Game-Based Virtual Worlds as Decentralized Virtual Activity Systems

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Introduction

There is widespread interest in the development and use of decentralized systems and virtual world environments as possible new places for engaging in collaborative work activities. Similarly, there is widespread interest in stimulating new technological innovations that enable people to come together through social networking, file/media sharing, and networked multi-player computer game play. A decentralized virtual activity system (DVAS) is a networked computer supported work/play system whose elements and social activities can be both virtual and decentralized [Scacchi, *et al.* 2008a]. Massively multi-player online games (MMOGs) like *World of Warcraft*, and online virtual worlds like *Second Life* are each popular examples of a DVAS. Furthermore, these systems are beginning to be used for research, development, and education activities in different science, technology, and engineering domains [Bainbridge 2007, Bohannon, *et al*. 2009, Rieber 2005, Scacchi and Adams 2007, Schaffer 2006], which is also of interest here. This chapter explores two case studies of DVAS's developed at UC Irvine that employ game-based virtual worlds to support collaborative work/play activities in different settings. The settings include those that model and simulate practical or imaginative physical worlds in different domains of science, technology or engineering through alternative virtual worlds where players/workers engage in different kinds of quests or quest-like workflows [Jakobsson 2006].

Each of the two case studies is presented in a manner that identifies a number of themes or variables that are used for comparative analysis. This analysis seeks to identify relationships between how development and usage variables are intertwined, such that understanding how development shapes subsequent usage, and how anticipated usage shaped development. Said differently, DVAS's are socio-technical systems, so to understand and compare their development and use helps draw attention to the socio-technical interaction networks and processes that emerge along the way [Scacchi, *et al.*, 2008b]. The variables of interest include: the target science, technology, or engineering domain; representative activities performed within the domain through games or virtual worlds; how they are used to support learning; what kinds of social, technological, or educational affordances are employed to facilitate collaborative activities [Kirschner and Kriejns 2004, Scacchi, *et al.*, 2008a]; and integrated or situated experiences (rather than disjoint system functions, computational services, or system capabilities) that arose through these activities. Finally, there is a discussion of outcomes and surprises that emerged from the development and use of these systems in their respective contexts of use.

Case 1: Science Learning Games for Informal Life Science Education

The first case is from a game-based virtual world called *DinoQuest Online* (DQO). DQO was designed for informal science education in the domains of life science and paleontology for K-6th grade students [Scacchi, *et al.*, 2008a]. DQO is a free-to-play, science learning game environment deployed on the Web at http://www.DQOnline.org. It was implemented using Flash, and the environment runs within common Web browsers on modest power (or older) personal computers connected to the Internet. Example screenshots from DQO appear in Figure 1. DQO was created to complement and interoperate with a mixed reality, game-based science exhibit called *DinoQuest*, that we also participated in its design, addressing similar issues at the Discovery Science Center (DSC) in Santa Ana, CA [DSC 2009]. Critical to the design of this game world was its focus on embodying California and national science education standards [NSES 1996] for the life sciences in grades K-6. During design activities, our focus was to create what we call science learning games that are both fun and scientifically grounded, rather than providing simply an entertaining but inauthentic or misleading characterization of scientific concepts and work practices [cf. Bohannon, *et al.* 2009].

Life science is a foundational area of education for young students, as it helps provide evidence-based approaches for understanding and reasoning about the development, survival, and evolution of living beings. This in turn serves as a basis for understanding human health and reasoning about living systems in the world around us, among other things [NSES 1996]. However, there are many challenges for how best to present such concepts in ways that are readily accessible to students in age, skill-level, and school grade appropriate manners. Though the study of dinosaurs is of study pre-historic life (paleontology), children are widely found to exhibit interest and curiosity in dinosaurs, and so our choice was to develop science learning games for life sciences for young learners that employ dinosaurs as characters who in-game activities are mediated or expressed through their life systems and processes. These systems and processes are designed as analogs of those found in humans or living creatures. Thus, activities central to successful play of DQO entails a variety of identification, recognition, discovery, interactive manipulation, and reasoning tasks that are scaffolded through in-game human characters that serve as collaborators and role models[1], topical graphics, animated visualizations, music and audio cues, situated tutorials and in-game help, multi-genre games and game play mechanics, progress and resource utilization scores (via in-game dashboards), and collaboration affordances [Clark and Mayer 2008, Rieber 2004, Scacchi, *et al.*, 2008a]. Figure 1 provides some examples of these through a collage of in-game screenshots. Starting from Figure 1a, play begins on entry into an in-game world that visually suggests a setting where computing and telecommunications activities occur, including a tiled, multi-screen display display with different in-game human characters (scientists) can be engaged, who each need assistance in solving problems at hand. These problems are embodied as mini-games, and a total of 13 are included, for about 3-5 hours of total game play. Next, to the right in Figure 1b, each player has their own research space where their research (game play) results will appear, so they can keep track of their progress and goals obtained or to be obtained in order to advance to more challenging games (i.e., multi-level game play).

1 These characters serve in different roles as scientists, specialists, or technicians who provide prompts, cues, and feedback (acknowledgement of accomplishments, or suggested alternative actions to take in response to failures) to players.

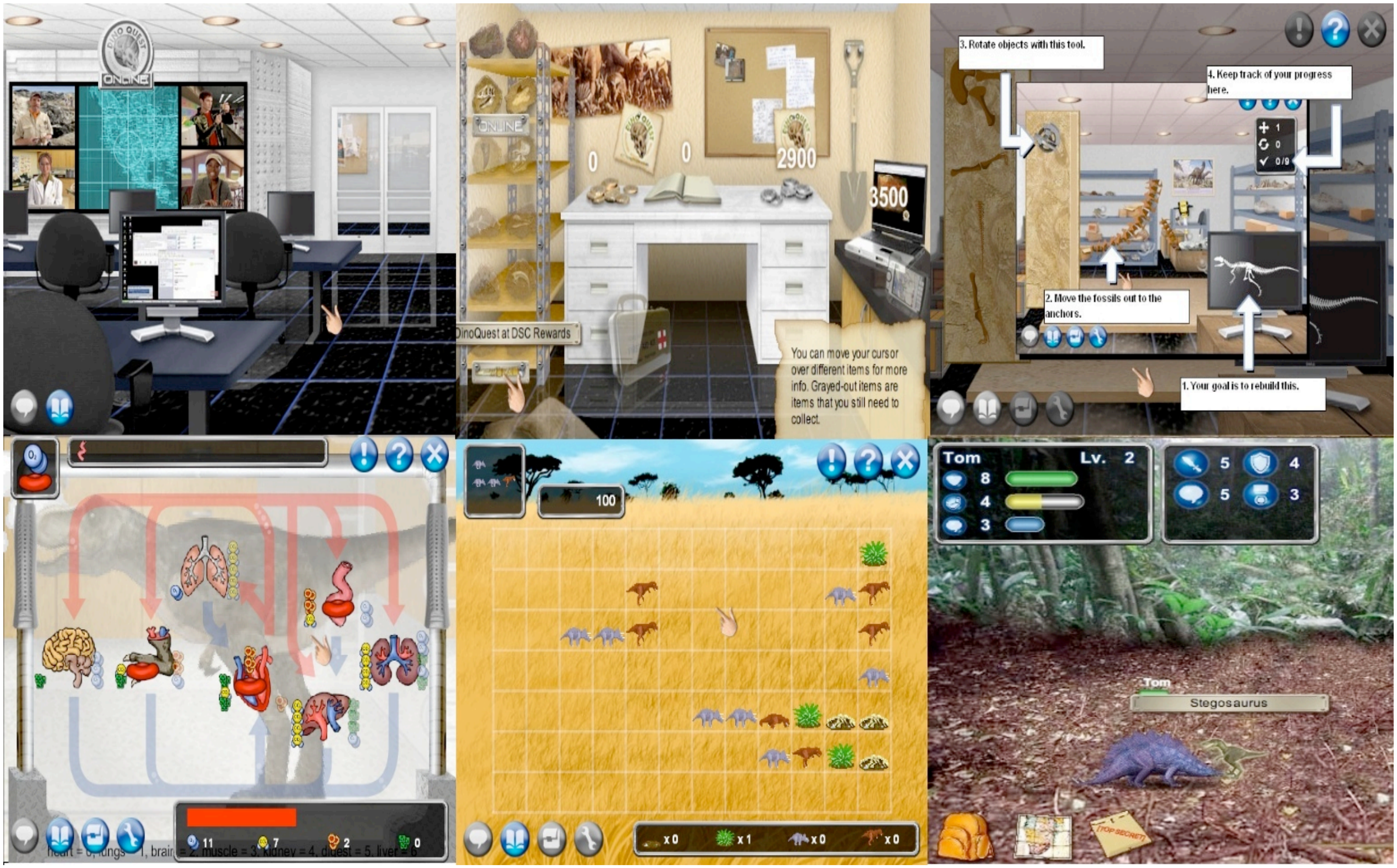

Figure 1. DinoQuest Online, left to right, top to bottom: (a) DQO virtual collaboratory; (b) player's research collection space; c) in-game tutorial for how to use game controls during skeletal re-assembly tasks; next row (d) screen of game for exchanging oxygen, CO2, and nutrients through the cardio-pulmonary system; (e) Tetris-like prey-predator game; (e) DinoSphere multi-player environment that simulate multiple creatures in different ecological niches [Scacchi, *et al.*, 2008a].

There are a variety of science learning experiences encountered while playing through DQO. Game play is partially ordered and leveled, so that early experiences establish the foundations of play and scientific concepts that need to be employed at later stages and higher challenge levels. Games include digging up dinosaur skeleton fossils whose configuration and orientation are hidden, identifying and classifying different skeletal bones or substructures, reconfiguring and assembling skeletal components into recognizable creatures, as well as others that exhibit concepts for how balance, proportion, and size affect the speed with which a creature travels, prey-predator relationships, and more. In each game, players act in the role of research assistants who help visually and aurally depicted scientists or technicians from different disciplines to help collect data, compose artifacts, observe relationships, and experience decision-making or problem-solving trade-offs. When unable to advance during game play due to errors, mistakes, or gaps in understanding, the in-game science characters offer guidance or reasoning tips to help scaffold the player toward discovering or engaging the causal relationships that provide the path forward. In-game textual help and tutorials are also provided, though their usage seems primarily of value to adults (parents or teachers) who do not understand how the game works, or who want to collaborate with, or work over the shoulder of [Twidale 2005] their children in enacting science learning through game play. Finally, play in the final level DinoSphere mini-game (displayed in Figure 1f) entails directing the in-game activities of simulated dinosaurs who react to the situation and surrounding environments (visually depicted) they are in, which generally includes goals like finding food and surviving (in the presence of limited food and/or predators), which can include collaborating with other players dinosaur characters to fulfill such goals. Game play here is modeled after *The Sims*, in that players direct their in-world characters (dinosaurs like a stegosaurus or velociraptor) in different ecological niches where different kinds of life sustaining behaviors may be important (e.g., finding food, eluding predators, socializing with other dinosaurs like yours for group activities including hunting for food/prey or overwhelming predators).

Finally, as suggested in the upper left corner of Figure 1, the DQO virtual world is situated within a virtual workplace that incorporates a wall-sized, multi-tile display that young players navigate in ways similar to an online scientific research collaboratory [Olson, *et al*., 2008, Scacchi, *et al.*, 2008a]. Young people, after all, need to learn about modern scientific work practices and instrumentalities if we hope for them to develop an interest in a possible career in science when they get older and consider college-level education. So both DQO and the DinoQuest interactive exhibit at DSC are designed to embody and reflect how scientists in field sites might collaborate over multi-media communication networks with colleagues in other disciplines in the course of their work practices [cf. Olson, *et al.* 2008]. Further information how this system supports various kinds of collaborative science learning activities and affordances can be found elsewhere [Scacchi, *et al.*, 2008a].

Case 2: Game Mod for Semiconductor Fabrication Operations and Service Training

The next case employs a custom-built game “mod” that creates a virtual world for the domain of semiconductor (or nanotechnology) manufacturing using a retail computer game, *Unreal Tournament* [Brown and Scacchi 2007]. The resulting game, called *FabLab*, is highlighted in Figure 2, and a demo video is available [Brown and Scacchi 2008]. Accordingly, we took the standard UT game and content assets and modified them to model, visualize, and simulate the workplace and work activities of technicians who operate and service complex manufacturing systems found in costly cleanroom factories [Brown and Scacchi 2007, Intel Education 2009]. In contrast to DQO, focus here is directed developing and deploying a game-based learning environment targeted to adults recently hired to become fabrication technicians, and to provide

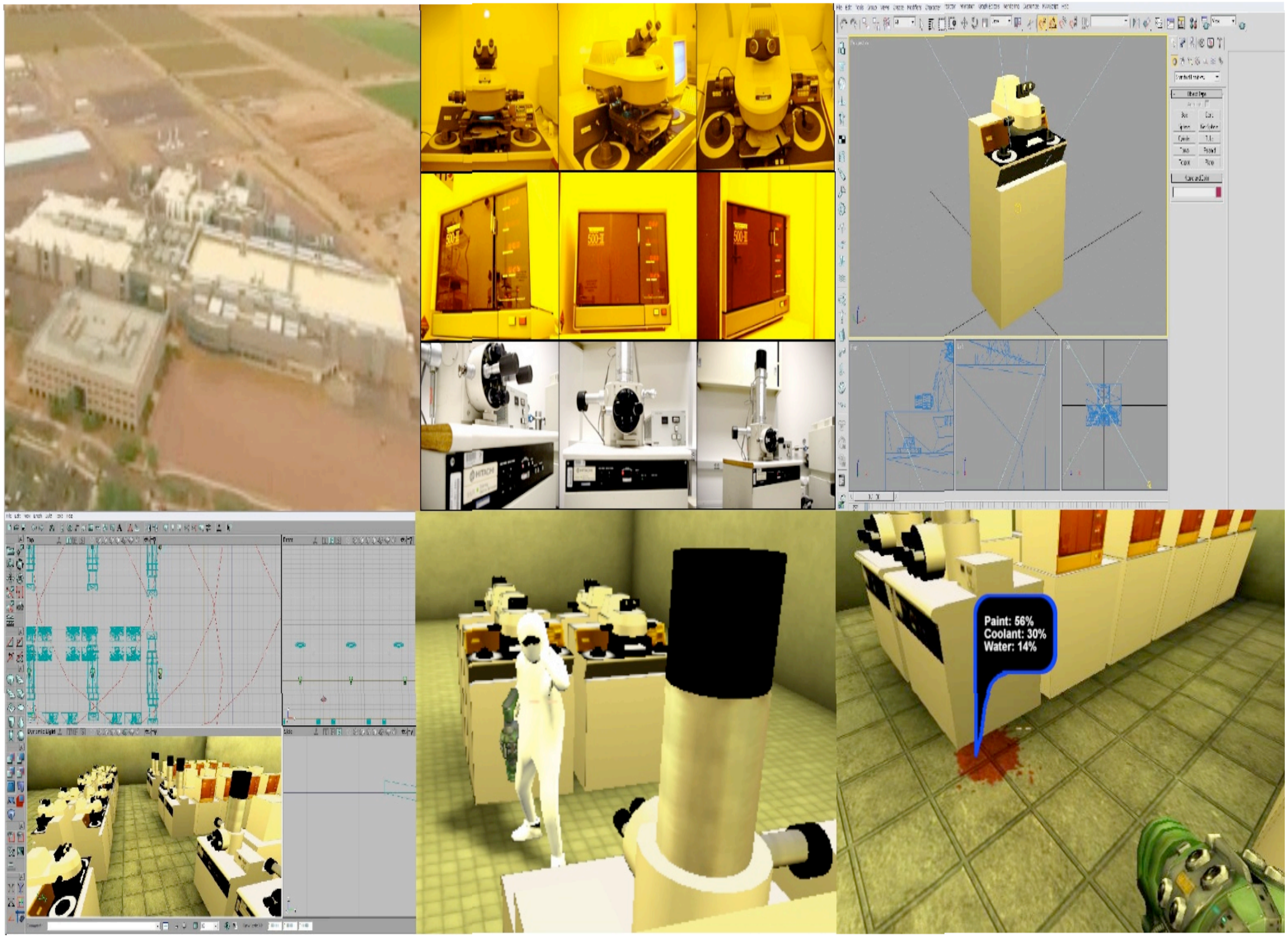

Figure 2: FabLab Game: (a) aerial view of Intel's Fab32 factory; (b) photographs or advancved manufacturing devices; (c) CAD model of of a manufacturing device; (d) UT SDK for configuring virtual manufacturing laboratory; (e) inside FabLab virtual laboratory world, with trainee avatar; (f) scene from FabLab spill diagnostic scenario [Brown and Scacchi 2007, 2008].

such training in a way that can scale to multiple, globally dispersed locations and workforces.

More than one hundred large-scale semiconductor fabrication factories are in operation worldwide. Many now cost more than $1B just to design and build, and companies like Intel operate dozens. Training technicians who can work competently with different manufacturing machines and processes can take years of elapsed time, and many such factories require thousands of technicians who work in shifts distributed 24x7x365 in order to satisfy global marketplace demands for innovative semiconductor devices. While on-the-job training is widespread, there is ongoing need to develop new training materials and experiences that can both streamline the time and cost of deploying such training, and thus there is great interest in e-learning systems and capabilities [Clark and Mayer 2008, Schank 2001].

UT is a game designed as an action-oriented, “first-person shooter” style, multi-player game world [UT 2007]. It provides ready-to-use functionality for up to 32 concurrent players, who can play over a network/Internet, with built-in support for in-game text or voice chat. It also includes an end-user extensible game engine (a programmable client-server run-time environment), and a game software development kit (SDK). Using the SDK, it is possible to modify the existing game levels, game play rules/action scripts, and other contents/assets, and all such mods can be redistributed as free/open source software [Scacchi 2004]. However, a licensed copy of UT is needed to play a modded game like *FabLab*. Working with a modded version of UT, we could create a game-based virtual world for semiconductor manufacturing, where game play is organized around fabrication technician training activities, master technician to trainee technician interactions, collaborative multi-technician diagnostic activities, and other workplace scenarios.

Work in an advanced manufacturing facility like a semiconductor fabrication laboratory entails many kinds of training and operational activities. One category of foundational training activities centers on new technicians learning how to prepare themselves for entry into a cleanroom environment, so as not to introduce contaminants that might compromise the integrity of microscopic or nano-scale manufacturing processes or equipment. As revealed in existing traditional text-based training materials, putting on a cleanroom gown (or “bunny suit”) entails dozens of steps in specific locations, some in certain postures or body positions [Intel Education 2009]. Modeling and simulating a cleanroom gowning process requires the creation of assets, in-game character behavior/animation scripts, and more as mods, as none of these features are part of the UT game. However, the ability to study and walk-through the gowning process avoids potentially awkward learning experiences associated with getting (un)dressed in a new workplace with new or unfamiliar co-workers, as well as minimizing the cost of manufacturing problems that emerge from the introduction of contaminants unintentionally brought in by technicians.

Another particularly vexing and challenging problem for such settings is how to collaboratively diagnose breakdowns in operations or complex equipment in geographically remote locations. This game mod demonstrates how manufacturing breakdowns due to faulty equipment or unanticipated materials spills/leaks can be modeled and collaboratively diagnosed, either locally and at a distance, as well as be used in training new manufacturing technicians [Brown and Scacchi 2007, 2008]. For example, in Figure 2f, shows a training scenario where a factory technician locates a liquid spill near a scanning electron microscope, and must determine whether the spill is associated with this device, and whether it involves a hazardous material. The trainee player can use a remote sensing instrument that provides a focus reticule that is aimed at the spill, and the trainee interprets the visual evidence and instrument readings to develop a diagnosis. If the problem lies with the device under scrutiny, the trainee has the potential to call up an animation that depicts the disassembly of the device for servicing. In contrast, in a remote diagnosis, master diagnostic technicians in one location can assist technicians on site in a remote factory location through networked game play mechanisms, when the remote factory equipment layout is configured to reflect current operations at the remote site. In both cases, players can use voice chat and mobile PCs to collaboratively engage in diagnosing visually observed evidence to determine possible causes and appropriate remedies/interventions.

Discussion

Many pleasant surprises arose during the development of DQO while working with our sponsors and collaborators at the DSC. Unpleasant surprises, grounded in dilemmas common to game and game software development (e.g., schedule overruns, poorly documented software functions,), are left out of the discussion here.

First, designing games that address explicit education standards (like the NSES [1996]) turned out to be quite liberating from a game design perspective. These standards helped make clear to the DQO developers what learning goals were needed and appropriate for learners of different ages/skill levels. The standards also highlight dependencies among concepts, which we found helped to simplify the challenges of what game play mechanics or game genre to employ to convey, embody, or experience specific science concepts. An example here is our repurposing of a Tetris game and play mechanics to depict prey-predator and food cycle relations (as displayed in Figure 2e), and awards in-game points to players who correctly match these relations as new dinosaurs enter the play space for sorting and matching.

Second, during early usage evaluation and feedback studies at DSC, we found we needed to support parents and teachers who experienced difficulty in comprehending what was going on (e.g., what scientific concepts or relations are in focus, how game play works, how in-game controls operate, how points and resource utilization are scored), while young players would readily dive into game play and start solving game play problems. Such support was subsequently developed and integrated (see Figure 1c), and this helped facilitate better parent/teacher-child collaborative learning, based on our observations and user feedback.

Third, we found that some young students are able to provide copious explanations about what is going on and how the game works to their adult companions, while others provide much less. Though we collected many examples of these during evaluations of DQO game play at DSC, it seems that science learning games like DQO can become more effective learning environments when they provide in-game mechanisms that elicit or encourage online discourse and questions that elicit age/skill appropriate written explanations to further improve and deepen the value of the scientific concepts that have been learned. Such accomplishments have recently been demonstrated in other science learning game environments [cf. Shaffer 2006, Schaller, *et al*. 2009].

In contrast to DQO, many technical and research challenges emerged with the development of the FabLab game world.

First, when the project began, our focus was to respond to a challenge from our industrial project collaborators and sponsor (Intel). The challenge was to identify potential refinements and applications for how best to support globally distributed project teams who could interact and manipulate shared online artifacts and tools through domain-independent, collaborative virtual worlds [cf. Pickering, *et al*. 2006] or other tools for visualizing socio-technical interaction networks whose members/elements were decentralized. This focus eventually led to a group of analysts and training personnel involved in finding ways for how to scale-up and optimize the training of thousands of technicians that are needed to operate and service a new semiconductor fabrication facility. Prior experience with multi-player FPS games brought to mind numerous in-game worlds (or levels) that situated game play in virtual laboratories, factories, or underground infrastructures. Recognizing this, along with the ways and means for modding such game-based virtual worlds, quickly pointed the way for what could be modded to recreate a domain-specific, modern semiconductor fabrication facility in which multi-player activity could produce complex work practices and situations that can be (re)mediated through player-directed in-game avatars. So, we quickly moved to mod a capable FPS game (UT) to effectively create a low-cost, game-based work practices simulator for semiconductor fabrication service training that could be readily deployed in a multi-player environment that could operate over the Internet or local-area network.

Second, our experience with the underlying game and game play mechanics of UT also gave rise to discovery for new ways to collaboratively diagnose operational problems like material spills or contamination across remote, networked facilities. Specifically, event-driven game play mechanics are often used to affect activities within the game world like opening a door when to touch (i.e., proximity detection) its handle, or enabling an interaction with a non-player character or in-world object whose behavior (e.g., an explosion that distributes object elements within a limited range) mediates what a player's avatar can do next. Similarly, by repurposing in-game FPS weapons to sense instead of shoot, allows a conceptual overloading of familiar play objects (weapons) to serve more instrumental and constructive ends. Using these, it then became possible to develop training scenarios where a taxonomy of potentially detrimental or hazardous material spills could be articulated, a given spill type could introduced essentially anywhere on/near a modeled manufacturing machine, and players could sense and diagnose the problem and determine an appropriate response (e.g., service a leaky manufacturing machine) or voice chat with another collaborator (technician trainer or remote consulting technician). Such capabilities represent a new technological innovation in semiconductor fabrication training and operational service, and such an innovation ultimately emerged from modification and repurposing of games, game play, and game play mechanics.

Conclusions

Overall, this chapter seeks to articulate and explore how game-based virtual worlds can enable new modes of collaborative experience in science, technology, and engineering domains where decentralized play-as-work and work-as-play activities can emerge. The domains of informal life science education for young learners acting in regional science centers or at home, and for training adult technicians in the operation and service of advanced, high technology manufacturing systems are each of practical import and high consequence. Each further demonstrates the range and diversity of activities and collaboration affordances within virtual worlds, as well as across domains for scientific research and education, that can be enhanced through collaborative play-work [Bainbridge 2007].

Game-based virtual worlds can be employed in ways that support scientific research practices, technological innovation, and development of advanced engineering/manufacturing systems. Science and technology oriented game-based virtual worlds like *DinoQuest Online* and *FabLab* represent an interesting experiment in the collaborative construction [O'Donnell 2009] and use of decentralized virtual activity systems that different audiences find provide playful, productive, and collaborative interactions and learning/discovery-focused quests.

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