Versatile mixed reality educational spaces; a medical education implementation case

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***Abstract*— Education has tapped into gaming to increase engagement and facilitate knowledge retention through experiential modalities. There have been several high technological intensity digital laboratories where learners are engaged with the subject matter through various activities. There are also several low intensity web based solutions that familiarize learners with curriculum material but in less experientially intensive manners.**

A ubiquitous approach to highly impactful, low cost, high reusability gamified educational approach is a versatile mixed reality educational environment. Using prolific technologies such as inexpensive AR headsets and a versatile low maintenance Database(DB) back ends, a real world environment can be transformed with 3d graphics and audio to various educational spaces of highly impactful content. Such a simple implementation is presented here for virtual patients in medicine. A simple DB backend supports a presentation frontend developed in Unity, utilizing the "vuforia" mixed reality platform. Based on this implementation future directions are explored.

Keywords—Medical Education, Virtual Patients, Augmented Reality, Livng Labs

I. Introduction

A. Education and Gaming

"Since the introduction of home computers and gaming consoles in the mid-1980s, school-aged children have spent more time with electronic media than ever before." This is the opening sentence of the, now seminal, review of educational serious games by Young et. al. [1]. This maxim was documented in 2012, at the beginning of the ubiquitous digital explosion, with digital devices such as tablets and smart phones carrying processing power similar to previous generation desktop computers. Even then, though fun and engaging interaction in a gamified digital context has been established as a valid tool in the contemporary educational arsenal.

Most serious gaming experiences have the potential to be fun and immersive, engaging students beyond the allotted classroom time. Form may vary with experiences being single or multiplayer, adaptable to learner interest with or without fictional elements according to the learners' age and experience [1]. While the exact educational impact (circa 2012) was still explored the engagement potential of serious games was, even then, not in question. Taking cues from the theory of Flow the games' inherent goal setting and achievement, intrinsically engages the learner with what almost constitutes the definition of "fun" [2].

A direct serious offshoot of games, Gamification is utilized for engagement and motivation through the usage of game-like techniques like scoreboards and personalized immediate feedback. This encourages users in tasks [3]. Gamification has been defined as "the use of game design elements in non-game contexts" [4]. Utilizing such elements can lead to a higher level of engagement if care is taken not to over-reward the learner and provide, thus, a false sense of achievement. Such techniques have been successfully implemented for maintaining healthy physical activity and exercise level in both children and the elderly [5], [6], thus validating gamification as a motivation and engagement instrument. In the overall educational domain, recent efforts have been made to explore user centric design [7], utilizing novel conceptual frameworks such as the Octalysis framework [8]. This "Human-Focused Design" puts in the spotlight not technical but affective and cognitive factors such as the learner's/ user's/ gamer's motives, goals and emotional states. [8]

B. The Medical education space.

Specifically in the medical education domain the main challenge faced was that of massive content. Since the 80s, medical

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knowledge was doubling almost every two years [9]. This has led educators to turn towards technology in order to cope with the volume and critical nature of medical education content. [10] The overall goal of all such endeavors was ubiquitous access to clinical skill development tools [11]. Web and Information, Communication Technologies became key enablers in medical education offering the necessary means for immediate and interactive learning environments away from location and time limitations [12]. A, now established ICT tool in contemporary medical education is the Virtual Patient (VP). It has been formally defined by the MedBiquitous Consortium as "interactive computer simulations of real-life clinical scenarios for the purpose of medical training, education, or assessment" [13]. Its importance was evident, hence a formal standard for exchangeability has been formulated [14]. VPs became practically accepted through the development of platforms that enable the web based development and deployment of them in many, mostly problem based learning educational scenarios [15] [16]. Such wide acceptance of VPs led to the development of several VP platforms. One such widespread platform is OpenLabyrinth (OLab) [16]. It is defined in its user guide as "…an open source online activity modelling system that allows users to build interactive 'game-informed' educational activities such as virtual patients, simulations, games, mazes and algorithms. It has been designed to be adaptable and simple to use while retaining a wealth of game-like features." [17]. This web based tool is ubiquitous in its accessibility through almost all modern browsers and requires minimal hardware and learning overhead. This ubiquity was in fact the reason that this platform was the base upon which repurposing efforts of VPs to more interactive 3-dimensional (3d) Multiuser-Virtual Environments have taken it as their starting point [18].
These efforts were spurred by the immediacy and immersion potential of the Virtual environment as well as the inherence collaboration potential that multi user interactivity can bring to education [19]. The very definition of the virtual world "A synchronous, persistent network of people, represented as avatars, facilitated by networked computers" demonstrates these advantages [20]. So it is no wonder that immersive interactivity found such acceptance that the concept of virtual laboratories became a reality.

C. *Virtual Laboratories and Augmented reality.*

Virtual labs utilize the strengths of computerized models and simulations as well a host of other instructional technologies (video etc.) to replace real life laboratory interactions. A Virtual lab, for example could consist of a host of digital simulations accompanied by discussion forums and video demonstrations along with collaboration tools all the way to complex virtual reality simulations [21]. This kind of interactive environments allow the students to pace their learning process by repeating content, accessing it at off hours and overall maintaining the initiative in their learning process. Beyond that, training and honing such sound laboratory skills covers some of the core weaknesses of contemporary medical curriculums. Fundamental knowledge in medical sciences such as biology and genetics goes hand to hand with expertise in medical laboratory methods. With the current status of state of the art diagnostic methods such as genome analyses it is imperative that physicians have a strong scientific background [22]. New laboratory techniques are most of the times not available for hands on training to students because of cost, time or safety constraints [23], [24]. This limits medical education to theoretical understanding leaving practicing physicians lacking in real world lab and clinical skills [24].
An approach that has been followed to bring real world skills to education (albeit so far mainly in the sciences) has been the incorporation of emerging virtual and augmented reality (VR/AR) technologies. It has been demonstrated that AR technology can significantly increase educational impact of the learning episode and thus greatly affect the educational outcome [25]. Examples included world exploration at a very experiential level [26], or experiencing chemistry and physics concepts in a way that is impossible to achieve without it. Visualizing chemical or environmental interactions [27] or the concepts of magnetic fields or airflow [28], [29] is something that cannot be achieved outside an AR environment with such immediacy. This kind of immersive immediacy is also responsible for motivating and engaging students to further explore the subject matter and, even, inherently learn to avoid conceptual errors. [30]
This work presents the effort to coalesce the immediacy of a mixed real/virtual space laboratory with the interactivity of the gamified virtual patient to create a novel but accessible clinical skills training environment utilizing low cost and low development overhead hardware and techniques.

II. Implementing Mixed Reality Medical Education Environments.

A. *Presentation Front End*

The presentation part of the implementation consists of an educational laboratory decorated with an array of AR targets that shall present, through an inexpensive digital eyewear

Figure 1 Inexpensive Digital Eyewear Headset utilizing mobile devices as application digital deployment platforms

headset (Figure 1) utilizing the mobile device's speaker as the application deployment platform the digital content of the virtual patient scenario. To that end a number of AR targets with the 3d content overlaid were implemented (Figure 2). These augment a real environment (The Lab of Medical Physics' Living Lab when the user wears the mixed reality headset. The

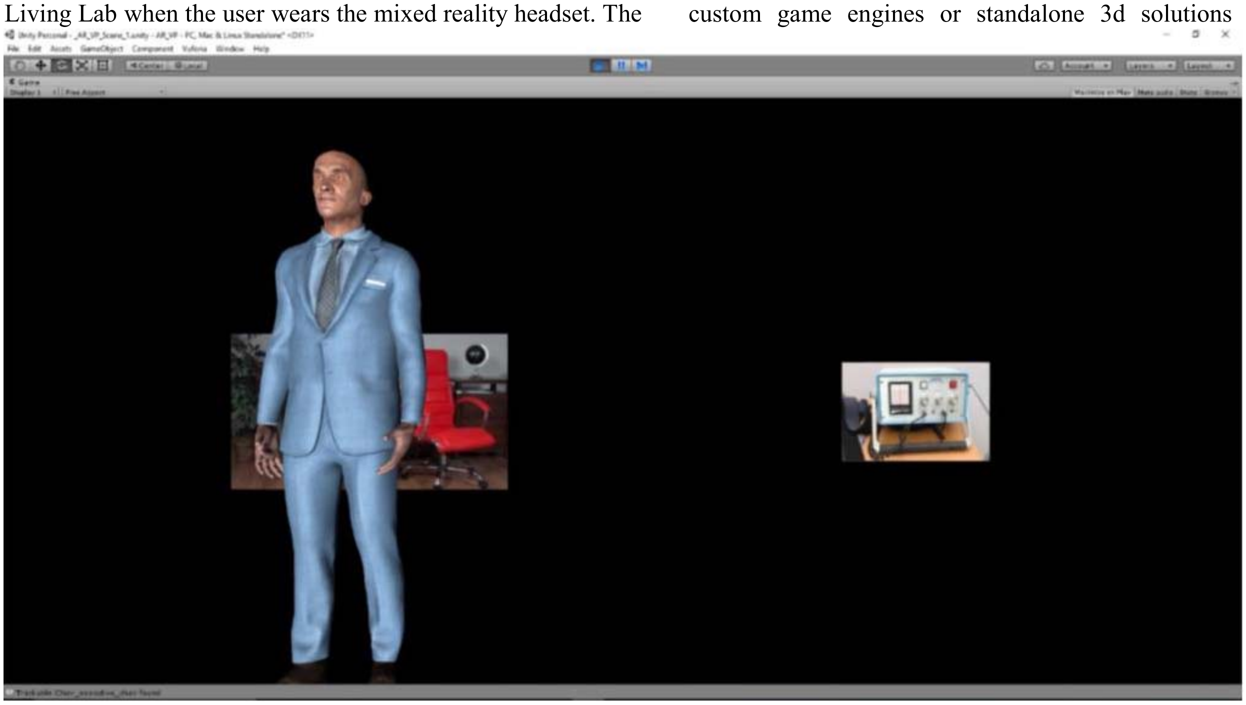

Figure 2 3D Assets overlaid on Augmented Reality Image targets

implementation of the virtual patient scenario follows a stateful approach as has previously implemented in other platforms [18]. In short, the game logic keeps track of the progress across the nodes of the Virtual Patient episode as it unfolds in the mixed reality environment and displays content and feedback as the user progresses through the VP nodes. The choice of the

Figure 3 The Lab of Medical Physics' Living Lab environment

development platform was dictated by the educational objectives of this content. This was the repurposing of Virtual Patients for clinical decision making skills, instead of training for complex manual procedures. This kind of educational content has relatively low asset complexity overhead. Thus, custom game engines or standalone 3d solutions are not warranted for effectively translating the educational narrative to the envisioned gamefied mixed reality environment. Given these development attributes, the application front end is developed using Unity 3d and the "Vuforia" AR/digital eyewear platform. This development environment provides the ease of use necessary for rapid development, while maintaining a sufficient level of versatility for the type and volume of content that is foreseen to be necessary within the scope of this work.

B. Database infrastructure/Back-end

The back end of this application is utilizing previous experiences from our group [31] in designing an effective database scheme to support VP repurposing environment. It is a schema comprising of 3 parts. The VP part supports storing the links nodes and cases as they are describing whole virtual patients. The Environment part supports the storage of information regarding the configuration of 3d assets and environments. These parts combine in the 3dCase part to store the meaningful representation of a virtual case as it is presented through 3d environment. A detailed depiction of this schema is demonstrated in Figure 4

C. Evaluation Strategy

At this stage both components are developed and linking between the two is finalized. The evaluation of this application shall be conducted in the Lab of medical physics Living Lab environment which shall be augmented by the developed digital content.

The validation of this technology shall be achieved by piloting it with volunteer medical students. The platform shall be utilized as a teaching aid in problem based, blended learning scenarios. Specifically it will be piloted in a virtual laboratory of clinical decision making regarding cardiology and more specifically dealing with an emergency (code blue) cardiological admission. Students shall utilize the case as both an initiatory point and as a closing/summation event in a problem based learning episode regarding emergency cardiology procedures.

The evaluation strategy is a straightforward three-pronged usability/engagement/efficacy approach. Usability shall be assessed through the standard SUS usability questionnaire [32]. This simple 10 item questionnaire shall be used for this stage of the evaluation. The much more elaborate SUMI [33] instrument would be cost effectively utilized only in a broader piloting base. Affective engagement shall be measured through the use and adaption of the student engagement instrument (SEI) [34]. Knowledge retention shall be assessed through exam performance of the participating students.

The results of this evaluation cycle are expected to be fed back to wider pilot scenarios that shall provide more specific results for refining the technology towards user expectations and requirements.

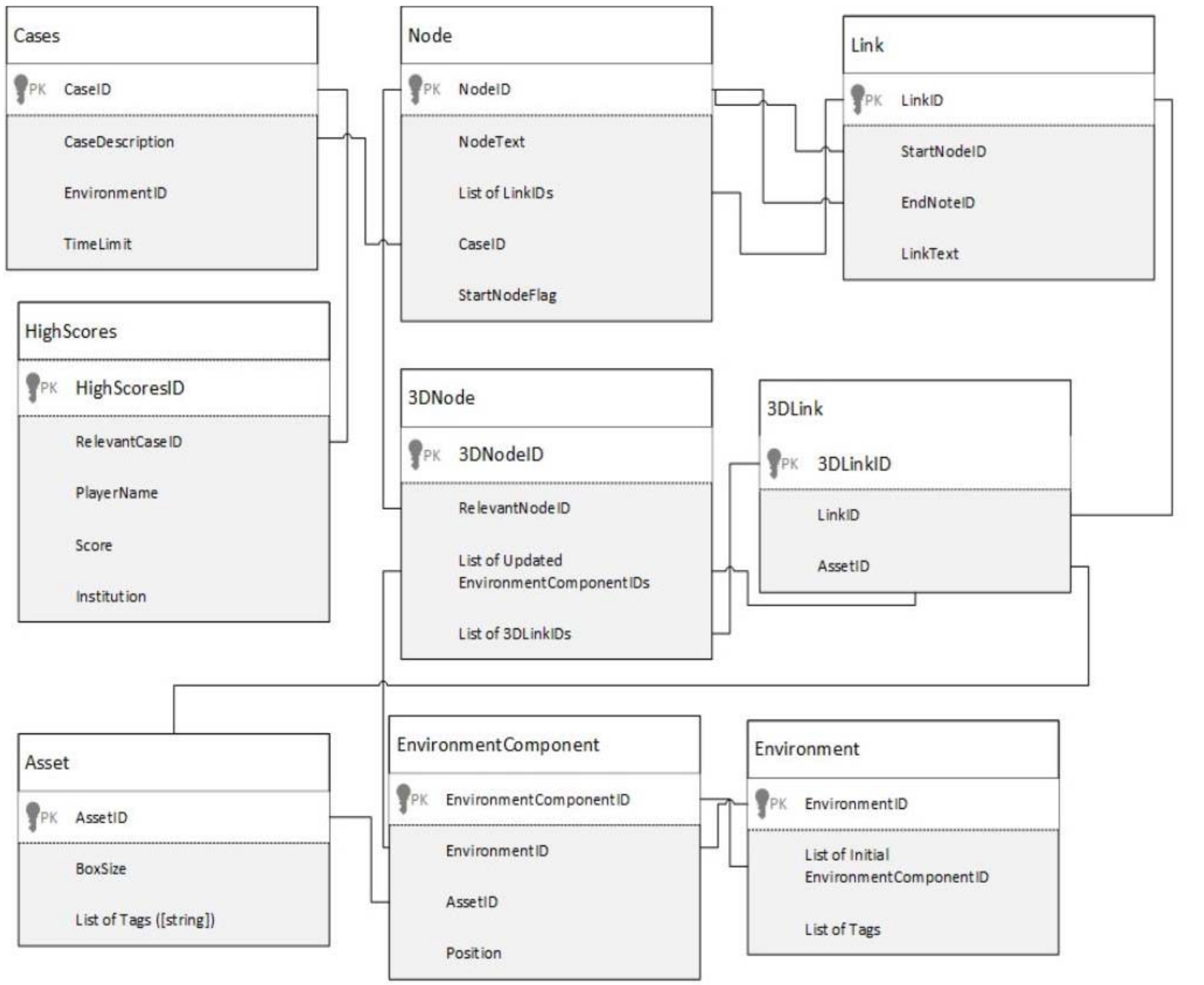

Figure 4 Back-end DB Schema for mixed reality Virtual Patients repurposing

III. DISCUSSION

The work presented here describes an integrative environment for repurposing virtual scenario content in a mixed reality educational environment. Efforts are currently directed at piloting the platform and populating its database back end with additional educational and 3d content.

Virtual Learning Environment (VLE) have evolved significantly since their inception. From stand-alone online repositories where content was uploaded to MOOCs [35] VLEs are now envisioned as collaborative, decentralized, educational activity guide-lights that, expertly, participant towards appropriate content for the specific learning objectives. This paradigm of decentralization aligns well with the repurposing effort presented in this work. With the immersion potential, the capacity for collaboration and engagement of a mixed reality environment, the inclusion of this educational medium in the arsenal of medical education instruments appears as a natural evolution. The main barriers to such an evolution are both the maturity of the technology, the integration to the infrastructure and the creation of a non-trivial amount of quality content in this medium. However, with the aforementioned decentralization of the infrastructure, the integration problem becomes less important. With VPs as an implementation being around for almost 40 years [36] and web deployment and development platforms like OpenLabyrinth passing a decade of existence [16], web based VPs can be considered a mainstream tool in medical education. Hence streamlining transfer of such cases to a MUVE can provide a significant content boost in MUVE VPs. Furthermore, the reusability of 3d assets in a multitude of case narratives (supported by the back end database scheme) alleviate to a significant degree the need for massive amounts of 3d content creation.

It has been demonstrated that the use of AR technology positively affected students' learning and skills by experientially and interactively immersing them into the subject matter [37]–[39], [29], [40]. In the current technological environment AR applications are supported by mobile devices. Thus, educators wishing to use AR technology have a ubiquitous platform for immediate access to a mixed reality learning environment available in both laboratory and personal context. It has been claimed that it is better for learners to not interact in an entirely virtual laboratory, so the mixed reality learning environment was supported to be the optimal solution [30]. Studies also have demonstrated that mixed reality laboratory learning environments have had positive impact in the time it takes to complete lab experiments against non-digitally enhanced ones [37]. The reported reason for this difference was the ability of learner's to establish underlying scientific rationale and mechanisms faster through experiential immersion. This same psychological/cognitive process was also reported to be a factor in improving learner's outlook toward difficult the overall subject matter thus increasing engagement and commitment to the learning process. [37]. Beyond established motivation, retention and engagement results, transferring that kind of experiential immersion in the medical education domain, the incorporation of digital content in a real world environment provides the same amount of versatility and impact as Living Labs have provided in other sectors of research and business.

A Living Lab (LL) is a living environment housing people and technology (facilitators and sensors/actuators), in an unobtrusive, semi experimental setting fostering symbiotic research development and innovation [41]. A key facet of a LL is that it transforms the users, from observed subjects, into members of a co-creative ecosystem. More formally Living Labs have been defined as a "a user-centric innovation milieu built on every-day practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values" [42]. From this definition it is clear that living labs can enable businesses, authorities, researchers, and customers to collaborate towards innovation, research, co-creation, and marketing applicable in many real-life environments [42]. Existing literature offers conceptual discussions about co-creation in LLs. Results coming from recent research, through focus groups, interviews and observations, combined with the results from systematic literature review coalesce to six critical factors for fostering co-creation in living labs environments [43]: Engagement, Relationship Management, Operating Principle, Design Layout and Data collection Approach.

The first factor, Engagement is also a crucial goal for the development and deployment of a mixed reality educational environment in a real world setting. The second factor, Relationship Management refers mostly to the functional inter- and intra- institutional relationship between the living lab management and the end user of it [44]. There is a direct analogy to be drawn from that to the relationship of the educational environment and facilitator personnel with the learners, the educational "end users". The third factor, Atmosphere, is exactly the immersion and facilitation enabler that a mixed reality environment is aiming for. Operating principles, in Living Labs, as a set of overarching guidelines for optimal use of the facility in its context, is directly relevant to the specific educational paradigms (PBL, curriculum optimization) that support the mixed reality educational environment. Furthermore, Design Layout as a crucial factor for fostering co-creation in living labs is a direct outcome and specific requirement upon which a mixed reality educational environment is devised. The creation of (the verisimilitude of) a specific and different each time educational environment is the very reason for which the real educational environment is enriched through mixed reality technologies. Finally the Data Collection Approach of a living lab environment involves both the sensors' configuration and the data collection strategy. In that comparison a mixed reality educational environment moves in parallel with ready provisions for in app analytics augmenting the physical space's data collection capacities.

Given the previous brief discourse, this work's demonstrated mixed reality environment finds a place beyond just a teaching aid. It aims to become an instrument for immersive engaging and collaborative medical education. This, combined with the aforementioned ubiquity of AR development makes this work a step toward the creation of low technological intensity, financially viable and versatile educational living lab environments.

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