A Novel Approach to Medical Team Training: Blended Reality Built on Open Source Platforms

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ABSTRACT

One of the most effective means of reducing medical errors is through good communication. The Immersive Modular Patient Care Team Trainer (IMPACTT) project is funded by the Defense Health Agency Joint Program Committee-1 (DHA/JPC-1) in conjunction with Army Futures Command Simulation and Training Technology Center (STTC), who provides technical guidance to the project. Initially targeting pre-deployment medical teams, IMPACTT is designed to address gaps in team training, specifically, ways to improve communication and enhance performance of teams working in emergency rooms and austere environments. This multi-user training simulation runs on commercial tablet computers and is built on the U.S. Government-funded Open Source Advanced Modular Manikin (AMM™) platform. Using touchscreen tablets, learners assess and treat interactive 3D virtual patients suffering from multi-system trauma. Learners select the appropriate Advanced Trauma Life Support® (ATLS) interventions from radial menus on their screen and, since the virtual patients' physiology is driven by the Government-funded BioGears® Open Source Physiology Engine, their vital signs, behavior, and appearance improve or deteriorate, based on the appropriateness and timeliness of each treatment.

The program supports a range of practitioners, including doctors, nurses, techs, and respiratory technicians/therapists. The virtual patient is displayed on each learners' tablet, as well as on a shared large screen. A separate array of tablets serves as virtual medical equipment, to include a patient monitor, IV pump, ventilator, labs, and a urine meter, making the system affordable and portable.

Hands-on interventions, such as establishing vascular access (Intravenous or Intraosseous) or intubating the patient, can be performed virtually or via an AMM-compliant part-task trainer, making the system scalable, based on learner needs. During virtual interventions, learners are presented with a task-specific cognitive exercise that engages them for the time it would normally take to perform the intervention.

The IMPACTT system is designed to improve team communication and enhance performance, thereby reducing life-threatening medical errors in emergency settings. This paper will discuss implementation of this blended reality training capability, its challenges, lessons learned, and future applications.

ABOUT THE AUTHORS

Dr. Ed Sims is Chief Technology Officer of Vcom3D, Inc. Most recently, his focus has been on developing multi-modal medical simulations that blend virtual and physical representations. Prior to co-founding Vcom3D, Dr. Sims held the positions of Chief Scientist and Technical Director for Lockheed Martin Information Systems Company, where he led several projects related to distributed interactive simulation and computer image generation. Dr. Sims received a BS degree in Mathematics from the College of William and Mary and MS and PhD degrees in Systems Engineering from Rensselaer Polytechnic Institute. He has been awarded five patents in the areas of real-time visual simulation and human behavior modeling.

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BACKGROUND: THE NEED FOR EFFECTIVE AND AFFORDABLE MEDICAL TEAM TRAINING

Patient care is a complex activity that requires effective teamwork and communication skills among interprofessional providers to optimize patient outcomes and to minimize errors (Leonard et al., 2004). In a military environment, these professionals – including doctors, nurses, technicians, and respiratory specialists – may never have worked together, and they may find themselves deployed to an environment with unfamiliar, austere resources for providing care. This lack of familiarity can present further problems in communication, which can hamper patient care and lead to critical medical mistakes and, in worst case scenarios, patient death.

Nearly two decades ago, the concept of Crew Resource Management (CRM) training was first applied to training emergency department personnel via the MedTeams Project (Morey et al., 2002.) CRM had proven an effective training tool for high-stakes, time stressed environments, such as the aviation industry, where personnel rely on clear and concise communication to relay complex information between team members. The success of CRM for medical team training led to the development of the Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS) program. Created by the Agency for Healthcare Research and Quality (AHRQ) and the Department of Defense, TeamSTEPPS "focuses on teaching competencies in team leadership, mutual performance monitoring, backup behaviors, adaptability, team/collective orientation, shared mental models, mutual trust, and closed loop communication." (Robertson et al., 2010.) TeamSTEPPS is commonly taught to established teams using simulations presented either in situ or at simulation centers. In both cases, equipment, instructors, and learners must be scheduled and brought together for training at a site at significant expense.

Screen-based patient simulations offer a lower-cost means for training medical skills at the point of need. However, with few exceptions, these simulations are limited to single player serious games, with no opportunity to interact with other professionals. These simulations generally place the learner in a low-fidelity simulation of a medical treatment facility with simplified patient and equipment interactions, and no communication with others.

The need for ***Advanced Virtual Patient Applications*** was recently recognized in a request for white papers initiated by the Defense Health Agency (DHA) in which medical teams could collaborate while treating simulated complex patient cases. The Immersive Modular Patient Care Team Trainer (IMPACTT) has been developed in response to that need.

Addressing Medical Communication Skills

The core concepts of TeamSTEPPS, which rely on leadership, communication, situation monitoring, and mutual support, enhance patient safety by enabling medical team members to relay critical information in a precise and succinct manner. For example, in an emergency room setting, when a critical trauma patient is brought in, a trauma team is assembled. The team consists of physicians, nurses, and technicians (X-ray, clinical, and respiratory), all of whom work together to stabilize the patient. Typically, an attending physician will take the lead, coordinating care through direct orders to the team. Using clear and concise language, the doctor will call out the desired treatment and the responding team member will repeat the order, to ensure accuracy, prevent miscommunications, and to ensure situation monitoring. This "closed loop" communication via call outs and check-backs also prevents mistakes, since it provides an opportunity for the order to be repeated back to the physician and, when necessary, clarified as to appropriateness by other team members. Closed loop communication also provides a continuing narrative concerning patient treatment, allowing proper documentation by a designated team member and informing all members as to the treatment progress.

IMPACTT builds on these concepts by promoting effective communication between learners, as they work together to stabilize a virtual trauma patient.

Technical Objectives for IMPACTT

IMPACTT was developed not only to serve as an effective medical team training system, but to achieve a novel approach to medical simulation that is scalable, affordable, and utilizes the latest technologies on open source platforms.

The technical objectives of this project were to:

- Develop and demonstrate an interoperable Virtual Patient (VP) Module, capable of running on tablet computers, with maximum compatibility with other medical simulation standards, including Advanced Modular Manikin (AMM).
- Extend the open source BioGears physiology engine to model the systemic and local physiology of burns and other wounds.
- Develop, implement, and evaluate innovative user interface concepts that maximize the utility of touchscreen tablet computers for performing medical interventions used in the treatment of trauma.
- Deliver the training using client/server technology in a shared, persistent virtual world with support for voice communication between members of an interprofessional team.
- Apply these technical innovations to create and evaluate effective, exemplar training for treating victims of trauma.

CONCEPT OF OPERATION

Figures 1 through 3 show the general concept for IMPACTT. The default display for the application is an interactive, 3D patient being treated at an appropriate Medical Treatment Facility (MTF).

Figure 1. Shared components of an IMPACTT training system, including (clockwise from top) shared Virtual Patient, triple IV pump, IMPACTT Core (blue box), urine gauge, lab reports, ventilator, and patient monitor.

A large screen monitor Virtual Patient view, which can be mounted on the wall or placed flat on a table, provides a consistent overhead view of the patient's appearance and behaviors, and of each intervention initiated by the learners, including its effects. Each player also has their own tablet with a personal view of the patient, as shown in Figure 2. In this view, they can maneuver around the patient to change the perspective or perform an intervention. Interventions can be performed by tapping on a body part and then selecting from alternatives displayed in context-sensitive radial menus. However, it is also possible for any of the providers to:

- Interact with any of the virtual equipment, including a patient monitor, a ventilator, lab reports, urine gauge, and triple IV pump.
- Verbally request that another player perform a task.
- Verbally report observations to other learners.
- Acknowledge another player's request using a "call-back."
- Raise concerns about the patient's status or safety.
- Challenge another player's statement or request.

In this way, IMPACTT provides the perceptual cues, affordances, and communications needed to simulate an authentic patient case.

Figure 2. Individual Virtual Patient Tablets

Figure 3. Instructor/Assessment Tablet

As the team works together to diagnose and treat a patient case, the patient's physiological condition is constantly recomputed by a "physiology engine", reflecting both the passage of time, and the appropriateness of interventions. For example, oxygen saturation improves when oxygen is applied, and the patient becomes unresponsive when a sedative is administered. The virtual patient provides realistic visual cues, such as chest rise when ventilations are assisted and the appearance of interventions as they are performed. All changes in patient physiology and behaviors are computed by the IMPACTT Compact Core computer, housed in the 6" x 5" x 2" blue box shown in the upper right corner of the table in Figure 1. As described later in this paper, this device supports all computing and wireless networking for the IMPACTT system.

Initial IMPACTT scenarios have been developed based on Advanced Trauma Life Support (ATLS) and Advanced Burn Life Support (ABLS) principles and feature a variety of polytrauma patients, from blast injuries to vehicle crashes. Using the Instructor Tablet, shown in Figure 3, instructors select and launch the scenario, then monitor the team's performance as the patient case plays out in real time. The player assuming the role of physician leads the treatment, calling out orders while team members respond by repeating the order to ensure accuracy, then performing interventions using radial menus on their personal tablets. They then check back with the physician when the treatment has been administered. The team can track each members' actions via task bars displayed on the large screen of shared Virtual Patient.

IMPACTT provides a unique training experience in that it affords the opportunity to practice both technical and non-technical skills in an immersive, authentic simulation environment. During an IMPACTT training scenario, an instructor:

- Selects, starts, stops, pauses, and resets training simulations.
- Observes all aspects of the simulation and records those learner actions that are not automatically registered by interactions with learner tablets.
- May override or supplement patient behaviors.

Instructors assess team performance with a built-in assessment tool using criteria from TeamSTEPPS. The assessment can then be used during debriefing to identify strengths and weaknesses, and to gauge the team's progress as they perform subsequent scenarios.

USE OF OPEN SOURCE AND OPEN STANDARDS

Rather than implement IMPACTT as a closed, proprietary system, we maximized the use of both open standards and open source technologies. The most important of these were the BioGears® Open Source Physiology Engine and the Advanced Modular Manikin architecture.

Open Source Physiology Engine

Most screen-based virtual patient simulations use state machines to represent the physiological state of the patient (Talbot, 2013). State machines can depict patient physiology for cases that involve a small number of physiological systems (e.g., circulatory and respiratory) and where the number and types of interventions are limited. In these cases, the state machine is hard coded to fit a specific scenario, with only a few possible variations in treatment. For IMPACTT, our goal was to provide significant scope of interventions for a wide range of patients. We therefore used a "physiology engine" that computes the patient's response to injuries, conditions, and interventions in real time. Specifically, we are using the BioGears open source physiology engine (www.biogearsengine.com), funded by the Joint Program Committee-1 (JPC-1), which is responsible for programming research in Medical Simulation & Training and Health Information Sciences. The BioGears engine runs in a constant 50 frames per second loop and simulates all of the major human physiological systems (including cardiovascular, endocrine, energy, gastrointestinal, nervous, renal, and respiratory) and several anatomical compartments. Interventions include a large number of common emergency procedures, medications, and fluid infusions. BioGears provides accurate and timely physiological responses for simulated patients, improving the realism of medical simulation scenarios.

Advanced Modular Manikin (AMM) Standards

The AMM program has developed standards, open source software, and data models for the interoperability of patient simulators, their component modules, and their associated training scenarios (Sims et al., 2016; Sweet and Hananel, 2018). Although the primary focus of AMM has been to enable the development of modules that can be physically assembled to create a full-body manikin, the same architecture and models can be used for virtual or blended simulations. IMPACTT uses the AMM standards to simulate virtual patient physiology, appearance, and behaviors. AMM provides specifications for:

- A common data bus, based on the Data Distribution Services (DDS) Object Management Group (OMG) open standard (OMG, 2014), for communication between manikin modules, virtual patients, virtual and blended reality simulations, simulated medical equipment, physiology models, user interfaces, and performance assessment.
- Core software modules, including simulator and physiology managers, data archiving, and module management. These core software services are provided as open source.
- Standard representations of male and female patient anatomy.
- Standardized requirements for module configuration and communication.
- Mechanical, power, fluid, and data connectors between the torso and the head, arms, and legs.
- Power and fluid distribution and management among physical modules.

Figure 4 shows the AMM architecture, as adapted for IMPACTT, emphasizing the role of the DDS-based common data bus. All modules publish and subscribe to shared data via this bus. Except for data required to manage, configure, and test hardware modules, modules publish and subscribe to *clinically relevant* learner actions, patient events, and physiological variables in terms that are independent of the implementation. For example, a hemorrhage is represented as a loss of blood at a certain rate from a body segment or specific vessel, as opposed to a control voltage for a pump or valve. This makes it possible for the same data to be used to recognize actions and render events in multiple simulator modalities, whether whole-body manikins, part-task trainers, virtual patients, virtual reality, or standardized patient actors.

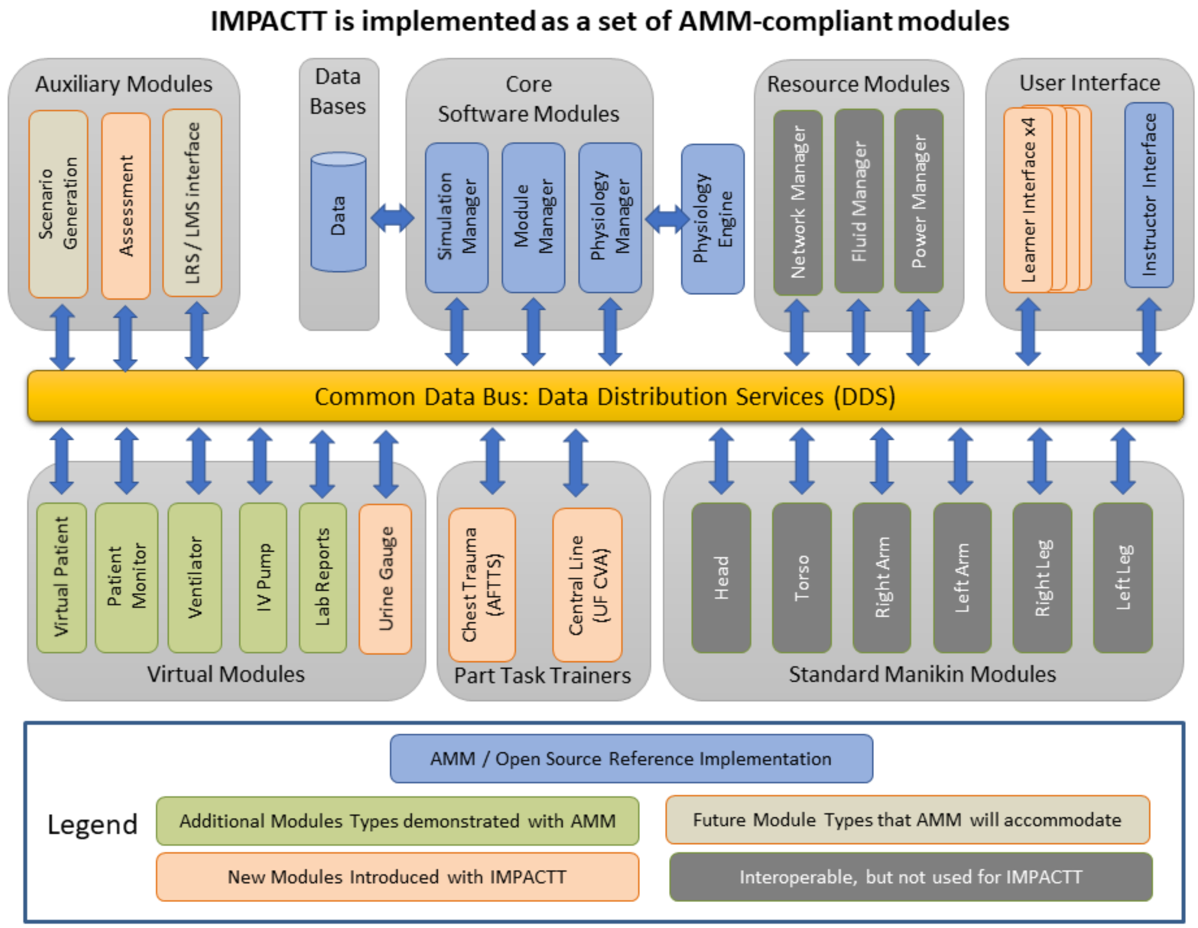

Figure 4. IMPACTT is implemented as a set of AMM-compliant modules

Referring to Figure 4:

- The Core Software Modules are all AMM 1.0 Open Source, directly available from the AMM project (https://github.com/AdvancedModularManikin). These all run on the Compact Core shown in Figure 1.
- The BioGears 7.3.1 Physiology Engine also runs on the Compact Core.
- The Virtual Modules are all implemented as AMM 1.0-compliant Modules, running on Android tablets.
- The primary new developments for the IMPACTT project are the individual Learner Interface modules and the Assessment module, also implemented as AMM 1.0-compliant Modules, running on Android tablets.
- By virtue of the system's AMM 1.0-compliance, part-task trainers can be integrated with the virtual modules to provide multi-modal simulation.

The IMPACTT system has been designed to be highly portable and deployable to austere point-of-need environments. The entire system, excluding the large screen display, can be packed in a single case meeting standard weight and size requirements for checked luggage. Power requirements are low, and no Internet connection is required. The entire system can be set up in less than 30 minutes.

THE IMPACTT EXPERIENCE

One of the challenges of a virtual medical simulation such as IMPACTT is how to keep learners engaged when treatment interventions are reduced to touchscreen interactions. For example, time consuming interventions, such as intubation or inserting an IV, would normally involve a hands-on skill that would engage the provider for several minutes. Since IMPACTT relies on radial menu items to represent interventions, we devised a way to engage the learner while they are involved in performing a virtual task. We achieved this by integrating cognitive exercises that appear on the learner's screen when they select a time-consuming intervention. For example, when the physician decides to intubate the virtual patient, he/she selects from the radial menu and a "minigame" appears on their screen. These minigames are short quizzes that test the user's knowledge in content related to the intervention being performed. The minigame keeps the learner engaged for the appropriate amount of time it would normally take to perform the intervention, while a countdown clock on the shared screen shows how much time is left in the learner's game. When the time to perform the intervention ends, the learner is released from their task and the intervention appears on the Virtual Patient.

Figure 5 shows the Concept of Operation for both the shared screen (top row) and the individual user screen (bottom row, in this case, a nurse).

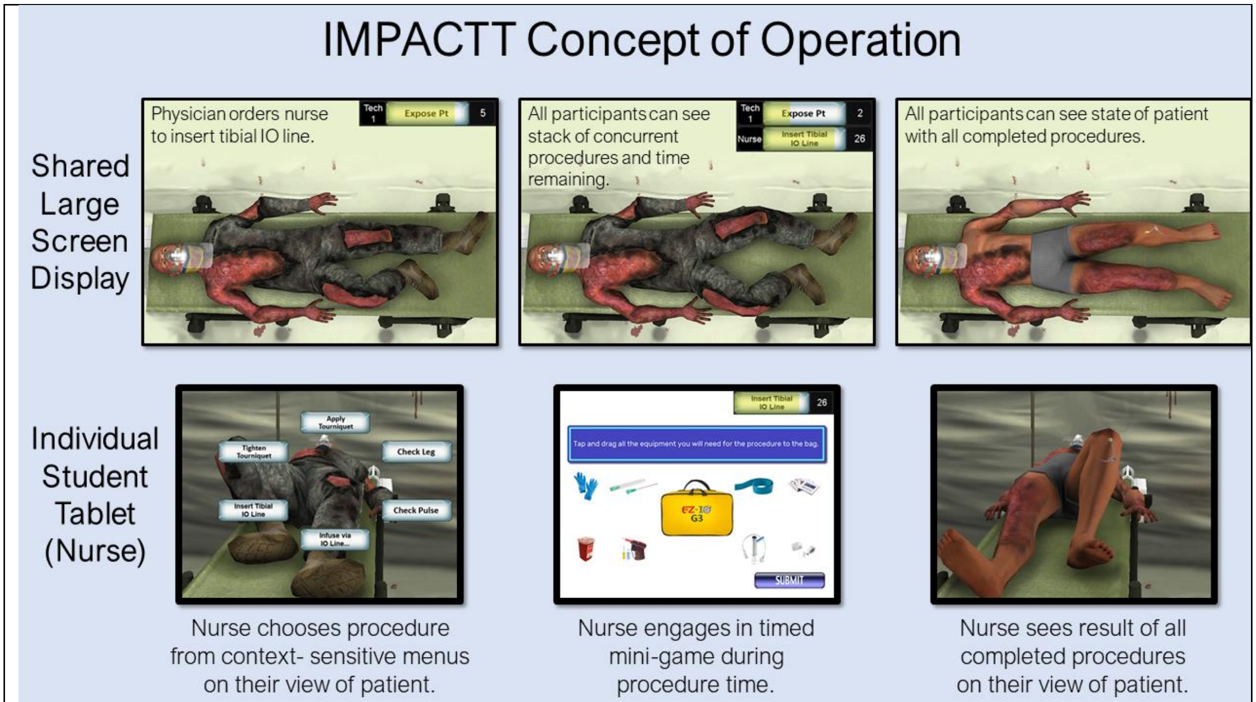

Figure 5. IMPACTT Concept of Operation

Although a nominal trauma team using the IMPACTT system includes four roles, more or fewer learners can train together. Any learner or the instructor can take one or more of the four roles; and two or more learners can share a single role.

INTEGRATION WITH TASK TRAINERS

Another way to engage learners is to include procedural training for selected tasks. Since IMPACTT was developed to AMM standards, it is possible to integrate physical task trainers that are used to perform critical procedures. For example, we integrated the Advanced Female Trauma Training System (AFTTS) manikin (Sotomayor et al., 2018) with IMPACTT. AFTTS provides a realistic human torso that enables learners to perform emergency needle decompression to relieve simulated tension pneumothorax, which develops when a lung collapses secondary to injury and pressure builds within the chest. We have also integrated Central Venous Catheter (CVC) and Humeral Head Intraosseous (HHIO) task trainers. The mixed modality simulations have value for procedures in which a physician requires the support of a team while performing a critical task. For example, when intubating a patient, the physician needs to coordinate with a nurse who monitors vital signs and administers sedatives and paralytics, and a respiratory technician who hyperventilates the patient before intubation and then assures proper settings of inspired oxygen, breath rate, and pressures when the ventilator is attached. Integrating an airway trainer with IMPACTT enables a physician to practice with a full Emergency Room team.

RESULTS

IMPACTT is currently being pilot tested for trauma response and team communication skills. Initial evaluators have included the University of Florida and University of Washington Medical Schools.

FUTURE PLANS

The IMPACTT project has been selected for second-year funding. Primary tasks for the second year will include:

- Independent test and evaluation by multiple organizations training both technical skills such as Advanced Trauma Life Support (ATLS) and non-technical skills such as TeamSTEPPS.
- Development of a multi-site version of IMPACTT in which instructors and learners can be located at geographically distinct sites.
- Development of new patient cases.

Independent of the IMPACTT project, development has started on a Speech Understanding Interface that supports assessment of team communications skills.

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