. **Fernandez R**, Grand JA: Leveraging Social Science-Healthcare Collaborations to Improve Teamwork and Patient Safety. *Curr Probl Pediatr Adolesc Health Care*, 2015; 45(12):370-377. PubMed PMID: 26573242. (Attachment 10)
2. Fernandez R, Shah S, Rosenman ED, Kozlowski SWJ, Parker SH, Grand JA. Developing team cognition: A role for simulation. *Simul Healthc*. 2017, 12(2):96-103. (Attachment 11)
3. McCusker ME, Parker SH, Perry SKB, Fernandez R, Grand JA, Pappada SM. Research methods for healthcare teams: Technology, opportunities and lessons learned. *2018 Society for Industrial and Organizational Psychology*, Chicago, IL.
4. Using simulation to develop adaptive capacity in individuals and teams: 10 key principles for training design (In preparation; Attachment 8)
5. Using Bayesian Belief Networks to inform team training: A methodology and healthcare trauma team exemplar (In preparation; Attachment 9)

Military meetings (* indicates manuscript resulted)

1. *Fernandez R, Rosenman ER; Santoro J, Pacic E, Golden SJ, Brolliar SM, Chao GT, Grand JA, Kozlowski SWJ. A multicenter, observational study of teamwork, team cognition, and leadership. *2016 Military Health System Research Symposium*, Orlando, FL. (Attachment 12)
2. *Fernandez R, Rosenman ED, Brolliar S, Kozlowski SWJ, Chao GT, Levine B, Grand JA. Development of an integrated team training design architecture to support adaptability in healthcare teams. *2018 Military Health System Research Symposium,* Orlando, FL. (Attachment 6)
3. *Levine B, Grand JA, Fernandez R, Rosenman ED, Brolliar S, Kozlowski SWJ, Chao GT. Development of a generalizable method for assessing, predicting, and improving team adaptability. *2018 Military Health System Research Symposium,* Orlando, FL. (Attachment 7)

Other Products
None

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Elizabeth Rosenman, MD
Principal Investigator
No Change

Rosemarie Fernandez, MD
Co-Principal Investigator
No Change

James Grand, PhD
Co-Principal Investigator
No Change

Georgia Chao, PhD
Co-Investigator
No Change

CPT. Lindsay K. Grubish, DO
Military investigator
No Change

Marie Vrablik, MD
Co-Investigator
No Change

Colleen Kalynych, EdD
Project Manager / Co-investigator
No Change

Ly Huynh, BA
Research assistant
No Change

Benjamin Levine, BA
Graduate student research assistant
No Change

Jessica Santoro, MA
Graduate student research assistant
No Change

Joseph Shuluk, BA
Subproject coordinator – University of Florida
No Change

Student Hourly Employees (all assisted with video processing and coding)
Nicole Freyholtz: 3.6 calendar months
Callum McCulloch: 3.1 calendar months
Lauren Donahue: 1.9 calendar months
Brian Le: 0.5 calendar months

Has there been a change in the active other support of the PD/PIs or senior/key personnel since the last reporting period?

No

What other organizations were involved as partners?

University of Maryland
Department of Psychology
College Park, Maryland
The Co-PI, Dr. Grand, and a graduate student, Mr. Benjamin Levine, are both supported at the University of Maryland. There, they have office space, computer access, and support for virtual meetings with the research team.

Madigan Army Medical Center
9040 Jackson Ave.
Tacoma, WA 98431
Co-I: CAPT. L. Grubish
CAPT. Grubish will assist with subject matter expert queries and will also assist with simulations and performance coding.

Eli Broad College of Business / Michigan State University
East Lansing, Michigan
Dr. Chao (collaborator) and a graduate student, Ms. Jessica Santoro, are both supported at Michigan State University. There, they have office space, computer access, and support for virtual meetings with the research team.

University of Florida – Jacksonville
Department of Emergency Medicine
Jacksonville, FL
Dr. Fernandez recently relocated to the University of Florida. She continues to co-lead the project and is working with Dr. Crichlow at her site to complete simulation and performance coding.

SPECIAL REPORTING REQUIREMENTS

QUAD CHART
Please see Attachment 13 for updated Quad Chart.

ATTACHMENTS

Attachment 1: Training principles to target adaptive processes at different levels.

Principle and Applicable Level(s)	Rationale	Simulation application	TeamSTEPPS Associations
Use pre-training materials to provide appropriate orientation to trainees. (Individual Level)	Pre-training materials presented at the start of training provide an initial organizing structure of the subject matter discussed in training. Pre-training materials provide conceptual information, help to build connections between similar ideas, and delineate different concepts from one another. Trainees who use or begin to develop their own pre-training materials are more likely to adaptively transfer knowledge and skills.	• Inform trainees about training focus. This does not necessarily mean informing them of key critical content planned for simulations; rather, tell trainees they will be focusing on team (or individual) skills • Suggest that trainees consider personal strengths and weaknesses prior to coming to training.	• No associations
Promote trainees to have a learning goal orientation during training. (Individual and Team Level)	Training design that promotes a learning goal orientation (e.g., a focus on self-improvement and task mastery in achievement situations) has been linked to positive training outcomes, such as goal setting, self-regulatory activities, learning, and performance. This is in stark contrast to promoting a performance goal orientation (e.g., a focus on demonstrating ability to others in achievement situations) which has been shown to negatively relate to goal striving processes and performance.	• Promote a learning goal orientation by encouraging trainees to set goals about achieving learning objectives and acquiring relevant knowledge and skills. • Establish psychological safety	• Psychological safety is about being able to take interpersonal risks on a team. The concept of psychological safety has similarity to TeamSTEPPS' mutual trust dimensions of "advocacy and assertion" and "two-challenge rule". These two dimensions discuss the role of speaking up about decisions being made within the team. The advocacy and assertion piece asks team members to voice new viewpoints that clash with the leader's viewpoint. They are asked to assert themselves firmly and respectfully. The two-challenge rule piece describes that if an initial assertion goes unanswered, the team member should assert at least twice to ensure their viewpoint is heard. (Ferguson, p. 123)
Trainees should be provided with higher-level coordination strategy instruction later in training once appropriate foundational knowledge has been developed. (Individual)	The KSAs required to effectively engage in individual and team adaptation are advanced learning outcomes. Without achieving proficiency in the basic and procedural knowledge necessary to carry out core task/job requirements in a domain, efforts to improve the adaptation process will be less effective.	• Assess individuals for team-based simulation "readiness" • Use low fidelity non-clinical simulations to begin building team skills while individuals are still developing clinical knowledge. • At this stage, interdisciplinary training is not important; however institutions should ensure consistency of curriculum across professions/units/schools	• No associations

Adopt a **Crawl-Walk-Run** approach to training design. Training material should be structured so that instruction proceeds from general to detailed, specific to complex. (Individual and Team Level)	Successful team adaptation requires integrating, coordinating, and regulating a variety of different KSAs, resources, and members. Developing the capacities to manage these processes should be built around a Crawl-Walk-Run curriculum model to allow learners to first achieve basic competencies and then practice/engage in more complex applications. Note that this also applies to actively training members as part of intact teams -- team-based training designed to enhance adaptability is a complex environment and should be postponed until learners have engaged in more foundational training exercises.	• Team-based simulations should initially use basic clinical scenarios rather than unusual or highly complex situations. Once basic team skills have transferred from "non-clinical" simulations (above) to straightforward clinical issues, more complex team and environmental issues can be added. • Use EBAT to create a simulation experience where modules can be added to model more complexity as well as to target specific team skills.	• No associations
Trainees learning a complex task should be encouraged to monitor rate of learning progress rather than just learning performance. (Individual Level)	Training that emphasizes learning trajectories, development, and velocity is more likely to minimize goal abandonment, promote self-efficacy, and encourage trainees to view training as "learning" rather than "evaluation." Additionally, emphasizing "future-focused" cognitive appraisals (i.e., focusing on how learning outcomes/capabilities are evolving) reinforces the cognitive appraisal frames critical to team adaptation.	• During pre-brief, make it clear to learners that there may be no "right answer". • Establish a learning environment that supports psychological safety. • If using a modular EBAT approach, consider guiding teams to recognize how similar problems were addressed in the past so they can monitor their progress.	• Psychological safety is about being able to take interpersonal risks on a team. The concept of psychological safety has similarity to TeamSTEPPS' mutual trust dimensions of "advocacy and assertion" and "two-challenge rule". These two dimensions discuss the role of speaking up about decisions being made within the team. The advocacy and assertion piece asks team members to voice new viewpoints that clash with the leader's viewpoint. They are asked to assert themselves firmly and respectfully. The two-challenge rule piece describes that if an initial assertion goes unanswered, the team member should assert at least twice to ensure their viewpoint is heard. (Ferguson, p. 123)
Trainees learning complex tasks should be provided with proximal subgoals that break the task into smaller parts. (Individual and Team Level)	Team adaptation is a process characterized by an ongoing cycle of situation assessment and team/task management. The KSAs which underlie successfully execution of these stages can be developed through "part-learning" and by breaking the adaptation process into meaningful chunks. This approach is more likely to increase learner self-efficacy and persistence, and allow practice opportunities & feedback to be tailored towards more focused learning objectives.	• Break down adaptive behaviors into clear activities that can be practiced in isolation. If necessary, remove learners from the clinical setting to work on key activities prior to re-entering a high-fidelity simulation.	• No associations

Trainees presented with extremely difficult problems that appear unsolvable should be assisted in making some consistent progress during training. (Individual Level)	The structure of the training environment and practice opportunities for team adaptability should not be "sink or swim" (esp. during initial stages of practice). Feedback and direction that actively guides teams through how to think through a complex task and make decisions about resources is a critical foundation of team adaptability training. Providing guidance that prompts teams to explore options for task completion during training helps to avoid discouragement, anxiety, and abandonment of effort.	• Use triggers and backup triggers during simulations to allow learners to attempt the behavior and, if unsuccessful, observe an "expert" (confederate) execute the behavior with success. • Junior learners that may lack clinical knowledge should be encouraged to seek assistance for help at any time. Using confederates as "mentors" can not only assist learners through difficult tasks but also will build comfort with seeking help from other team members and those outside the team.	• In performance episodes, task assistance occurs through TeamSTEPPS' mutual support tool when "team members foster a climate where it is expected that assistance will be actively sought and offered" (Ferguson, p. 123)
Variability in practice trials should be provided during training to maximize retention & transfer. (Individual and Team Level)	Whereas early stages of training are enhanced by repetition and rehearsal (i.e., developing declarative & procedural knowledge), advanced stages of training are enhanced by exposing trainees to as diverse an array of scenarios in which to apply their KSAs as possible. It is particularly critical to expose trainees to situations where previously learned, frequently used, and/or typically reliable courses of action are ineffective. Providing variability in practice trials promotes the development of broader associative knowledge structures and contingency-based thinking.	• Use EBAT to build simulations that contain appropriate task complexity • Shorten intervals between prompts to increase time pressures as appropriate. • Use confederates to add interpersonal challenges. • Build in environmental challenges (e.g., additional patients, equipment failure) to increase complexity	• No associations
Training should be permissive of, embrace, and even encourage errors made by learners during training. (Individual and Team Level)	Errors are an inevitable component of real-world performance. Errorless training leads to effective training performance, but is often related to poor training transfer. Although errors during training should be brought to learners' attention, learning that is focused on error management as opposed to error prevention is more successful. Framing training as an opportunity to make and learn from errors encourages trainees to develop problem-solving or hypothesis-testing skills and strategies for managing affective responses (e.g., frustration and anxiety).	• Use confederates to "force" errors during simulations. This requires considerable expertise in debriefing to ensure learners do not feel "tricked". Appropriate pre-briefing and establishment of a learning environment can help. Be sure that "errors" meet a minimum level of psychological fidelity for learners.	TeamSTEPPS takes a slightly different view of errors and does not specifically address the use of errors in training. • TeamSTEPPS argues that *performance* should be error free, but does not talk about the conditions for training. They advocate for situation monitoring whereby team members monitor the actions of other team members for the purpose of reducing and avoiding errors. (Ferguson, p. 123) • TeamSTEPPS would advocate for team members to monitor the environment to look for these errors so that they are caught "quickly and easily". They encourage for team members to watch each other's backs.

Incorporate lessons on how to alter coordination strategies in training. (Team Level)	When task demands are low, trainees should learn to discuss possible problems that could arise later in the task. By discussing their coordination strategies during this period, they will likely reduce the amount of communication necessary to achieve successful team performance later and allow them to be adaptive when novel problems arise in the environment.	• Encourage learners to develop contingency plans • Discuss team member understanding and mental model development during debriefing to help reinforce the importance of discussing and practicing team coordination	• TeamSTEPPS offers the leadership tool called the "brief", which is a "short session prior to start to share the plan, discuss team formation, assign roles and responsibilities, establish expectations and climate, anticipate outcomes and likely contingencies". (Pocket Guide, p. 16) • Use of the term "mental model" is consistent with TeamSTEPPS language. A situation monitoring tool is the shared mental model, which Ferguson defines as "the perception of, understanding of, or knowledge about a situation or process that is share among team members through communication. Having team members on the same page is the desired team outcome." (p. 123) • Debriefing in TeamSTEPPS is referred to as "Process improvement – Debrief" where an after-action review is used "to provide feedback and improve team performance". (Ferguson, p. 123)
Integrate metacognitive prompts into training. (Individual Level)	Metacognition is the process of actively reflecting on one's thought processes. Encouraging metacognitive activity during training can help learners identify and focus on the goals, assumptions, and strategies guiding their decision-making and task performance. This is especially important for less experienced trainees learning to perform in complex and dynamic environments and who may struggle with such "big picture" thinking.	• Employ "think aloud" protocols during simulation-based training in which the trainee verbalizes their thought process during practice • Build in opportunities for more frequent huddles during simulation-based training in which the trainee is prompted to explicitly discuss their rationale for previous decisions and considerations for future plans.	• TeamSTEPPS encourages talking out loud even during performance episodes. It's referred to as a "call-out" where team members are informed simultaneously. While this isn't a "thinking" procedure, the two methods are similar in the way that they are performed.

Attachment 2. Identifying Task Complexity and Associated Best Practice Training Principles

<u>Adapting to changes in Component complexity</u> Changes in number and/or difficulty of tasks		**<u>Adapting to changes in Coordinative complexity</u>** Changes in sequencing, prioritization, & interdependence among tasks		**<u>Adapting to changes in Dynamic complexity</u>** Volatility in component & coordinative complexity within a task	
Principle	**Rationale**	**Principle**	**Rationale**	**Principle**	**Rationale**
Trainees should not be provided complex coordinative instruction until later in training	Emphasizing breaking down tasks into subtasks and how to complete small numbers of simple, manageable tasks during early knowledge/skill acquisition promotes self-efficacy and draws focus away from premature comparative & normative evaluations	Trainees should not be provided complex, coordinative instruction until later in training	Shifting training towards prioritization, how to develop contingencies*, and managing distal vs. proximal goals once trainees have achieved proficiency in basic knowledge and skill promotes mastery learning and promotes "big picture" thinking	Trainees should not be provided complex, coordinative instruction until later in training	Shifting training towards recognizing when change is needed and when/how to implement contingencies* focuses trainees appropriately on normative expectations and being proactive.
Training material should be structured so that instruction proceeds from general to detailed, specific to complex	Training experiences should support trainees learning to deal with few/simple tasks --> more/simple tasks --> few/difficult tasks --> more/difficult tasks. This enables training/feedback to focus on quantity vs. complexity of tasks, which pose different considerations	Training material should be structured so that instruction proceeds from general to detailed, specific to complex	Training experiences should support trainees learn to deal with few/simple tasks --> more/simple tasks --> few/difficult tasks --> more/difficult tasks. This enables training/feedback to focus on quantity vs. complexity of tasks, which pose different considerations	Training material should be structured so that instruction proceeds from general to detailed, specific to complex	Training that allows practice shifting from few/simple tasks to more/complex tasks *within the learning environment* allows learners to practice situation assessment and task regulation cycles under different demands
Trainees learning a complex task should be encouraged to monitor rate of learning progress rather than just learning performance	Focusing feedback on how and what KSAs trainees have developed that **involve managing different quantities of tasks** minimizes goal abandonment and promotes learning how to deal with situations where resources (time, persons, etc.) are strained	Trainees learning a complex task should be encouraged to monitor rate of learning progress rather than just learning performance	Focusing feedback on how and what KSAs trainees have developed that **involve managing tasks with fewer vs. more interdependencies and considerations** minimizes goal abandonment and promotes learning how to deal with situations where resources must be highly coordinated	Trainees learning a complex task should be encouraged to monitor rate of learning progress rather than just learning performance	Focusing feedback on how and what KSAs trainees have developed that are **involve managing sudden changes in task demands** minimizes goal abandonment and promotes learning how to deal with situations where resources must be quickly assessed, gathered, and distributed
Provide & emphasize proximal subgoals that allows trainees to break task down into	Focusing on how to deal with multiple competing demands and strained resources improves capacity to manage tasks	Provide & emphasize proximal subgoals that allows trainees to break task down into	Focusing on how to prioritize and structure task activity improves capacity to make informed decisions & communicate what must be	Provide & emphasize proximal subgoals that allows trainees to break task down into	Focusing on how to deal with variability in task demands/resources within a single performance event improves capacity to shape

Adapting to changes in Component complexity Changes in number and/or difficulty of tasks		**Adapting to changes in Coordinative complexity** Changes in sequencing, prioritization, & interdependence among tasks		**Adapting to changes in Dynamic complexity** Volatility in component & coordinative complexity within a task	
Principle	**Rationale**	**Principle**	**Rationale**	**Principle**	**Rationale**
manageable components	where demands >= supply	manageable components	accomplished to reach task goals	manageable components	and implement contingencies*
Variability in practice trials / simulated clinical events should be provided during training to maximize retention & transfer	Practicing multiple situations with fewer/simple, fewer/difficult, more/simple, more/difficult exposes trainees to more exemplars, prepares them for more situations, and encourages flexible modes of thinking/problem-solving (Crawl-Walk-Run)	Variability in practice trials / simulated clinical events should be provided during training to maximize retention & transfer	Practicing multiple situations with fewer/simple, fewer/difficult, more/simple, more/difficult exposes trainees to more exemplars, prepares them for more situations, and encourages flexible modes of thinking/problem-solving (Crawl-Walk-Run)	Variability in practice trials / simulated clinical events should be provided during training to maximize retention & transfer	Practicing situations that transition from fewer/simple, fewer/difficult, more/simple, more/difficult *within the learning environment* exposes trainees to more exemplars, prepares them for more situations, and encourages flexible modes of thinking/problem-solving (Crawl-Walk-Run)
Trainees should be encouraged to experience errors	Errors of omission & commission are common stimulus for adaptation.* Placing trainees in situations where few vs. many, little vs. big, salient vs. subtle, etc. errors are likely and/or have happened reinforces situation awareness and decision-making skills in unexpected and unplanned situations	Trainees should be encouraged to experience errors	Errors of omission commission are common stimuli for adaptation. Placing trainees in situations where errors push them down a wrong path reinforces situation awareness and decision-making skills in unexpected and unplanned situations	Trainees should be encouraged to experience errors	Errors of omission & commission are common stimuli for adaptation. Placing trainees in situations where tasks change suddenly and errors are more likely reinforces situation awareness and decision-making skills in unexpected and unplanned situations

*TeamSTEPPS includes several concepts that are consistent with the material above. Specifically, TeamSTEPPS supports the idea of a "brief" where planning behaviors support the ability of teams to prioritize their work and develop contingency plans that facilitate the ability to adapt quickly in response to changes. TeamSTEPPS also emphasizes monitoring behaviors, which enable teams to detect changes that require them to adapt their approach. TeamSTEPPS also describes the need to monitor team members to help prevent errors. Key TeamSTEPPS concepts are summarized here:

Brief: Encourages team members to share their **plan**, assign roles and responsibilities, anticipate outcomes and likely contingencies. (Pocket Guide, p. 16)
Monitoring: TeamSTEPPS' situation monitoring refers to monitoring "progress toward goals and identifying changes that could alter the plan." TeamSTEPPS encourages team members to monitor their environments for errors. Specifically, situation monitoring includes monitoring "fellow team members to ensure safety and prevent errors" (Pocket Guide, p. 32)
Leadership: TeamSTEPPS believes that effective team leaders should organize the team, identify clear goals, assign tasks and responsibility, monitor and modify the plan, communicate changes to the plan, provide feedback when needed, manage and allocate resources, and facilitate information sharing. (Pocket Guide, p. 15)

Attachment 3. Principles of providing adaptive feedback

Principle 1. Trainees should be provided with accurate and credible feedback.

Ensuring feedback is accurate helps trainees understand what task behaviors need improvement. Making feedback credible/authentic improves the likelihood that trainees perceive the feedback as something important to which they should attend. There are instances in which the accuracy of feedback should be "altered" if it benefits self-efficacy and effort of trainees (e.g., learning a complex task that results in many mistakes, poor training performance, etc.) TeamSTEPPS and other training programs support the provision of feedback but do not provide concrete recommendations to ensure delivery of *adaptive* feedback.

Simulation Recommendations:

- Explain learning objectives to trainees and explain clear benchmarks for performance. By setting benchmarks, trainees can see where their performance gaps lie. Setting benchmarks also helps ensure feedback is diagnostic.
- The feedback facilitator should have significant skill in debriefing techniques.
- Consider pairing a content expert with feedback expert when needed

Principle 2. The frequency and timing of feedback should be appropriately tailored to trainees and the goal of training.

In general, directive, immediate, and frequent feedback tends to facilitate the acquisition of declarative & procedural knowledge and improve learner's self-efficacy. However, when the goal of training is to promote how to identify and handle errors and/or develop strategies and contingency-based thinking, feedback should be less frequent to discourage trainees from assuming there is "one correct answer" they should be learning.

Simulation Recommendations:

- Process feedback should be more frequent than outcome feedback
- With more experienced teams, moving from a formalized feedback to facilitation of a high-level debrief that allows objectives to emerge based on performance and team challenges might be more appropriate
- When performing a more high-level debrief, it should occur as close to the event as possible
- Be sure to build in adequate time for debriefs, usually a minimum of 2x the length of the simulation
- Ensure that the simulation objectives are finite and can be covered during the debrief
- Build in feedback delivery mechanisms into the Crawl-Walk-Run training framework

Principle 3. Feedback related to practice behaviors and clinical performance strategy development should be specific.

When it is appropriate to provide such feedback (see principle above), feedback about the behaviors in which trainees engaged; how, why, and what clinical performance strategies trainees attempted to implement; and the manner by which they addressed errors or unexpected events should be specific and detailed. Providing specific feedback facilitates the retention and automatizing of learned material and helps to avoid ineffective strategy or behavioral changes.

Simulation Recommendations:

- Ensure that team members have a working knowledge of team processes prior to executing the simulation; this will allow the facilitator to use this common language during the debrief
- Refer to specific examples during the simulation to highlight strengths and weaknesses of team process.
- Video review may be helpful
- Providing individuals with feedback is important; however, must be done with care in a team debrief
- Using self-assessment "cognitive aids" can help individuals assess their contribution to team performance. One example would be the TeamSTEPPS debrief checklist available in the TeamSTEPPS Pocket Guide
    - Was communication clear?
    - Were roles and responsibilities understood?
    - Was situation awareness maintained?
    - Was workload distribution equitable?
    - Was task assistance requested or offered?
    - Were errors made or avoided?
    - Were resources available?
    - What went well?
    - What should improve?

Principle 4. Feedback should be more heavily focused towards process rather than outcome.
Outcome feedback conveys the extent to which trainees met/are meeting learning objectives. Alternatively, process feedback focuses on how trainees are using information, performing behaviors, and the steps used to complete task activities. Process feedback directs learners to reflect on the strategies and decisions that led to particular outcomes, and is thus particularly important when the goal of training is to improve regulatory/strategic thinking.

Simulation Recommendations:

- Allow teams to discuss medical content and address any concerns quickly to help learners focus on processes of care
- Encourage learners to consider other circumstances where similar processes are employed and can fail. This helps team focus on processes instead of the specific clinical issues presented in the simulation.

Principle 5. Trainees should be encouraged to believe substantial negative performance discrepancies are moderate.
Acquiring KSAs in complex task environments is challenging, and learners are not likely to perform well during initial stages of training. Providing accurate and credible feedback is important, but it is equally critical to ensure that trainees do not become overwhelmed and/or discouraged by actions they have performed incorrectly. This balance can be achieved by framing feedback such that: (1) feedback emphasizes trainee performance is attributable to controllable factors; (2) feedback de-emphasizes outcome-focused feedback in favor of process feedback and feedback that highlights how learners are developing; (3) initially poor performance be labeled as only moderately negative. Doing so decreases the likelihood of goal abandonment while increasing the likelihood that effort and self-efficacy will be maintained.

Simulation Recommendations:

- Encourage learners to note positive as well as negative behaviors (What should you change? What should you do the same?)
- Encourage learners to see how even effective processes can result in poor outcomes
- Limit the focus of the debrief to just learning objectives to avoid talking about too many issues
- Focus on process, not outcomes

Principle 6. The provision of negative and/or normative feedback should be minimized to trainees learning a complex task.
Negative feedback (i.e., learners are failing to meet learning objectives) and normative feedback (i.e., comparing learners to an external standard) tends to shift trainees' attributions towards the self & ego protection, which generally interferes with the acquisition of KSAs. Negative feedback--especially when learning a complex task--is demotivating and tends to decrease self-efficacy. In general, positive performance feedback tends to improve self-efficacy, though it must be accurate and credible to prevent complacency and/or disengagement. Similar recommendations are noted in TeamSTEPPS training documents, where it states feedback should be timely, respectful (focusing on behaviors, not personal attributes), specific (directed toward future improvement), and considerate.

Simulation Recommendations:

- Provide a supportive climate that allows participants to share opinions openly and honestly
- Critical step, as learners cite a fear of educator and peer judgment as barrier
- Use "good judgment" framework or advocacy/inquiry to discuss negative performance and uncover learner mental models and frames that are supporting suboptimal performance

Principle 7. Guidance that directs trainees to consider what they should think about and how to think about it should be provided to trainees in learner control environments.
Guidance is a proactive "feed-forward" mechanism that encourages learners to take an active role in considering how and why they are engaging in particular learning behaviors. Guidance promotes learning through both increased metacognition (i.e., "thinking about thinking") and encouraging an exploratory/future-focused perspective on learning--both of which are critical conditions for learning complex tasks and strategies. There are many options for what type of guidance can be provided, but typical categories include focusing trainees on how and where to direct attention during training (cognition), manage effort and emotions (affect), and sequence actions (behaviors).

Simulation Recommendation:

- Learners should be encouraged to identify their strengths and weaknesses. With instructor input, this information should be used to guide training content and emphasis. In this way, learners can focus on more basic skills where they need development and challenge themselves in areas where they excel.
- Guidance can also come in the form of affect/error regulation that emphasizes to learners that good processes don't always result in good outcomes.

Principle 8. Match the level of feedback provided to the level of the goals in training.

Feedback provided in training directs individuals to allocate resources and perform self-regulation activities in relation to specific goals. However, trainees can have goals across multiple levels thereby complicating trainees' decisions about which goals to strive toward. Therefore, if the focus of training is to achieve individual-level goals, feedback providers should provide individual-level feedback so resources are directed to individual goal attainment. Similarly, if trainees should focus on team-level goals, feedback providers should provide team-level feedback to direct resources toward team goal attainment.

Simulation Recommendations:

- The debriefing plan should be pre-planned and should target appropriate level(s) based upon learning objectives.
- When individual feedback is necessary within a team context, the learner should be approached separately if there is an issue with individual clinical competence or procedural skills.
- If individual feedback on a team skill is necessary, feedback should be framed as a team-based learning point.

Attachment 4. Variables identified for use in BBN Predictive Model

	Behavioral Type	Team Clinical Behavior or Process
Intubation	Information Gathering	Assessed pupil reactivity
		Checks presence of gag reflex
		Attempts to elicit speech
		Elicit speech physical
	Communication	Communicates information about signs of head trauma
		Calculates patient's Glasgow coma scale
		Communicates patient's Glasgow coma scale
		Makes decision to intubate patient
		Obtains fingerstick glucose
	Action	Discusses which intubation medications to use
		Discusses dosage of medications
		Gives 1 sedation medication
		Appropriately pretreatments patient
		If paralytic used, choice and dose correct
		Orders proper sequence of drugs for rapid sequence intubation
		Stabilizes neck by holding cervical spine immobilization
		Preoxygenates patient
		Team members follow rapid sequence intubation order
		"Bags" patient following intubated
		Total duration of intubation
	Monitoring	Monitors and communicates blood pressure during intubation
		Monitors and communicates heart rate during intubation
		Monitors and communicates pulse oxygen during intubation
	Information Gathering	Verifies endotracheal tube placement
		Auscultates chest
		Checks CO_2 monitor
		Evaluates oxygen saturation after intubation
		Checks blood pressure after intubation
		Orders post intubation X ray
		Interprets post intubation X ray
		Calls radiologist for X ray clarification
		Communicates information about incorrect ETT placement
	Decision	Makes decision to adjust ETT based on X ray results
	Action	Correctly repositions ETT
		Orders repeat CXR
Circulation	Information Gathering	Requests initial vital signs
		Confirms IV line is in place
		Orders cardiac monitoring
		Undresses patient
		Request new/updated vitals
		Assesses chest wall
		Assesses abdominal area
		Checks pulse on arm/neck
		Assesses back
	Communication	Communicates prehospital vital signs
		Communicates updated vital signs
		Communicates reason for admission
		Communicates cardiac rhythm
		Orders IV fluids
		Orders second IV
	Information Gathering	Verifies IV fluids administration
		Monitors and communicates blood pressure
		Monitors and communicates heart rate
		Rhythm assessed to be "tachycardic"
	Communication	Uses word "shock"
		Discusses causes of hypertension

	Behavioral Type	Team Clinical Behavior or Process
	Action	Orders coagulation studies
		Orders type and cross match
		Orders blood transfusion
		Orders uncross-matched pprbc
		Transfuses a minimum of 2 units of uncross-matched pprbc
		Obtains a surgical consult
	Information Gathering	Assesses if blood is ready for transfusion
		Monitor vitals during transfusion
Femur	Information Gathering	Checks pulse feet
	Communication	Communicates absent right dorsalis pedis pulse
		Communicates presence of femur abrasion
	Action	Orders femur X-ray
		Orders pelvis X-ray
		Orders head CT
		Orders CT of cervical spine
		Obtains FAST exam
	Communication	Communicates finding of displaced femur fracture
		Communicates finding of widened symphysis pubis on x-ray
	Action	Applies traction to right leg
		Time to placement of traction
		Maintains traction
		Checks right dorsalis pulse after traction
		Consults orthopedic surgeon
		Places pelvis binding

pprbc = prepacked red blood cells
FAST = focused assessment with sonography for trauma
CT = computed tomography
ETT = endotracheal tube

DRAFT: Manuscript for Aim 1a

USING SIMULATION TO DEVELOP ADAPTIVE CAPACITY IN INDIVIDUALS AND TEAMS: 10 KEY PRINCIPLES FOR TRAINING DESIGN

INTRODUCTION

Team adaptability is necessary for effective health care team performance. *Adaptability* is defined as the ability of a team or individual team members to adjust their strategy, behaviors, and/or capacity in response to unanticipated changes in the task, environment, or team. In other words, teams need to be able to identify situations that require change, and then efficiently and appropriately modify their performance. This "adaptive cycle" may repeat frequently depending upon the level of uncertainty and degree of instability present in the clinical situation.[6] Adaptive teams can perform at a high level under novel, highly dynamic conditions due to the ability to quickly alter behaviors to match the changing demands of the environment. In action teams, such as rapid response teams, trauma teams, and disaster management teams, success often depends upon the ability to alter behavior in response to unforeseen changes without the ability to pause their current work and plan a course of action.[15] Teams that are not highly adaptive will function in a reactive mode that is fraught with potential safety and error risks.[7,8] While adaptability has received attention in the team science literature, health care team training and research efforts do not specifically target the development of team adaptive behaviors.

Team training interventions that incorporate active learning strategies increase adaptive capacity in non-health care teams.[5] Active learning approaches develop the underlying behavioral, cognitive, and motivational processes needed to support the application of existing knowledge and skills to unfamiliar situations. To be effective, these interventions should (a) represent the clinical, i.e., performance, context and (b) prompt adaptive behaviors in response to dynamic changes in the patient and the environment.[16] Additionally, training design and implementation should consider the individual, team, and task variables that impact training effectiveness and team performance.[14] Current models of adaptability, training, and team effectiveness exist; however, these models have not been integrated and used to guide development and implementation of health care team training.[17]

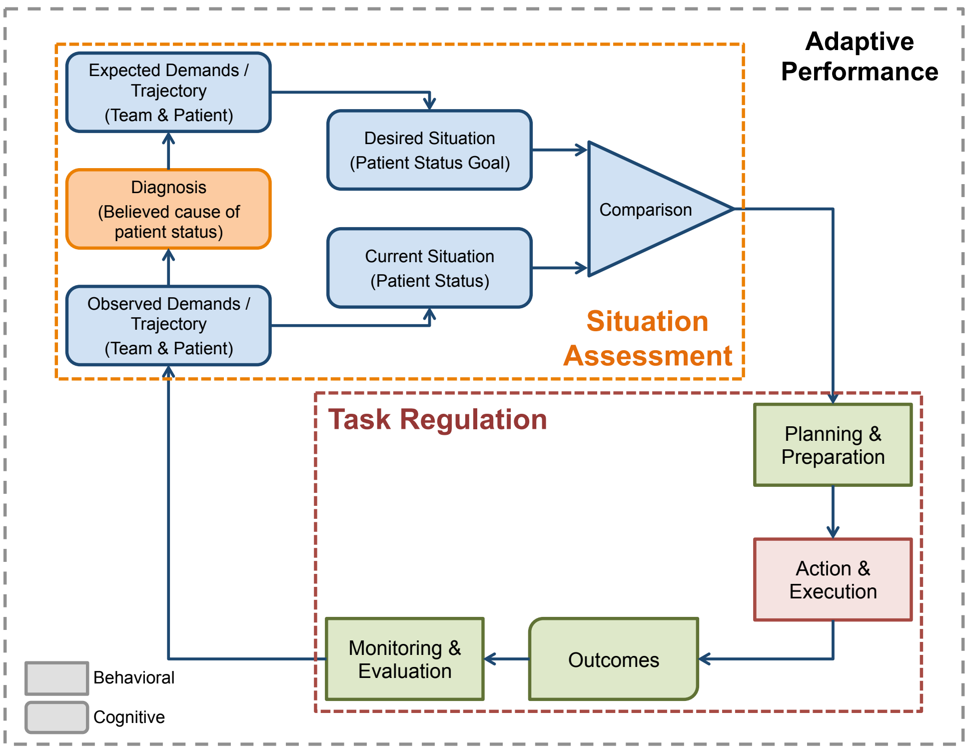
Rigorously designed simulation systems can support active learning experiences and improve adaptability and performance in both individuals and teams.[4,5,18] Simulations recreate the underlying tasks or problems experienced within the clinical environment to stimulate critical, dynamic decision-making processes. Technological advances have expanded the breadth and depth of simulation-based training in healthcare; however, there remain gaps in identifying and implementing key underlying instructional design elements that support the development of highly effective, adaptive teams. While several frameworks and conceptual models of team adaptation and training to build adaptive performance exist within the team science research, they have not been adequately integrated and translated for healthcare application.

Our overall objective is to describe simulation design and training principles that foster the development of adaptive performance. We present a framework of adaptive performance in healthcare teams and translate evidence-based principles from the team and instructional design sciences to healthcare simulation. This framework and set of principles can be applied to a variety of learners, simulation modalities, and clinical situations.

Adaptive Performance Model

We used the literature review and subject matter expert review described above to identify all individual and team-performance concepts and constructs that are relevant to training, assessing, and supporting adaptive trauma team performance. Our initial adaptive performance model did not reflect the need for trauma teams to rapidly incorporate new diagnostic information into the team's plans and processes. Subject matter experts raised an issue that cognitive processes were not adequately represented. We therefore reviewed the diagnostic error literature, diagnostic decision-making literature, and team learning research to augment our model. The result is listed in Figure 1.

Figure 1.

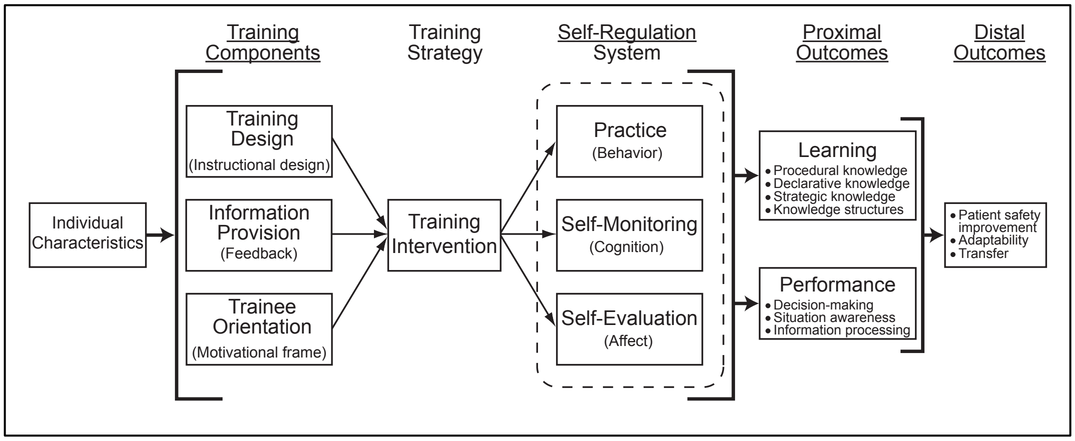


This model reflects the cognitive and behavioral process components of trauma team performance. First, cognition is represented by the team's efforts to make sense of the situation (Situation Assessment). Briefly, the team must use existing data/observations to identify the patient- and team-related tasks and demands. This information is then used to develop a differential diagnosis. Based on this/these diagnoses, the team has expectations regarding how the patient will respond to treatments and how his/her condition will evolve over time. The team continuously compares this "expected" state to the "observed" state of the patient. This comparison informs the team and helps regulate the team processes that regulate task performance. If the team notes a mismatch between expected patient improvement and current patient condition, this should prompt the team to review their plan, make adjustments, and execute the modified plan. The results of these new actions should be monitored and evaluated. The observations made during evaluation become the information that the team uses to reassess the situation, reconsider the differential diagnosis(es), and the adaptive cycle continues. In a rapidly evolving trauma resuscitation, this cycle repeats continuously to ensure the team is adapting to the unstable patient/team/environment.

GUIDELINES FOR TRAINING TO IMPROVE ADAPTIVE PERFORMANCE

Simulation-based team training can leverage specific design elements to target the development of adaptive expertise. Kozlowski, et al provide an Adaptive Learning System (ALS) design framework (Figure 2) to guide the development, implementation, and outcome evaluation of active learning interventions that target adaptive expertise.[14] Briefly, the ALS is based on a self-regulatory model of learning, motivation, and performance.[44,45] Self-regulation involves monitoring the differences between goals and current states.[46] That is, individuals must recognize when they are not progressing adequately toward meeting their goals and redirect effort and resources, i.e., adapt, to remedy these shortcomings. The ALS can thus inform the design of training strategies that selectively influence self-regulatory processes and enhance adaptability.[47,48] Data from empirical studies support the validity of the ALS heuristic as a framework for developing individual training that improves self-regulation and adaptation.[47,49] Our work will expand on the ALS to include team-level relationships, variables, and outcomes.

Figure 2. Adaptive Learning System



10 KEY TRAINING PRINCIPLES TO DEVELOP ADAPTIVE CAPACITY

1. **Use pre-training materials to provide appropriate orientation to trainees. (Individual Level)**
   Pre-training materials presented at the start of training provide an initial organizing structure of the subject matter discussed in training. Pre-training materials provide conceptual information, help to build connections between similar ideas, and delineate different concepts from one another. Trainees who use or begin to develop their own pre-training materials are more likely to adaptively transfer knowledge and skills.
   Simulation Application
   a. Inform trainees about training focus. This does not necessarily mean informing them of key critical content planned for simulations; rather, tell trainees they will be focusing on team (or individual) skills
   b. Suggest that trainees consider personal strengths and weaknesses prior to coming to training.
   Simulation Example

2. **Promote trainees to have a learning goal orientation during training. (Individual and Team Level)**
   Training design that promotes a learning goal orientation (e.g., a focus on self-improvement and task mastery in achievement situations) has been linked to positive training outcomes, such as goal setting, self-regulatory activities, learning, and performance. This is in stark contrast to promoting a performance goal orientation (e.g., a focus on demonstrating ability to others in achievement situations) which has been shown to negatively relate to goal striving processes and performance.
   Simulation Application
   a. Promote a learning goal orientation by encouraging trainees to set goals about achieving learning objectives and acquiring relevant knowledge and skills.
   b. Establish psychological safety
   Simulation Example

3. **Trainees should be provided with strategy instruction later in training once appropriate foundational knowledge has been developed. (Individual)**

The KSAs required to effectively engage in individual and team adaptation are advanced learning outcomes. Without achieving proficiency in the basic and procedural knowledge necessary to carry out core task/job requirements in a domain, efforts to improve the adaptation process will be less effective.

Simulation Application

a. Assess individuals for team-based simulation "readiness"
b. Use low fidelity non-clinical simulations to begin building team skills while individuals are still developing clinical knowledge.
c. At this stage, interdisciplinary training is not important; however institutions should ensure consistency of curriculum across professions/units/schools

Simulation Example

4. **Training material should be structured so that instruction proceeds from general to detailed, specific to complex. (Individual and Team Level)**

Successful team adaptation requires integrating, coordinating, and regulating a variety of different KSAs, resources, and members. Developing the capacities to manage these processes should be scaffolded to allow learners to first build basic competencies and then practice/engage in more complex applications. Note that this also applies to actively training members as part of intact teams -- team-based training designed to enhance adaptability is a complex environment and should be postponed until learners have engaged in more foundational training exercises.

Simulation Application

a. Team-based simulations should initially use basic clinical scenarios rather than unusual or highly complex situations. Once basic team skills have transferred from "non-clinical" simulations (above) to straightforward clinical issues, more complex team and environmental issues can be added.
b. Use an event-based approach to training (EBAT) to create a simulation experience where modules can be added to model more complexity as well as to target specific team skills.

Simulation Example

5. **Trainees learning a complex task should be encouraged to monitor rate of learning progress rather than just learning performance. (Individual Level)**

Training that emphasizes learning trajectories, development, and velocity is more likely to minimize goal abandonment, promote self-efficacy, and encourage trainees to view training as "learning" rather than "evaluation." Additionally, emphasizing "future-focused" cognitive appraisals (i.e., focusing on how learning outcomes/capabilities are evolving) reinforces the cognitive appraisal frames critical to team adaptation.

Simulation Application

a. During pre-brief, make it clear to learners that there may be no "right answer".
b. Establish a learning environment that supports psychological safety.
c. If using a modular EBAT approach, consider guiding teams to recognize how similar problems were addressed in the past so they can monitor their progress.

Simulation Example

6. **Trainees learning complex tasks should be provided with proximal subgoals that break the task into smaller parts. (Individual and Team Level)**

Team adaptation is a process characterized by an ongoing cycle of situation assessment and team/task management. The KSAs which underlie successfully execution of these stages can be developed through "part-learning" and by breaking the adaptation process into meaningful chunks. This approach is more likely to increase learner self-efficacy and persistence, and allow practice opportunities & feedback to be tailored towards more focused learning objectives.

Simulation Application

a. Break down adaptive behaviors into clear activities that can be practiced in isolation. If necessary, remove learners from the clinical setting to work on key activities prior to re-entering a high-fidelity simulation.

Simulation Example

7. **Trainees presented with extremely difficult problems that appear unsolvable should be assisted in making some consistent progress during training. (Individual Level)**

The structure of the training environment and practice opportunities for team adaptability should not be "sink or swim" (esp. during initial stages of practice). Feedback and direction that actively guides teams through how to think through a complex task and make decisions about resources is a critical foundation of team adaptability training. Providing guidance that prompts teams to explore options for task completion during training helps to avoid discouragement, anxiety, and abandonment of effort.

Simulation Application

a. Use triggers and backup triggers during simulations to allow learners to attempt the behavior and, if unsuccessful, observe an "expert" (confederate) execute the behavior with success.
b. Junior learners that may lack clinical knowledge should be encouraged to seek assistance for help at any time. Using confederates as "mentors" can not only assist learners through difficult tasks but also will build comfort with seeking help from other team members and those outside the team.

Simulation Example

8. **Variability in practice trials should be provided during training to maximize retention & transfer. (Individual and Team Level)**

Whereas early stages of training are enhanced by repetition and rehearsal (i.e., developing declarative & procedural knowledge), advanced stages of training are enhanced by exposing trainees to as diverse an array of scenarios in which to apply their KSAs as possible. It is particularly critical to expose trainees to situations where previously learned, frequently used, and/or typically reliable courses of action are ineffective. Providing variability in practice trials promotes the development of broader associative knowledge structures and contingency-based thinking.

Simulation Application

a. Use EBAT to build simulations that contain appropriate task complexity
b. Shorten intervals between prompts to increase time pressures as appropriate.
c. Use confederates to add interpersonal challenges.
d. Build in environmental challenges (e.g., additional patients, equipment failure) to increase complexity

Simulation Example

9. **Training should be permissive of, embrace, and even encourage errors made by learners during training. (Individual and Team Level)**

Errors are an inevitable component of real-world performance. Errorless training leads to effective training performance, but is often related to poor training transfer. Although errors during training should be brought to learners' attention, learning that is focused on error management as opposed to error prevention is more successful. Framing training as an opportunity to make and learn from errors encourages trainees to develop problem-solving or hypothesis-testing skills and strategies for managing affective responses (e.g., frustration and anxiety).

Simulation Application

a. Use confederates to "force" errors during simulations. This requires considerable expertise in debriefing to ensure learners do not feel "tricked". Appropriate pre-briefing and establishment of a learning environment can help. Be sure that "errors" meet a minimum level of psychological fidelity for learners.

Simulation Example

10. **Incorporate lessons on how to alter coordination strategies in training. (Team Level)**

When task demands are low, trainees should learn to discuss possible problems that could arise later in the task. By discussing their coordination strategies during this period, they will likely reduce the amount of communication necessary to achieve successful team performance later and allow them to be adaptive when novel problems arise in the environment.

Simulation Application

a. Encourage learners to develop contingency plans
b. Discuss team member understanding and mental model development during debriefing to help reinforce the importance of discussing and practicing team coordination

Simulation Example

DISCUSSION

a. Potential key role for simulation in developing adaptability
b. Ability to build adaptive performance in individuals and teams
c. Need to develop metrics
d. Ability to modify existing curricula to improve adaptability

DRAFT: Manuscript for Aim 2

USING BAYESIAN BELIEF NETWORKS TO INFORM TEAM TRAINING: A METHODOLOGY AND HEALTHCARE TRAUMA TEAM EXEMPLAR

- **BBN Tutorial**
  - **Current state of data analysis in psychology**
    1. Focus of most analyses in psychological research is *descriptive* and *interpretative*
       A. Description → correlation coefficients, regression coefficients, *t*- and *F*-statistics, effect sizes, meta-analyses, etc. to quantify magnitude of observed bivariate relations
       B. Interpretation → *p*-values, confidence & credibility intervals, etc. to provide metrics for evaluating the size, "presence," and or meaningfulness of observed relationship
    2. Analytic approaches seldom oriented towards *prediction* and *inference*
       A. Prediction → using data to quantify likelihood of occurrence, expected impact of variables/inputs/interventions under various conditions, etc.
       B. Inference → using data to explicitly generalize/project to future observations
    3. Could argue that such goals are/should be realm of "applied" psychology…but a key criteria of evidence-based theory is the extent to which it reduces uncertainty about how, why, and when psychological phenomena happen and are meaningful
       A. Analytic approaches which enable researchers and practitioners to translate theory/empirical evidence into predictive models of the world are thus valuable for developing better theory (e.g., identifying when theory X doesn't apply) and generating impactful science
  - **Introduction to BBNs**
    1. What is a BBN in general
       A. Directed acyclic graph representing relational interdependencies among variables
       B. Computationally efficient method for representing full joint probability distributions over many variables
       C. "BBNs are holistic representations of multivariate outcomes" (Marcot et al., p. 3071)
    2. Basic Elements of a BBN
       A. <u>Nodes</u>: set of variables from a domain that are relevant to drawing inferences
          a. Parent & children nodes
          b. Posterior probability distributions for each node represents probability of occurrence given state of other variables in the model
          c. Nodes defined as discretized states/categories that are mutually exhaustive and exclusive
          d. "Types" of nodes
             1a. <u>Query</u>: outputs that you most want to know/predict (DVs, unknowns)
             1b. <u>Evidence/observation</u>: inputs that are diagnostic/indicators of other variables
             1c. <u>Context/contributing</u>: inputs that reflect preexisting conditions, environmental characteristics, etc.
             1d. <u>Controllable</u>: inputs that can be manipulated and/or set (experimental IVs)
             1e. Classification of nodes is not required or set in stone; interpretation of node can change depending on how BBN is used
       B. <u>Links</u>: representation of direct influence between variables
          a. Direction of arrow reflects qualitative indication of direct/causal influence
             1a. [Can be counterintuitive at times, we provide recommendations for how to think about structuring the problem later]
          b. Relationship between variables summarized in conditional probability tables
             1a. CPT for a node is conditional on probability of parent nodes
             1b. Stronger associations = stronger influence on CPT of children nodes
             1c. CPT remain unchanged unless informed by new data
          c. CPTs for nodes can be determined in multiple ways
             1a. Data → utilize data mining/learning algorithms to extract conditional dependencies
             1b. Experts, rational, or value → query individual raters to extract conditional dependencies
             1c. Literature, existing research → translate published correlations, effect sizes, etc. into conditional dependencies
       C. Regression equations → utilize existing empirical relationships to populate CPTs
    3. What are BBNs useful for
       A. BBNs are tools for guiding predictions, inferences, decisions, and updating beliefs/knowledge through the accumulation of new evidence
          a. Belief updating → through application of Bayes Theorem, the probability of both predictors and outcomes is altered

b. Example applications of BBNs [see Korb and others for more examples here]
    1a. Medical diagnoses
    1b. Decision analyses
    1c. Policy setting
    1d. Artificial intelligence
    1e. Weather forecasting

B. General types of inferential reasoning that BBNs enable
  a. <u>Prediction</u>
    1a. BBNs convey the probability of occurrence for one or more outcome variables given some known observations or prior data
    1b. "Top-down" reasoning (causes to effects)
  b. <u>Diagnosis</u>
    1a. If an outcome is observed, BBNs can convey the probabilities of the likely contributors to that observation
    1b. "Bottom-up" reasoning (effects to causes)
  c. <u>Intercausal</u>
    1a. As evidence of key observations and predictive causes accumulates, their impact propagates through the BBN and changes the probability of alternative causes
    1b. "Explaining away" (knowledge of some causes reduces probability of alternative causes)

C. Types of questions BBNs are ideally suited for examining:
  a. What is expected value of one or more variables given data and/or beliefs about the world (e.g., $p(\theta|\text{many observations})$)?
  b. What is the relative importance of variables to a particular set of outcomes?
  c. What is the configuration/level of variables most likely to lead to a particular outcome (or set of outcomes)?
  d. What are the practical implications for influencing a particular variable, implementing a particular set of decisions, or employing a given intervention?

4. How are BBNs similar to & different from other statistical approaches

A. Structural Equation Models (SEM)
  a. Similar to SEM, BBNs can reflect both the measurement (manifest items as indicators of latent constructs) and structural (relationships among latent constructs) portions of a model
  b. Unlike SEM, BBNs focus on the probability of particular values of a variable/construct being observed given the value of other variables/constructs in the model
    1a. BBNs are "outcome-focused" as opposed to "relationship-focused"

B. Regression/correlation
  a. BBNs do not derive indices (e.g., beta coefficients) of bivariate relationship strength, but this factor is reflected in the probabilistic relationships among nodes
  b. Output from GLMs can be expressed in a BBN to provide a predictive tool if desired (beta coefficients with standard errors and observed variables with distributions are inputs to a model)

C. Factor analysis and latent profile analyses
  a. BBNs can include latent variables in their estimation (variables for which no observable data is available)
  b. Like observable/discrete variables, latent variables are comprised of states
  c. Unlike factor analysis, the goal of modeling the latent variable is not to identify unique dimensions or to achieve dimension reduction; rather, the latent variable modeling identifies specific patterns/configurations of observable indicators associated with a given state
    1a. In other words, each state of a latent variable is probabilistically associated with a specific configuration of observable indicators → similar to LPA
  d. Unlike LPA, once a latent profile structure has been established, the BBN can be used to estimate the probability of profile membership given an observation on a *single item* (LPA requires observations of all the variables within a profile)
  e. Additionally, the methodology provides an integrated, simple, and convenient method for using the probability of profile membership to generate predictions about the value of other observable variables or latent profiles

    1a. e.g., probability that an individual with a particular profile comprised of some variables A-C (e.g., pattern of variables associated with affect management) is related to some other profile comprised of different variables D-F (e.g., pattern of variables associated with leadership style)
    1b. Allows for predicting relationships between profiles

- **Procedure for creating, testing, calibrating, and updating BBN models**
  1. Alpha model
     A. Create influence diagram
        a. Influence diagram = box & arrow conceptual model/causal web showing influence among key variables, mediators, and outcomes
        b. Consult SMEs, relevant literature, etc. to identify network of causal linkages
           1a. <u>Cannot</u> have reciprocal relationships/loops – BBN is a directed acyclic graph
     B. Convert influence diagram to an initial BBN with nodes comprised of discrete states
     C. Create CPTs for each node
        a. Can use data and algorithms for converting influence diagrams and building BBNs, but need to be aware of overfitting to dataset – better to rely on expert judgment/theory at this stage
        b. Parentless nodes → unconditional probability tables representing prior knowledge on frequencies of states or uniform probabilities reflecting complete uncertainty
        c. Child nodes → CPTs reflecting probability of child note states given all possible combinations of parent node states
           1a. Not all cells must be nonzero (i.e., some can be zero)
           1b. Not all cells must represent possible predictor combinations (i.e., impossible combinations of parent nodes can be represented)
           1c. Each "row" in the CPT sums to 100% (sum of probabilities for all outcome states or some combination of prior states)
           1d. Each "column" in the CPT does NOT sum to 100% (sum of likelihoods for a given outcome state across all combinations of prior states)
           1e. Column values in a CPT can be interpreted as likelihood of prior conditions given an outcome state (i.e., if outcome state = X, what are most probable states of prior conditions?) → can normalize column values to get normalized likelihoods for each outcome state
        d. Methods for establishing initial CPTs
           1a. Mathematical formula (this likely won't exist in psyc research)
           1b. Have experts set extreme cases to 0%/100%, adjust middle/moderate conditions appropriately, and then infer any remaining combinations
           1c. Identify the single-most probable outcome for every combination of inputs and then adjust probability distributions within each row of output node to reflect uncertainty
           1d. Checking initial CPTs: scan down column of each outcome state and evaluate whether highest/lowest outcome probabilities are associated with most/least causal conditions for that state
        e. Testing and adjusting initial BBN → evaluating logic of model
           1a. Evaluate behavior of BBN by testing different combinations of input values and observing resultant probabilities for intermediate/output nodes
           1b. If model exhibits unrealistic/undesirable behavior:
               2a. Readjust poorly behaving CPT
               2b. Combine, split, or redefine nodes/states
               2c. Adapt BBN structure (add links, intermediate/summary nodes)
           1c. Conduct sensitivity analyses to determine absolute/relative degree of influence each parent node has on children node
               2a. "Goal is to get model to tell you what you think it should tell you, that is, to represent expert judgment and any initial empirical data (or equations) on how the system works" (Marcot et al., p. 3067)
  2. Beta model
     A. Initial model subjected to formal peer review from domain SMEs
     B. Purpose is to have other experts not involved in model development to review model structure, CPT values, and model behavior to suggest edits or confirm model construction

a. Suggestions to model can be incorporated as revisions or treated as competing model for later validation testing

3. Gamma model
   A. Testing prediction accuracy of BBN against case data
      a. Confusion matrix
         1a. Confusion matrix tallies number of times model calculated higher probability for actual outcome state(s) given actual input states
         1b. Overall model error rate = number of incorrect predictions / total number of predictions
         1c. Depending on nature of outcome state (i.e., if outcome state is of yes/no variety), can be used to classify whether prediction errors were false positives (model predicted yes when actual data was no) versus false negatives errors (i.e., model predicted no when actual was yes)
         1d. Caution! Confusion matrices typically overstate false negatives when outcomes are rare
            2a. Confusion matrices provide information about predictions based on most probable outcome, not whether prediction is *relatively* effective
            2b. i.e., Model may suggest that probability of yes under particular conditions = 30% and so confusion matrix would suggest that these conditions are unlikely to lead to this outcome. However, that 30% probability of yes may be much higher than the probability of yes under any other combination of inputs
            2c. Thus, usually a good idea to recalibrate error rates from confusion rate outcomes based on predicted probabilities rather than only the most probable outcome states
      b. Classification success rate (e.g., spherical payoff, logarithmic loss, quadratic loss)
         1a. Evaluates classification success of model using belief level of outcome states rather than the most likely state for each prediction
      c. Can also pursue ROC curve analysis if outcome state is binary
   B. Updating BBN with case data
      a. Using test results to calibrate model states so that they better align with data
         1a. Calculate calibration curves that identify data-based "cutoff" values to identify points at which the probability of outcome states change
         1b. Use different "rules" as model prediction for a given case (i.e., rather than predicted state = state with probability > 50%)
            2a. May want to take into account rarity of event, objectives of prediction, etc.
            2b. Can use sensitivity analyses to identify several probability cutoff values that may be better suited for purposes of model
      b. Using case data to automatically update CPTs
         1a. Utilize Bayesian updating methods/learning algorithms such as expectation maximization, learning gradient analysis, etc. to update initial BBN values with new case data
         1b. Can be continually fed new datasets to improve overall predictions

– **Two exemplars: Research and practice**
1. Practical: Modeling a selection decision for a new departmental hire
2. Research: Modeling the probability that a team adapts to an unexpected event
   A. Tool for summarizing *predictions* given a multivariate network of relationships within a domain; think a multivariate "meta-analytic-like" tool

– **Recommendations/best practices for constructing, interpreting, and using BBN models in research and practice**
1. Objectives and specific uses of model must be clear
2. Recommendations for developing initial structure of BBN [many of these from Marcot et al]
   A. Often effective to begin with most desired query nodes and build out links from there
      a. What factors influence this variable? [helps identify parents of children nodes]
      b. What are indicators of this variable? [helps identify children of parent nodes]
   B. Keep number of parent nodes for any given node <= 3
   C. Keep number of discrete states per node <= 5
   D. Parentless nodes (i.e., usually context/contributing nodes and/or controllable nodes) should be items that can be informed by empirical data

E. Intermediate nodes (i.e., usually evidence/observation nodes nodes) typically reflect "latent variables" related to key outcome nodes
F. Make as many nodes as possible observable, quantifiable, and testable entities. Any node that is "latent" should be carefully documented and explained
G. Balance precision versus parsimony. Fewer discrete states per node reflects parsimony, while more discrete states per node usually reflects precision.
H. Keep depth of model (i.e., number of layers between input and output nodes) <= 4. Having deep BBN may unnecessarily propagate uncertainty through the model and desensitize output nodes to inputs
I. If spanning multiple levels of analysis, can consider developing multiple "linked" models as opposed to large singular model (e.g., output of one BBN used as input to another BBN)
J. Input nodes should be connected if they are likely to be correlated
K. Context/contributing nodes should ideally represent true environmental input data; however, more observable proxy variables can be used if such data are unavailable
    a. Observable proxy node → context/contributing node → …
    b. In such cases, the CPT for the context/contributing node should be adjusted to represent the degree of correlation/uncertainty between the observable proxy node and the context/contributing node

Link to Google Doc for Entire BBN file:

https://drive.google.com/drive/folders/1LiMxuiLDD4tDtm0cnWLBQ_617Mgq_Bg2?usp=sharing

Includes:

- Pictorial representation of BBN (.eps and .svg file)

- BBN with data (.neta) file that can be imported into Netica software and manipulated.

Development of an Integrated Team Training Design Architecture to Support Adaptability in Healthcare Teams

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BACKGROUND

Team adaptability is necessary for effective healthcare team performance. *Adaptability* is defined as the ability of a team or individual team members to adjust their strategy, behaviors, and/or capacity in response to unanticipated changes in the task, environment, or team. Teams that lack adaptive capacity present considerable risk to patient safety. In both medicine and the military, failure to enact adaptive behaviors can be linked to significant teamwork failures and catastrophic outcomes. Team adaptability is especially critical for trauma teams, who must execute tasks that are often ambiguous, rapidly changing, and emergent.

Simulation-based team training interventions that incorporate active learning strategies increase adaptive capacity in non-healthcare teams. Active learning approaches develop the underlying behavioral, cognitive, and motivational processes needed to support the application of existing knowledge and skills to unfamiliar situations.

KNOWLEDGE GAP

Frameworks and conceptual models of team adaptation and team training have not been adequately integrated and translated for healthcare application.

OBJECTIVE

The objective of this project is to develop a conceptually and empirically supported adaptive performance training design architecture that provides guidance for training development, implementation, and evaluation, and defines critical antecedents and modifiers that impact team training effectiveness and team performance.

METHODS

Using an approach outlined by Rousseau, et al. the investigators conducted an extensive literature review, both within the healthcare and the team science literature, to identify key components of team adaptability. We focused specifically on identifying the individual and team processes that drive adaptive behaviors, as well as possible metrics that would indicate adaptability at individual and team levels. We then convened a multidisciplinary group of nurses and physicians from both civilian and military healthcare settings to provide expertise and insight into how these adaptive behaviors translate to the healthcare setting, and how they might develop over different levels of expertise. Finally, we observed both simulated and actual trauma team performance to augment our data and further our understanding of how adaptive performance unfolds during highly complex clinical activities. This information was then integrated to create key conceptual models and principles for training and assessment.

FIGURES

Figure 1. Model of adaptive performance in trauma teams

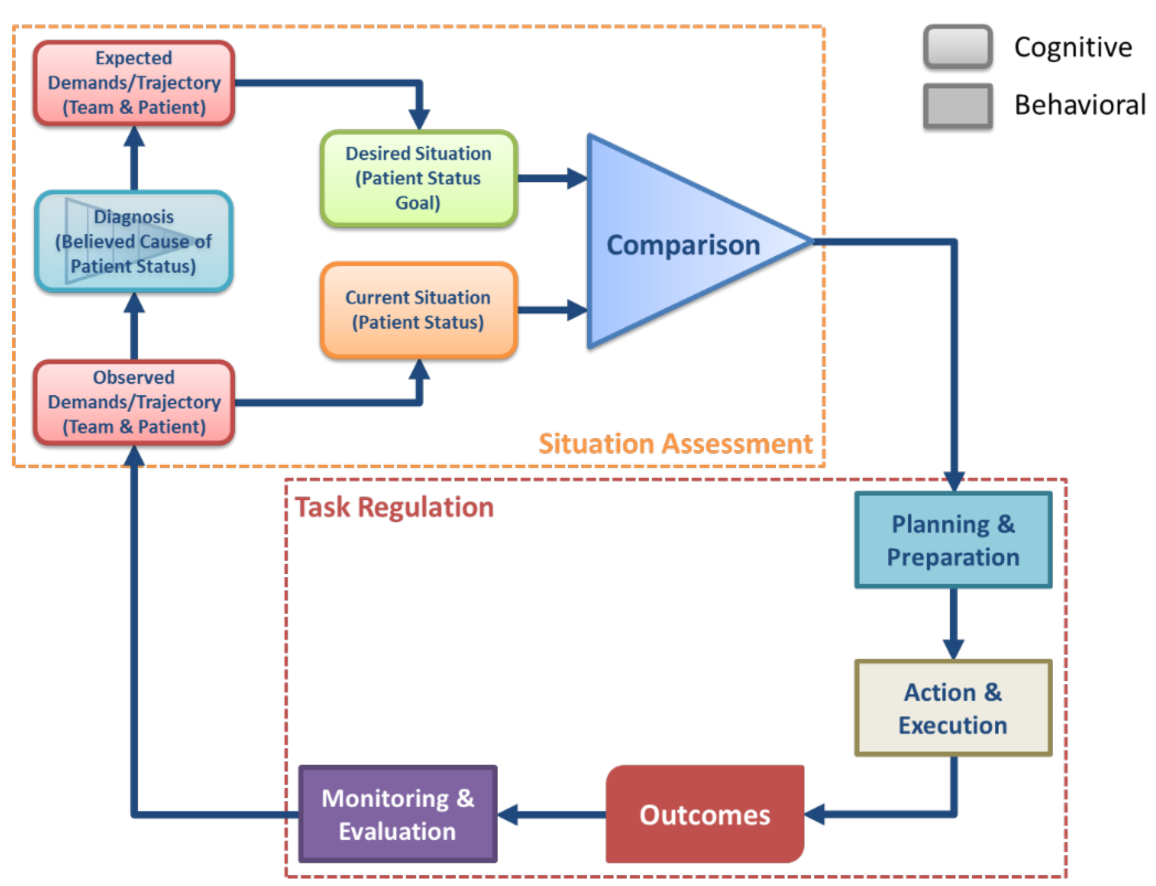


Figure 2. Adaptive training targets and training techniques

	Instructional Goal			
	Declarative Knowledge / Skill	Procedural Knowledge / Skill	Strategic Knowledge / Skill	Adaptive Knowledge / Skill
Targeted Knowledge / Skill	Facts, concepts, rules; Definitions, meaning *(What?)*	Task principles; Rule application *(How?)*	Task contingencies; selective application *(Where, when, why?)*	Generalization of task rules, principles, contingencies *(What now, what next)*
Exemplar Task-based KSAs	Risk factors for ACS	ACLS algorithms ATLS algorithms	Treating undifferentiated shock	Contingency planning based on patient response to treatment
Exemplar Team-based KSAs	Team processes Shared cognition Leadership functions	Communication protocol Feedback/debriefing Conflict management	Resource management Consensus-building Problem definition	Situation awareness Task regulation Affect regulation
Instructional Delivery Technique	Memorization Static practice Consistent Automaticity	⟷	⟷	Experimentation Dynamic practice Variable mapping Controlled processing

ACS = acute coronary syndrome; ACLS = Advanced Cardiovascular Life Support; ATLS = Advanced Trauma Life Support

Figure 3. Model of task complexity, processes, and level(s) of analysis when developing adaptive processes

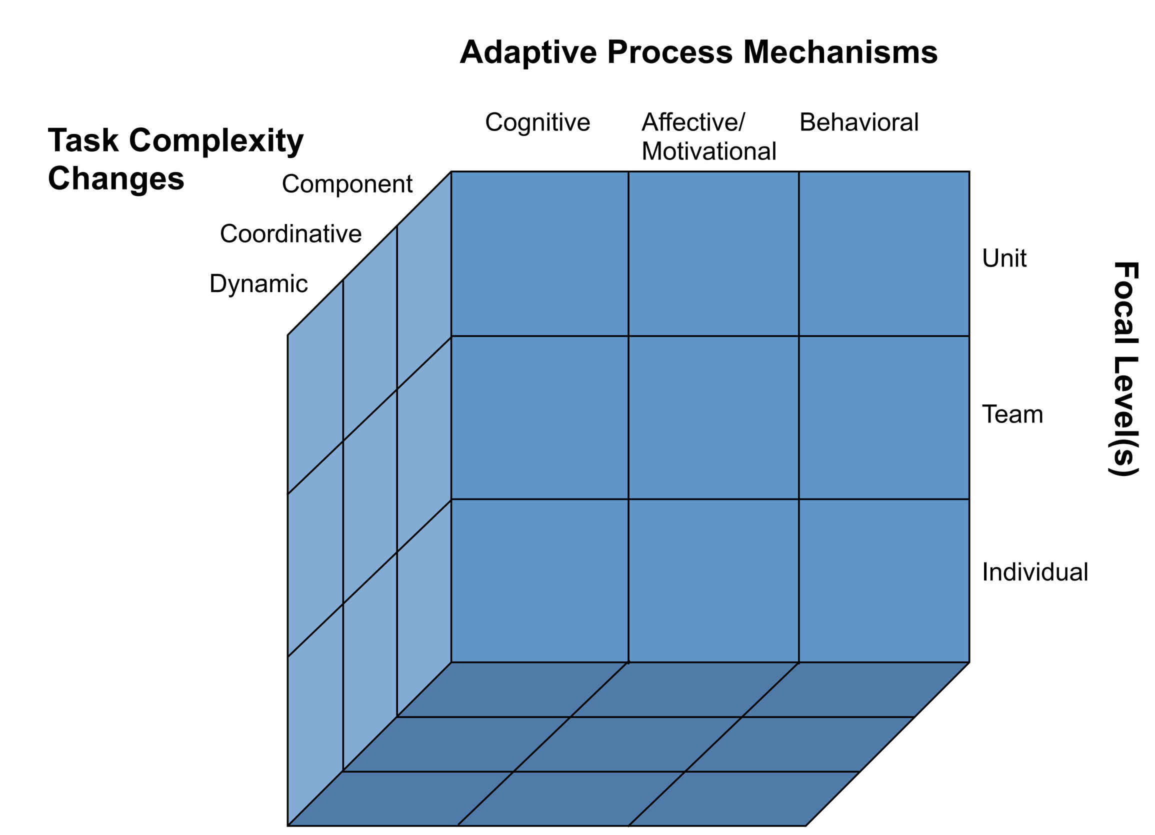
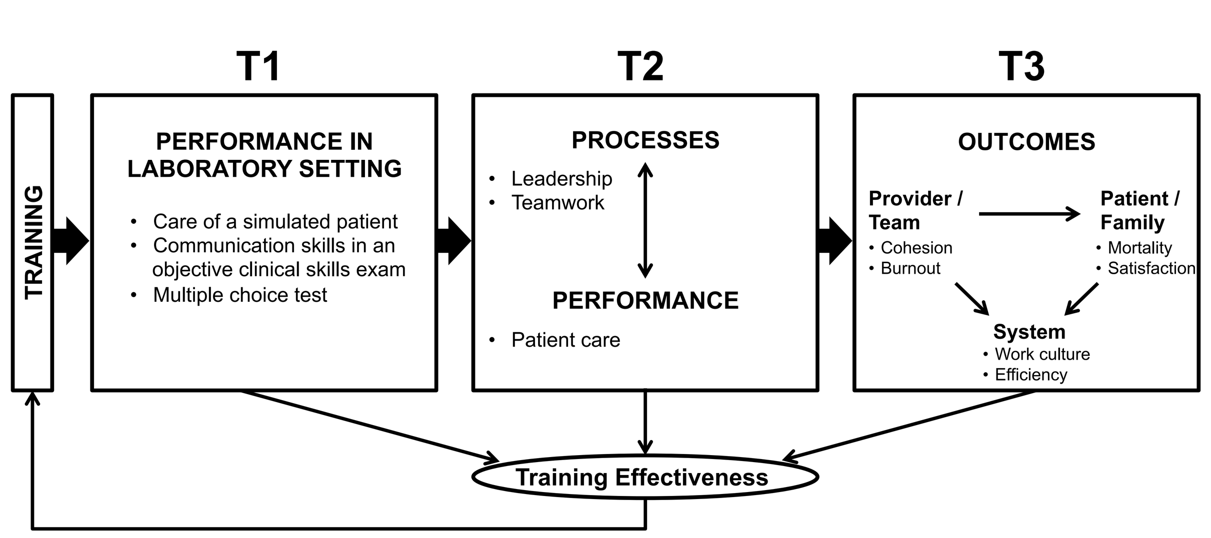


Figure 4. Translational simulation-based research model to identify outcomes for adaptive training



RESULTS

(Figure 1) We identified individual and team-performance concepts and constructs that are relevant to training, assessing, and supporting adaptive trauma team performance. Subject matter experts raised an issue that cognitive processes were not adequately represented. We reviewed the diagnostic error literature, diagnostic decision-making literature, and team learning research to augment our model.

(Figure 2) We identified a staged approach to training that targets appropriate skills necessary to develop adaptive capacity. We include both individual and team-based processes as well as training mechanisms.

(Figure 3) We developed a multilevel conceptual architecture of adaptation that considers (1) the types of events teams must adapt to (i.e., what type of change is occurring), (2) the types of processes teams use to adapt, and (3) at what level these processes occur. This taxonomy can help guide the selection of appropriate training targets.

(Figure 4) Proximal outcomes include both learning and performance-based outcomes. Distal outcomes that are trainee-focused include the transfer of learned skills to the work (clinical) environment as well as the application of learned skills to novel situations, i.e., adaptability. High-level distal outcomes include patient, system, and organization-level outcomes.

CONCLUSIONS

This conceptual work provides a roadmap and principles to guide the development of effective training and team adaptability in healthcare teams.

ACKNOWLEDGEMENTS

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Development of a Generalizable Method for Assessing, Predicting, and Improving Team Adaptability

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Overview and Objectives

This research was designed to provide the infrastructure to support simulation-training systems that optimize adaptive team performance. We created a predictive team performance assessment tool that is capable of supporting adaptive guidance and feedback during simulation-based training for emergency trauma teams (Fig 1). The assessment tool utilized Bayesian Belief Networks (BBNs), a statistical technique for summarizing and updating relational interdependencies among variables based on the accumulation of observations/evidence[13], to provide adaptive guidance and facilitate the development of adaptive expertise and team performance. We utilized existing conceptual models and simulation based trauma team performance data to construct a BBN that incorporates the relationships between key team and individual characteristics, behavioral outcomes, and patient care events in a validated simulated scenario (Fig 2). The BBN leverages the probabilistic interdependencies among these variables to enable the assessment of the likelihood of critical team and patient outcomes in the simulated environment. Thus, this project established a technique to provide adaptive guidance in real time to emergency trauma teams that can support learners of all levels across military and medical field applications.

Theoretical Background

Health care team performance is critical to the provision of safe, efficient, and effective care.[1-3] Team adaptability is necessary for effective team performance and is especially vital for trauma teams, whose members must anticipate change and rapidly coordinate effective responses.

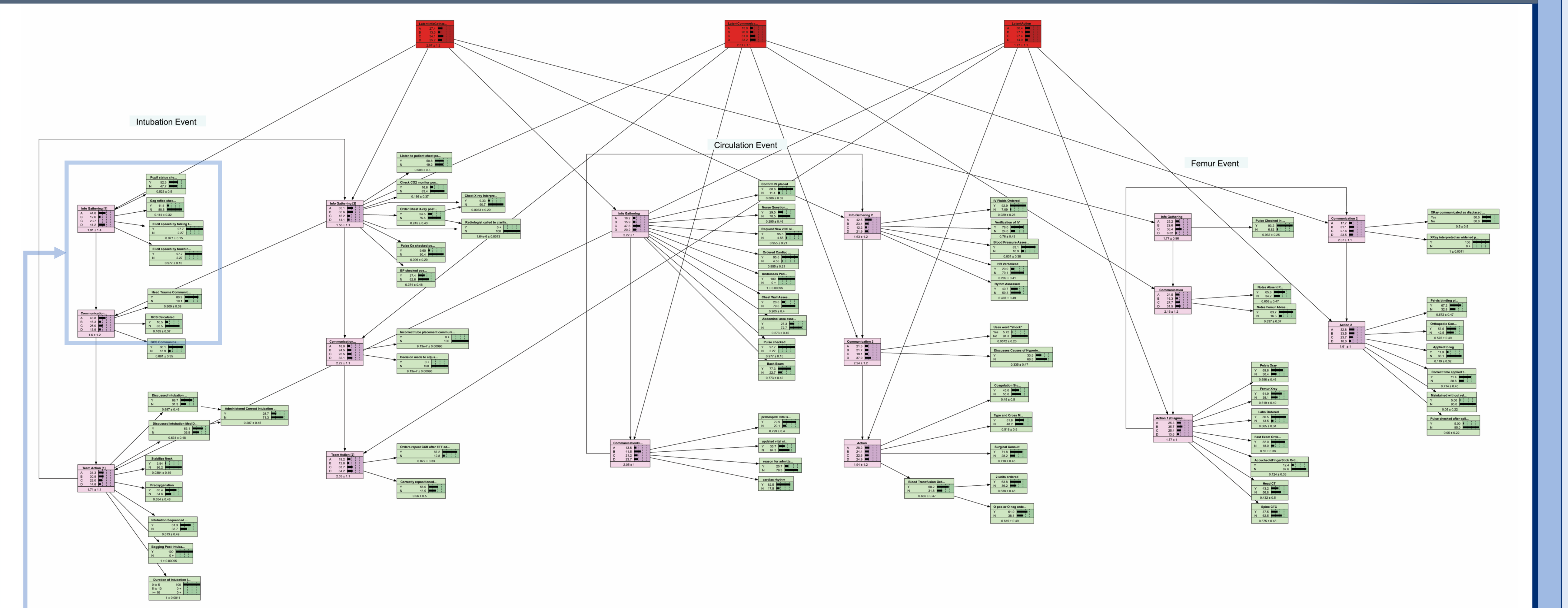
Adaptability:

- Adaptability is defined as the ability of a team or individual team members to adjust their strategy, behaviors, and/or capacity in response to unanticipated changes in the task, environment, or team.
- In both medicine and the military, failure to enact adaptive behaviors can be linked to significant teamwork failures and catastrophic outcomes.[4,6,7,8,9,10] Team adaptability is therefore a major leverage point for improving patient safety and decreasing adverse events.

Increasing Adaptability:

- Adaptive guidance is an active learning instructional strategy that provides trainees with diagnostic and interpretive information to help them make effective learning decisions.[14] Incorporating adaptive guidance into simulation systems have proven to be effective in improving performance and developing adaptability[5,11,12,14].
- However, available healthcare team assessment tools are not designed to deliver adaptive guidance, since most are designed to provide learners with a retrospective assessment of their performance. [15] Currently, there are no well-researched mechanisms to support the provision of adaptive guidance within healthcare team training. We present and utilize Bayesian Belief Networks as a model to bridge this gap.

Figure 1. Adaptability Feedback Tool - Bayesian Belief Network Pictorial Representation



Magnified image

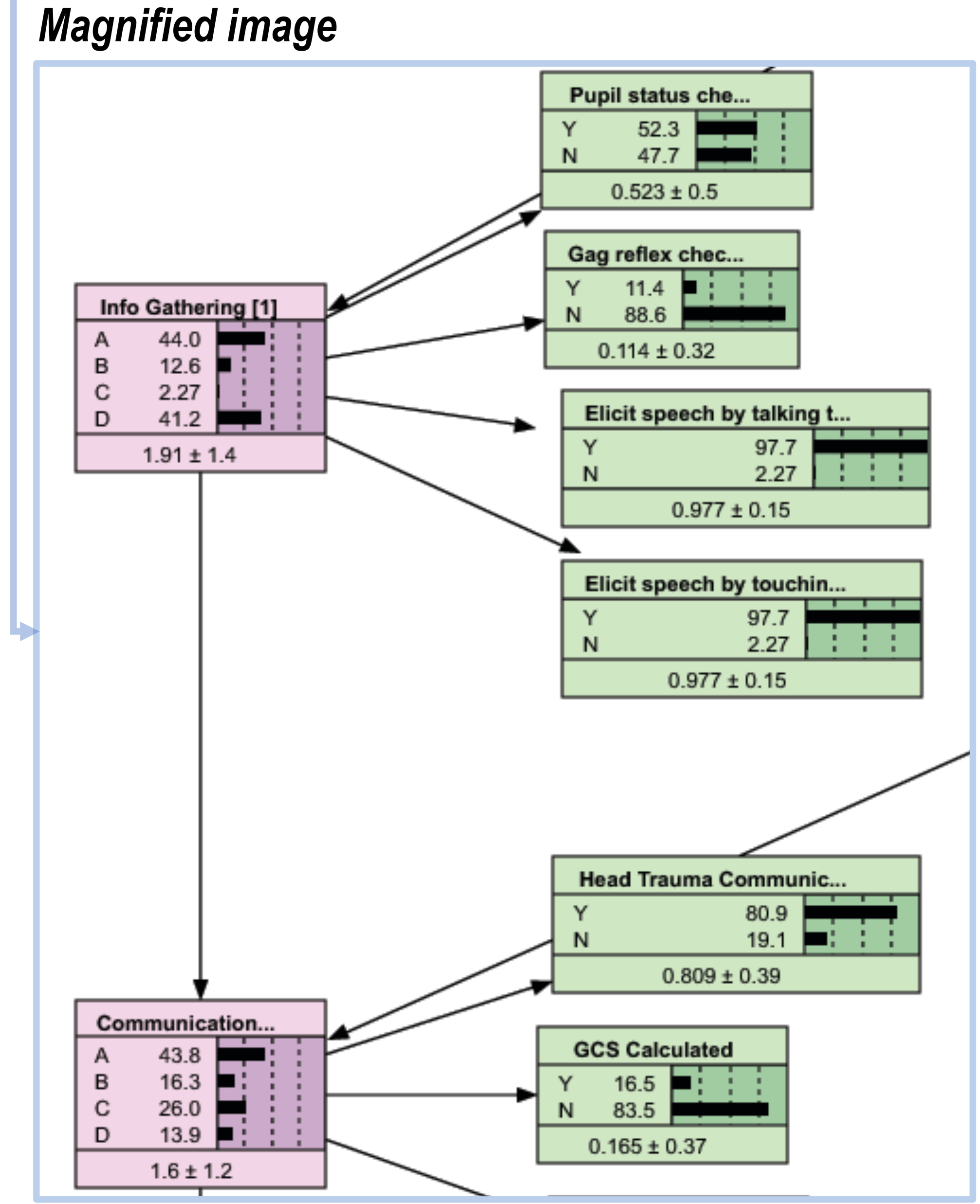
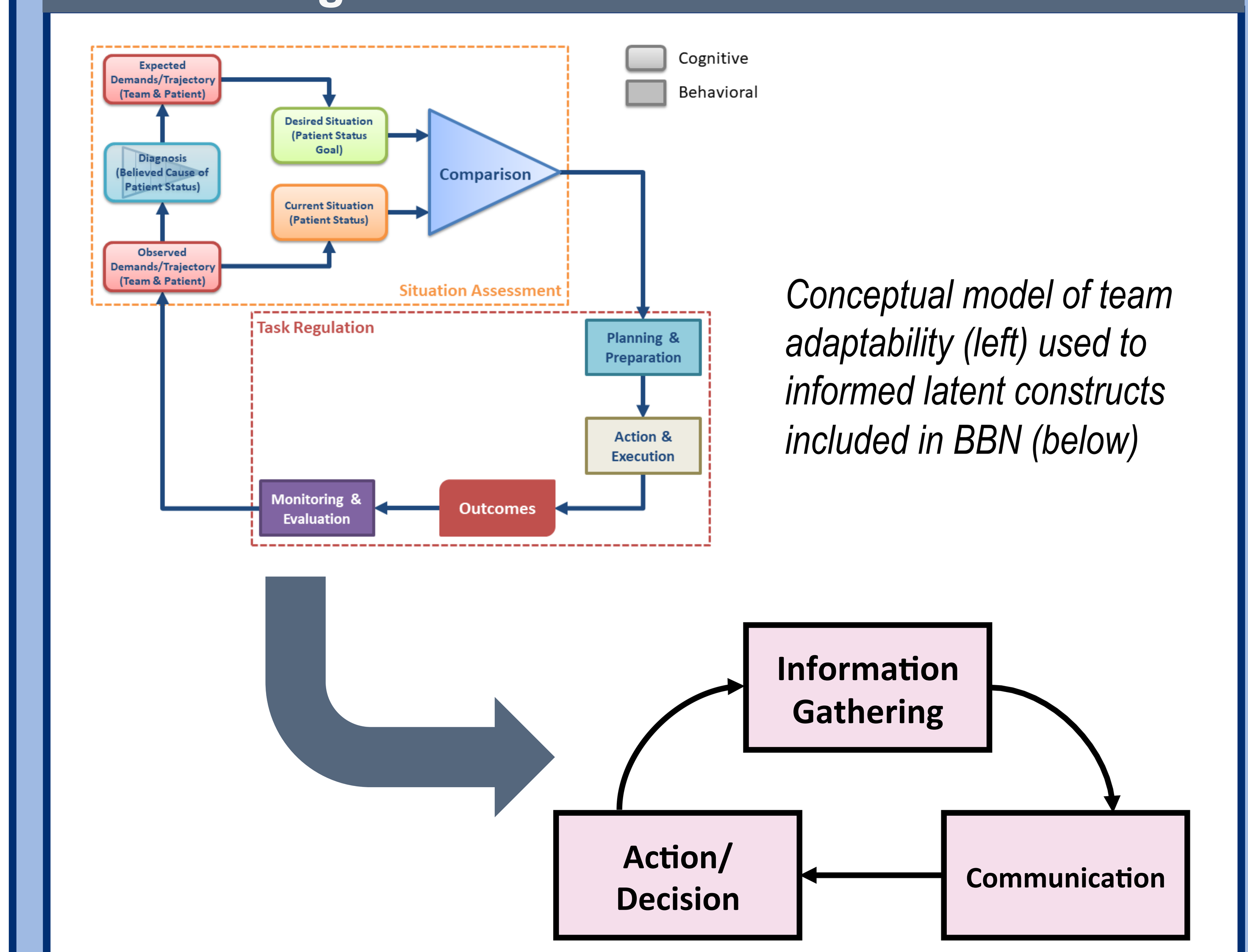


Figure 2. Theoretical Framework



Conceptual model of team adaptability (left) used to informed latent constructs included in BBN (below)

Background Continued

Bayesian belief networks (BBNs):

- BBNs are statistical models that allow predictive modeling of complex systems with uncertain inputs and outcomes.[13] Functionally, a BBN is a collection of nodes (variables) that are linked by directed arcs (lines). BBNs are able to incorporate real-time observations to inform future outcomes and thus guide learners toward more effective behavior.
- They are uniquely suited for simulations with real-time, adaptive guidance because the system can incorporate events as they occur and change outcome predictions. We therefore developed a predictive trauma team performance assessment tool using a BBN-based trauma team model. The BBN platform afforded us the ability to model team and task performance as a dynamic system, and facilitates the provision of feedback that is tailored to the needs of a particular team. To our knowledge, BBNs have not been used to support the provision of adaptive guidance in health care teams.

Method and Results

The creation and validation of the BBN assessment tool occurred in the following steps:

- First, we utilized previously collected simulation data from emergency trauma teams to identify key endogenous and exogenous variables for inclusion in our model. In total, we incorporated 90 variables into the model. After selecting the variables, the internal structure of the BBN was created by linking the endogenous and exogenous variables of interest in a graphical model using the Netica software package.[16]
- Next, a training dataset was used to derive the likelihood that critical behavioral outcomes related to team adaptability would occur given previous observations of a team's behavior.
- To calibrate the extent to which the model's predictions were related to the delivery of effective medical care, performance data from simulation based trauma teams and subject matter experts were used to calibrate the BBN. This final step permits the assessment tool to reflect how the performance of team behaviors critical to team adaptability relate to effective patient care and thus points at which real-time adaptive guidance would be particularly important to provide.

Conclusions & Implications

This research created a functional prototype of a predictive trauma team performance assessment tool, capable of supporting embedded, adaptive guidance during simulation-based team training. It also is a proof of concept for using BBNs as an infrastructure to provide adaptive guidance. Although the overall assessment approach can be generalized to any type of medical team training situation, it does require behavioral-level observations to effectively develop and implement. Additionally, it is likely to be less valuable in training contexts that lack variability in behaviors and outcomes (i.e., highly proceduralized treatments, non-acute patient care, etc.).

In sum, the prototype tool we have developed establishes a technique that can be utilized in future training designs to strengthen simulation-based training for both medical and military teams. Since it is adaptable to a wide variety of simulation modalities, it also has the ability to benefit learners of all levels across specialties and disciplines.

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DHA Defense Health Agency
University of Maryland
UFHealth University of Florida Health
University of Washington
Michigan State University

Leveraging Social Science-Healthcare Collaborations to Improve Teamwork and Patient Safety

Rosemarie Fernandez, MD,[a] and James A. Grand, PhD[b]

Effective teamwork is critical to the provision of safe, effective healthcare. High functioning teams adapt to rapidly changing patient and environmental factors, preventing diagnostic and treatment errors. While the emphasis on teamwork and patient safety is relatively new, significant team-related foundational and implementation research exists in disciplines outside of healthcare. Social scientists, including, organizational psychologists, have expertise in the study of teams, multi-team units, and organizations. This article highlights guiding team science principles from the organizational psychology literature that can be applied to the study of teams in healthcare. The authors' goal is to provide some common language and understanding around teams and teamwork. Additionally, they hope to impart an appreciation for the potential synergy present within clinician-social scientist collaborations.

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Teams and teamwork are ubiquitous in healthcare. Healthcare teams consist of two or more individuals with specialized skills who must improvise and coordinate their actions in high-pressured, unforgiving situations.[1] Such teams direct day-to-day patient care activities, respond to acute events (e.g., resuscitations), and manage institution-wide events (e.g., disaster response). Effective teams are capable of responding more quickly to changes in a patient's condition, noticing when "things aren't right" and adapting their plans and course of action accordingly.

High quality team leadership can further improve team performance by promoting clear goals, facilitating coordination and cooperation, and planning patient care-related tasks.[2–4] By maintaining a "big picture" overview, leaders can monitor multiple aspects of the patient's care, identify unexpected threats, and ensure the team adapts accordingly.[5] Notably, these functions take on even greater importance as task complexity and interdependency increase, and environmental stability and level of training become more variable[6]—conditions common in pediatric resuscitations and critical care settings.

It should come as no surprise then that teamwork and leadership have been identified as major influences on patient safety[7–10] and performance during acute pediatric emergencies.[11] This recognition has spurred an exponential increase in the number of empirical publications and reviews on teamwork and leadership in healthcare teams over the past decade. For example, within pediatric medicine, a sizeable body of work examining leadership performance and team effectiveness with graduate medical trainees during neonatal and pediatric resuscitation has begun to emerge.[12] We share in the promise this direction holds for bettering patient safety and care, and encourage and welcome a continued focus on team performance and leadership in healthcare practice.

A Problem With a Solution

However, with new opportunities come new challenges. Although physicians are highly skilled at providing guidance on medical decision-making and treatment plans, they are less knowledgeable in how to train, participate in, and lead effective teams.[13] Teamwork, communication, and leadership—so-called "non-technical skills"—are rarely included in formal curricula; yet provide the backbone of patient care implementation. Consequently, and despite increased

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emphasis on the importance of teamwork and team leadership in recent years, many healthcare professionals and residents continue to feel underprepared to effectively work as part of or adopt leadership roles within the healthcare team.[14]

In any clinical area or specialty, there is a body of "basic science" that supports research and practice. Team and leadership science is no different. While healthcare has only recently recognized the importance of teamwork and leadership skills, fortunately there exists a significant body of theoretical and foundational work focused on understanding, improving, and measuring these capabilities outside of healthcare. Accessing and leveraging these resources represents a significant avenue for improving healthcare team performance and patient care during acute pediatric care events.

The significance of a well-developed and conceptually grounded understanding of teamwork and leadership models cannot be overstated. They provide healthcare researchers, educators, and professionals with knowledge, skills, and developmental targets for developing and training critical non-technical skills. Likewise, they can inform the development of improved assessments that are better equipped to detect deficiencies in teamwork and leadership performance. Such measures can also serve as the basis for establishing competency norms to ensure that practitioners have the necessary skills to respond effectively as a resuscitation event leader. Unfortunately, healthcare providers tasked with improving team effectiveness and mitigating teamwork-related adverse events are often rarely trained in the scientific principles necessary to guide these efforts.[15]

The significance of a well-developed and conceptually grounded understanding of teamwork and leadership models cannot be overstated.

Without the explicit use of sound evidence-based models of effective teamwork and leadership, it is not possible to systematically advance research or practice around team-related training and evaluation programs in healthcare.[15,16] We are already seeing this play out in the healthcare community today. Considerable resources and efforts are being dedicated to develop and implement teamwork and leadership training programs; however, their widespread impact has not been demonstrated.[17,18] The decisions regarding training content, application, and evaluation are complex. Without guiding principles and scientific support, it is difficult to determine cost effectiveness and potential success of such choices.

Without the explicit use of sound evidence-based models of effective teamwork and leadership, it is not possible to systematically advance research or practice around team-related training and evaluation programs in healthcare

Significant gaps in the knowledge and methodologies employed in healthcare inhibit efforts to improve patient care through team and leadership training and assessment.[12,13,19] Fortunately, there is a wealth of research and best practices from the applied social sciences (e.g., industrial/organizational psychology, organizational behavior, and human factors) that can be drawn upon to inform the educational criteria, models, and frameworks needed to support healthcare teamwork and leadership training. Consequently, we believe that interdisciplinary collaborations between the applied social sciences and healthcare communities are critical to bridging this gap and improving team and leadership training in pediatric care.

The authors are part of a decade-long research collaboration between healthcare (RF) and organizational psychology (JAG) focused on developing, implementing, and evaluating team and leadership training in resuscitation teams. Industrial-organizational psychologists apply the rigor and methods of psychology to the scientific study of the workplace. That is, industrial-organizational psychologists study how the thoughts, behaviors, emotions, and relationships of people in organizations shape and are shaped by individual, group, unit, and organizational factors. In the remainder of this paper, we highlight some of the insights and lessons from our collaborative efforts as well as provide practical recommendations for forging meaningful partnerships between healthcare and social science researchers. Where appropriate, we also suggest sources for further information.

Lesson #1: Context Matters

Even amongst healthcare teams, not all teams are the same.[20] Clinic-based teams differ from inpatient care teams, which differ from resuscitation teams. Additionally, resuscitation teams in an ICU setting likely face different challenges than those within an emergency department or those that care for soldiers on a battlefield. Carefully defining the nature of the healthcare team is a critical step when translating team science into healthcare. It is deceptively easy to define a team based solely on its physical location (e.g., operating room, emergency department, and outpatient clinic). However, this approach oversimplifies important differences in the nature, needs, and characteristics of teamwork and leaders in these groups, and does not facilitate translating knowledge from other disciplines and team science.

Social scientists studying team performance have devised a variety of useful conceptual frameworks for understanding different types of teams.[21–24] These frameworks encourage defining teams by examining questions such as "Are the team members consistent from day to day? Does the team consist of all experts, or are there trainees? Does the team have consistent tasks or are they dynamic/changing frequently?" Answers to these questions provide insight into the team and leadership skills necessary to support this type of team effectively. For example, resuscitation teams have highly variable team members, frequently changing or poorly defined tasks, and, in academic settings, often include trainee (novice) members.[25] An effective team leader in this context thus requires strong coaching skills, skills to quickly familiarize team members with one another and rapidly establish mutual trust/support, and the capability to readily establish and modify plans based upon changes in patient condition.[12]

Recommendation: Spend the time to understand the team, environment, and organizational culture present in the setting you wish to study.

Further Reading and Exemplars

Sundstrom E, De Meuse KP, Futrell D. Work teams: applications and effectiveness. *Am Psychol*. 1990;45: 120–133.

Andreatta PB. A typology for health care teams. *Health Care Manag R*. 2010;35(4):345–354.

Lesson #2: Never Underestimate the Value of a Conceptual Framework

The famed social psychologist Kurt Lewin once noted "There is nothing so practical as a good theory."[26] A theory provides an organized conceptual framework for identifying key variables relevant to a particular domain and explains how they are related. To Lewin's point regarding practical utility, conceptual frameworks are critically important to the development of team and leadership training programs as they (1) guide selection of appropriate instructional targets and (2) provide a blueprint of the variables and relationships that should be the focus of measurement and analysis.[16]

Healthcare team research has been criticized for not adhering to evidence-based, theoretically sound models of team effectiveness.[1] Building a conceptual model is not trivial and requires extensive empiric testing and revision to establish its validity. As clinicians however, we can work with team science experts to identify models from the social sciences literature appropriate for healthcare teams. The Figure provides one such example of a conceptual model for teamwork and leadership in resuscitation teams. This framework is described by Kozlowski et al.[27] and is

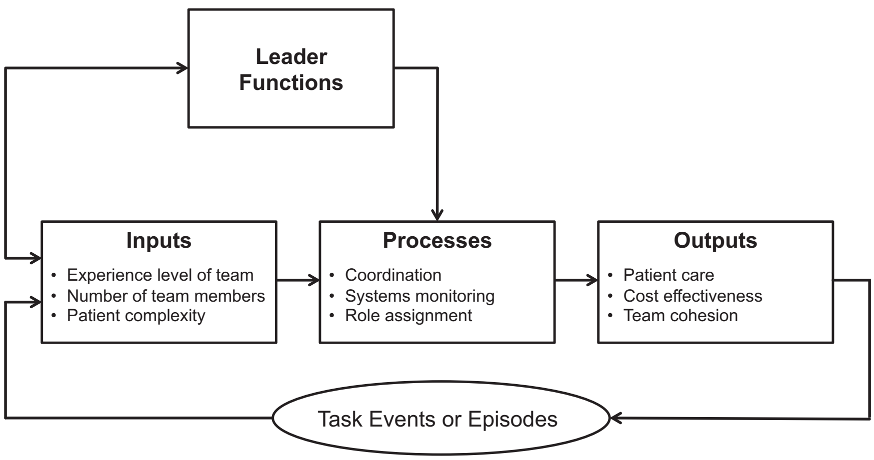

FIG. Dynamic team leadership model.

based upon a much earlier theory of team functioning[28] that characterizes how performance in teams is generated. In brief, this model provides a structure for understanding how team leadership relates to inputs (e.g., training, experience, and resources), teamwork behaviors (e.g., coordination, monitoring, and strategizing) and outcomes (e.g., patient care, team efficacy, and cohesion). In highly dynamic teams, i.e., resuscitation teams, leadership and teamwork processes underlie performance effectiveness and act to mitigate threats to patient safety through improved situation monitoring, coordination, and communication.[29,30] This highlights the dynamic nature of teams and teamwork, where outputs from one team event feedback as inputs into the next.[28,31,32] Such feedback is necessary if teams are to adapt to new knowledge, tasks, or situations.[33]

From a research standpoint, conceptual models such as the Dynamic Team Leadership Model (Figure) outline predicted relationships between critical variables and demonstrates where team and leadership effects should be measured. As one of its first tasks, our research group led a consensus-building effort involving emergency medicine and team science experts. The result of this work was an emergency medicine teamwork taxonomy and framework that has been cited as an example of a robust conceptual framework for healthcare teams and research.[29,34] This conceptual work has since provided the foundation of our interdisciplinary research and continues to inform our determination of targets for training and assessment.

Recommendation: Frame training design, measurement, and research questions around a conceptual model. This will support the development of an evidence-based product and sustainable research program rather than constant pursuit of stand-alone studies.

Further Reading and Exemplars

Fernandez R, Kozlowski SWJ, Shapiro MJ, Salas E. Toward a definition of teamwork in emergency medicine. *Acad Emerg Med*. 2008;15(11):1104–1112.

Burke CS, Stagl KC, Salas E, Pierce L, Kendall D. Understanding team adaptation: a conceptual analysis and model. *J Appl Psychol*. 2006;91(6):1189–1207.

Lesson #3: Develop a Shared Mental Model Among Collaborators

Despite best intentions, describing the activities of a healthcare team from a team science perspective is challenging for clinicians. We think in terms of patients, orders, results, diagnostics, and disposition. Describing the nature of the clinical environment, how tasks are presented, and how clinicians receive information is foreign to us, and we often lack the language and terminology needed to effectively communicate with our team science collaborators.

By the same token, social scientists think in terms of how the thoughts, behaviors, and relationships among people shape and are shaped by individual, group or organizational factors. Although they possess general expertise in general theory, research methodologies, and practical program implementation, they lack specific understanding of what it is like to work on a healthcare team, the tasks and procedures that define our jobs or positions, and the institutional/systemic conditions, which make up the healthcare system. To be effective collaborators and partner, social scientists and healthcare providers must work closely to develop a shared understanding of healthcare teams and organizations.

Consequently, efforts must be made to facilitate development of a common mental model around healthcare teams and leadership. For team science experts, it is critical to facilitate direct observation of a healthcare setting and teams of interest. They will bring a very different perspective, and as a result will observe interactions, environmental factors, and processes that clinicians consider routine and therefore unremarkable. However, these "unremarkable" phenomena often explain why trained skills and behaviors do not transfer to the clinical setting, and why measurement systems fail to capture the complex nature of teams in the work environment.

It is equally important for clinicians to develop a working understanding of relevant theory and terminology from the social sciences to allow them to effectively incorporate research and practice from these domains. An easy method to facilitate this education is by engaging in conversation with social science collaborators during their direct observations of healthcare teams or potential projects of mutual interest. Such exchanges provide opportunities to elaborate and explore theories and concepts that are new to us in a more familiar context. In Table we provide a brief glossary of terms used commonly in the team training literature. This list is by no means comprehensive, but is offered as a starting point for further reading.

Recommendation: Seeing is believing. Never underestimate the value of direct observation. Invite social science collaborators into the clinical environment for

TABLE. Team-related terms and definitions

Term or construct	Definition	References
Industrial-organizational psychologist	Industrial-organizational psychologists (IOPs)[a] apply the rigor and methods of psychology to the scientific study of the workplace. IOPs study how the thoughts, behaviors, emotions, and relationships of people in organizations shape and are shaped by individual, group, unit, and organizational factors.	Society of Industrial and Organizational Psychology (www.siop.org)
Work team	Two or more individuals who share common goals, are part of a larger organizational system, and are formed to execute organizational tasks.	Hackman[43]
Interdisciplinary action team (IAT)	Work teams in which members with specialized skills must improvise and coordinate their actions in high-pressured, unforgiving situations; IATs often function within "high reliability organizations" characterized by high level of risk in an arena where failure has dire consequences.	Edmondson[44] Klein et al.[25]
Team process	The interactions among team members that combine their collective resources to resolve (or fail to resolve) task demands. Processes therefore form the basis of teamwork competencies.	Kozlowski et al.[45] McGrath[28]
Coordination	Organizing the sequencing and timing of team activities.	Fernandez et al.[29]
Back-up behavior	Team members' assist other team members with their tasks, balance workloads, and compensate for areas of deficiencies.	LePine et al.[46] Marks et al.[32]
Monitoring	Tracking and communicating information related to the team's progress toward goals.	
Debriefing	Team leader or team member–driven critical evaluation of the events that transpired during the team's performance, often used to allow individuals to discuss individual and team-level performance, identify errors, and develop a plan to improve their next performance.	Brett-Fleegler et al.[47] Salas et al.[48]
Team leaders	Directs and coordinates activities, assesses overall team performance, assigns roles, monitors and develops team attitudes and behaviors, facilitates problem solving and error recognition, facilitates feedback/debriefing.	Kozlowski et al.[4] Kunzle et al.[5] Rosenman et al.[12]
Team task work	Represents what teams have to do, forms the basis of assigned roles and team goals, and determines the workflow structure and need for coordination to accomplish team goals.	Bowers et al.[49]
Team mental models	Shared, organized understanding and mental representation of knowledge or beliefs relevant to the team and the team's tasks.	Burtscher[50] Klimoski and Mohammed[51]
Team cohesion	Desire of group members to remain united to reach a common goal; the commitment of members to the group's tasks	Beal et al.[52] Kozlowski and Ilgen[53]
Adaptability	The ability of a team or individual team members to adjust their strategy, behaviors, and/or capacity in response to unanticipated changes in the task, environment, or team.	Burke et al.[33] Kozlowski[54]
Team efficacy	A shared belief in a team's collective capability to organize and execute courses of action required to meet the team's task demands.	Gully et al.[55] Zaccaro et al.[56]
Closed loop communication	Following-up with a team member to verify that a message was correctly received and clarifying with the sender of a message that the message was received as intended.	Salas et al.[57]

[a]IOP, industrial-organizational psychologist.

extended observation periods. It is highly likely they will notice critical team interactions, environmental factors, and communication patterns that had gone previously unnoticed.

Recommendation: Develop a working knowledge of the "language" of social sciences. When a term or construct is unclear or seems duplicative, consult with an expert to ensure you apply the concept correctly in your work.

Lesson #4: Training is More Than an Experience

Increases in team and leadership training research have paralleled the widespread implementation of simulation-based healthcare education. Simulation-based training recreates the contextual background of a healthcare environment, allowing individuals and teams to experience an authentic clinical interaction with patients and other healthcare team members in a safe and controlled environment.[35] While the potential advantages of simulation are obvious, simulation is just a technique. Without strong instructional strategies and supporting learning mechanisms, simulation-based training is simply very expensive *practice* rather than well-designed *training*.

Many areas in the "applied" social sciences (industrial/organizational psychology, organizational behavior, and human factors) specialize in the development of theory and evidence-based recommendations for constructing team and leadership training.[4,36,37] These frameworks go beyond considering only the physical fidelity of a training environment and include comprehensive treatments of instructional design.[38] For example, as physicians, we rarely consider how training design impacts learner motivation or how error management during training impacts the acquisition of new skills. However, these—and many other factors—reside within the purview of team and leadership training scientists. The point of this lesson is to acknowledge that the selection of instructional strategies should be supported by scientific principles[15]—and the application of those scientific principles to improve the performance of healthcare teams and leaders can be greatly informed by meaningful collaborations with social scientists.

Recommendation: Choose instructional strategies that will optimize training outcomes based on the learners, teams, and healthcare environment.

Further Reading

Goldstein I, Ford JK. *Training in Organizations* (4th ed.). Belmont, CA: Wadsworth Thomson Learning; 2002.

Salas E, DiazGranados D, Klein C, Burke CS, Stagl KC, Goodwin GF, Halpin SM. Does team training improve team performance? A meta-analysis. *Hum Fact*. 2008;50:903–933.

Lesson #5: Assessment Should be the First Thought, Not the Afterthought

It is quite easy to get lost in the "glitz and glam" of designing a new training program; however, without an adequate understanding of *what* trainees should learn and *how* that can be measured, training is all show and no substance. In the context of teams and leadership training, assessing team and team leader performance is challenging. Physicians tend to focus on performance-based outcomes, such as getting the correct diagnosis, recognizing errors, and following clinical guidelines. While these are important outcomes to assess, it is equally critical that the teamwork and leadership processes, which directly impact such team performance and clinical outcomes, are also measured (Fig.).[39,40] Social scientists who study group functioning possess expertise in measurement development and the analysis of complex work teams and team leaders. They can guide decisions related to the design of appropriate measurement tools, methods for data collection, and analysis of multilevel phenomena such as team leadership. Without their expertise, we risk oversimplifying the assessment of important teamwork behaviors and leadership skills.

We have recently published guidelines for the development of team-based measures in simulation-based training that incorporate best practices from team science.[39] These guidelines highlight the importance of measuring both team process (teamwork effectiveness) and performance (medical effectiveness). Further, they provide recommendations for constructing measurement items, establishing evidence of content validity, and implementing a measurement system in a reliable, effective manner. This work is just one example of how collaborative efforts with team scientists have informed rigorous approaches to assessment; other excellent examples are available as well.[41,42] Once again, the lesson here is that the practices we adopt in healthcare team and leadership training should follow rigorous standards of best practice, many of which have been elaborated by our social science colleagues.

Recommendation: The assessment of team and leadership performance is a science! Social scientists can provide expertise beyond standard medical education assessment and psychometrics.

Further Reading

Grand JA, Pearce M, Rench TA, et al. Going DEEP: guidelines for building simulation-based team assessments. *BMJ Qual Saf*. 2013;22(5):436–448.

Rosen MA, Salas E, Wilson KA, et al. Measuring team performance in simulation based training: adopting best practices for healthcare. *Simul Healthc*. 2008;3(1):33–41.

Conclusion

In summary, the provision of healthcare is accomplished through complex interactions of individuals, teams, units, and organizations. The skills and knowledge needed to understand how to train, measure, and improve these components are not provided during standard medical education. Partnerships between clinical providers (pediatricians, nurses, and social workers) and applied social scientists can be highly rewarding and result in robust research and training programs. We as clinicians provide the opportunity for measurement in a discipline that is still largely understudied from a workplace perspective. They provide the insight and expertise to improve the way we interact with one another to provide safe patient care. These partnerships result in more robust training and research programs, and, as a result, are highly valued by funding agencies.

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Steve W.J. Kozlowski, PhD (Professor, Department of Psychology, Michigan State University).

Georgia T. Chao, PhD (Associate Professor, Broad School of Management, Michigan State University).

References

1. Baker DP, Day R, Salas E. Teamwork as an essential component of high-reliability organizations. *Health Serv Res* 2006;41(4):1576–98.
2. Morgeson FP, DeRue DS, Karam EP. Leadership in teams: a functional approach to understanding leadership structures and processes. *J Manag* 2010;36(1):5–39.
3. Zaccaro SJ, Rittman AL, Marks MA. Team leadership. *Leadersh Q* 2001;12(4):451–83.
4. Kozlowski SWJ, Gully SM, Salas E, Cannon-Bowers JA. Team leadership and development: theory, principles, and guidelines for training leaders and teams. In: Beyerlein MM, Johnson DA, Beyerlein ST, (eds). *Advances in Interdisciplinary Studies of Work Teams: Team Leadership, 3*. US: Elsevier Science/JAI Press, 1996. pp. 253–91.
5. Kunzle B, Kolbe M, Grote G. Ensuring patient safety through effective leadership behaviour: a literature review. *Saf Sci* 2010;48(1):1–17.
6. Kozlowski SWJ, Watola DJ, Nowakowski JM, Kim BH, Botero IC. Developing adaptive teams: a theory of dynamic team leadership. In: Salas E, Goodwin GF, Burke CS, (eds). *Team Effectiveness in Complex Organizations: Cross-disciplinary Perspectives and Approaches.* New York, NY: Routledge Academic, 2009. pp. 113–55.
7. Risser DT, Rice MM, Salisbury ML, et al. The potential for improved teamwork to reduce medical errors in the emergency department. *Ann Emerg Med* 1999;34(3):373–83.
8. Leape LL, Berwick DM. Five years after to err is human—what have we learned. *J Am Med Assoc* 2005;293(19):2384–90.
9. Bleetman A, Sanusi S, Dale T, Brace S. Human factors and error prevention in emergency medicine. *Emerg Med J* 2012;29(5):389–93.
10. Cosby KS. A framework for classifying factors that contribute to error in the emergency department. *Ann Emerg Med* 2003;42(6):815–23.
11. Who is the resuscitation team leader? *American Academy of Pediatrics/American Heart Association NRP Instructor Update*, vol. 22; 2013.
12. Rosenman ED, Shandro JR, Ilgen JS, Harper AL, Fernandez R. Leadership training in health care action teams: a systematic review. *Acad Med* 2014;89(9):1295–306.
13. Blumenthal DM, Bernard K, Bohnen J, Bohmer R. Addressing the leadership gap in medicine: residents' need for systematic leadership development training. *Acad Med* 2012;87(4):513–22.
14. van Schaik SM, Von Kohorn I, O'Sullivan P. Pediatric resident confidence in resuscitation skills relates to mock code experience. *Clin Pediatr (Phila)* 2008;47(8):777–83.
15. Baker D, Gustafson S, Beaubien J. *Medical Teamwork and Patient Safety: The Evidence-based Relation.* Rockville, MD: Agency for Healthcare Research and Quality, 2007.
16. Bordage G. Conceptual frameworks to illuminate and magnify. *Med Educ* 2009;43(4):312–9.
17. Pronovost PJ, Holzmueller CG, Ennen CS, Fox HE. Overview of progress in patient safety. *Am J Obstet Gynecol* 2011;204(1):5–10.
18. Salas E, Rosen MA, King HB. Integrating teamwork into the DNA of graduate medical education: principles for simulation-based training. *J Grad Med Educ* 2009;1(2):243–4.
19. Rosenman ED, Ilgen JS, Shandro JA, Harper AL, Fernandez R. Team leadership assessment tools in health care action teams: a systematic review. *Acad Med* 2015;90(10):1408–22.
20. Andreatta PB. A typology for health care teams. *Health Care Manag Rev* 2010;35(4):345–54.
21. Sundstrom E, de Meuse KP, Futrell D. Work teams: applications and effectiveness. *Am Psychol* 1990;45(2):120–33.
22. Steiner ID. *Group Process and Productivity.* New York: Academic Press, 1972.
23. Van de Ven AH, Delbecq AL, Koenig R Jr. Determinants of coordination modes within organizations. *Am Sociol Rev* 1976:322–338.
24. Hackman JR. The psychology of self-management in organizations. In: Pallack MS, Perloff RO, (eds). *Psychology and Work: Productivity, Change, and Employment.* Washington, DC: American Psychological Association, 1986.
25. Klein KJ, Ziegert JC, Knight AR, Xiao Y. Dynamic delegation: hierarchical, shared and deindividualized leadership in extreme action teams. *Adm Sci Q* 2006;51(4):590–621.
26. Lewin K, Cartwright D. Field Theory in Social Science: Selected Theoretical Papers; 1951.
27. Kozlowski SWJ, Gully SM, McHugh PP, Salas E, Cannon-Bowers JA. A dynamic theory of leadership and team effectiveness: developmental and task contingent leader roles. In: Ferris GR, editor. *Research in Personnel and Human Resource Management.* Greenwich, CT: JAI Press, 1996. pp. 253–305.
28. McGrath J. *Groups: Interaction and Performance.* Englewood Cliffs, NJ: Prentice-Hall, 1984.
29. Fernandez R, Kozlowski SWJ, Shapiro MJ, Salas E. Toward a definition of teamwork in emergency medicine. *Acad Emerg Med* 2008;15(11):1104–12.
30. Fernandez R, Pearce M, Grand JA, et al. Evaluation of a computer-based educational intervention to improve medical teamwork and performance during simulated patient resuscitations. *Crit Care Med* 2013;41(11):2551–62.

31. Kozlowski SWJ, Gully SM, Nason ER, Smith EM. Developing adaptive teams: a theory of compilation and performance across levels and time. In: Ilgen DR, Pulakos ED, (eds). *The Changing Nature of Performance: Implications For Staffing, Motivation, and Performance.* San Franscisco, CA: Jossey-Bass, 1999. pp. 241–92.
32. Marks MA, Mathieu JE, Zaccaro SJ. A temporally based framework and taxonomy of team processes. *Acad Manag Rev* 2001;26(3):356–76.
33. Burke CS, Stagl KC, Salas E, Pierce L, Kendall D. Understanding team adaptation: a conceptual analysis and model. *J Appl Psychol* 2006;91(6):1189–207.
34. Eppich W, Howard V, Vozenilek J, Curran I. Simulation-based team training in healthcare. *Simul Healthc* 2011;6:S14–9.
35. Bradley P. The history of simulation in medical education and possible future directions. *Med Educ* 2006;40:254–62.
36. Salas E, Nichols DR, Driskell JE. Testing three team training strategies in intact teams—a meta-analysis. *Small Group Res* 2007;38(4):471–88.
37. Salas E, DiazGranados D, Klein C, et al. Does team training improve team performance? A meta-analysis *Hum Factors* 2008;50(6):903–33.
38. Goldstein IL, Ford JK. *Training in Organizations: Needs Assessment, Development, and Evaluation.* Belmont, CA: Wadsworth, 2002.
39. Grand JA, Pearce M, Rench TA, et al. Going DEEP: guidelines for building simulation-based team assessments. *Br Med J Qual Saf* 2013;22(5):436–48.
40. Cannon-Bowers JA, Salas E. A framework for developing team performance measures in training. In: Brannick MT, Salas E, Prince C, (eds). *Team Performance Assessment and Measurement: Theory, Methods, and Applications.* Mahwah, NJ: Lawrence Erlbaum Associates Publishers, 1997. pp. 45–62.
41. Healey AN, Undre S, Vincent CA. Developing observational measures of performance in surgical teams. *BMJ Qual Saf* 2004;13:I33–40.
42. Rosen MA, Salas E, Wilson KA, et al. Measuring team performance in simulation-based training: adopting best practices for healthcare. *Simul Healthc* 2008;3(1):33–41.
43. Hackman JR. The design of work teams. In: Lorsch JW, editor. *Handbook of Organizational Behavior.* Englewood Cliffs, NJ: Prentice-Hall, 1987. pp. 315–42.
44. Edmondson AC. Speaking up in the operating room: how team leaders promote learning in interdisciplinary action teams. *J Manag Stud* 2003;40(6):1419–52.
45. Kozlowski SWJ, Grand JA, Baard SK, Teams Pearce M. Teamwork, and team effectiveness: Implications for human systems integration. In: Boehm-Davis D, Durso F, Lee J, (eds). *The Handbook of Human Systems Integration.* Washington, DC: APA, 2015.
46. LePine JA, Piccolo RF, Jackson CL, Mathieu JE, Saul JR. A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers Psychol* 2008;61:273–307.
47. Brett-Fleegler M, Rudolph J, Eppich W, et al. Debriefing assessment for simulation in healthcare development and psychometric properties. *Simul Healthc* 2012;7(5):288–94.
48. Salas E, Klein C, King H, et al. Debriefing medical teams: 12 evidence-based practices and tips. *Jt Comm J Qual Saf* 2008; 34(9):518–27.
49. Bowers CA, Braun CC, Morgan BB Jr. Team workload: its meaning and measurement. In: Brannick MT, Salas E, Prince C, (eds). *Team Performance Assessment and Measurement: Theory, Methods, and Applications.* Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers, 1997. pp. 85–108.
50. Burtscher MJ, Manser T. Team mental models and their potential to improve teamwork and safety: a review and implications for future research in healthcare. *Saf Sci* 2012;50(5): 1344–54.
51. Klimoski R, Mohammed S. Team mental model: construct or metaphor? *J Manag* 1994;20(2):403–37.
52. Beal DJ, Cohen RR, Burke MJ, McLendon CL. Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J Appl Psychol* 2003;88(6):989–1004.
53. Kozlowski SWJ, Ilgen DR. Enhancing the effectiveness of work groups and teams (Monograph). *Psychol Sci Public Interest* 2006;7(3):77–124.
54. Kozlowski SWJ, Bell BS. Team learning, development, and adaptation. In: Sessa VI, London M, (eds). *Group Learning.* Mahwah, NJ: Lawrence Erbaum Associates, 2008. pp. 15–44.
55. Gully SM, Incalcaterra KA, Joshi A, Beauien JM. A meta-analysis of team-efficacy, potency, and performance: interdependence and level of analysis as moderators of observed relationships. *J Appl Psychol* 2002;87(5):819–32.
56. Zaccaro SJ, Blair V, Peterson C, Zazanis M. Collective efficacy. In: Maddux J, editor. *Self-efficacy, Adaptation, and Adjustment.* New York: Plenum Press, 1995. pp. 305–28.
57. Salas E, Sims DE, Burke CS. Is there a big five in teamwork? *Small Group Res* 2005;36(5):555–99.

Developing Team Cognition

A Role for Simulation

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Summary Statement: Simulation has had a major impact in the advancement of healthcare team training and assessment. To date, most simulation-based training and assessments focus on the teamwork behaviors that impact team performance, often ignoring critical cognitive, motivational, and affective team processes. Evidence from team science research demonstrates a strong relationship between team cognition and team performance and suggests a role for simulation in the development of this team-level construct. In this article, we synthesize research from the broader team science literature to provide foundational knowledge regarding team cognition and highlight best practices for using simulation to target team cognition.
(*Sim Healthcare* 12:96–103, 2017)

Key Words: Teamwork, Cognition, Patient safety, Simulation, Team training.

Team cognition is critical to effective teamwork and team performance.[1] The current working definition of team cognition encompasses the organized structures that support team members' ability to acquire, distribute, store, and retrieve critical knowledge.[2] An ability to share crucial information and to know where in the team unique knowledge resides allows members to anticipate and execute actions as a unit rather than as individuals. Team cognition emerges through team learning and team member interaction and thus is highly amenable to team training.

Healthcare simulation is widely used as a mechanism for improving team performance[3]; however, simulation-based team training interventions focus primarily on developing team *behavioral processes* (eg, the communication, monitoring, and coordination behaviors that support high performing teams) and tend to neglect team cognition.[4] As a result, teams do not maximally leverage the collective knowledge, skills, and attitudes of their members. Team science researchers advocate for the use of simulation as a mechanism to both develop and assess team cognition[5]; however, current healthcare simulation-based team interventions rarely focus on team learning or the knowledge structures underlying effective team performance.

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The first goal of this article is to provide the healthcare simulation community with an understanding and appreciation for team-level cognitive structures as important mediating factors in team performance. We focus on 2 unique team cognition domains—team mental models (TMMs) and transactive memory systems (TMSs)—that are critical to team effectiveness and responsive to team training efforts. The second goal is to provide principles to guide educators and researchers in the design and implementation of healthcare-based simulation to target team cognition development.

TEAM MENTAL MODELS

Definition

Klimoski and Mohammed[6] define *TMMs* as team members' shared understanding and mental representation of knowledge relevant to key elements of the team's task environment (Fig. 1). Team mental models describe the content and organization of both task- and team-related knowledge held by the team as a unit. This focus on both content and structure distinguishes TMMs from other forms of cognition. Team mental models represent different types of knowledge, including declarative (knowledge of what), procedural (knowledge of how), and strategic (knowledge of context and application).[7] Team mental models also fulfill multiple functions, such as allowing team members to interpret information similarly (description), share expectations concerning future events (prediction), and develop similar causal accounts for a situation (explanation). Ultimately, TMMs ensure that the entire team has a collective understanding of the current and future state of the task and an understanding of how to achieve task goals. Team mental models facilitate coordination by enabling individuals to accurately anticipate the needs of other team members and quickly direct resources when and where they are needed.

There is no single, all-encompassing TMM for any team. Rather, teams are thought to hold multiple different TMMs

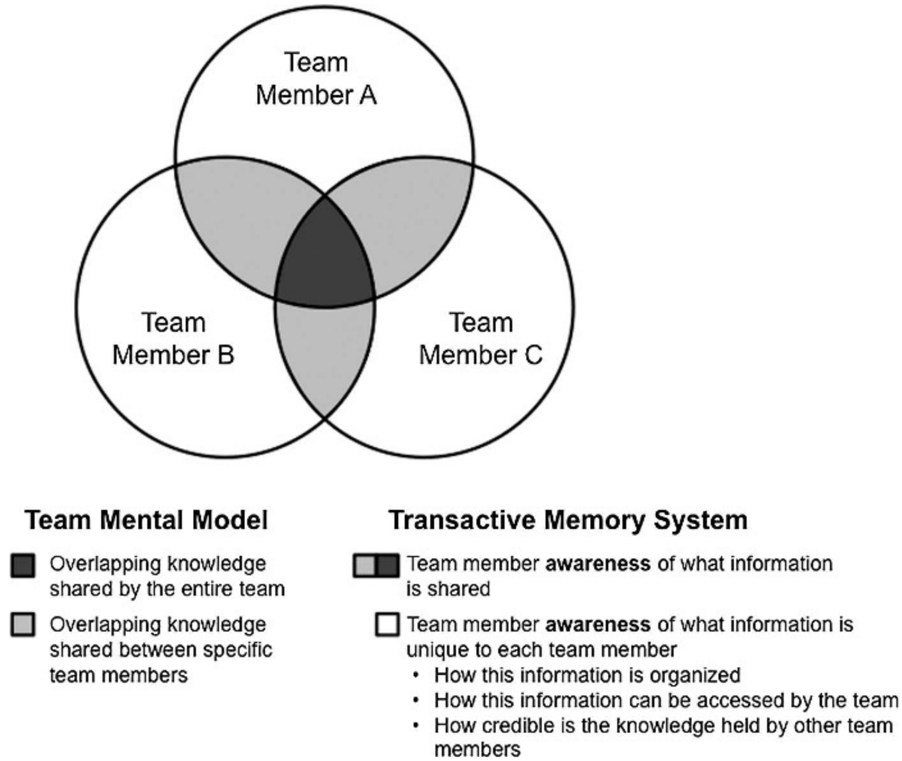

FIGURE 1. Team mental model and transactive memory system definitions.

simultaneously.[7] Cannon-Bowers et al[8] initially proposed the following 4 content domains of TMMs: (*a*) equipment model, (*b*) task model, (*c*) team member model, and (*d*) team interaction model (Table 1). These 4 types can be collapsed into 2 broad categories: task-related mental models that focus on work goals and performance requirements and team-related mental models that focus on team member interactions, teamwork beliefs, and skill distribution among team members.[9] Task-related mental models reflect shared knowledge about what a team needs to do and how they can do it, whereas team-related mental models reflect shared beliefs about the team's capabilities and expectations for how to interact with one another.

From a conceptual perspective, TMMs are often operationalized as having 2 properties: similarity and accuracy. Similarity refers to the degree to which mental models are shared among team members, whereas accuracy refers to the correctness of individual team members' knowledge structures, usually determined by task subject matter experts or a "criterion standard" protocol. Thus, similarity reflects if team members are "on the same page," whereas accuracy reflects if members are "on the correct page." Most TMM research focuses on similarity; however, both similarity and accuracy are needed for effective team performance.[10,11]

Importance in Healthcare

Research across different domains and contexts supports the notion that TMMs positively impact both team processes and performance.[12] Well-developed TMMs allow teams to rapidly adapt to changes in patient condition. When team members are working toward a shared goal, with a common understanding of how to get there, they can anticipate fellow team members' actions and know how to respond to expected challenges. [13,14] When plans need to change, a common understanding of the shared goals and objectives can streamline communication and decrease inefficiencies because team members are already on the same page. The goal is to have TMMs that are not only similar but also accurate; that is, they

TABLE 1. Content Domains of TMMs

	Type of Mental Model	Definition	Example of Knowledge Content
Task-related	Equipment model	Shared knowledge about the equipment and technology used or available to the team	Availability of cardiac catheterization after routine hours
	Task model	Shared, organized knowledge about how a task is accomplished in terms of existing protocols, necessary team member skills, procedures, and likely contingencies	Checklist for procedural sedation
Team-related	Team member model	Shared information specific to the team's membership, including individual team member's skills, attitudes, strengths, weaknesses, and preferences	Understanding limited knowledge/skills of trainees
	Team interaction model	Shared conceptions of how the team interacts and which teamwork behaviors are appropriate and effective—includes roles and responsibilities of team members, role interdependencies, and information flow/communication channels	Standard role assignment during a cardiac arrest resuscitation

reflect the true nature of the clinical problem. Inaccurate, highly similar TMMs can result in an entire team going down the wrong path. Not surprisingly, TMMs are most critical during tasks requiring high levels of interaction and team member interdependence.[15] Task interdependence is a key characteristic of high-reliability organizations and noted to be an attribute of healthcare teams and systems.[16] Because healthcare continues to move toward team-based systems of care, the need to establish shared understanding around patient diagnoses, treatment plans, and goals of care becomes crucial to patient and system-based outcomes.

TRANSACTIVE MEMORY SYSTEMS

Definition

Transactive memory systems and TMMs refer to conceptually distinct team-level cognitive structures (Fig. 1). Transactive memory systems are a shared memory "network" among multiple team members. While TMMs focus on shared knowledge and understanding, TMSs focus on the distribution of specialized knowledge within the team. DeChurch and Mesmer-Magnus note that TMSs are a form of cognitive architecture that includes both the knowledge uniquely held by particular team members, as well as a collective awareness of who knows what.[1] Transactive memory consists of the following 3 dimensions: (1) knowledge specialization or the level of memory differentiation within the team, (2) credibility or team members' beliefs about the reliability of other team members' knowledge, and (3) the ability of the team members to coordinate information retrieval effectively.[17] Teams with well-developed TMSs are able to rapidly determine which team members can provide the information or expertise needed, to whom particular types of information should be provided, how to access this information, and whether this information is credible.[18] Transactive memory systems are especially helpful in highly complex tasks that require specialized knowledge that is accurate and applicable.

A team's TMSs and TMMs can be viewed as a continuous, dynamic trade-off between specialization and integration. As outlined previously, having shared knowledge and mental models are critical to coordination. However, it is not practical, realistic, nor beneficial for teams to have members with completely identical mental models. Teams with a large pool of overlapping knowledge may create redundancy of effort and not be as nimble when adapting to novel threats. Mohammed and Dumville[19] provide the following example:

> Within surgical teams, there will be some knowledge that needs to be held in common by all team members (identical), some knowledge that needs to overlap among various dyads and triads (eg, nurse and surgeon, surgeon and anesthesiologist), and some knowledge that will be unique to individual roles within the team (complementary).
>
> In such teams, it would be important to have a shared understanding (TMM) of the team's goals (eg, indication for procedure), plan of action (eg, surgical procedure and approach), any anticipated challenges (eg, risk factors, comorbidities), and available resources or resource limitations (eg, time challenges, equipment issues). However, TMSs would represent the knowledge of which team members hold specific task expertise (eg, managing general anesthesia), decision-making capabilities (eg, decision to change surgical approach), and resource availability (eg, organization of surgical supplies).

Importance in Healthcare

Transactive memory systems provide an additional knowledge structure to support team performance. Transactive memory systems promote a shared understanding of specific task expertise, such as technical skills or nontechnical skills such as leadership, and allow teams to become highly specialized and diverse. Not surprisingly, TMSs are most critical in heterogeneous teams with high levels of specialization and in situations where teams must adapt and solve dynamic, ill-defined problems.[2,18] Transactive memory systems decrease overall cognitive load and redundancy, thus improving efficiency and increasing the capacity for specialization.[20] In healthcare teams, where expertise is distributed throughout the team, awareness of "which team member knows what" and trusting that team member's expertise is critical. A respiratory therapist, intensivist, and nurse could not (and should not) have completely overlapping knowledge domains. Their success as a team hinges on developing an appropriate TMM for the task at hand and a strong TMS to allow efficient and appropriate sharing of individual expertise. Overall, both TMSs and TMMs are necessary for a team to possess excellent shared cognition.

SIMULATION

Simulation is a potentially powerful tool to develop and assess team cognition. Simulation-based training allows for the design of a "synthetic world" that emulates key aspects of a real-world work setting, evokes its critical task, psychological and behavioral processes, and allows assessment of a range of possible performance outcomes.[21] As such, simulation-based training can be used to develop task-related TMMs and TMSs that can then be generalized to any team configuration.[8,22] Simulations can also build specific skills, such as proficiency in prebriefing and debriefing, that support the development of team cognition, particularly in settings with low levels of team member familiarity.[23]

Training intact teams using simulation creates shared team experiences. Intact teams have stable team memberships from day to day. Simulation-based training provides opportunities for teams to work together and develop both shared understanding of the team, tasks, equipment, and patterns of communication (TMM) as well as a networked system of expertise accessible to team members when needed (TMS). Simulated experiences can provide opportunities for team members to exchange ideas and insights, thus building collaborative knowledge and shared understanding.[24] Team members have the opportunity to practice their roles and develop skills necessary to determine who needs to know what, thus strengthening TMS formation.

Unfortunately, not all healthcare teams are stable, and training intact teams is not always possible. Ad hoc teams (eg, resuscitation teams, trauma teams, and rapid response teams) lack consistent, stable memberships. Such teams do not have the repeated interactions needed to develop a significant "team history." In addition, because their memberships are not defined, it is not possible to train these teams as a unit. As a result, they cannot rely on traditional methods for developing strong team-related TMMs and TMSs. Burtscher and Manser[25] highlight this challenge and note that ad hoc teams must build TMM through mechanisms other than longstanding experience. Simulation-based training can be used to develop individual skills that will translate to team settings, thus addressing some of the challenges associated with ad hoc teams. Simulated clinical experiences can help individuals develop knowledge about the expertise and skills held by other professions and about the various roles within the team. In addition, individuals can build knowledge of protocols and procedures (eg, sepsis care bundles, cardiac resuscitation algorithms) that facilitate a shared, consistent team approach.

Hereafter, we offer a summary of simulation-based training design and implementation principles that support development of team cognition. Although these principles are described here for the purpose of enhancing healthcare team cognition through experiential training, they represent best practices for simulation-based team training across multiple competencies. Table 2 offers a summary of the principles along with practical examples.

Principles to Guide the Use of Simulation to Develop Team Cognition

1. Use a systematic approach to simulation-based training design.

Event-based simulation design provides a clear set of principles to guide the development of effective simulation-based team training.[26] This methodology is centered on the discreet, purposeful placement of events within a simulated experience. Each event begins with a "trigger" that is strategically designed to provoke specific team behaviors and cognitive activities (Fig. 2). Triggers and back-up triggers ensure that the team experiences all components of the scenario even if the team fails to respond to early cues. Well-designed triggers and event sequences minimize the interdependence of performance quality from one task to the next and allow each event to unfold independent of the team's performance on a previous event. Taken together, the components of event-based simulation design offer realistic training exercises that can be linked to observable team behaviors and performance metrics. In addition, because all components of the simulation are tightly scripted, instructors can manipulate team, task, and environmental conditions to specifically target development of different types of mental models.

Event-based simulation design also provides a rigorous mechanism to determine expert mental models for specific clinical events. Because event-based simulations are easily replicated, they can be used to determine a criterion standard mental model or TMS using expert teams. This criterion standard could then serve as a benchmark when determining the accuracy of mental models for trainees. Areas where trainee TMMs or TMSs deviate from expert cognitive content or structures suggest opportunities for further training and discussion.

TABLE 2. Principles to Guide the Use of Simulation to Develop Team Cognition

Principle	Explanation	Example(s)
1. Use a systematic approach to simulation design	Use event-based simulation design[26] principles to ensure that targeted behaviors are elicited	• Use a standardized participant to trigger desired information-sharing behaviors, such as a brief or a huddle • Use a standardized trigger event (e.g., patient arrest) to force teams to access knowledge from its members
2. Use simulation to target information-sharing behaviors	Train teams to identify what information is pertinent, focusing on quality, applicability, and criticality rather than quantity	• Conduct simulation with leader blindfolded, thus forcing all team members to explicitly share key information • Pause simulations at key points to query team members to see how information sharing is contributing to TMM and TMS • Use a standardized junior participant (e.g., student) to ask predefined questions if the team is struggling to share information
3. Design simulations to target team processes and behaviors that positively influence TMMs and TMSs	Focus on team processes known to improve team cognition, such as planning behaviors	• Incorporate an unexpected change in patient condition to trigger rapid reprioritization • Remove team leader midsimulation • Have team members arrive asynchronously
4. Use simulation to equip team leaders with the skills necessary to develop TMMs and TMSs	Train team leaders who can then develop and influence the team—important when unable to train intact teams because of variability in team composition	• Use a standardized team to train team leaders • Expose team leaders to teams with varying backgrounds and skillsets
5. Use team training strategies that support development of TMMs and TMSs	Incorporate established team training strategies that are well suited to simulation-based training	• Cross-training[27] • Reflexivity training[28] • Team interaction training[24] • Guided self-correction training[23]
6. Purposefully structure team debriefs to support development of team cognition	Design debriefs to maximize impact on team cognition development	• Use an expert model of teamwork as a reference to promote a universal framework that is not scenario specific • Focus on and reinforce positive behavior, in addition to highlighting opportunities for improvement
7. Design simulation-based systems to assess elements of team cognition	Simulations provide a standardized platform to assess both TMMs and TMSs. Several measurement options exist.[29]	• Cognitive interviewing[30] • Concept mapping[11] • Pathfinder[31] • Communication coding[32]

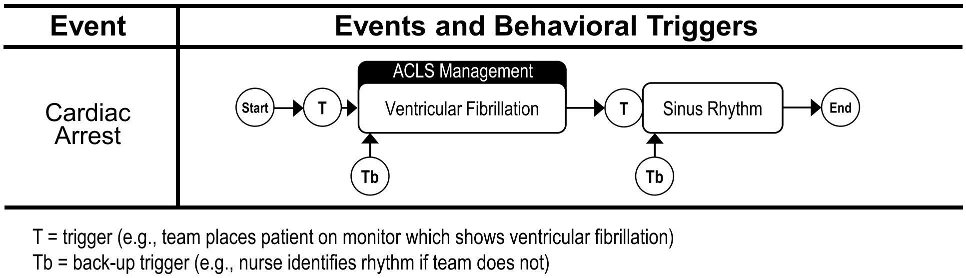

FIGURE 2. Example of event-based simulation design.

2. Use simulation to target information-sharing behaviors.

Communication and information sharing are necessary for the development of team cognition.[33] These processes distribute new knowledge among team members, so it can become a shared property within the team (TMM). In addition, information highlighting which team members are responsible for specific or unique knowledge helps build TMSs. Interdisciplinary simulation-based training gives team members the skills necessary to determine *who* needs to know *what*, thus strengthening team cognition. Because teams cannot continuously communicate every bit of available information, knowing *what* to communicate and *when* influences team performance. A meta-analysis of team performance and information sharing suggested that information sharing had a greater influence on team performance when the information was unique and relevant to performance outcomes.[34] This suggests that sharing of nonrelevant or redundant information can be ineffective and hinder team performance.[33]

Simulation-based training provides a mechanism to improve the recognition and sharing of knowledge that is directly relevant to the task, team, and environment. This skill can be targeted through techniques that force explicit communication between team members. For example, performing a basic resuscitation simulation with a blindfolded team leader requires all team members to explicitly share key information in a well-organized manner. Video or audio playback of performance can be employed during debriefs to help learners become more aware of their communication patterns. Trainers can also pause simulations at key points and query team members to see how their information sharing is (or is not) contributing to their mental model. Although this has some drawbacks in terms of simulation flow, it is a powerful tool that can pinpoint examples of ineffective information sharing and the deleterious impact on team cognition.

3. Design simulations to target team processes and behaviors that positively influence TMMs and TMSs.

Evidence suggests that certain team processes are particularly relevant for the development of team cognition. Planning behaviors, specifically those involving information gathering and strategic planning, positively influence the development of TMMs with high levels of similarity.[35] These behaviors help team members make sense of their task and environment and ensure that the team's objectives are clear. In addition, strategizing behaviors not only help teams plan their approach to a task but also create contingency plans that help establish mental models capable of facilitating adaptability when unexpected challenges arise.[36]

Simulations can be specifically designed to target these high-yield planning behaviors. The degree to which the simulation forces the team to perform key planning behaviors under time pressure can be altered depending on the skills of the team members. In addition, instructors can manipulate key environmental factors such as the asynchronous arrival of team members to challenge teams to execute effective planning behaviors under realistic, time-pressured, and dynamic conditions.

4. Use simulation to equip team leaders with the skills necessary to develop TMMs and TMSs in healthcare teams.

Empirical research supports the link between effective leadership behaviors and mental model development.[24,37] Leader behaviors and leader cognition shape the development and accuracy of team-level mental models. Team leaders must gather and interpret critical information about the task, team, and environment to form their own mental representation of the situation.[38] This mental model should reflect not only the clinical task but also factors such as resource constraints, team member capabilities, and potential challenges. Leader-initiated briefings, in which team leaders provide an overview of the team's goals, potential strategies for dealing with challenges, and information about task prioritization, can positively influence development of similar and accurate TMM.[24] Team leaders also monitor team performance and provide feedback to the team, thus helping team members build a shared understanding of their progress in relation to their goals.[39] A well-developed mental model then positions the team leader to begin strategizing and forming a plan to address the clinical problem. Each step in this process influences the accuracy and similarity of TMM as well as what information is distributed to specific team members.

Simulation-based training is a recommended mechanism for training team leaders and leadership processes.[38,40] In addition to training entire teams, simulations can recreate a "team" experience for team leader training and assessment even when intact teams (ie, teams containing their full membership) are unavailable. Simulation allows learners to practice the specific behaviors that influence team cognition, including facilitating knowledge sharing among the team, setting team goals and priorities, and providing continuous status updates.[2,38]

5. Use team training strategies that support development of TMMs and TMSs.

Simulation-based training can support team training design elements that develop and strengthen elements of team cognition.[41] Evidence supports using several training strategies to positively influence team cognition (Table 3). Cross-training improves

TABLE 3. Instructional Training Strategies That Support the Development of Team Cognition

Instructional Strategy	Description	Reference
Cross training/interpositional knowledge training	Team members receive specific instruction on the roles and responsibilities of other team members.	Volpe et al (2006)[27]
Reflexivity training	Teams are guided to reflect on progress toward their goals, consider how they might adjust their approach and plan how to implement new strategies	West (2000)[28]
Team interaction training	Team members are trained on teamwork skills embedded within a high-fidelity environment that replicates the work (clinical) setting	Marks et al[24]
Guided self-correction training	Team members are guided to diagnose performance deficiencies and engage in problem solving to find more effective strategies	Smith-Jentsch et al[23]

team interaction mental models, leading to increases in coordination and back-up behavior and, ultimately, improved team performance.[42] In addition, team self-correction training, which focuses on skills relevant to (*a*) event review (following a task episode), (*b*) error identification, (*c*) feedback exchange, and (*d*) planning for subsequent task episodes, is thought to foster the development of TMMs.[43] These instructional training design approaches can all be implemented using a simulation-based platform. In fact, the ability to create highly realistic behavioral triggers makes simulation a logical choice for such training.

6. Purposefully structure team debriefs to support development of team cognition.

Simulation educators can optimize the development of team cognition by using an evidence-based, guided approach to debriefing. Feedback is classically defined as the delivery of information regarding one's performance results, often to inform trainees about what they did in relationship to what should have been done.[44] Providing feedback through debriefing is a cornerstone of effective team training and is recognized as one of the most valuable components of simulation-based training. However, simply providing teams with an opportunity to debrief does not necessarily facilitate the development of shared team cognition.[10] The degree to which feedback positively influences learning and team performance depends largely on the manner in which it is delivered, the content of the information discussed, and the way it is interpreted.[45] By using a debriefing framework that incorporates these factors, educators can optimize team cognition and strengthen TMM and TMS development.

First and foremost, debriefing should be structured around an expert model of teamwork and performance. Team members tend to organize their debriefing around the chronology of the task. As a result, the discussion focuses on what happened and why it happened in a very situation-specific context. This may improve team performance in similar situations and contexts but does not necessarily develop the cognitive skills and structures necessary to think or act under different conditions, that is, to adapt.[46] In fact, it could lead to negative learning if trainees attempt to generalize highly context-specific knowledge from simulations of rarely occurring events.[23,47] Without the guidance of an expert model, team members may adopt similar, but inaccurate, models of the team and/or task. Using an expert model of teamwork to guide debriefing would help teams focus on team behaviors rather than situation-specific outcomes.

Second, debriefings should incorporate both positive and negative feedback to maximize the development of team cognition. Research suggests that when postevent debriefs include both positive and negative performance elements, trainees develop more detailed mental models and demonstrate improved performance on complex skills.[48] However, instructors and team leaders often focus on performance problems and view the discussion of positive behaviors as a waste of time.[49] Using a structured approach to debriefing would encourage the discussion of both effective and ineffective behaviors.

Third, using a framework to guide debriefing can also help facilitate shared understanding in teams whose members hold high quality, yet dissimilar, mental models. This is particularly relevant in healthcare teams, where all team members are trained experts in their respective fields and bring highly specialized, often divergent views to the team. In these situations, it can be difficult for team members to communicate their point of view and negotiate a shared vision of the task, associated challenges, and possible solutions.[23] Using a team-oriented framework to guide debriefing can avoid conflict and facilitate the development of overlapping mental models among team members from different disciplines.

7. Design simulation-based systems to assess elements of team cognition.

An essential component of team science and training is measurement.[50] Team cognition is a critical component of teamwork that is rarely assessed as a training outcome. A detailed discussion of team cognition measurement is well beyond the scope of this article. However, we feel that it is important to note the critical role simulation has played in advancing team cognition research in other domains. To evaluate interventions, a simulation system can serve as a standardized platform to determine whether a targeted intervention such as team training improves teamwork, team cognition, and patient management. As teams progress through the simulation(s), the need for knowledge acquisition, storage, and sharing is triggered, resulting in the development of, or the failure to develop, supporting cognitive structures (e.g., TMMs and TMSs). Using a variety of techniques, TMMs and TMSs can be assessed for both similarity among team members as well as accuracy against subject matter experts who also completed the simulation. We refer readers to Langan-Fox et al[29] and Mohammed et al[51] for additional detail regarding measurement of TMMs and TMSs.

FUTURE DIRECTIONS

Healthcare team cognition research is still in its infancy, and significant opportunities exist to advance theory, methodology, and empiric knowledge. From a conceptual standpoint, Kozlowski and Ilgen note, "Empirical research on transactive memory is not commensurate with its theoretical development."[39] Research across multiple domains demonstrates that TMSs are positively related to both team effectiveness and team performance.[52,53] However, this area is underexplored in healthcare teams. Future research should consider both TMMs and TMSs as complementary, critical factors that influence team effectiveness and performance.

From a methodologic standpoint, studies comparing educational interventions targeting team cognition can help define best practices and evidence-based approaches. Moreover, robust research evaluating team cognition assessment tools can provide evidence supporting assessment validity and reliability. Such tools are necessary if educators and clinicians are to consider the contribution of team cognition to team effectiveness and patient care.

Several areas of empirical research are particularly relevant for healthcare teams. The optimal balance between shared knowledge and distributed knowledge depend on the nature of the healthcare team, the task, and the clinical environment. It will be important to understand how these factors interact within healthcare teams and how training can be used to correctly target development of TMSs along with TMMs. Research focusing on TMSs should consider not only the constituent components of the TMS (ie, what, where, and how knowledge is distributed) but also whether or not all team members share the same vision of the TMS. Finally, there is a need to understand and mitigate potential barriers to accessing distributed knowledge, such as professional hierarchies and communication issues (eg, profession-specific jargon).

CONCLUSIONS

Team cognition plays a critical role in team effectiveness and performance outcomes yet is poorly studied in healthcare. Simulation-based training provides experiential opportunities for development of team cognition that may build upon, or even replace, actual clinical experience. In addition, simulation-based training can address issues related to healthcare reliance on ad hoc team structures by providing opportunities to develop role-related TMM within individual team members. As with any scientific endeavor, we recommend that clinicians, educators, and simulation experts partner with experts in team science to develop robust approaches to simulation-based training that targets team cognition constructs.

REFERENCES

1. DeChurch LA, Mesmer-Magnus JR. The cognitive underpinnings of effective teamwork: a meta-analysis. *J Appl Psychol* 2010;95(1):32–53.
2. Bell BS, Kozlowski SWJ, Blawath S. Team learning: a theoretical integration and review. In: Kozlowski SW, ed. *The Oxford Handbook of Organizational Psychology*. New York, NY: Oxford University Press; 2012.
3. Eppich W, Howard V, Vozenilek J, Curran I. Simulation-based team training in healthcare. *Simul Healthc* 2011;6(Suppl):S14–S19.
4. Weaver SJ, Lyons R, DiazGranados D, et al. The anatomy of health care team training and the state of practice: a critical review. *Acad Med* 2010; 85(11):1746–1760.
5. Salas E, Rosen MA, Burke CS, Nicholson D, Howse WR. Markers for enhancing team cognition in complex environments: the power of team performance diagnosis. *Aviat Space Environ Med* 2007; 78(5):B77–B85.
6. Klimoski R, Mohammed S. Team mental model: construct or metaphor? *J Manage* 1994;20(2):403–437.
7. Rouse WB, Cannon-Bowers JA, Salas E. The role of mental models in team performance in complex systems. *IEEE Trans Syst Man Cyb* 1992; 22(6):1296–1308.
8. Cannon-Bowers J, Salas E, Converse SA. Shared mental models in expert team decision making. In: Castellan NJ, ed. *Individual and Group Decision Making: Current Issues*. Hillsdale, NJ: Erlbaum; 1993:221–246.
9. Mathieu JE, Heffner TS, Goodwin GF, Salas E, Cannon-Bowers JA. The influence of shared mental models on team process and performance. *J Appl Psychol* 2000;85(2):273–283.
10. Edwards BD, Day EA, Arthur W Jr, Bell ST. Relationships among team ability composition, team mental models, and team performance. *J Appl Psychol* 2006;91(3):727–736.
11. Burtscher MJ, Kolbe M, Wacker J, Manser T. Interactions of team mental models and monitoring behaviors predict team performance in simulated anesthesia inductions. *J Exp Psychol Appl* 2011; 17(3):257–269.
12. DeChurch LA, Mesmer-Magnus JR. Measuring shared team mental models: a meta-analysis. *Group Dyn* 2010;14(1):1–14.
13. Rico R, Sánchez-Manzanares M, Gil F, Gibson C. Team implicit coordination processes: a team knowledge-based approach. *Acad Manage Rev* 2008;33(1):163–184.
14. Cannon-Bowers JA, Salas E. Reflections on shared cognition. *J Organ Behav* 2001;22:195–202.
15. Minionis DP, Zaccaro SJ, Perez R. Shared mental models, team coordination, and team performance. In: *10th Annual Meeting of the Society for Industrial and Organizational Psychology*. Orlando, FL: 1995.
16. Baker DP, Day R, Salas E. Teamwork as an essential component of high-reliability organizations. *Health Serv Res* 2006;41(4):1576–1598.
17. Lewis K. Measuring transactive memory systems in the field: scale development and validation. *J Appl Psychol* 2003;88(4):587–604.
18. Zajac S, Gregory ME, Bedwell WL, Kramer WS, Salas E. The cognitive underpinnings of adaptive team performance in ill-defined task situations: a closer look at team cognition. *Organ Psychol Rev* 2014;4(1):49–73.
19. Mohammed S, Dumville BC. Team mental models in a team knowledge framework: Expanding theory and measurement across disciplinary boundaries. *J Organ Behav.* 2001;22(2):89–106.
20. Hollingshead AB. Retrieval processes in transactive memory systems. *J Pers Soc Psychol* 1998;74(3):659–671.
21. Bell BS, Kanar AM, Kozlowski SWJ. Current issues and future directions in simulation-based training in North America. *Int J Hum Res Man* 2008; 19(8):1416–1434.
22. Bedwell WL, Ramsay PS, Salas E. Helping fluid teams work: a research agenda for effective team adaptation in healthcare. *Transl Behav Med* 2012;2(4):504–509.
23. Smith-Jentsch KA, Cannon-Bowers JA, Tannenbaum SI, Salas E. Guided team self-correction: impacts on team mental models, processes, and effectiveness. *Small Gr Res* 2008;39(3):303–327.
24. Marks MA, Zaccaro SJ, Mathieu JE. Performance implications of leader briefings and team-interaction training for team adaptation to novel environments. *J Appl Psychol* 2000;85(6):971–986.
25. Burtscher MJ, Manser T. Team mental models and their potential to improve teamwork and safety: a review and implications for future research in healthcare. *Safety Sci* 2012;50(5):1344–1354.
26. Fowlkes J, Dwyer DJ, Oser RL, Salas E. Event-based approach to training (EBAT). *Int J Aviat Psychol* 1998;8(3):209–221.
27. Volpe CE, CannonBowers JA, Salas E, Spector PE. The impact of cross-training on team functioning: an empirical investigation. *Hum Factors* 1996;38(1):87–100.

28. West MA. Reflexivity, revolution and innovation in work teams. In: Beyerlein M, Johnson D, Beyerlein S, eds. *Product Development Teams.* Stanford: Jai Press; 2000;5:1.

29. Langan-Fox J, Code S, Langfield-Smith K. Team mental models: techniques, methods, and analytic approaches. *Hum Factors* 2000; 42(2):242–271.

30. Seamster TL, Redding RE, Cannon JR, Ryder JM, Purcell JA. Cognitive task analysis of expertise in air traffic control. *Int J Aviat Psychol* 1993; 3(4):257–283.

31. Wyman BG, Randel JM. The relation of knowledge organization to performance of a complex cognitive task. *Appl Cogn Psychol* 1998; 12(3):251–264.

32. Christian JS, Pearsall MJ, Christian MS, Ellis APJ. Exploring the benefits and boundaries of transactive memory systems in adapting to team member loss. *Group Dyn* 2014;18(1):69–86.

33. Grand JA, Braun MT, Kuljanin G, Kozlowski SW, Chao GT. The dynamics of team cognition: a process-oriented theory of knowledge emergence in teams. *J Appl Psychol.* In press .

34. Mesmer-Magnus JR, DeChurch LA. Information sharing and team performance: a meta-analysis. *J Appl Psychol* 2009;94(2):535.

35. Murase T, Carter DR, DeChurch LA, Marks MA. Mind the gap: the role of leadership in multiteam system collective cognition. *Leadership Q* 2014;25(5):972–986.

36. Waller MJ, Gupta N, Giambatista RC. Effects of adaptive behaviors and shared mental models on control crew performance. *Manage Sci* 2004;50(11):1534–1544.

37. Dionne SD, Sayama H, Hao CY, Bush BJ. The role of leadership in shared mental model convergence and team performance improvement: an agent-based computational model. *Leadership Q* 2010;21(6):1035–1049.

38. Rosenman ED, Shandro JR, Ilgen JS, Harper AL, Fernandez R. Leadership training in health care action teams: a systematic review. *Acad Med* 2014;89(9):1295–1306.

39. Kozlowski SWJ, Ilgen DR. Enhancing the effectiveness of work groups and teams. *Psychol Sci Public Interest* 2006;7(3):77–124.

40. Fernandez R, Vozenilek JA, Hegarty CB, et al. Developing expert medical teams: toward an evidence-based approach. *Acad Emerg Med* 2008; 15(11):1025–1036.

41. Burke CS, Salas E, Wilson-Donnelly K, Priest H. How to turn a team of experts into an expert medical team: guidance from the aviation and military communities. *Qual Saf Health Care* 2004;13:I96–I104.

42. Marks MA, Sabella MJ, Burke CS, Zaccaro SJ. The impact of cross-training on team effectiveness. *J Appl Psychol* 2002;87(1):3–13.

43. Blickensderfer E, Cannon-Bowers JA, Salas E. Theoretical bases for team self-correction: fostering shared mental models. *Adv Interdiscip Stud Work Teams* 1997;4:249–279.

44. Kluger AN, DeNisi A. The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychol Bull* 1996;119(2):254–284.

45. Kozlowski SWJ, Toney RJ, Mullins ME, et al. Developing adaptability: a theory for the design of integrated-embedded training systems. In: Salas E, ed. *Advances in Human Performance and Cognitive Engineering Research.* Vol 1. Amsterdam: JAI/Elsevier Science; 2001:59–123.

46. Bell BS, Kozlowski SWJ. Adaptive guidance: enhancing self-regulation, knowledge, and performance in technology-based training. *Pers Psychol* 2002;55(2):267–306.

47. Leboe JP, Whittlesea BW, Milliken B. Selective and nonselective transfer: positive and negative priming in a multiple-task environment. *J Exp Psychol Learn Mem Cogn* 2005;31(5):1001.

48. Ellis S, Davidi I. After-event reviews: drawing lessons from successful and failed experience. *J Appl Psychol* 2005;90(5):857.

49. Tannenbaum SI, Smith-Jentsch KA, Behson SJ. Training team leaders to facilitate team learning and performance. In: Cannon-Bowers JA, Salas E, eds. *Making Decisions Under Stress: Implications for Individual and Team Training.* Washington, DC: American Psychological Association; 1998:247–270.

50. Grand JA, Pearce M, Rench TA, et al. Going DEEP: guidelines for building simulation-based team assessments. *BMJ Qual Saf* 2013; 22(5):436–448.

51. Mohammed S, Klimoski R, Rentsch JR. The measurement of team mental models: we have no shared schema. *Organ Res Methods* 2000;3(2):123–165.

52. Pearsall MJ, Ellis APJ, Bell BS. Building the infrastructure: the effects of role identification behaviors on team cognition development and performance. *J Appl Psychol* 2010;95(1):192–200.

53. Ren YQ, Carley KM, Argote L. The contingent effects of transactive memory: when is it more beneficial to know what others know? *Manage Sci* 2006;52(5):671–682.

A Multicenter, Observational Study of Teamwork, Team Cognition, and Leadership

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BACKGROUND

Current literature cites high quality interdisciplinary team performance as critical to patient safety and error reduction. Emergency medical teams in particular depend upon effective team member interactions to coordinate, monitor, and adapt their collective skills to accomplish patient care activities. Effective team leaders directly impact team performance by building shared understanding of the team's task (team mental model) and influencing teamwork behaviors. Healthcare research has not evaluated relationships between team process, team leadership, and development of team mental models.

OBJECTIVE

To begin to evaluate relationships between patient care and key team-level constructs – team leadership, team cognition, and team process.

METHODS

Design: This is a multicenter, observational simulation-based study of team performance.

Subjects: Subjects (n = 132) were emergency department practitioners recruited from two different academic, urban medical centers. Subjects were assigned to four-member teams (1 physician, 1 nurse, 1 medical student) based on availability (N_{teams} = 44).

Measurement: All subjects were assessed on SimTEAM-L (Simulated Team Experience and Assessment Methodology for Leaders), a high-fidelity patient simulation modified to allow evaluation of interdisciplinary teams directed by a physician team leader (Figure 1). Simulations were video recorded and later coded using Noldus Observer®XT (Leesburg, VA) software.

Outcome Measures

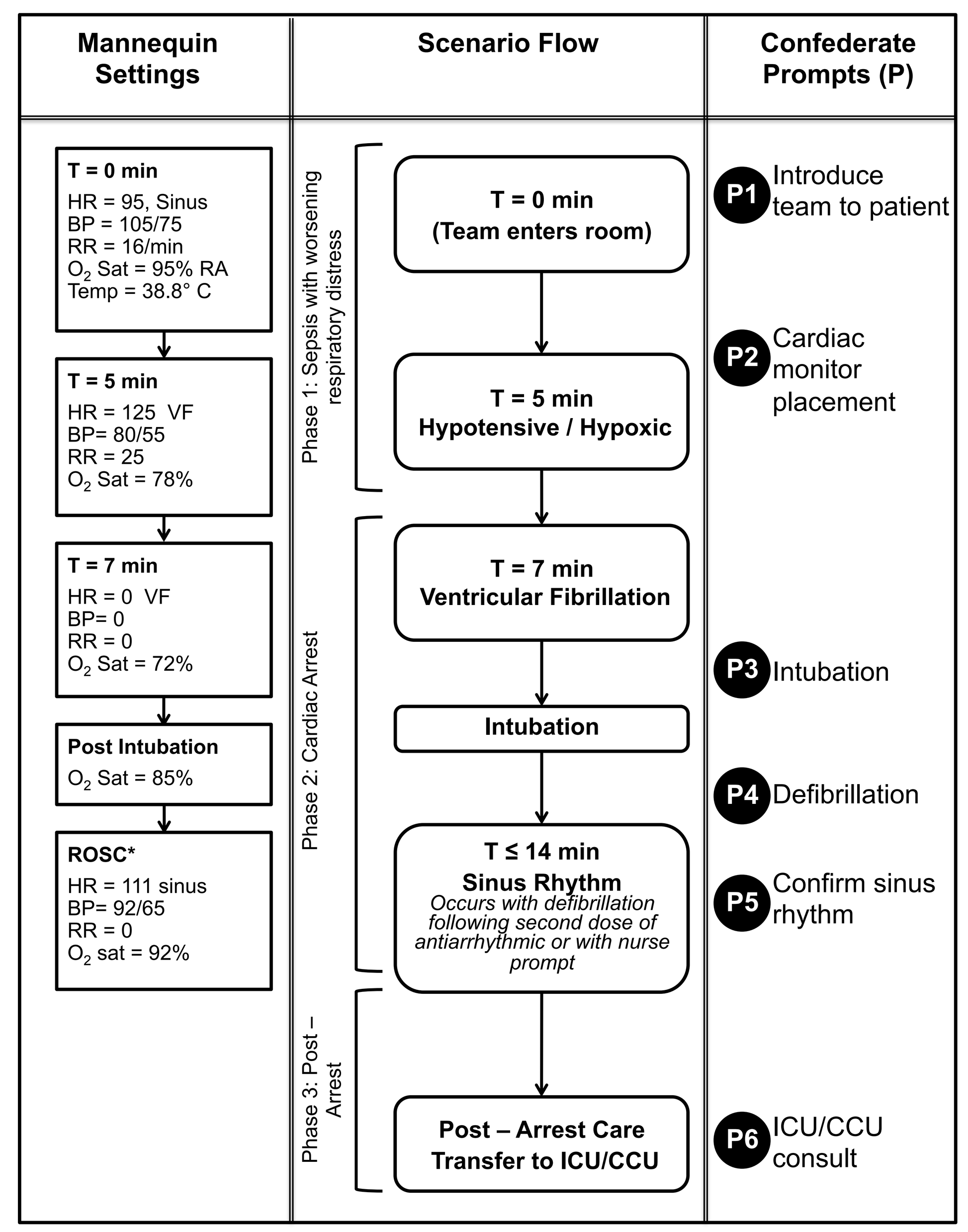
Behavioral
- Team process checklist (120 items)
- Patient management checklist (84 items)

Cognitive
- Team mental model measure

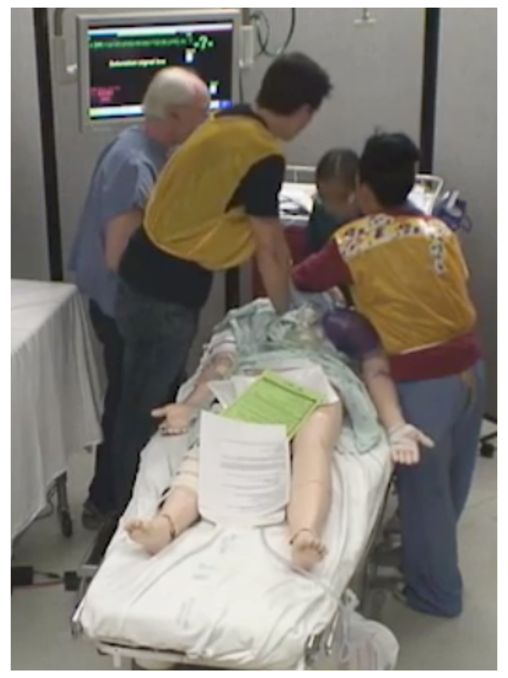
Perception
- Leadership perception measure

FIGURES AND TABLES

Figure 1. Simulation

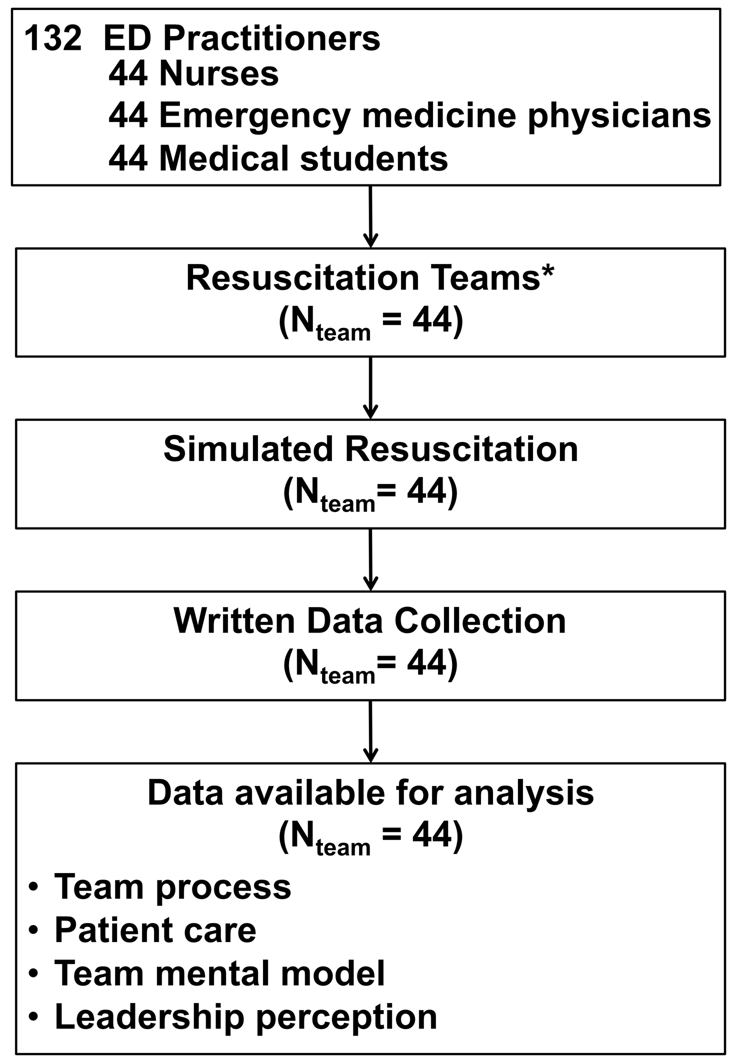


Scenario overview:
A young 34 year old male with a history of quadriplegia from trauma is brought in from a rehabilitation center for hypoxia and "respiratory distress." The patient has pneumonia and is in septic shock. He becomes unstable and goes into cardiac arrest (ventricular fibrillation). The patient remains in ventricular fibrillation until the defibrillation after his second dose of antiarrhythmic medication or 14 minutes, whichever comes first. Once the patient has return of spontaneous circulation in a sinus rhythm, the team has a short time to manage post – arrest issues and initiate disposition to an intensive care unit.



*ROSC = return of spontaneous circulation

Figure 2. Study design



*Each team contains: 1 nurse, 1 EM physician, 1 - 4th year medical student

Table 1. Means, standard deviations, and correlations of study measures

Outcome measure^{a}	Mean (SD)	1	2	3	4	5	6
1. Patient care	0.46 (0.08)	1					
2. Teamwork	0.41 (0.05)	0.34*	1				
3. Work site^{b}	0.64 (0.49)	0.09	0.26†	1			
4. Team leadership knowledge	9.41 (2.80)	-0.20	-0.18	0.07	1		
5. Team mental model	73.85 (14.80)	0.25†	0.06	0.36*	0.11	1	
6. Leader effectiveness (team member ratings)	3.80 (0.40)	-0.11	0.12	-0.01	0.05	0.10	1
7. Leader effectiveness (leader self – ratings)	3.26 (0.51)	0.14	0.13	0.28†	0.08	0.17	0.24

^{a}n = 44 teams for all outcome measures
^{b}Work site: 0=Detroit, 1=Seattle
*$p<0.05$
†$p<0.1$

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RESULTS

A total of 44 teams were recruited from two institutions. All participants completed the study. Interrater reliability scores (Cohen's Kappa) for both teamwork (90.6) and patient care (0.86) were high.

- Teamwork and patient care outcomes correlated (r=0.336, p=.026, n=44) as predicted by team effectiveness models.
- Team mental model measure scores were significantly correlated with work site (r=.356, p=.018, n=44) and marginally correlated with patient care (r=.250, p=.101, n=44).
- Leader perception (team) and leader perception (self) measure internal consistency was estimated by Cronbach's alpha and were .844 and .869, respectively. Neither scale was found to significantly correlate with other measures in this study. L
- Leader self-rating was marginally correlated with work site (r=.281, p=.064, n=44).

CONCLUSIONS

Teamwork and team mental model formation is important to patient care. Multicenter studies on teamwork and team performance are important, as there are critical site-specific differences that can impact outcomes. Further experimental studies should be performed to determine how training can improve team effectiveness and patient care by targeting leadership, teamwork, and team mental models.

Development of an Integrated Team Training Design and Assessment Architecture to Support Adaptability in Healthcare Teams

MSIS-Team Performance Training Research Initiative

PI: E. Rosenman / J. Grand **Org:** University of Washington 06/30/2019 Final Report

DMRDP

Problem, Rationale, and Military Relevance

- **Problem:** Conceptual models and assessment approaches to support effective team training that maximizes team adaptability and performance do not exist.
- **Rationale:** An integrated team training model will identify ***which*** individual, team, and training design factors can be manipulated to maximize team training effectiveness and impact on patient safety outcomes. Additionally, a predictive model of team performance will demonstrate ***how*** team behaviors predict future team performance and patient care outcomes.
- **Military Relevance:** This proposal directly addresses the TPT research initiative by providing a detailed framework and predictive assessment system to support team performance training to improve teamwork behaviors and patient outcomes.

Conceptual Model of Team Training Elements + **Predictive Model of Team Performance**

OPTIMIZED TRAINING

IMPROVED ADAPTABILITY AND PATIENT SAFETY

Proposed Solution

- **Objective:** To develop a simulation design architecture and predictive model of trauma team performance to support team training and team effectiveness.
- **Summary of Aims:** Integrate individual- and team-level team performance frameworks to develop a simulation design architecture and a predictive model of trauma team performance to support effective team training with automated individual and team feedback and performance assessment.
- **Outcomes:** (1) A detailed framework of the individual, team, and training design factors related to effective team performance training and (2) A predictive model of team performance that identifies how teams can adapt their behaviors to maximize their teamwork and minimize errors

Timeline and Cost (Expenditures to Date = $1.148M)

	Activities FY	15	16	17	NCE
X	Integrate individual-level and team-level simulation design frameworks to develop a simulation design architecture (Aim 1)				
X	Develop a predictive model of trauma team performance and outcomes using Bayesian Belief Networks (Aim 2)				
	Prospectively test and refine the model of trauma team performance on simulated trauma team resuscitations (Aim 2)				
	Data analysis and dissemination				
	Actual Expenditures ($K)	$170	$382	$404	$192