EXPLORING MEDICAL CYBERLEARNING FOR WORK AT THE HUMAN/TECHNOLOGY FRONTIER WITH THE MIXED-REALITY EMOTIVE VIRTUAL HUMAN SYSTEM PLATFORM

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***Abstract*— This paper describes the Mixed-Reality Emotive Virtual Human System Platform – a machine for cyberlearning at the human/technology frontier. Our initial use case is for medical school students practicing patient interviewing in preparation for Objective Structured Clinical Exams (OSCEs). The work is deliberately focused on a futures environment where students can seamlessly enter a virtual learning experience and return to the face-to-face. For the context of our work, we define mixed reality as the ability to traverse real and synthetic learning experiences utilizing a variety of technologies such as augmented reality and virtual reality in a dynamic, emergent environment. Much of the work is based on the Emotive Virtual-Reality Patient research sponsored by the Southwestern Medical Foundation and exploration of the US Ignite ultra-high speed network, sponsored by the National Science Foundation. We use the US Ignite network to facilitate the development of virtual humans and the overall platform. We also explore evolving learning theory that supports the development of this knowledge system which blends real and synthetic roles of professors, mentors, and standardized patients in an emergent artificial intelligence and machine learning driven environment. Future applications of the model are also discussed.**

Keywords—mixed reality, high-speed networks, augmented reality, virtual reality, Connectivism, Activity Theory, ICAP

I. INTRODUCTION

What are the potential factors driving medical cyberlearning at the human/technology frontier? Watson-like AI assisting medical students at every juncture along their educational journey, potentially replacing traditional rote learning. Machine learning creating personal educational experiences. Student-defined educational paths that still meet the criteria of medical boards. A seamless networked environment with superb access to expert human and synthetic resources such as professors and mentors. Students interning in telemedicine environments where robotic and human teams seamlessly interact for patient care in a mixture of actual and synthetic experiences. The distinct need for just-in–time and lifelong learning to allow human medical experts to cognitively sprint with the fast-changing pace of available information.

We can imagine that, just like other future workers identified by the National Academies of Sciences Engineering and Medicine, future physicians will require skills that "increasingly emphasize creativity, adaptability, and interpersonal skills over routine information processing and manual tasks" [1]. At the frontier of medical cyberlearning, students and professors will be continually rediscovering and redefining their human role in future medical practice within the context of constantly evolving technology in a mixed reality environment. For the context of our work, we define mixed reality as the seamless ability to enter real and synthetic learning experiences utilizing a variety of technologies such as augmented reality and virtual reality in a dynamic, emergent environment. To this end, The Center for Modeling and Simulation/Virtual Humans and Synthetic Societies Lab (The Center) at the University of Texas at Dallas (UT Dallas) has developed a mixed reality learning machine entitled The Emotive Virtual Human System Platform which enables the way students will learn at the human/technology frontier.

II. TRANSLATING A USE CASE ONTO THE PLATFORM – TEACHING AND EVALUATING COMMUNICATIONS SKILLS IN MEDICAL SCHOOL STUDENTS – THE OBJECTIVE STRUCTURED CLINICAL EXAMINATIONS (OSCES):

Learning good communication skills and developing the ability to show compassion for patients are important aspects of a physician's education. Therefore, the current use case we are exploring on the platform is the Objective Structured Clinical Examinations (OSCEs) – used to evaluate a medical school student's clinical skills, including communication skills used during a medical interview. For this purpose, standardized patient (SP) actors are meticulously trained to reproduce various clinical cases. These SPs are also responsible for assessing students' clinical skills performance through carefully designed evaluation criteria. OSCEs present several challenges that the platform can address. OSCEs are often introduced fairly late in the curriculum – typically after students have taken extensive theory lectures – delaying the desired early patient contact [2]. SPs can be costly in terms of time and money to train and implement, have limited access, and it may be difficult to objectively reproduce their performance. SP teachers are not always perceived as effective compared to lectures [2]. Finally, the role of the professor can be minimal in the OSCEs, typically reserved to occasional review of the student-SP interaction and summative feedback [2].

III. Other Work on Mixed Reality Platforms – Progress and Challenges

The literature documents learning science labs around the world that are exploring implications of a future learning environment where students, professors and other key stakeholders seamlessly move in and out of virtual environments. In several studies, researchers have observed that students increasingly prefer interactive visual learning environments to traditional lectures, indicating a trend towards a visual learning style [3]. With this shift, mixed reality environments are becoming increasingly important for education, especially those educational contexts in which practical skills are taught as opposed to mere theoretical knowledge [3].

For example, most people would not want paramedics practicing their techniques on them, but there is nevertheless a need for paramedics to get the practical training they need to effectively perform their jobs [3]. While paramedic students enrolled in in-person classes have opportunities to practice on mannequins with real instruments, online paramedic students have expressed frustration with lack of opportunities to practice skills [3]. This problem has been addressed with a mixed reality solution. In a study in which online paramedic students were offered a virtual reality simulation that allowed them to practice their laryngoscopy technique, results indicated that the simulation was beneficial [3].

Mixed reality also has economic advantages. The cost of post-secondary education is rising, but at the same time, the costs of mixed reality hardware is decreasing [4]. This is an opportunity for mixed reality to economically meet the needs of the growing numbers of visual learners and the demand for post-secondary education. For example, Mangina, Campbell, Hoo, and Santiago observe that mixed reality could be used to deliver education to remote areas such as sub-Saharan Africa [4].

In the Media Lab at the Massachusetts Institute of Technology (MIT), research has been done with mixed reality involving components that can transcend the boundary between real and virtual worlds [5]. MIT has created a robot used in an entertainment game [5]. The robot is a physical object present in the real world, and it plays a game similar to ping pong with characters on a screen [5]. The robot and the on-screen characters pass a beach ball across the boundary between the real and virtual worlds [5]. The beach ball was shown in the real world using a projector system, and was displayed onscreen in the virtual world [5]. Future work in this area could involve allowing the player-controlled character itself to cross the boundary between the real and virtual worlds [5].

In another study, MIT researchers Vazquez, Fu, Nyati, Aikawa, Luh and Maes coined the term "Serendipitous Learning," referring to learning opportunities that are encountered incidentally in the course of everyday life [6]. These researchers identified three aspects to Serendipitous Learning in a mixed reality setting: contextual affinity -- the capacity to accurately interpret the environment; uninhibited curiosity -- the capacity to tailor the content to the user's own interests and curiosity; and dynamically linked content -- pre-existing relevant information provided to the user for reference [6].

Serendipitous Learning can be a valuable tool for language learning. In this research, one area explored is the integration of social and collaborative aspects [6]. Further, other available technologies could also lend capability to the transcendence between the real and the virtual. For example, the addition of GPS capabilities to mixed reality platforms would open up an entirely new range of possibilities [7].

Of course, while mixed reality has high potential for use in cyberlearning, there are several challenges that need to be overcome to aid seamless immersion. One such challenge often cited in the literature is with the equipment itself. Currently, mixed reality headsets are still heavy enough to notice, particularly in extended sessions, and some users end up using their hands to support these headsets while wearing them [7]. The weight of other peripherals can be equally distracting [7]. Our research discovered additional nuanced challenges, which will be discussed further below, related to the hardware we used, the type of physical space accessible to us for the experiment, and the general challenges of using technology in its early stages of development. These challenges and the resulting limitations in user experience helped us to begin uncovering key heuristics of a mixed-reality platform.

IV. Concurrent Evolution of Learning Theory for a Mixed Reality Environment

Research on the learning environment at the medical cyberlearning frontier certainly requires technology. However, as shown in Figure 1, equally important are the learning and cognitive/behavioral theories which provide a framework for understanding emerging technology dynamics. Much is unknown about medical cyberlearning at the human/ technology frontier. For example, what do students consider to be the appropriate balance between human and synthetic teaching? What rules and guidelines do students need to integrate human, synthetic and hybrid interfaces, and when do students turn to each? How do human, synthetic and hybrid teaching interfaces work together? How do students balance human, synthetic and hybrid learning resources – maximizing what is distinctly human about their real professors and patient interactions with the value of artificial intelligence and emergent machine learning. Succinctly put, when do students naturally move out of the real to the synthetic and back again? In developing a learning theory based framework, we rely on a few different theorists whose models offer a compatible framework with a mixed reality environment – Connectivism, ICAP and Activity Theory as it specifically relates to an educational context.

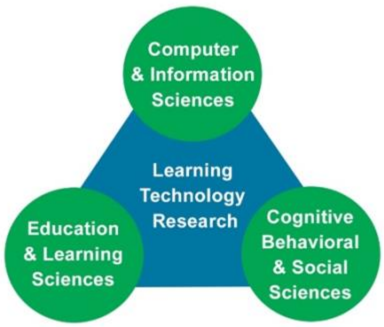

Figure 1. Computer and information science; education and learning science; and cognitive, behavioral and social science form the combined view of learning technology research.

Connectivism is one useful framework that recognizes the future environment described above where much of the cognitive work is offloaded to technology -- stressing the importance of where to find knowledge as opposed to gaining know-how [9]. In Connectivism, both the individual and organizations are living learning organisms – fueled by novel sources of big data and unique forms of data that hide clues to here-to-fore undefined information such as emotions [8] [9]. Interestingly, Connectivism focuses on networks, recognizing that learning is a process which cannot be enforced by educators but is facilitated by maintaining connections outside the traditional classroom model [9]. The theory puts emphasis on student decision making as a learning process which includes connecting different formal and informal information sources and accurately interpreting them in changing scenarios. These information exchanges with the help of electronic tools or non-human appliances become particularly significant for lifelong learning in the digital age [9] [10]. Hence, the Connectivism model eventually leads to a better unification of the global learner environment [10].

Key principles of Connectivism include [9]: learning and knowledge rests in diversity of opinions; learning is a process of connecting specialized nodes or information sources; learning may reside in non-human appliances; capacity to know more is more critical than what is currently known; nurturing and maintaining connections is needed to facilitate continual learning; ability to see connections between fields, ideas, and concepts is a core skill; currency (accurate, up-to-date knowledge) is the intent of all Connectivist learning activities; decision-making is itself a learning process; choosing what to learn and the meaning of incoming information is seen through the lens of a shifting reality; and while there is a right answer now, it may be wrong tomorrow due to alterations in the information climate affecting the decision [9].

ICAP is another model of cognitive engagement which potentially lends structure to a mixed reality environment. ICAP places student engagement behavior into one of four categories [11]: Interactive, Constructive, Active, and Passive, with the underlying theory being that a student's learning will increase as their cognitive engagement increases from passive (the lowest level) to active to constructive to interactive (the highest level) [11]. In ICAP, passive learning occurs in activities such as listening to lectures or watching videos, active learning occurs in activities such as taking notes during lectures or highlighting pertinent information in books [11]. Constructive learning occurs when students engage in "teaching themselves," and interactive learning occurs in activities involving collaboration and discussion with others

Constructivism, another theory of learning, is similar to ICAP in that it places high value in students taking an active role in their own learning [11]. Constructivism holds that a student should bear the responsibility to be actively engaged in their own learning rather than to sit back and listen to an instructor's lecture [11]. Cognitive load theory holds that, as there are limits on how much working memory people have, a student will only be able to handle a certain amount of information at one time [11]. This differs from ICAP in that it is concerned with instructor activities as opposed to student activities which is the ICAP focus [11]. Another theory of learning that can be contrasted with ICAP is Bloom's Taxonomy. Bloom's Taxonomy is concerned with categorizing learning objectives and the best ways to measure how well they have been achieved, whereas ICAP is concerned with identifying the most effective means to achieve a learning objective [11]. These two theories need not be seen as contradictory. ICAP is concerned with the means to achieve a learning objective and Bloom's Taxonomy is concerned with measuring how well that learning objective has been achieved [11].

Finally, Activity Theory focuses on roles in a system and we find this helpful for analyzing the future. Activity Theory sees the integration of technology as tools which mediate action [12]. These tools, or artifacts, include instruments, signs, language, machines and computers [12]. The use of Activity Theory in technological contexts supports the application of design solutions and the enhancement of student learning. For example, during the early development of Activity Theory, Vygotsky used a double stimulation method in experiments to find out how subjects made use of available tools in their environment to complete tasks [13]. Vygotsky first presented the task of memorizing a series of images to the participants of an experiment. Then he provided the participants with a set of tools (pencil and paper) that could be used to help solve the task [13]. Vygotsky highlighted the need to focus on what artifacts the participants chose, viewing the experimental subject as "an active agent who selects for his own use whatever objects or tools are available." The idea was to find out how meaningful a stimulus was to the participant for problem solving [13].

Another example of applied Activity Theory -- the Inquiry Hub (iHub) -- focused on new teaching approaches and curriculum development for a Denver school [14]. Teachers worked in small groups using collaborative software -- The Storyline Tool -- for designing lessons [14]. In this way the project used small group structures with tools to analyze the collaborative process for improving curriculum.

The application of Activity Theory in schools can also include video analysis of various learning activities combined with traditional ethnographic approaches of observations and interviews [15]. Similarly, the Activity Theory framework can inform the design of medical education software by providing historical and cultural context to our mixed reality research.

V. RELEVANT TECHNOLOGIES FOR A MIXED REALITY ENVIRONMENT

At the human/technology frontier for medical cyberlearning, augmented reality, virtual reality, artificial intelligence, machine learning, and big data are expected to be among the resources and tools available. Therefore, a network that enables the efficient movement of increasingly high band width, massive data and complex graphics in a low latency, secure, reliable manner becomes critical. Figure 2 below shows an example of augmented reality for medical education through the Microsoft HoloLens.

Figure 2. Microsoft HoloLens is an example of a technology enabling augmented reality at the medical cyberlearning frontier [16].

These technologies form the basis of medical cyberlearning for work at the human technology frontier as illustrated in Table 1.

TABLE I. IMPORTANT TECHNOLOGIES FOR THE HUMAN/TECHNOLOGY MEDICAL CYBERLEARNING FRONTIER

Technology	Role at the Human/Technology Medical Cyberlearning Frontier
Augmented Reality	Blending of real and synthetic environments in a single view
Virtual Reality	Fully virtual experiences
Artificial Intelligence	Synthetic replication of human intelligence to drive virtual entities
Machine Learning	Software which can learn from experiences and data
Big Data	Broad streams of data from real-life and synthetic experiences that inform the system
Network	A network capable of enabling, distributing and adapting the system

The use of each of these technologies in The Emotive Virtual Human System Platform will be discussed further below.

VI. THE US IGNITE NETWORK – BUILDING A PROTOTYPE FOR THE HUMAN/TECHNOLOGY FRONTIER:

US Ignite is a National Science Foundation (NSF) affiliated nonprofit organization that helps to accelerate new wired and wireless networking advances. One of the group's core objectives is the development of advanced gigabit applications on high-speed networks. Key features of the network include low-latency, higher levels of security, high bandwidth, and guarantee of service. Richardson, Texas – the home of UT Dallas and The Center – is a recipient of Smart Gigabit Communities infrastructure from NSF and thereby the network is at the core of our Virtual Human Research.

The Center is a winner of the 2017 and 2018 Richardson US Ignite Smart Cities Gigabit Application Challenge which will be discussed further below. Further, The Center's research has been demonstrated at the Smart Cities Connect Conference and Expo in Austin, Texas. The research also was presented in October 2017 in Toronto at the NSF Network Innovators Community event (GENI NICE), a premier event for discussing works in progress related to the Global Environment for Network Innovations (GENI), which is funded by NSF's Computer Information Science and Engineering (CISE) and the Computer and Network Systems (CNS) directorates. In October 2017 The Center was awarded additional funding from NSF to add audio and text communication tools to the prototype. The Center director was also invited to a related NSF Workshop on Effective Community-University-Industry Collaboration Models in December 2017. The Center will again present the prototype at the Smart Cities Connect Conference Expo in March 2018 in Kansas City.

VII. The Emotive Virtual Human System Platform

With this network-based, mixed-reality view of medical cyberlearning at the human/technology frontier, The Center in conjunction with UT Southwestern Medical Center (UTSW) and sponsored by the Southwestern Medical Foundation and NSF is developing Emotive Virtual Patient (EVP) technology to explore learning paradigms to teach soft social skill-oriented patient interactions such as interpersonal empathy. As explained above, the general EVP project allows medical school students to practice interviewing with a virtual patient in an augmented reality experience, currently using the Microsoft HoloLens. As shown in Figure 3, the EVPs utilize complex neural-network-based natural-language conversations that represent the emotions, unique cultures and overall behavior patterns of real-life patients. Our current high-fidelity EVP, which is natural language processing (NLP)-enabled, has a unique personality, emotions and overall behavior patterns of a real-life stroke patient.

Figure 3. Walter is an augmented-reality hologram. EVPs can be customized to represent various cultures and demographics. Neural-network-based NLP allows EVPs to communicate naturally and learn over time. Network-enabled machine learning will further enhance EVPs by isolating additional nuanced data types and feeding them into the EVPs intelligence.

As mentioned above, The Center has completed a prototype of the EVP System App, as shown in Figure 4, which builds upon and enhances the general EVP project by allowing professors to remotely view and assess student performance during the medical interview in real-time by taking advantage of the NSF US Ignite GENI capabilities. The EVP System App prototype is the first layer of the planned distributed augmented reality platform and was successfully completed in October 2017. Also in October 2017, it was announced that US Ignite is providing The Center an additional round of funding for the development of the platform's second layer, a real-time text and audio based feedback module that enables professors to not only observe but also communicate with students during the virtual patient scenario.

The high-speed, low-latency software defined US Ignite GENI network enables massive real-time transfer of audio, video, meta-, and other types of interaction data between participants and real-time analysis of these data using machine learning algorithms. The EVP System App utilizes the UT Dallas "Smart Campus" infrastructure such as the GENI Rack, OpenFlow Software Defined Networks (SDN) and Layer 2 connectivity to meet the complex requirements for real-time HD video streaming, natural language processing, real-time audio and textual feedback channels, and usage metric data collection and analyses. Ultra HD video streams (up to 500Mbps) and dual-direction audio channels will rely heavily on low latency and networking features such as quality of service guarantees to deliver uninterrupted real-time instructor feedback.

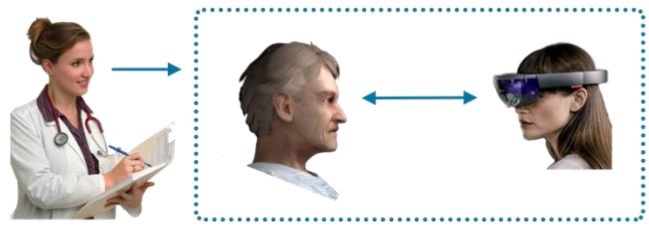

Figure 4. With the EVP System App funded by the NSF US Ignite program we are enhancing the general UTSW project by allowing professors to remotely view and assess student performance in an augmented reality experience with Microsoft HoloLens.

As outlined above, a critical component of the learning and evaluation process in our system is *professor participation and critique* of the medical student's virtual clinical performance. With the EVP System APP, we have developed a system where medical school students experience a virtual patient scenario *and* medical school professors can remotely see the same augmented reality simulation and the student's body language real-time. As part of the US Ignite development, we have added the HoloLens Spectator View system to provide the expert evaluator component to the EVP System. Ultimately, the GENI enabled EVP System App could provide highly individualized real-time coaching and assessment to medical school students practicing clinical communication skills with the EVPs.

Further, AI-driven virtual professors, enabled by machine learning, will be seeded by this initial process. As outlined above, in the current OSCE process the human standardized patient is also very important in providing communications feedback to the student. In the EVP System App, the EVP also learns from the system and is able to provide better feedback to the student as it learns from human interactions. Overall, the EVP System App is developing a combined learning environment between students, professors, virtual professors and the EVP. This environment presents a framework for investigating the dynamics of a medical cyberlearning system that includes both human and synthetic resources to study mixed-reality and network-based learning paradigms -- creating a distributed augmented reality education platform. As shown in Figure 5, the US Ignite GENI network-enabled EVP prototype transcends conventional standardized patients, mannequins, static videos, role-playing, non-network based virtual patients and other traditional learning methods to teach customized empathetic patient communication.

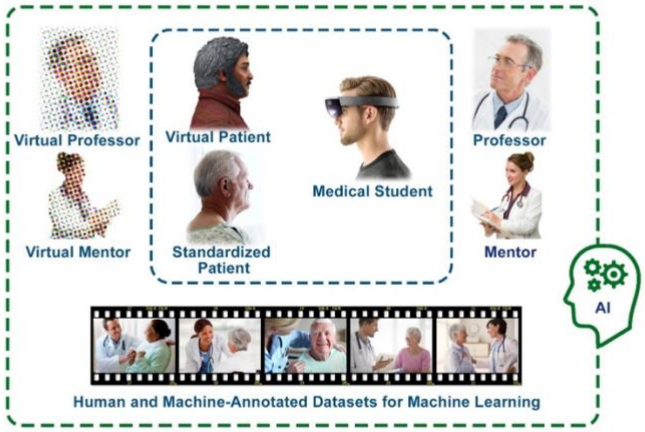

Figure 5. The conceptual EVP System App enables interaction between students, EVPs, human professors and virtual professors. This interaction data feeds the intelligence of both the virtual professor and the EVP, improving evaluation and feedback to the student by the virtual entities. The video icon represents integrating historical interaction data into the model. Over time, other types of roles such as real and virtual mentors may be added.

In this conceptual network-based learning system, the student has access to real and synthetic professors, and real and virtual standardized patients to practice and receive feedback on patient interaction. We are also exploring functionality to learn from historical data, as illustrated by the physician-patient interview videos. Over time we may add other roles such as real and virtual mentors or clinical preceptors. As a result, learners will then need to learn how to manage information coming from both the human and AI-provided knowledge sources. Similarly, professors will need to learn ways to work collaboratively with the synthetic EVP, real standardized patients, the virtual professors and the real and virtual mentors to participate in The Emotive Virtual Human System Platform.

VIII. Early Findings from Research

As part of the platform development, an experiment was conducted by The Center at UTSW where medical school students participated to explore three different technology platforms for virtual medical interviews using the EVP system. The main objective was to evaluate differences in ease of use, comfort, accessibility, and physical ergonomics between augmented reality, virtual reality, and monitor-based delivery methods of a virtual human protocol. Another important goal of the experiment was to get students' feedback on the conceptual mixed reality platform. The experiment was aimed at getting early feedback on platform choice. This phase of the research was deliberately done very early in the process before key functionality, such as the NLP and professor feedback, were completed. Keeping in mind the context, purpose and timing of the experiment, we will discuss the student feedback.

A total of 36 students from UTSW participated in this experiment which ended early 2018. Of these 36 students, 28 participants were first year and eight were second year medical school students. The students were randomly assigned into three groups so as to get efficient feedback for each of the three interview delivery methods. In the first group, students used monitor-based and virtual reality for medical interviewing. In group two, participants used monitor-based and augmented reality. The third group used virtual reality and augmented reality. The experiment used a virtual patient module for medical interviews using the HTC Vive as the virtual reality headset, the Microsoft HoloLens as the augmented reality headset, and a desktop computer for the monitor-based delivery method. Pre-and-post surveys were conducted to capture demographic data, perceptions of students regarding the three methods, and qualitative feedback.

The feedback from the post survey open-ended questions emphasizes the emerging need for a mixed reality environment where medical students can access a set of real and virtual patients to learn the patient interviewing process. The post survey information also provides insight into how the system might function. Overall, participants found synthetic intelligence like the EVP system good for practice if used side-by-side with real patients and professors. A participant shared: *"I think this would be a useful tool to practice patient interviews (learn what types of questions to ask, be able to practice more often, not be nervous like with a real patient) but that it should still be supplementary to interviews with live standardized patients. Real SP's would be better able to adapt to things you say and give you a more integrated realistic experience, and be useful for other things like practicing the physical exam."* Students also shared how using synthetic intelligence could be used to continuously practice taking the patient's history without the patient getting irritated.

Overall, the students believe they would benefit from practicing on virtual patients in less stressful environments to gain confidence before handling live human patients. A student shared: *"I absolutely see the value in using this. As an EMT, I've had patient experience before coming to medical school and was comfortable interacting with live standardized patients, but many of my peers wish they had a consequence-free form of practicing their questions before these experiences."* One student summarized the opportunity as follows: *"I think this is a great initiative! I've long wished that we as medical students could get more experience interviewing patients outside of just our standardized patient encounters, or role-playing with friends or people we know in real life. This would be a great way for us to do that."*

Students shared deep unique insights about their experience with the mixed platform: *"I would prefer to practice patient interviews with virtual patients before live standardized patients, so that I make the novice mistakes with the virtual patient"* wrote one of the participants. Another participant who used the HoloLens stated that *"The virtual experience felt* *natural like I was in the room with the patient. The headset felt a bit weird but once I got used to it, I enjoyed being able to look around the virtual room."* Another wrote: *"The implementation of a virtual patient interview could be useful as they could be accessed from anywhere and would be convenient (possibly save time and resources by not having to hire standardized patients). Additionally, it provides a safe and non-judgmental environment, reducing anxiety."* One student commented about the virtual reality modality "it felt *so realistic, as if I was in the clinic with the patient."* Some students found the monitor-based platform to be distant, less responsive to voice, formulaic and contrived.

As part of our research we used The Immersive Tendencies Questionnaire (ITQ). The ITQ measures the capability or tendency of individuals to be involved or immersed in an experience by looking at factors such as involvement in an activity, maintaining focus on an activity, and propensity to play and enjoy video games [17]. Our data analysis shows that, on average, participants with higher focus and involvement scores preferred augmented reality over virtual reality and monitor-based delivery methods. These results were statistically significant at a 5 percent level. While still in its initial developmental phase, medical students concluded that the EVP mixed reality platform is a promising teaching tool which could reduce the high cost of time and training for medical students by significantly increasing their engagement and interviewing skills.

IX. Comparison of the Three Delivery Methods for the EVP Platform

We also used The System Usability Scale (SUS) in our research. The SUS is a ten-item scale giving a global view of subjective assessment of usability [18]. SUS is a validated instrument for assessing usability where a score below 40 represents "Poor" usability, a score of 50 represents "OK" usability, a score of 70 represents "Good" usability, and a score of 80 and above signifies "Excellent" usability. In terms of overall usability, as measured by the SUS, the participants ranked virtual reality, augmented reality and monitor-based delivery methods in the 70-80 range. The monitor-based delivery method had the highest SUS score of 78, followed by virtual reality at 76, and augmented reality at 72. However, the difference between the three was not statistically significant at a 5 percent significance level. We also used The Presence Questionnaire (PQ) in our work. The PQ measures the degree to which individuals experience presence in a virtual environment and the influence of possible contributing factors, such as hardware and interface distractors, degree of control in the system, sensory modalities, and level of realism, on the intensity of the experience [17]. In terms of realism, or how natural the environment felt, as measured by the PQ, virtual reality outperformed monitor-based and augmented reality delivery methods by 56 percent and 34 percent respectively at a 5 percent level of significance. As for the quality of interface, which is another factor of the PQ, augmented reality outperformed virtual reality by 2.75 percent and monitor-based reality by 15 percent. These results are significant at a 5 percent level.

X. Challenges and Implication of Experiment Findings

Our early-prototype findings on hardware-related challenges largely mirror those found in the literature. The virtual reality experiment participants commented that the HTC Vive felt heavy on their head and that they felt uncomfortable with the wires that restricted their movement in the VR tethered system. Some who used both the Microsoft HoloLens and HTC Vive found the former to be heavier and more uncomfortable. Students also commented on Microsoft HoloLens's narrow field of view which restricted how much of the virtual patient they could see at any given time.

We also discovered more nuanced challenges which might lend insight to the best uses of augmented and virtual reality. For example, simply due to scheduling, we did not have access to an actual medical examining room on the UTSW campus to use as a backdrop for the augmented reality delivery method. A meeting room was used instead. As a result, some participants found seeing the virtual patient hologram projected inside a meeting room, and not an examining room, distracting. This is a unique finding as we assumed that students would not be distracted by informal environments – such as a dorm room or a meeting room – during augmented reality experiences. The ability to use any environment during augmented reality experiences is one of the core advantages of this technology, and thus more thought and consideration needs to go into designing educational augmented reality-based experiences that rely on realistic representations of both the characters and the environments. We also feel that better explaining the core purpose of the technology – to practice patient interviewing – could also help with this type of feedback.

Using technology in early stages of development also proposes unique challenges. In general we found that any system glitch breaks immersion, which would be particularly relevant to a mixed reality platform that relies on seamless passage between real and virtual states. Serendipitously, these challenges and the initial limitations in the user experience have begun to reveal desired characteristics of a mixed reality platform, such as the need for a robust high-speed network to ensure uninterrupted immersion across all content delivery platforms. We are also beginning to gain insight as to when augmented reality, virtual reality and even monitor-based applications may be most appropriate to facilitate learning.

XI. Future Work

With the capabilities of high-speed networks like that possible with the US Ignite GENI framework, growing acceptance and development of technologies like augmented reality and virtual reality, and ways to capture and process both historical data and real-time data, we imagine a future world where we can develop and do experiments on a mixed reality platform like that described here. We believe our work is key to the exploration of the human/technology frontier of medical cyberlearning. As shown in Figure 6, we anticipate further development of the platform with subsequent experiments on what this future world will be like, enabled by parallel constantly evolving learning science frameworks. We anticipate that the cyberlearning frameworks developed in this medical education research will be extendable to other STEM educational domains as well as life-long learning.

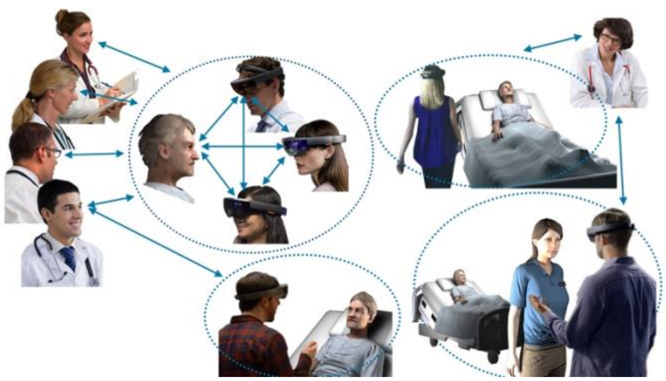

Figure 6. We envision that medical cyberlearning for work at the human/technology frontier will be a fully networked environment where students, professors, mentors and other medical system entities such as standardized patients will move in and out of the virtual and real for effective teaching. Our work fully encompasses the evolution of learning science frameworks parallel to our technical development.

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