Establishing and Maintaining a Research Agenda for Healthcare Modeling and Simulation

Brian Goldiez, Ph.D.
Old Dominion University
Virginia Modeling, Simulation & Analysis Center
Norfolk, VA
bgoldiez@odu.edu

ABSTRACT

This paper presents the development, execution, and complete results of a survey seeking community input and research priorities for healthcare simulation used for training. A goal of this survey is to inform users, simulator developers, and other interested parties of potential areas for research development. A secondary goal is to look for simulation related synergies across vertical areas of the economy (e.g., defense, energy, etc.). A list of twelve research topics was initially created by Dr. Yue Dong, MD (Mayo Clinic), Dr. Gilbert Munoz (recently retired Deputy Director at Val G. Hemming Simulation Center at USUHS), and the author of this paper. A sampling of the research topics applicable to healthcare simulation includes various subtopics related to AR/VR displays, new materials for mannequins, fast and efficient training transfer studies, remote simulator operation, and others. Respondents were invited to add topics to the list. The complete list topics, and rationale for their selection is in the paper. The survey was created in 2020 using Google Forms and distributed electronically through Society for Simulation in Healthcare, LinkedIn, and Facebook. Those viewing the survey were encouraged to distribute it to others as well as suggest other topics. AR/VR displays, remote simulator operation, and improvements to learning management systems were rated highest. In August 2021 the topics were explained, and the methodology and survey results were briefed to interested parties in the SSH with encouragement to comment and update the list, as needed. Progress on the research topics were updated for this paper. Other updates and releases are planned.

ABOUT THE AUTHOR

Brian Goldiez is a Program Manager at the Virginia Modeling, Simulation, and Analysis Center (VMASC) at Old Dominion University based in Orlando Florida. He has over 40 years of experience in modeling and simulation working in government, industry, and academia. Goldiez experience has also spanned the range of fundamental MS&T research through simulator development and testing. He was the University of Central Florida's first recipient of Ph.D. in Modeling and Simulation. He also has an MS in Computer Engineering from UCF and a BS in Aerospace Engineering from the University of Kansas.

Establishing and Maintaining a Research Agenda for Healthcare Modeling and Simulation

Brian Goldiez, Ph.D.
Old Dominion University
Virginia Modeling, Simulation & Analysis Center
Norfolk, VA
bgoldiez@odu.edu

MOTIVATION

The motivation to conducting the work summarized in this paper is to inform interested parties of needed and present an update on current research progress in healthcare simulation. The author desires that this and future reports (by others) will keep the healthcare simulation domain at the forefront of technological development and assessment methodologies as well as seek synergies with other communities using and leveraging simulation technology. An explanation and brief update is presented on research work being conducted since this paper was submitted.

The motivation to conduct the work reported on grew from several personal observations. These included:

1. The rapid growth and use of simulation in healthcare by a variety of constituencies.
2. What appeared to be a commercially driven approach to product development vice a formalized user requirements driven approach.
3. Similar work performed under the guidance of the National Training and Simulation Association to identify research needs for simulation used for training principally oriented to US Department of Defense training.
4. Early initiatives led by William Waite (deceased), President of Aegis Corporation to facilitate Simulation Summit meetings where research needs principally oriented around the defense community and a simulation related Body of Knowledge were discussed.

An overarching motivation is to better define the science of simulation in a broad context. To do so, it is important to reach out to vertical (and often stove piped) segments of the economy who use simulation for a variety of purposes. By example, defense, transportation, energy, drug discovery, and healthcare. Gathering data on use and research needs should then facilitate common underpinnings and usage of research products.

BACKGROUND

Modeling and simulation (M&S) is a diverse field serving several different communities such as defense, transportation, design, and healthcare. There are some fundamentals of M&S that should span these communities, such as numerical integration. Additionally, there are some M&S features which are unique to a specific community. In an analogous vain, some research needs in M&S span multiple communities (e.g., numerical integration) while some are unique to a specific group (weapon effects). In this paper I seek to explain an approach taken to arrive at research needs for developers and users of M&S specifically for training healthcare professionals. The approach taken is similar to crowd sourcing in that inputs, including critiques, are open to anyone interested in contributing. The results presented are non-attributed to any one individual.

Simulation in healthcare is strongly influenced by work done by commercial vendors who respond to real and perceived needs from the government, hospital systems, university medical and nursing schools, and others. A significant part of the creation of new healthcare simulations is based on development and production costs as well as potential market penetration. There is, however, significant investment in healthcare simulation research and development being sponsored by Federal Agencies such as the DoD and VHA.

METHODOLOGY

In 2019 the author developed a short list of research areas which he felt were needed to keep medical simulation moving forward technologically. The goal was to promulgate this list to begin an effort where others could contribute by agreeing, disagreeing, and adding to the list with items and their own thoughts on research initiatives in the healthcare domain. Priorities could then be created to assess which item(s) a larger community thought most important to address. The author approached the Society for Simulation in Healthcare (SSH) and was linked to Gilbert Muniz, Ph.D. and Yue Dong, MD. Both individuals provided invaluable insights on topical areas as well as how to involve a larger community.

A brief background on Drs. Muniz and Dong demonstrates their level of knowledge and competence. Gilbert Muniz retired in 2015 as the Deputy Director of the Val G. Heming Simulation Center at the Uniformed Services University of the Health Sciences. Dr. Yue Dong is a medical doctor at the Mayo Clinic. He is also a research scientist in multidisciplinary epidemiology. Both individuals are extremely well versed in the use of simulation in healthcare and are also engaged in leading various groups within the SSH.

Muniz and Dong suggested that a survey instrument be prepared and widely distributed. There is an introduction to the survey stating its purpose. A list of research areas follows and is presented as shown, below. Please note that respondents to the survey only received the list of topics. No further explanation would be provided allowing for the broadest interpretation by respondents.

1. Learning management systems (easy to use and data transferable formats, efficient processing of data and data analysis).
2. New materials for mannequins (e.g., self-healing, ease of storage, …).
3. New sensory modalities (e.g., aural, odors).
4. AR & VR visualization and displays. A partial list of challenges include, but are not limited to:
    - 4.1. Specific use cases where AR and/or VR will be useful,
    - 4.2. Free movement of the user,
    - 4.3. Elimination of simulator sickness
    - 4.4. Accommodation for close-in work and manipulation of objects,
    - 4.5. Accurate display on non-planar surfaces,
    - 4.6. Quick transfer of real and virtual computer-generated images,
    - 4.7. Emerging digital imaging technology (e.g., holography),
    - 4.8. Ease of setup and operation.
5. Interoperability and real-time data transfer between simulators
6. Integration of simulation with other systems (instruments, ICD-10, DICOM images)
7. Virtual patient charts (EHRs)
8. Remote simulator operation
9. Fast and efficient training transfer studies
10. Other (please be as specific as possible in listing a research topic so that they can be combined as needed)

It is important to re-emphasize that each topic was felt to be self-explanatory, even though each topic can be broadly interpreted. Each of the topic areas listed above are explained later in this paper.

Respondents were asked to select no more than six areas that are of interest to them. The list need not be ordered.

Additionally, the survey asked for demographic information of the respondents including professional title, the type of organization where the respondent is employed and its geographic location, professional society and type of affiliation (principally oriented around the Society for Simulation in Healthcare), email address and knowledge of healthcare group on LinkedIn, and other SSH groups. It should be emphasized that not all demographic information was required to be completed and responses could be anonymous.

The survey was posted on line at the SSH Affinity Group site, on LinkedIn, and Facebook. Additionally, Goldiez, Munoz, and Dong sent the survey to individuals they knew and asked them to forward to others. Dr. Dong prepared the posting. The complete survey instrument can be found at:

https://docs.google.com/forms/d/10fYqv3oF2J0PVX_N9IF4270waQA4eVoduqM0WX0izeo/viewform?edit_requested=true

SURVEY RESULTS

The following results are an aggregate from initial respondents indicating six or less research areas of interest.

Topic	Number of Responses
1. Learning Mgmt Systems	13
2. New Materials	6
3. Sensory Modalities	7
4. AR/VR and Displays	15
5. Interoperability & Data Transfer	11
6. Integration with Other Systems	11
7. Patient Chart	11
8. Remote Operation	14
9. Fast Data Transfer	11
10. Other (Specify)	7 Unique

Table 1: Research Topic Responses

Other topics suggested by respondents were physiological modeling and visualization, use of systems and resilience engineering principles, and future medical and clinician re-education. These additional items, though, were not immediately known to other respondents.

The demographic distribution of respondents is shown below:

Medical Doctor	5
Doctorate Degree	9
Registered Nurse	4
Other Clinical (e.g., PA, Paramedic)	3
MS or MBA	4
Other	1

Table 2: Demographics of Survey Respondents

It should also be noted that due to the modest response there was no attempt to align demographic information in Table 2 with research areas in Table 1.

INITIAL ANALYSIS

The responses shown above clearly delineated most interest in conducting research in AR/VR and Displays, Remote Operation, and Learning Management Systems. There is a clear break between these three areas and the others. Secondary interest fell in the areas of Interoperability and Data Transfer, Integration with Other Systems, Virtual Patient Charts, and Fast Data Transfer. Demographics were also widely spread between different vocations as well as academic training. Topical areas noted in Table 1 were intentionally kept broad to keep the survey instrument compact and to reflect a diversity of backgrounds expected from respondents.

DISCUSSION OF RESEARCH AREAS IN THE INITIAL SURVEY

1. <u>Learning management systems (easy to use and data transferable formats, efficient processing of data and data analysis).</u> There are a large number of learning management systems offered by companies and in use by educational institutions. Additionally, the US Department of Defense has been supporting the Advanced Distributed Learning Initiative for many years with progress being made in areas such as shareable content, and application programmer interfaces (APIs). What is not known is the broad adoption of learning management systems among healthcare simulation professionals nor the degree to which ease of development, common or

intuitive user interfaces, common data formats, are achieved among various user groups such as clinical professionals. Independent evaluations (similar to Consumer Reports) would be useful.

2. New materials for mannequins (e.g., self-healing, ease of storage, …). Materials are needed that realistically reflect the material properties of the anatomy they represent. Additionally, products should be affordable, reusable (e.g., not show multiple injection sites), and easy to store. Informal discussions with a simulator manufacturer who chose to remain nameless indicated cost, support, and realism remain difficult to balance. What this manufacturer indicated was that very realistic products were achievable, but cost and support would severely limit the marketability of such products. It is important to note that I reached out to several manufacturers but only one responded.
3. New sensory modalities (e.g., aural, odors). Aural modalities have made great progress, but spatial audio from a simulator is difficult and expensive from the engineering perspective, especially in a variety of operational settings. Odors (olfaction) represent several challenges including placement of an olfaction device in or near the simulator, providing multiple and changing olfaction cues in real time, and control over dispensing and relieving the odor in varying environmental conditions.
4. AR & VR visualization and displays. While AR and VR are currently of significant interest throughout the training community, the technology faces multiple challenges in healthcare simulation settings. A partial list of challenges includes, but are not limited to:
   - 4.1. Specific use cases where AR and/or VR will be useful,
   - 4.2. Free movement of the user,
   - 4.3. Elimination of simulator sickness,
   - 4.4. Accommodation for close-in work and manipulation of objects,
   - 4.5. Accurate display on non-planar surfaces,
   - 4.6. Quick transfer of real and virtual computer-generated images,
   - 4.7. Emerging digital imaging technology (e.g., holography),
   - 4.8. Ease of setup and operation,
   - 4.9. Development and operating costs.
5. Interoperability and real-time data transfer between simulators. Ease of connecting simulators has long been an objective of the Department of Defense. Two standards exist; Distributed Interactive Simulation (IEEE 1278) and the High Level Architecture (IEEE 1516). While both standards exist, they have some limitations, such as limited accommodations for adding more simulators (requiring preselection of the simulators of interest), correlation of data bases, efficient and timely conveyance of data, etc.
6. Integration of simulation with other systems (instruments, ICD-10, DICOM images). Simulation could offer a useful tool to augment other systems used in the healthcare world. Examples include a simulation receiving and using images to guide the simulated treatment, ease of incorporating images to create simulation prototypes to use in developing surgical strategies, use of some common instruments with a simulator (e.g., Otoscope), and the teaching and subsequent use of diagnostic and treatment codes in simulation hand-off. There are technical hurdles in achieving individual as well as and integrated solution. Topics to be considered are unique (and many times) proprietary interfaces, differences in granularity (e.g., high detailed images use with a low fidelity mannequin), and mixing deterministic and stochastic systems in a realistic manner.
7. Virtual patient charts (EHRs). A natural follow on to the use of simulation with other system is the generation of electronic health records. The principal issues relate to the proprietary nature of many EHR systems, the evolving nature of EHR products and vendors (e.g., purchase of Cerner by Oracle), and a simulator's ability to supply and receive the information needed to generate a realistic EHR.
8. Remote simulator operation. Simulators are expensive to setup, operate, and maintain. Additionally smaller and rural communities may not have access to simulators nor staff to effectively operate them. Therefore, it would be useful to be able to send a simulator to a remote location and have the simulator control and instructor station at a different centralized location. Connectivity between sites as well as setup and operation represent technical challenges. Cloud computing paradigms should also be investigated.
9. Fast and efficient training transfer studies. Typically, one must wait until a new simulator system is built to conduct and determine training transfer and training effectiveness. Additionally, such studies, regardless of the maturity of the simulator, typical take a long time to conduct and analyze as well as require significant human resources. New approaches are needed to conducting studies in a more time and labor efficient manner so that the results can influence development processes and purchasing decisions.

UPDATE SINCE THE FIRST RELEASE OF THE SURVEY

Since the initial survey was released and inputs received in early 2021, there has been an informal effort to look for selective research activities to assess their progress on advancing healthcare simulation. Informal discussions were held with the SSH Affinity Group and the Veteran's Health Administration SimLEARN program office. The effort has also consisted of finding press releases, reviewing papers, and contacting individuals known to be involved in supporting or conducting research in the areas noted above. This informal review is by no means comprehensive but is intended to give an idea that the field is progressing, and research issues identified herein are being addressed.

In the area of new materials for mannequins there has been some notable examples of progress. One example is the work of a relatively new company, Digital Anatomy Simulations for Healthcare (WWW.DASH-ORLANDO.COM). The firm has a collaborative relationship with Orlando Health (a major healthcare system headquartered in Orlando) and has created several 3D printed models. They have developed processes and demonstrated the ability to take medical images and rapidly produce 3D printed anatomical products. The 3D images are used for surgical planning, training, medical device testing, etc. The company has several patents and is working on new technologies such as accommodation for fluids. See Figure 1 for an example of a fetus with spina bifida. The 3D model was used to study surgical approaches for addressing the deformity.

Figure 1: Image of Fetus with Spina bifida (Courtesy of DASH-Orlando)

In the area of olfaction, the work of Pike (2018) characterized human factors aspects of malodors on training performance. His work was performed using cadets from the US Army Military Academy. It showed that adaptation to malodors occurs (in this case simulated burnt flesh), but there was no statistical change in stress, escape behavior, or performance improvement. No direct mention of new technical approaches is mentioned by Pike (2018) which would reduce challenges noted elsewhere in this paper. Employment in a more realistic operational setting with a broader population of personnel might be helpful.

There is significant work being done in AR/VR in research that has been or can be applied to enhancing simulation applications in healthcare. It appears to be mixture of rapid technological advances and other work indicating possible weaknesses on usefulness with respect to where and how to best use AR or VR in healthcare simulation. For example, there are new AR displays such as those by Varjo and Microsoft as well as VR displays such as the Vive, but little information available on the technical characteristics of such devices nor how well they work in a healthcare setting. Additionally, efforts such as those documented by Lawson and Stanney (2021), Schubert (2021) show a murky picture as to the direct applicability of AR and VR to medical simulation. Simulator sickness, resolution, vection remain issues that must be addressed.

A particularly exciting research effort that may be applicable to healthcare simulation is development of dynamic holography. Two companies, FOV3D (fovi3d.com) and Avalon Holographics (avalonholographics.com) have nascent development efforts to prototype dynamic holography. Holograms offer the user the ability to view an environment with some vertical relief and from various viewpoints without the need for special glasses. Static holography has been shown to be beneficial in healthcare simulation environments (Allen, 2019). Dynamic holograms have been demonstrated at trade shows, for example by Avalon Graphics at the 2021 IITSEC. While this work is exciting and should be continued, there are many current limitations such as update rate, scene detail, and content generation that are being pursued. Cost will certainly become a factor as products are developed and compete with other forms of AR. Nevertheless, there is significant interest from the military and commercial firms on continuing to develop dynamic holography for other situations such as simultaneous situational awareness from various viewpoints using one image.

A significant research effort to connect simulation for healthcare offers the opportunity to greatly enhance interoperability. The research effort is being conducted for the military by Information Visualization and Innovative Research, Inc (IVIRINC.COM). The firm is creating an architecture for patient handoff through the various stages of care from point of injury, through evacuation, to a treatment in a military hospital. The program is known as the Joint Enroute Training System (JETS). The system uses the DoD High Level Architecture (IEEE 1516) to facilitate connectivity between simulators. It also will support conveyance of ancillary information related to the patient. JETS has been under research and development for several years and has demonstrated interim results to the sponsoring agency.

Integration with other systems is being prototyped by several firms. For example, Design Interactive, Inc. has a program called Augmed (Moralez, et.al., 2021) which has demonstrated the using iPads to provide information to the user while they view a mannequin. Lawson (2021) has also shown the use of augmented reality and novel visualization overlayed onto specialized physical mannequins. These nascent efforts require further technological development and usability studies to assess their utility in operational settings.

Integration with other systems is currently in use by Digital Anatomy Simulations for Healthcare (DASH-Orlando). As mentioned, above, DASH can ingest imaging data and generate 3D models of various anatomical structures. Their work continues to progress by modeling and 3D printing heterogeneous tissue structures (including mixed solids and liquids) with different and realistic material properties, as well as refining prototyping and manufacturing processes to improve utility and reduce cost.

Remote operation is often desired for smaller facilities or when instructors and/or operators are not present. There is much activity, in general, in the field of Software as a Service (SaaS). The Synthetic Training Environment program by the US Army and similar programs by the other services are experimenting with the extent to which software and hardware can be operated and monitored remotely by an operator. Issues to be explored are where different components of the simulation should be located (i.e., at the remote or local site), latency problems, interfaces with potentially specialized hardware, level of simulator fidelity supported, bandwidth limitations, freeze and restart, among other issues. There are clearly possibilities for simulation in healthcare by offering simulators that can be sent to rural locations and are operated and controlled from centralized control center.

Fast and efficient training transfer studies have plagued the simulator industry from several perspectives and research progress has been slow. First, studies are often conducted after a simulator is developed making changes often difficult to accomplish and costly. It does little good to find out that a simulator is deficient when it is entering the field. Secondly, studies should provide results in a timely manner to have a positive impact on users. Thirdly, many healthcare simulation systems are commercial products and companies either do not conduct studies or keep all or parts of such studies proprietary. More focused research efforts are needed to ameliorate these issues.

NEXT STEPS

Simulation in healthcare is a dynamic field with respect to innovation and market growth. The market has generally been driven by the private sector for products. Research has been largely driven by universities and small firms with support from foundations and the public sector. The government has supported more specialized prototypes and products. The time scale for moving many research results to products often appears to be slow and new methods should be investigated for speeding the process from research to product across government and academia.

More generally and in addition to healthcare, simulation is widely used by various segments of society such as defense, energy, and transportation. These vertical segments of the economy progress based on the real or perceived needs of their constituencies. There are synergies that should be more fully explored by academics and professional societies and conferences. Exploring the broader use of simulation and its constructs will contribute to establishing the science of simulation.

Finally, topics in this paper should be revisited and updated on a periodic basis because the topics identified in this paper have a shelf life. Some of the topics discussed will be successfully dispositioned in time. Others will fail. New research efforts will arise that should be recognized and documented with others. While we were able to discuss our work with other organizations, better methods are needed to enlarge the population receiving and responding to the survey. A possibility is to use paper surveys which can be distributed at various venues or an on-line response system at conferences.

REFERENCES

Allen, C., Willis, S., Hernandez, C., Wismer, A., Reinerman, L., Teo, G., Goldiez, B., Mazzeo, M., Hackett, M. (2019). Holographic and related technologies for medical simulation (ID 1632). *Presentation at Human Computer Interaction International Conference*.

Lawson, B., Stanney, K. (2021). Editorial: cybersickness in virtual reality and augmented reality, virtual real .

Moralez, L., Hughes, C., Archer, J., Miller, C., Stanney, K., Frye, D., Karluk, F., Vazquez, R. (2021). Usability evaluation of augmented reality training for battlefield care tasks. *Interservice/Industry Training Systems and Education Conference*.

Pike, W. (2018). Human factors effects of simulating battlefield malodors in field training. *Dissertation Ph.D. University of Central Florida.*

Schubert, R., Bruder, G., Tanaka, A., Guido-Sanz, F., Welch, G. (2021). Mixed reality technology capabilities for combat-casualty handoff training., *Springer Nature*, HCII..