Mining Innovation Prospects at the Virtual Seams

in Pasteur's Quadrant

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Abstract

Immersive virtual reality (VR) offers the means for a situated place wherein resources and communication services can be provided for a range of distributed and emergent collaborations between government agencies, universities, industry, and federal laboratories in support of innovation. This paper describes a collaborative design-build (CDB) ecosystem employed by a consortium, involving the United States Air Force, NASA/Jet Propulsion Laboratory and several universities, to explore, examine, and implement learning innovations enabled by new media. The consortium, named the Global Learning Forum (GLF), is a social network operating within the immersive VR of Second Life. Innovation prototypes, derived from the use of a CDB ecosystem by the GLF consortium, are offered as exploratory examples.

Introduction

The traditional *design-transfer-build* (DTB) method is commonly used by educators to implement changes to curriculum, instruction, or delivery methods benefiting from advances in technology. In many cases, changes made under the DTB method are fixed in place within the learning environment until the next round of technology-driven change. The use of a traditional DTB method typically involves a technology event-driven process, facilitated by instructional systems designers, which produces a design that is ultimately handed over or transferred to builders (or implementers) of the technology. Under DTB, the builder accepts responsibility for constructing and/or integrating the technology into the learning environment to meet fixed design requirements. However, the intensive number of disputes and the growing emphasis on user-centered learning designs, enabled by new media, have triggered the need for other alternatives to prototype and implement learning innovations through technology. *Collaborative design-build* (CDB) is one such alternative.

CDB is an ecosystem wherein a user-centered consortium, involving instructors, learners, designers, and builders, engage for collaborative design, rapid prototyping, and implementation of learning innovations enabled by new media. New media is a term used to denote a media ecology supporting emergent behavior associated with interactive media and media for social communication. New media enabled learning environments support multi-purpose, multi-functional devices and tools for user-centered design and collaboration. The new media ecology can also support synthetic reason, intelligent machines, augmented knowledge and culture, networked and mobile devices, computers supporting immersive virtual reality and blended or hybrid virtual and physical environments and systems (Veltman, K. H., 2006, and Ito, M., et. al., 2008). A core advantage offered by the CDB ecosystem is collective belief among acquaintances regarding the importance of emergence for innovation. The meaning of emergence in this context is

defined as a set of individual and collective behaviors from which innovations emerge largely due to the health of interdependency among acquaintances of the community. Our observation is the most promising learning innovation prospects emerge as an interdependent effort among acquaintances geographically distributed across several organizations spanning the globe. A geographically distributed community, involving a heterogeneous mix of worldviews and skills, is inherently beneficial for learning innovation work. Another observation we can make is that learning innovations are not only dependent on the health of the interdependency among acquaintances but also the relationship of how acquaintances are clustered into collaborative communities within the innovation prototyping ecosystem.

Role of Place for Collaborative Innovation Prototyping

We believe collaborative innovation prototyping is dependent on having access to a shared and situated place, capable of supporting and sustaining long-term efforts by a consortium of acquaintances. Traditionally, non-immersive web-based knowledge management services and resources and group conferencing software have been the primary means to support collaborative efforts at a distance using combinations of asynchronous and synchronous connection and communication tools. On one level, the non-immersive web-based services and forms of connection and communication tools have been successful with increasing accessibility to shared knowledge and resources. On another level, however, persistent collaboration by people geographically distributed across multiple organizations at a distance can suffer when there is the absence of an immersive shared-situated place, similar to physical space, for offering contiguous and interactive spatial navigation, and emergent participatory co-action. Also, importantly, it can be difficult for people to form and sustain a collective belief and community identity apart from inhabiting a shared and situated place.

From our observation, successful collaborative innovation prototyping depends on participatory learning and interdependent contributions proximal to or within a community environment. Thus, we place importance on architecture for community participation that can support inhabitable, shared-situated places suited for collaborative and emergent design-build prototyping activities. Immersive VR can provide an inhabitable place, offering geographical independence for user-centered social networks, to collaboratively design, test, and improve emergent innovation prototypes within a learning community.

Meredith Bricken (1991) and Hilary McLellan (1991) argued immersive VR can be very supportive of situated and constructivist learning.[1] Immersive VR provides the means for a person to enter a virtual spatial multi-sensory environment and embody it in such a way as to actively inhabit, interact, and create the next event (Bailenson, et. al., 2008 and Walser, 1992). Situated learning (Lave and Wenger, 1991; Wenger 1998) posits that how people learn is very much a social process involving communities.[2] Social and cultural practices are embedded in what people learn. A related learning theory, constructivist theory (Piaget, 1977; Bruner 1986, and Brown, et. al., 1989) places importance on how people construct understanding of knowledge. People construct understanding based on life experiences and

[1] In the late 1980s Jaron Lanier first coined the term "virtual reality" to describe interactive computer-generated three-dimensional immersive displays (Lanier, 2001; Schroeder, 1996, p. 23; Rheingold, 1991, pp. 15-16). Much progress has occurred since the first commercially-available multiparticipant or multiuser virtual reality (VR) system was introduced by Jaron Lanier's "Reality Built For Two" or RB2 (McLellan, 2004).

[2] See also Bransford, et. al., 1999; and Brown and Campione, 1996.

beliefs to help associate new knowledge. Learning, in the constructivist view, is very iterative, via active-experiential engagement, to associate existing understanding with new information. According to Bricken (1991) immersive VR learning environments can be designed to be experiential and intuitive; providing learners with control over time, scale, and physics for a shared experience and information context supporting interactive hands-on learning, group projects and discussions, field trips, simulations, concept visualization, and to observe from many perspectives.

A related important design quality of immersive VR learning environments is "worldness." This concept addresses the degree of how well VR participants can situate in a learning community and co-engage in the collective creation of belief about the coherence, completeness, and consistency within the immersive virtual reality environment, regarding its' aesthetics, and rules (Pearce, 2009, p. 20).

The Global Learning Forum: Community Architecture for CDB Prototyping

An immersive VR situated community, named the Global Learning Forum (GLF), was designed and established to support CDB prototyping for learning innovations with new media. A key feature of GLF is dependence on bridging "weak interpersonal tie" social networks for obtaining the maximum channels through which novel ideas and information are gathered from the broadest outreach of social and cultural perspectives. The novel ideas and information are then distilled, using design studios, to obtain the best innovation prospects for prototyping.

Mark Granovetter (1973, 1983) pioneered research on how strong and weak interpersonal ties hold members of society together. In particular, he argued weak interpersonal ties define most social networks in society as well as account for the greatest novelty of ideas and information passing through such networks. A weak interpersonal tie is defined as a network consisting mostly of acquaintances. Consequently, novel information tends to flow through weak rather than strong tie networks since acquaintances are more likely to know other people not generally known to others in the network; many of which can be a source of novel ideas or information. In contrast, a strong interpersonal tie is defined as a network of friends or peers closely associated via a common clique, organization or culture. Thus strong interpersonal tie networks are likely to share common or overlapped information since close peers tend to circulate among similar sources.

GLF members host open-house "innovation-sharing events" to help bridge across multiple "weak interpersonal tie" networks. GLF events help members to discover and leverage "unlikely" interpersonal ties for obtaining the greatest novelty of ideas and information. The "unlikely" weak ties expand the GLF network of team members while helping to keep the community from becoming encapsulated. Thus, from our observation, weak ties are important sources for feeding new ideas and information into the CDB prototyping ecosystem to innovatively transform ways to learn, instruct, and discover using new media.

An excellent source of "weak interpersonal tie" networks is the open-ended metaverse of Second Life. Second Life was opened to the public on June 23rd, 2003. Since its inception in 2003, the metaverse of Second Life has become the world's largest open virtual world with over a million registered users. The Second Life metaverse (virtual world) physically resembles the real world. It consists of interlinked regions containing land, water, and air. Physics is applied with gravity, weather, and a sun and moon that regularly cut across the horizon. Each region has an area of 65,536 Second Life square meters (about 16 virtual acres of land). Second Life regions are both geographical and administrative units and are governed by rules

and regulations that may change from region to region. There is also a Teen grid reserved for Second Life members between the ages of 13 and 17. Residents of Second Life are the creators of the various virtual regions. (Rymaszewski, M., et. al., 2008, pp. 4-6, 332).

GLF acquaintances bring different experience levels with inhabiting, navigating, organizing, and creating virtual space via embodiment of an avatar. The word "avatar" comes from a Sanskrit term meaning a god's embodiment on Earth, and has been adopted universally in English to describe a person's representation in a virtual world (Pearce, 2009, p. 21). People shape and dress an avatar's virtual body intentionally to convey gender, body proportions, style and dress appearance to express a desired "in-world" persona. Behind GLF community interactions, a person is in command of an avatar. On occasions, however, autonomous agents, which can look and behave like human-controlled avatars, are used as co-player agents in serious games for learning prototyped by the GLF community.

GLF acquaintances, and team members, engage in CDB prototyping via interlocking clusters spanning several functional areas. GLF cluster acquaintances have no direct business ties with one another. The interlock is incidental, or weak. Weak interlocks help to create and sustain interdependence, cooperation and coordination across diverse organizations and cultures involved with the following prototyping areas:

- Immersive Learning Environments Enabled by New Media. This functional area integrates multiple areas of innovation into composite learning environment prototypes enabled by new media. Also, immersive VR design studios are hosted, including a Virtual Educational Technology Support Center (VETSC). Housed within VETSC is the Cognition and Instructional Technologies Laboratory (CITL), a trans-institutional research group studying augmented learning through technology. CITL applied research, supporting prototyping effort, includes:

  - Collective Intelligence Supporting Collaborative Problem Solving. This area of research examines the emergent qualities of collective intelligence for collaborative problem solving, as augmented by cybernetic feedback systems.
  - Adaptive Electronic Performance Support and Intelligent Tutoring Systems. Model-tracing performance modeling and intelligent tutor designs are designed, prototyped, and tested for promoting higher levels of real-world problem-solving skills.
  - Metacognitive-Learning Frameworks Supporting Enduring Understanding. Research is conducted on the design of augmented learning frameworks for forming and shaping habits of mind to help learners develop and reinforce mature lifelong learning and values.
  - New Media Literacy and Networked Cultures. Assessment models and tools are investigated for determining developmental levels associated with new media literacy and helping to understand the ethnography of virtual communities in shaping new media literacy levels.

- Learning expeditions. Interactive scenarios, involving the use of challenge-based cycles, are prototyped along with a repository of reusable 3-D objects.
- Educational Holograms. On-demand educational learning environments are made available in the form an instantly "rezzed" or visible 3-D composite of

objects. The holograms are designed with interactive components and can be removed from the immersive space after use. Digital libraries are also prototyped along with resource applications and mashup tools for remixing data and web services.

- Educational Informatics. Educational informatics studies the structures, behaviors, and interactions of natural and artificial systems that store, process, and communicate information in support of learning, instruction, and discovery.
- Simulation Gaming for Learning. Serious games, and supporting infrastructure for capturing and assessing performance, are prototyped in support of team learning using real-life challenges or scenarios (Stricker & Clemons, 2009). Serious game prototypes are also tested for mixed or blended learning environments involving live, constructive, and virtual reality. Prototyping in this area includes integration and testing of mobile learning devices and intelligent tutoring co-player agents in support of serious games for learning (see Klopfer, 2008).

The most important infrastructure for the GLF is a form of social capital consisting of shared commitment and trust among networked acquaintances and team members, incubated and sustained through extended interactions and collaborative problem-solving involved with prototyping (Richards, et. al., 2001). A report from a workshop on innovation, sponsored by the National Science Foundation (NSF), highlights the importance for establishing and nurturing an innovation culture and why it matters for organizational and societal effects (Larson, E. V., et. al., 2002).

The NSF report stressed the importance of a clear vision, performance goals, benchmarks, passionate and visionary leaders, and acquaintances bounded by an essential interdependency and shared commitment as key ingredients for an innovation culture. The work of innovation also involves resources embedded in a situated place, that can provide a context for incubation; technical, management, and administrative support; laboratory and other capacity; and communication services (Larson, E. V., et. al., 2002). Thus, immersive VR offers the means for a situated place wherein resources and communication services can be provided for a range of distributed collaborations between government agencies, universities, industry, and federal laboratories in support of innovation.

Innovation prospects are often found at the seams of where disciplines intersect with the needs of government agencies, universities, and industry. Solutions not obvious in one discipline or organization might be very obvious in another and it is through weak-tie interactions that prospects emerge for innovative solutions.

Pasteur's Quadrant

Inherent tension comes along with innovation work from the need to acquire fundamental understanding (rigor), regarding promising prospects, while also wanting to achieve practical benefits and use (relevance) (Tushman, M., & O'Reilly, C., 2002). The nature of this tension was first articulated by Donald E. Stokes, a professor of politics and public affairs in the Woodrow Wilson School of Public and International Affairs at Princeton University (Stokes, 1997).

Stokes recommended the development of innovation communities in professional education that jointly valued the quest for fundamental understanding along with considerations of use. He called this type of innovation research Pasteur's Quadrant after the pioneering research conducted by Louis Pasteur that focused on solving practical problems inspired by societal needs.

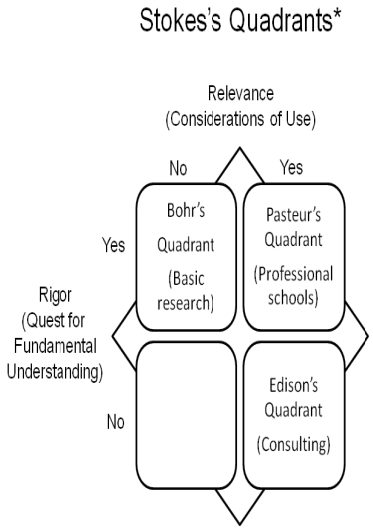

Figure 1. Stokes's quadrants.
*Note: adapted from Stokes (1997, p. 73) and Tushman & O'Reilly (2007, p. 770)

Figure 1 depicts the research quadrants described by Stokes. Bohr's Quadrant represents research focused on developing understanding with no thought of specific use (e.g., Neils Bohr and the discovery of atomic structure). And, Edison's Quadrant covers research focused strictly on the development of applied use (e.g., Thomas Edison and the invention of the phonograph). For learning innovation with new media, there is a need to acquire a fundamental understanding of how best to design learning environments that support how people interact with information and with others in new socio-technical relationships independent of geographical distance and proximity (Kakihara & Sorensen, 2002).

Researchers on human learning have developed deeper appreciation for how knowledge is embedded in context and the media allowing its expression (Bransford, et. al., 1999; Cognition and Technology Group at Vanderbilt, 1997; Kafai and Resnick, 1996). This appreciation has expanded fundamental research on the deeper and ubiquitous connections between people and technology via the use of personal and cultural tools now supporting human minds, senses, and bodies.[3]

Also, there is growing research interest on the symbiotic connection between human minds and digital tools making possible phenomenal capabilities via interconnected and distributed ways of knowing and learning. For example, new media digital technologies can support innovative cycles whereby knowing affects learning by doing and doing, in turn, affects knowing in several fundamental ways. Innovative configurations of immersive VR learning environments, enabled by new media, can introduce new social relevance and consequences of mobilization for how people learn and the mobility of the learning place itself (Stricker, 2009).

Innovation Work in Pasteur's Quadrant

The synthesis of augmented learning with innovative configurations of immersive VR environments lead to iterative innovation design-build cycles that are fundamentally social and collaborative in nature. Understanding new media configurations require research rigor while meeting practical needs and constraints associated with learning environments and education systems. Figure 2 depicts a broad view of a design-build prototyping process modified from a RAND capabilities-based planning model (Davis, 2002, p. 9). In many important ways, the work of innovation involves interdependent and collaborative effort to conceive, design, and build from a broad concept for how to achieve a shared objective (Hughes & Stricker, 2009). Starting with a broad concept for the "art-of-the-possible" is the initial step in the design-build process.

[3] See VaNTH ERC, Vanderbilt University, Northwestern University, University of Texas at Austin, and Health, Science and Technology at Harvard/MIT Engineering Research Center. Available: http://www.vanth.org; also see SMETE, Science, Mathematics, Engineering and Technology Education. Available: http://www.smete.org.

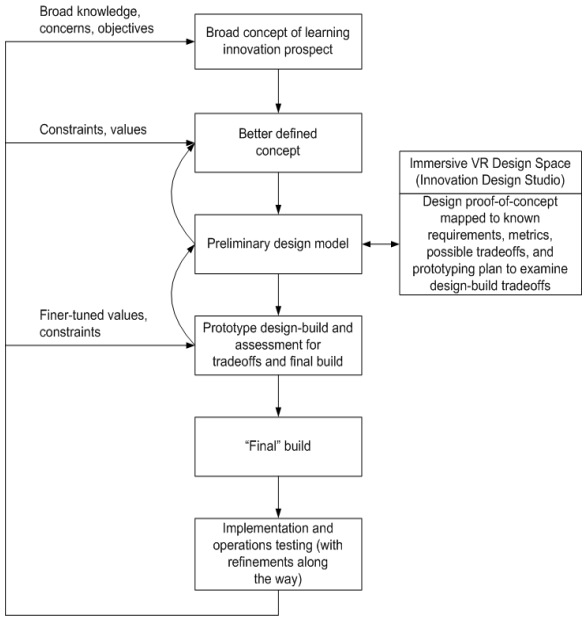

Figure 2. Collaborative design-build (CDB) prototyping method process.
Note: Figure adapted from RAND, "Analytic Architecture for Capabilities-Based Planning, Mission-system Analysis, and Transformation," National Defense Research Institute, by Paul K. Davis (2002, p. 9).

Next, thinking about the innovation prospect undergoes greater specificity to not only account for current needs, requirements, challenges, or constraints but those that can be imagined into the future. It is at this stage in the process where plausible scenarios are imagined for the innovation prospect to further help define the concept and formulate the preliminary design model.

The prototype scenarios help to put context into considerations of use for the innovation. This helps to focus the innovation mining effort in Pasteur's Quadrant for achieving practical benefits and use. Also, maintaining focus on Pasteur's Quadrant can be assisted with the use of a framework for mining innovations at the virtual seams between the physical world and immersive virtual reality (see Figure 3).

The framework, depicted in Figure 3, is used to examine learning innovation prospects for enterprise-level benefits spanning people, process, technology, and organization impact levels.

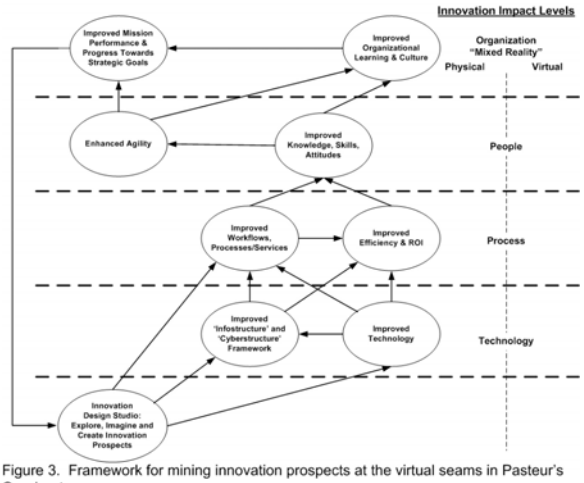

Figure 3. Framework for mining innovation prospects at the virtual seams in Pasteur's Quadrant.

Of particular interest are innovation prospects potentially porous across inter- or intra-organizational seams: capable of bridging between or transcending organizational boundaries spanning physical and virtual realities.[4] A key feature of the framework is a collaborative methodology applied during an "Innovation Design Studio" wherein weak-tie acquaintances and team members can come together in an immersive VR space, and through intensive sessions of exploring, imagining, and creating, design and plan for CDB-based learning innovations prototyping (see Figure 4).

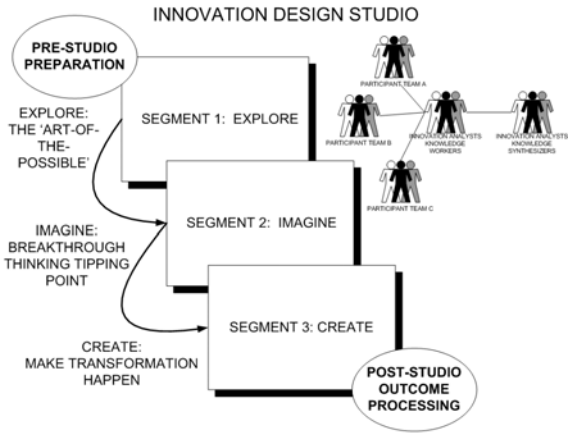

Figure 4. Innovation Design Studio structure.

[4] See Milgram and Kishino's (1994) mixed reality spectrum, spanning from real to virtual environments.

The VR Innovation Design Studio structure takes acquaintances and team members through various stages of CDB-based exploring, imagining, and implementing innovation prototyping prospects requiring focus and cooperation among multiple acquaintances and disciplines.[5] Breakthrough thinking can be methodologically facilitated during the stages so acquaintances and team members can figure out, in compressed time, fundamentally different interactions among people, process and technology that will result in innovative ways to provide a step function improvement or transformation.

Systematically, with the help of studio facilitators, participants address change barriers (e.g., technology, regulatory/policy, financial, cultural, and organizational) to achieve transformative breakthroughs and results. The studio innovation-analyst facilitators help collect and synthesize vast amounts of knowledge sharing and group work over the course of the event to help acquaintances and team members distill the essence of challenges, barriers, breakthroughs, and implementation plans made possible by weak-tie collaborations and cluster teaming.

Event innovation-analyst facilitators also collect preparatory information and resources, prepare pre-event activities, and organize event products and results, and manage post-event activities and follow-up. Figure 5 depicts screen snapshots from the GLF immersive VR innovation design studio space in Second Life.

5a. Innovation design studio entrance 5b. Studio breakout hall

5c. Top view of studio complex 5d. Studio work displays

Figure 5. Immersive virtual reality (VR) innovation design studio space in Second Life.

We have observed the following innovation-analyst facilitator skills and services to be helpful in supporting an immersive VR Innovation Design Studio:

1. Front End Needs Assessment and Requirements Analysis. Assistance with learner analysis and needs assessment, including methods to identify, analyze, specify, and design functional requirements associated with the use of immersive VR for supporting learning, instruction, and discovery (research). Assistance with translating functional requirements into technical requirements or presenting alternative technologies or approaches for supporting requirements.
2. Risk Management. Assistance with methods and tools used for risk assessment and mitigation of risk with various technical requirements.
3. Technical Analysis. Advice and evaluation services are provided on the technical features or capabilities of various immersive VR platforms and supporting infrastructure, hardware, and software requirements.

[5] The innovation design studio segments (Explore, Imagine, Create), used to support a CDB ecosystem for learning innovations, are an adaptation to Matt Taylor's Scan, Focus, Act model (see http://www.mgtaylor.com/). The use of a "Scan-Focus-Act" process was first formulated by Jim Channon, Frank Burns and Linda Nelson in support of architecture design activities; later a Scan Focus Act model was copyrighted by Metasystems Design Group in 1983. MG Taylor Corporation subsequently expanded upon it and implemented the model in its processes.

4. Functional immersive VR Expertise. Advice on the trends, issues, and emerging functional capabilities offered by immersive VR platforms. Can also advise on approaches used by other institutions of higher education regarding trends, issues, and efforts with the use of immersive VR.
5. Configuration Management. Advice on ways to plan and manage the implementation of immersive VR capabilities or components. Can also provide assistance with CDB-based prototyping, testing, analysis, and evaluation of immersive VR capabilities/projects for possible enterprise-wide scalability, operational support and sustainability.
6. Learning Architecture. Can offer advice and assistance with the CDB-based design of immersive VR or mixed-reality learning environments (e.g., blended uses of immersive VR with real-world spaces, or combinations of live, virtual, and constructive realities).
7. Educational Informatics and Learning Technologies. Can offer advice and assistance with the design and use of educational informatics and learning technologies across live, virtual, and constructive realities, to include support for mobile learning, gaming and simulation frameworks.
8. Media Awareness. Can offer advice and assistance with using new media and methods creatively for proof-of-concept and CDB-based prototyping efforts involving the use of immersive VR in support of learning, instruction, and discovery.
9. Curriculum Design. Assistance with the selection and use of a variety of learning models and techniques to define and sequence instructional content and strategies involving the use of immersive VR or variations of mixed-reality models.
10. Instructional Systems Design. Assistance with the selection and modification of existing materials, or assistance with the design of instructional materials and methods that reflects an understanding of the diversity of individual learning styles and social-collaborative models for enhancing learning and performance.
11. Instructional Management Systems. Can share knowledge of approaches taken towards the use of course management systems (CMS) and learning management systems (LMS) across both physical and immersive VR learning environments.
12. Project Management. Can share knowledge and assistance with the design of project structures supporting instructional systems design and CDB-based prototyping of learning environments by GLF cluster teams. Can also advise on methods and tools for developing, scheduling, coordinating, and managing larger-scale projects and resources involving contractors, including advice on approaches for monitoring and inspecting work and contractor performance.

Examples of learning innovation prototypes, arising from GLF's use of a CDB ecosystem, are illustrated below. One set of the prototypes depict classical-oriented, learning environment designs. Recognizable visual cues of social roles for instructors and learners, interactive learning tools (e.g., virtual computers, plasma screens, and books), auditory features, help to establish a sense of a situated place supporting classical learning environments. Digital immigrant learners are more likely to recognize and accept the validity of the classical-oriented designs as suitable places for situated learning.

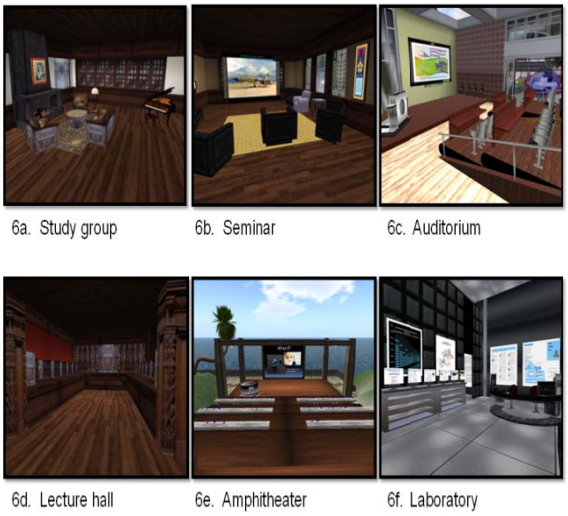

Figure 6. Classical-oriented, immersive virtual reality learning environments.

Each classical-oriented learning environment prototype, depicted in Figure 6, is briefly described below.

Study Group (Figure 6a). This prototype was designed to place emphasis on relational aspects associated with learning. The space, while elegant, is utilitarian in scope wherein relationships in learning can be nurtured amid a serene, dim, and contemplative interior. Crossing into the room from the entrance conveys an image of calm enclosure and of seeping light. Wrightian interior spaciousness is central to the design. The furniture in the study group area conveys a sense that they are built-in as part of the original scheme considering the whole as a unit. The fireplace is at the heart of the room, around which furniture is arranged but toward which attention always is drawn back.

Seminar (Figure 6b). The Seminar prototype conveys an interior learning design that is cozy while also suggesting a disciplined perspective with the placement of room artifacts and attention to detail. A higher information or stimuli load is given to consider with the plasma screen. The space also suggests an environmental psychology principle in how learners can be situated in a shared space for enhancing approachability with the seminar leader or facilitator.

Auditorium (Figure 6c)

The Auditorium prototype was designed to place greater emphasis on instructional function rather than form. The learner seating space by aisle is dense. The use of a stage, with a podium, suggests authority in the learning environment. Emphasis on aluminum, and ribbon windows, in the design suggests a machine-inspired aesthetic of European modernism. There is also a touch of neoclassical influence with the carved paneling and doors suggesting a touch of historicism blended into an eclectic atmosphere for learning. The glass ceiling offers semi-transparency with a suggestion of physical protection.

Lecture Hall (Figure 6d)

The Lecture Hall prototype creates a ceremonial atmosphere for learning. The placements and sizes and heights of learner chairs, with an open walkway in the center of the room, suggest a judicial environment wherein arguments are presented and dissected with formal Socratic rhetoric. The heavy paneled walls are an embodiment of the classical orders to create a strong masculine-oriented learning environment.

Amphitheater (Figure 6e)

The Amphitheater prototype bridges theater with learning in an antiquarian environment. Acceptable sight lines towards the stage are provided for learners. The design is stage front in the traditional Renaissance convention. The symbolic frontal stage design is the marker of instructional power involving deferential status of the instructor-learner relationship. Standing yards are present on each side of the stage in 16th-century tradition as places where stories

could be told and listened to without the distraction of elaborate sets.

Laboratory (Figure 6f)

The Laboratory prototype depicts a learning studio modeled after the Quickborner Team German design group. Workspace is clustered and furniture is open-plan to support a high-load learning environment with emphasis on efficiency. Various laboratory stations provide for mobile learning device connections (e.g., iPod broadcast downloads), streaming video controls, and virtual work stations and computers. The ground floor is focused on a central rectangular atrium in the Italian tradition to convey volume and continuous interior space. The overall effect is order, concentration on the essentials, and intelligent purpose.

Various future-oriented, immersive virtual reality learning environment designs are also represented in the prototypes (Figure 7).

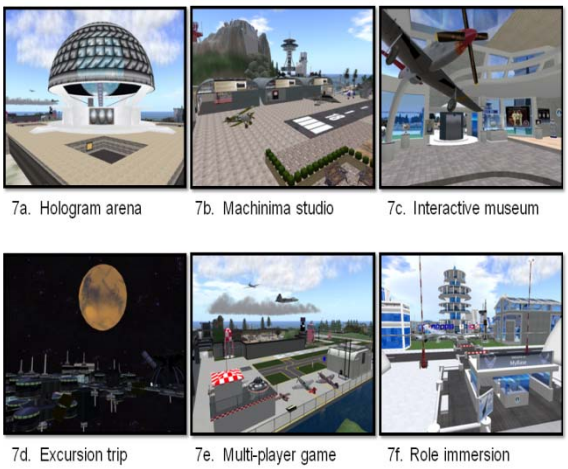

Figure 7. Future-oriented, immersive virtual reality learning environments.

The future designs offer affordances or opportunities for action (learn by doing), bundled together with learning tools and devices. Also, the future designs provide surrogate settings of actual work environments supporting apprenticeship, collaborative teamwork, coaching, and monitored performance feedback. Each future-oriented learning environment prototype, depicted in Figure 7, is briefly described below.

Hologram Arena (Figure 7a)

The Hologram arena prototype provides the means for learners to select from multiple learning environment options and have them appear (or rez) for immediate use. The base of the hologram rezzing area, and sandbox arenas for constructing 3D objects, is designed in the Sumerian tradition using a well-proportioned building with a long central inner space, side chambers (housing a digital library and learning resources), decorated with elaborate stone facades. Ziggurat-like steps on each side provide access to the upper terrace. In much the same way that Sumerian architectural design broke free from conventions in the pre-Sumerian settlements of southern Mesopotamia, the Hologram arena prototype suggests a break from conventions with ingenious prospects for new ways of thinking about learning environment design for harnessing capabilities offered by immersive virtual reality.

Machinima Studio (Figure 7b)

The Machinima studio prototype provides an environment for creating, editing, and showing animations using virtual equipment. The word machinima comes from combining machine and cinema together to convey the work of using virtual reality to create innovative animations and simulations, many of which are supported with avatars interacting in the scripts. The machinima studio setting is reminiscent of Howard Hughes production studios and conveys an air of innovative spirit involving direct engagement in shaping the way of the future via active learning.

Interactive Museum (Figure 7c)

The Interactive museum prototype offers opportunity to experience object-centered learning (digital rendering of physical objects surrounded with rich sets of contextual information that can inform, suggest analogies from other experiences, and stimulate thinking on related topics). Richer educational experiences are possible with multisensory input (visual, auditory, avatar movement and interaction with the object) to help foster a sense of place within a synthetic historical context. Various exhibits are also located throughout the prototype regions. For instance, learners can experience a virtual flight of the Tuskegee Airman P-51 Mustang.

Excursion Trip (Figure 7d)

The Excursion trip prototype provides learners with the opportunity to virtually travel to Mars by first taking a multistage Orion rocket to the Ayn Rand Space Station for transition to the Red Lion deep-space travel vehicle. Upon entering the orbit around Mars, learners are then taken to a surface station via a landing craft. Throughout the trip learners are interactively engaged with challenges associated with space travel and research. Excursion trips offer learners a planned linear or non-linear movement and set of activities toward an instructional goal. See also NASA JPL Explorer Island<http://slurl.com/secondlife/explorer%20island/182/151/23/>. This is an educational site for the Jet Propulsion Laboratory's robotic space missions. The site includes immersive experiences, such as avatars that can follow Mars Odyssey and Phoenix Lander excursions on the surface of the planet.

Multi-player Game (Figure 7e)

The Multi-player game prototype is a non-linear simulation game environment supported by a scenario-based learning framework for engaging learners with real-life challenges. A game kit for educators has been developed to support the creation of games for learning within virtual worlds (Stricker & Clemons, 2009; Hughes & Stricker, 2009). The game is played using avatars by participants (e.g., cadets, PME students, and instructors) and makes use of an immersive environment wherein game participants collaboratively problem solve in a decision-making environment to address the game's challenge surrounding the rescue of hostages held by insurgents. The game is designed to support the instruction and assessment of interdependent leadership in a simulated naturalistic environment constructed on a virtual world gaming range. The gaming range encompasses a large virtual world area wherein avatars freely move about and interact with life-like terrain, buildings, devices and equipment in the environment. The range can be readily configured to support adaptations to the game (e.g., cultural-geographic-history contexts, building structures, tools, and supporting documentation content); to include adaptations to the game on basis of participant performance. The range also is equipped with systems for supporting team membership identification, tracking, scoring, voice and text communication among team members, team briefing rooms, video recording of game activity, target damage and scoring, simulated weather, various day and night conditions, assignment of equipment and tools to each team member, and game goal-oriented task action, timing and feedback controls for use by game referees.

Role Immersion (Figure 7f)

The Role Immersion prototype is represented via a situated virtual Air Force base (MyBase). MyBase is an exploratory and interactive environment and architecture that supports both continuous and precision learning. Visitors can enter MyBase and immerse into various Air Force roles (e.g., military recruit/trainee, etc.). MyBase can be tailored to recruit the Millennial generation, inform the public, deliver precision

learning, provide pre-deployment training or even conduct operational rehearsals.

Visitors, within Second Life (http://secondlife.com) can tour each prototype and provide feedback on the designs (URL: http://slurl.com/secondlife/Huffman%20Prairie/104/179/25). Feedback is used to examine each design and improve on future prototypes and implementations for operational use.

Conclusion

The use of an immersive VR ecosystem for CDB-prototyping can help foster a sense of place, purpose, and community identity among weak tie networks to harness the best innovation prospects from a diffusion of knowledge and non-redundant information sources. Also, the use of an innovation design studio, facilitated by knowledge workers, can help bridge and interlock interdependent prototyping effort among acquaintances and team members across organizational boundaries and diverse cultures. Innovation prototyping, using an immersive VR landscape to span physical and virtual geography, offers breadth, depth, and endless frontiers for enhancing learning, instruction, and discovery.

Disclaimer

The opinions and viewpoints expressed in this paper are solely those of the authors and do not reflect official policy or position of the US government or the Department of Defense (DoD), NASA/Jet Propulsion Laboratory, Colorado Technical University, the United States Air Force, or Air University. Cleared for public release (AETC-2009-0629).

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