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Playing for Climate Change: The Design and Development of a Game Prototype to Promote Scientific Literacy

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This design case describes the work involved in developing a digital game-based learning environment, work that was part of a PhD research project. The designer was involved in all aspects of the project: conducting research into content that was included in the game, exploring the gaming platform (Second Life), adapting scientific literature for use in the game, consulting with science instructors, building the gaming environment, and writing scripts for objects in the environment. The gaming environment was a fictional town site called Budworm. The game was designed to promote scientific literacy in first and second year science undergraduate students through collaborative work on an open-ended problem related to the management of water resources in a region of western Canada subject to extremes in water availability. One of the design goals was to model the kind of environment that scientists encounter while they formulate research questions, a complex environment that involves collaboration with colleagues, creativity and a willingness to explore. Instructional experts in three scientific fields (biology, chemistry, and geosciences) were consulted during the course of this design, as was an expert in instructional design. The final product was the game and a set of game design principles that were informed by the literature on educational gaming and consultations with the instructional experts.

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CONTEXT FOR GAME DEVELOPMENT

The game that is described in this paper was under development from 2008 to 2011, going through a few iterations during that time. Changes made to the game were based on feedback from instructional and content experts, educational technology students, and an instructional design expert. The game was developed as part of work that was done to complete a PhD in Educational Technology. As designer she was involved in all aspects of game development and design. The choice to be involved in all aspects of the design and development was made, in part because of financial constraints, but also because of a desire to be responsive to suggestions made by instructors and other designers, and to be able to incorporate these suggestions as quickly as possible.

The game was intended to provide an engaging environment in which first and second year students could tackle an open-ended problem (e.g. a problem with unknown elements and multiple solution paths) and in the process improve their content knowledge and scientific literacy. Science educators suggest that one way to promote scientific literacy is to provide learners with the opportunity to tackle open-ended problems in relatively risk free settings (Hume, 2009; Krajcik, McNeill, and & Reiser, 2008; Linn, Eylon & Davis, 2004). Over the past decade, science educators have expressed concern about the preparedness of students enrolled in undergraduate science courses, specifically with regard to their level of scientific literacy. One of the approaches taken to increase levels of engagement in science is the use of games in educational settings. Either existing commercial games can be adapted to educational contexts, or educational games can be developed from the ground up. The latter approach was the one taken in this case.

Declining Enrollment in Sciences

Enrollments in the physical sciences, engineering, and mathematics disciplines in the USA have been declining at the post-secondary level in recent years. In the USA the number of students who actually complete a degree in any of the STEM (science, technology, engineering and mathematics) disciplines is quite low (Litzler & Young, 2012; National Research Council, 2007; National Science Board, 2007; Tan 2002). Lack of persistence in the science disciplines at the postsecondary level negatively impacts the availability of adequately prepared STEM teachers at the K-12 level (National Science Board, 2007) which in turn impacts the preparedness of secondary students for postsecondary science courses.

Perception of Scientists' Role in Society

Undergraduate students enrolled in the sciences can have serious misconceptions about the everyday practice of scientists and the role that scientists and technologists play in the broader society (Driver, Newton & Osborne, 2000; Cooper, Cox, Nammoux & Case, 2008; Tan 2002; Wong & Hodson, 2009). Science instructors who were consulted as part of the design process identified this lack of understanding of scientific process and the scientist's role in society as the rationales for developing an activity centered on increasing scientific literacy amongst first and second year undergraduate science students.

Emerging Trends: Game-Based Learning

In the last decade efforts have been made to assess the value of game-based learning and simulations in the teaching of scientific content knowledge and overall scientific literacy (Bailenson, Yee, Blascovich, Beall, Lundblad & Jin, 2008; Barab, Scott, Siyahhan, Goldstone, Ingram-Goble, Zuicker & Warren, 2009; Rice, 2007; Squires & Jan, 2007; Steinkuehler & Duncan, 2008; Thomas, Barab, & Tuzun, 2009; Toro-Traconis, Meeran, Higham, Mellstrom, & Partridge, 2010). Educational technology and the application of non-traditional (e.g. non- lecture based) approaches to instruction of learners such as collaboration and peer-to-peer learning, specifically through the formation of knowledge building community have been characterized as approaches that can play a role in improving scientific literacy (Kiili, 2007).

The designer was looking for a game genre that was flexible enough to allow for modifications on the fly and that would allow the designer or an instructor to occupy the role of the game's facilitator or puppet master. Alternate Reality Games (ARGs) seemed a good fit with the designer's skill set and had the flexibility needed to allow for changes on the fly (if players were having problems or needed additional support in order to complete their mission). ARGs are collaborative stories in which players try to find pieces of the storyline through online (e.g. websites, email) and offline information sources (e.g. phone messages, face-to-face interaction with actors). All of the game interaction in this case was designed to take place in the online environment, specifically a Multi-User Virtual Environment or MUVE called Second Life.

Whitton & Hollins (2009) suggested that ARGs have specific advantages over commercial games: customizability and reduced development costs (as compared to traditional computer games).

Instructor Facilitation

The game was designed with the intention that course instructors or tutors would play the role of facilitator of the game. Instructors who were consulted during the design process indicated that the technology chosen should be suitable even for neophytes (amongst instructors and students). There was an expectation that they would require technical assistance to set up the game and during the time over which the game was played. The game space could be re-purposed as is, or could be re-developed to support another scenario but re-development would likely require technical assistance or training of a graduate assistant.

Affordances of the Development Platform

MUVEs were designed to facilitate communication and interaction between participants through voice and text chat, proximity, and non-verbal communication (e.g. gestures). Four learning affordances of MUVEs are particularly relevant in the context of designing a collaborative game-based learning environment:

- Experiential learning
- Collaborative learning tools
- Multiple perspectives
- Engagement and immersion

MUVEs give learners the opportunity to interact with subject matter in the first person rather than as disembodied third persons. Winn (1993) argued that virtual environments bridge the gap between experiential learning and the information that the instructor/designer is trying to transmit to his or her learners.

Three-dimensional MUVEs are reputed to be better at facilitating collaborative learning than text-based virtual environments because the former are able to provide participants/players with a sense of place (Dede, 1995).

The decision to use the MUVE was made for a variety of reasons:

- Literature indicated that MUVEs promoted player engagement and immersion.
- Designer's skill set matched the development tools.
- Designer already had some experience working in the MUVE as part of her paid work.
- Designer had colleagues working in the MUVE who could provide advice and guidance as needed.
- MUVE features could support the types of interaction (player-to-player, player-to-facilitator, player-to-environment, player-to-artifact) and communication (voice and text chat, instant messaging, gestures) that the designer originally wanted to incorporate into the game.

Although certain elements were lacking during the initial design work on the game (e.g. collaboration tools) these tools were available at the time the game underwent evaluation.

DESIGN TEAM

Designer

In the context of this study the designer performed a number of roles. She interviewed science instructors, conducted a literature review, modeled the environment in the game development platform, wrote the game narrative, researched primary and secondary scientific literature for resources that could be used in the game, adapted those resources for use in the game, found and evaluated third party technology used in the game, wrote user guides on how to use certain technologies in the gaming environment, re-purposed existing scripts (i.e. scripted actions or animations) that were freely available, modeled a number of game artifacts particularly when an artifact was so specialized (e.g. blood collection chair) that it could not be found on the Second Life marketplace, purchased some objects from third parties such as vendors on the Second Life Marketplace, facilitated game play, and gathered and analyzed player feedback.

Science Instructors

The instructors provided the designer with insight into undergraduate students' areas of weakness and which skills and abilities should be the focus of the game. In the current case, scientific literacy specifically as that literacy is developed through exposure to primary and secondary literature. The designer's decision to use excerpts of recently published primary and secondary literature in the game was a result of the subject matter experts' (SMEs) recommendations.

Instructional Designers and Students

Both student and expert instructional designers provided critiques of and feedback on the design elements of the game throughout its development.

Content Reviewers

Content reviewers evaluated the content used in the game (e.g. primary and secondary scientific literature) and provided feedback to the designer on efficacy of resources and advice on alternative resources. For example, the geosciences reviewer suggested that specific Intergovernmental Panel on Climate Change (IPCC) frequently asked questions (FAQs) be directly linked to within the gaming environment.

PREMISE OF THE GAME

The game was to be played by teams of four individuals. Each team contained experts from each of the following four fields: geosciences, biology, health/medicine, and chemistry. The gaming environment was a town site that contained locations associated with each of the player streams (e.g. Biological Research Station, Geosciences Field Station) as well as with the operation of a traditional town (e.g. police station, town hall, restaurant, medical center, town newspaper).

The first point of contact for the players was with the mayor of the town of Budworm who had an interest in future-proofing the town against the expected impacts of climate change. The players received an orientation from the mayor who described their mission. In the context of the evaluation session, the designer played the role of mayor/facilitator however ultimately instructors will play that role. Players were randomly assigned to teams and asked to choose their expertise. Once players had selected their expertise they had associated tasks and were to receive communications from the directors of their various centers of expertise. Other players could also provide assistance through formal meetings or informal meetings / encounters in the gaming environment (see Figure 1).

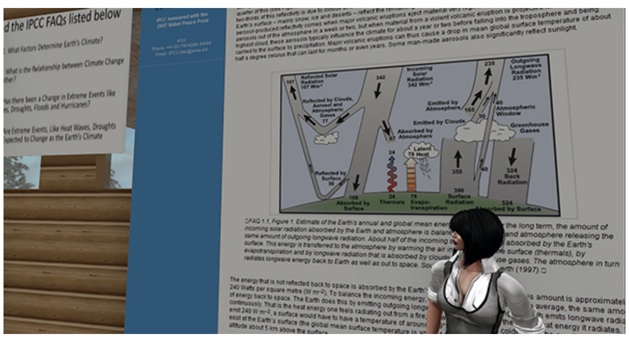

Figure 1. Player reviewing FAQs on the Intergovernmental Panel on Climate Change (IPCC) website.

A mystery narrative was also interwoven with the primary mission. The narrative involved the murder of a security guard at a local business (e.g. a company involved in the development of industrial and agricultural carbon dioxide sequestration technologies). There was a secondary narrative in which a local man, suspected as a saboteur of oil and gas pipelines and facilities, was also considered a prime murder suspect by police. Players encountered clues as to the circumstances surrounding the crime and to the identity of the killer as they explored the gaming environment in their role as scientific experts. For instance, visitors to the Geosciences Field Station who participated in a field trip to a nearby mountain range learned about precipitation levels for the area and were in proximity to a mobile phone that contained a text from someone who was involved with the murderer (see Figure 2).

Figure 2. Player on the geosciences field trip to a mountaintop to collect precipitation data.

After teams had developed a set of recommendations on how the town might manage its water resources in the context of climate change they were to reconvene at the town hall for a meeting with the mayor where each team would present their recommendations to those assembled. The recommendations were to be critiqued by both peers (e.g. other players) and experts (e.g. panel of experts in each of the four scientific streams).

DESIGN OF THE GAME

The design features of the game were meant to support an open-ended learning experience, give players with an opportunity to improve their domain knowledge in a particular discipline, hone their scientific habits of mind, and facilitate player-to-player collaboration. Players were exposed to domain knowledge as they interacted with other players, non-player characters (NPCs) and artifacts in the environment. Players needed to collaborate with each other in order to arrive at a solution to the mystery and provide the mayor with a set of recommendations. The game design was informed by discussions with disciplinary experts and instructors, a review of the literature on effective practices in game design in educational contexts and adoption of effective design practices in the MUVE in which the game was developed.

Chronology of Game Design Process

The following is a chronology of the game design process from initial steps to the evaluation session.

Activity	Dates
Literature review (science education)	January 2007-October 2008
Research on game design platforms	January 2007-January 2009
Purchase Second Life Island	February 2008
Design of early game prototype	March 2008 - July 2008
First consultation with science instructors	August 2008
Re-design of game based on instructor feedback	September 2008-June 2009
Second and third consultations with science instructors	June and July 2009
Re-design of game based on science instructor feedback and review of recently published literature on digital game-based education	August 2009 - July 2010
Attempt to recruit participants	August 2009 - December 2010
Consultation with instructor whose students participated in evaluation session	December 2010 - February 2011

Consultations with Science Instructors

A series of consultations with three science instructors at the University of Calgary in Calgary, Alberta, Canada took place over a two to three year period. The first consultation with the instructors revealed that they shared many of the same concerns about the scientific literacy of undergraduate students with the literature on science education. A second consultation took place in an early prototype of the game that had been developed in a 3D MUVE, Second Life, and involved a discussion of the prototype, strategies for participant recruitment, the kinds of activities that players would engage in based on their particular stream and a conversation about the organizing theme of the game (carbon sequestration). Notes from this session were saved as a text chat transcript in the MUVE. The third consultation involved a face-to-face discussion between the designer and the instructors about the potential for an evaluation session of the game in one of their classes, and the subject matter of the game.

These instructor consultations were essential to the design process because they helped to:

1. Refine the game's theme,
2. Elucidate concerns around the use of technology in the face-to-face classroom,
3. Expose sustainability issues with the project,
4. Raise issues with use of narrative plays in simulations and games used in the classroom, and
5. Reveal resistance to interdisciplinary work in the science classroom.

Refinement of the Game's Theme

Initially the game was built around the topic of sequestration – both industrial (e.g. old oil and gas wells) and biological (e.g. use of carbon neutral or negative plants, such as fescue grasses, to produce biofuels). Sequestration refers to the capture of carbon dioxide from the atmosphere using industrial or biological approaches with the aim of putting the carbon dioxide gas into long-term storage. The industrial approach to sequestration is represented by the capture of most of the emissions from a power plant or industrial facility. Biological sequestration refers to the use of natural systems (e.g. ecosystems) to sequester carbon dioxide. Wetlands, grasslands and forests are examples of natural systems that can be used to sequester carbon.

In the current design research was done on the role that native fescue grasses played in sequestering carbon on the Canadian prairies. Fescue grasslands are more efficient at sequestering carbon than non-native grasslands. The biosequestration research literature discusses the possibility of replacing a proportion of non-native grasslands used for grazing livestock with native grasslands (e.g. fescue grasslands) (Henderson, 2000). A remnant of the sequestration theme remained in the final iteration of the game in the form of a building that housed a non-profit corporation named BioSeq. The mandate of that corporation was to investigate both industrial and biological sequestration options in the town site. Discussions with the instructors, specifically the geosciences expert, indicated that there were issues of scientific efficacy of the sequestration theme. Tying that theme into regional impacts of climate change, proved difficult. It was suggested by the instructors that a more focused approach would be less confusing for students and more likely to result in increased uptake of domain knowledge and improvements in scientific literacy.

The theme that was arrived at was water availability and quality. At the time the decision was made to switch themes the designer had already collected several online resources on water availability in the region. The water resources theme was also one that could be fully explored in each of the four disciplines in which players were to assume the role of experts: geosciences, biology, health/medicine, and chemistry.

Concerns with Technology Use

One of the subject matter experts had specific concerns around the use of technology in the game as she had had a difficult experience on previous projects in which a custom simulation was developed for her courses. Her concerns are summarized below.

- Technology must fit the learning objectives in the course; the course shouldn't be adjusted to fit the technology.
- There needs to be clarity about expectations of the instructor's involvement with the technology.
- Technology needs to be sustainable.
- Any use of technology needs to add value.
- Students may not be technologically savvy.

The game was developed as an activity that could be used in any number of science (e.g. science literacy for science or non-science students) or social science-based (e.g. policy, social impact) courses. This meant it was not possible to address all of the instructors' concerns. The environment was designed so that it could be easily re-purposed by other instructors in the sciences or the social sciences (e.g. social impact assessment of impact of climate change on certain regions). If instructors did not require modifications they could use the environment as is; however, if they desired modifications they would have to perform the modifications themselves or use the services of someone who had the necessary technical skills. This meant that there were inherent issues with the sustainability of the technology, specifically around the platform on which the game was developed. In the present it is possible to develop on OpenSim, an open platform based on the Second Life architecture. The question of value was hard to address because the instructor was focused on customization while the game was developed as an activity that could be adapted for use in a number of different courses.

Concerns around student and instructor comfort level with technology were dealt with by providing a variety of aids and supports in the environment. Examples of the supports provided included:

- Second Life User Guide.
- Teleport-enabled town map.
- Instructions on how to use the collaboration tool.
- Instructions on how access content on the video players, presentation, and dynamic content boards.
- Summaries of the tasks associated with each of the expert streams.
- A summary of the locations in the town site (printed out and distributed to students during the orientation and also at the start of the evaluation session).

Feedback from players during an initial orientation session that was held prior to the evaluation session indicated that players felt that more interactive teleport-enabled maps were needed in the environment and that the maps should be visual rather than text-based (see Figure 3).

Players continued to have basic problems navigating the environment during the evaluation session (e.g. teleporting) and even had to be aided with the login process as some had forgotten that information in the period between the orientation and the evaluation session.

Figure 3. A teleport-enabled town map is an example of one of the supports that was adjusted based on player feedback.

Sustainability of the Technology

There were concerns around the sustainability of the project specifically related to how much technical skill a course instructor would need to modify the environment or maintain it over time. The designer was willing to make herself available to the instructors over time in the event that there was interest in customizing the environment. Second Life while still available to educational institutions, is less used than it was given the removal of the educational discount and the availability of OpenSim.

Role of Narrative in the Game

Discussions with the instructors indicated that there was some resistance to the use of a game narrative. Specifically, there was a concern that student interest in the narrative would decline over the course of game play. When the game was evaluated with a group of educational technology graduate students there were indications that the mystery narrative was more successful at getting students to think critically than their role-play as scientific experts. In the discussion following the evaluation session students indicated that solving the mystery involved more critical thinking than the role-play because the former "forced you to think outside of the box." In fact, chat logs from that same evaluation session record an intense discussion between three players about the identity of the killer (one player is a receiver of texts but does not send a text during the conversation).

> *Player 1 to Player 3: Panchev is bitter … guy lives in that cabin that has details on how to make a fertilizer bomb.*
>
> *Player 2 to Player 3 & 1: Did either of you find out anything about a guy named Geoffrey?"*
>
> *Player 1 to Players 2 & 3: Okay … so in my search, I got a letter from a J. Panchev. He is the guy who lives in the cabin where I found a note for a fertilizer bomb. He was really angry in his note and was upset that the town was built on an old gas well site. There was also the book the Anarchists Cookbook in his mailbox. I didn't see anything about a guy named Geoffrey.*

Many of the artifacts and activities in the environment were dual purpose in that they exposed the players to information they would need as their team's resident expert in a particular field and also presented elements of the mystery narrative. For example, a geosciences field trip to a mountaintop provided players with data about precipitation levels but also brought them into contact with a geocache that contained a discarded mobile phone with incriminating text messages that belonged to the killer.

Resistance to Collaboration and Interdisciplinary Activities

One of the instructors consulted by the designer was concerned that students would not be interested in participating in collaborative exercises. Science is a discipline that relies on collaboration however traditional university environments often work against students being exposed to interdisciplinary collaborations (Webb & Burgin, 2009). The designer felt that it was important to foster collaboration, as players would likely need to collaborate with others in their future professions. Direct observation of player interactions and a review of the chat logs and videos showed that players collaborated and supported each other. The following is a list of the type of interactions that were observed:

- Making contact (e.g. greetings, check-ins).
- Arranging for future meetings (e.g. "I was hoping that we could meet back in our collaborative space and put our heads together with what we have learned").
- Requesting or giving assistance (e.g."Tell me why the wetlands reduce microbial pollution from surface runoff").

Develaki (2008) argued that scientists were most comfortable communicating with peers within their disciplines and had difficulty tackling open-ended problems like climate change that required collaboration with laypersons or scientists in other disciplines. According to Develaki (2008) scientists need skills in translating their specialist knowledge into terms a non-expert can understand. The game was designed to bring players into contact with content and experts as well as with local residents (i.e. NPCs) who had local knowledge so as to model the kind of role players might assume in their future lives as a government scientists, research scientists, citizens, or policy makers.

Exploration of the Design Environment

An initial investigation of the environment in which the game (e.g. Second Life) was to be developed was undertaken. The designer visited multiple locations in Second Life to gather information about the kinds of navigational aids that were used to orient newcomers, the design of buildings (especially with respect to the fidelity to the real world), methods of entry and egress (e.g. doorways, landing platforms), and the design of formal and informal meeting spaces. Some locations were visited because expert instructional designers had recommended them. Examples of the kinds of locations that were visited included:

- Second Life's Orientation Island.
- Educational institutions/activities (e.g. University of Southern Queensland, Athabasca University, New Media Consortium (NMC) Campus, Ohio State Medical Center, San Jose State University, etc.).
- Theme-based Islands (e.g. Virtual Morocco, Dublin, etc.).
- Events-based Islands or locations (e.g. music venues, special events (e.g. seasonal), etc.).

An Excel spreadsheet functioned as a design log and was used to record resources that could be used in the game and examples of successful designs on which the current design could be modeled (see Figure 4).

The following is a list of the kind of content recorded in the design log:

- User supports present in other environments (e.g. way-finding devices such as maps, information kiosks).
- Floor plans of building types that would need to be built in environment (e.g. Leed certified public building).
- Content resources available on the Internet that could be associated with objects in the virtual environment (e.g. Environment Canada Adobe Flash presentation on the hydrological cycle).

- Examples of the kinds of scripted objects that were available in other environments (e.g. greeters).

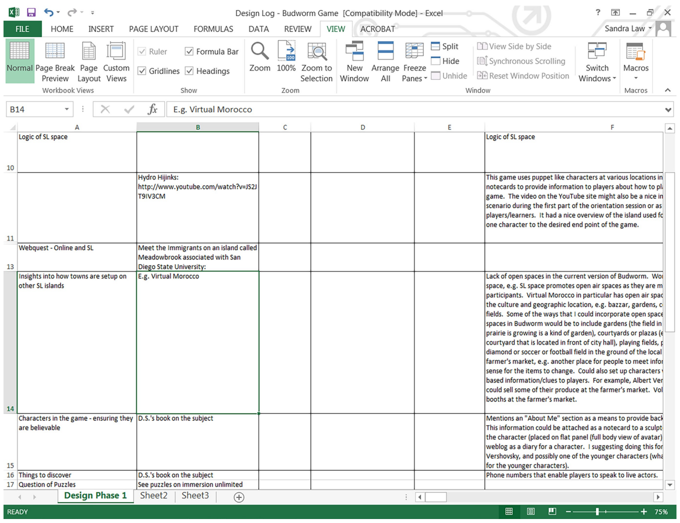

Figure 4. Screen capture of design log entries saved as a Microsoft Excel file.

Issue of Fidelity

Because of the need to link the activities of the virtual world with the real world, a great deal of background research and resource collection was undertaken:

- Photographing architecture in nearby small towns documenting their unique architectural features and capture building styles and textures (e.g. sandstone, brick, wood).
- Locating architectural and floor plans of green and other buildings online (see Figure 6).
- Finding examples of police reports, 911 call transcripts, and suicide notes (see Figure 5).
- Finding photographs of laboratory equipment and instruments (see Figure 7).
- Locating patient history forms and sample patient histories.
- Reading journalist blogs.
- Finding historical photographs in online museum archives for an exhibit in the provincial government building in the town site.
- Locating online resources on the region's watershed and river basins and reports/publications on water-related issues in the area:
    - o Town council meeting notes/agendas.
    - o Government webcasts on water rights/licenses.
    - o Resources on the hydrological cycle.
    - o Scientific articles on water-borne diseases.
    - o Water toxicology reports and articles.
    - o Interactive maps on government websites depicting precipitation levels at different locations.
    - o Federal government reports on regional impacts of climate change.

Figure 5. Police report detailing an explosion at a provincial park near the time of the murder at BioSeq.

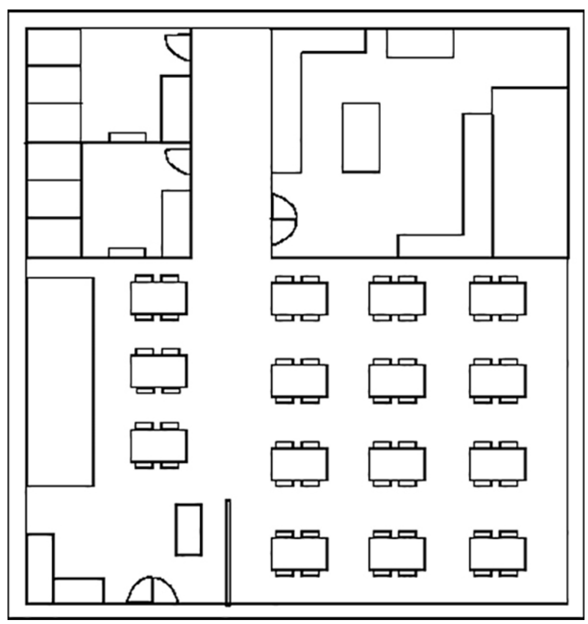

Figure 6. Floor plan of a restaurant that was used in the design of building in the first iteration of the gaming environment.

There were of course limits to how close the town site could be to the real world, given the limited virtual real estate decisions had to made as to which buildings, artifacts, and spaces were essential to the players' mission.

Derivation of Design Principles

The following principles were derived from a review of seven distinct game design models and consultations with science instructors:

- Relevance. Design authentic learning experiences which are embedded in a storyline and provide context.
- Interaction. Providing a variety of types of interaction for players: player-to-content, player-to-non-player character, real world experts and other players.
- Engagement. Design for multiple solution paths, provide dynamic content, and allow for exploration.
- Collaboration. Develop an environment in which players can refine their ideas.
- Reflection. Design a gaming environment that gives players a chance to engage in self-reflection, compare their solutions to those of their peers, including a debriefing.
- Support. The gaming environment should provide ongoing support, with considerable scaffolding early on in the game.
- Narrative. Design the game around a complex storyline but integrate the narrative with the instructional component of the game.
- Articulation. The game should involve players in problem solving and give them an opportunity to test their ideas and enhance their understanding.

Figure 7. Example of an image that was used to model flow hoods in the laboratories in BioSeq and Medical Centre.

Relevance: Present vs. the Future

The principle of relevance to the students' lived experience came into play throughout the design of the game. The thinking was that if learners were provided with the opportunity to apply what they learned to their own lives (Boon, 2009, Linn et al., 2004; Zohar & Nemet, 2002) they would gain a better understanding of the scientific phenomena being explored in the game.

Initially the game was to be set 20-25 years in the future when the negative impacts of climate change would be more obvious. However, if that decision had been made there would have been no opportunity to use contemporary data or publications. One of the elements of scientific literacy that the science consultants emphasized was students' inability to analyze or critique primary (research publications) and secondary scientific literature (sites that popularize scientific findings, for example, New Scientist). So a decision was made to set the game in the present rather than future. This design decision allowed for the use of a number of articles and reports on the environmental health of a regional river basin, current news stories about the impacts of climate change, contemporary scientific articles on the influence of water-borne disease on human health, and reports on the expected impacts of climate change in the region.

Fostering Interaction

The kinds of interaction supported by the digital game-based learning environment included: player-to-player, player-to-artifact, player-to-non-player character, player-to-expert, and player-to-content interactions. Player-to-player interaction was facilitated by the many communication and collaboration tools that were either available in the MUVE or by third party tools that were added to the environment (e.g. BrainBoard, see Figure 8). Players had the ability to send instant messages to other players (individual or a group), engage in text chat sessions, or to speak directly through voice chat using a headset or built-in microphone. Voice chat was not used in the evaluation session of the game due to logistical issues (i.e. everyone was in the same room).

Players also had the capacity to communicate through non-verbal communication methods like scripted gestures and actions. In the evaluation session of the game, players would occasionally use gestures, but primarily in an exploratory non-expert way, as most of the players were new to the MUVE. Player to NPC interactions were included in the initial design of the game however there were few opportunities in the evaluation session for such interactions given the limited time frame over which the game was played (4.5 hours vs. two weeks).

Some of the NPCs in the game included the directors of the various research stations who left directives and notes for the players to find, a local rancher with insight into the community and the environment, a local newspaper reporter whose blog discussed the background and actions of the oil industry saboteur, another non-player character. Player-to-content interaction occurred when players read notecards, viewed videos or presentations and interacted with objects to which scripted actions (e.g. movement) were associated. These objects had either been purchased from the Second Life Marketplace or the designer created the object and wrote simple scripts (e.g. link to URL) using the Linden Scripting Language (LSL).

Figure 8. The BrainBoard, the collaborative white board that was provided to each of the teams.

Designing for Engagement

The provision of an authentic and realistic problem that required a solution (i.e. set of recommendations for the mayor) was intended as a design element that would make the gaming experience an engaging one for players. The activities in each of the four expert streams were designed to support the four intrinsic motivation strategies that were proposed by Malone and Lepper (1987): challenge, curiosity, control and fantasy. The challenge component was the real world problem that players were asked to respond to by providing a set of recommendations on water management to the mayor. The correct balance of challenge and ability is speculated to lead to the total immersion of players in the digital game-based learning environment and their mission. If players find their experience too difficult they may become frustrated and give up; however if they find that it is too easy they may disengage. The optimal approach is one in which players are sufficiently challenged to support ongoing engagement in the game and the associated mission. As players meet goals they develop a sense of competence and are more willing to take on more challenging tasks (Wang & Reeves, 2007). In order to support challenge, learning activities need to have three characteristics:

- Allow learners to identify with proximal goals.
- Offer learners an uncertain outcome.
- Offer learners immediate, clear, or encouraging feedback.

The learning activities designed for this game demonstrated the first two characteristics: the immediate goal of the game was to gather and share information with teammates while the outcome (how the game was played and the end product of the game (set of recommendations)) varied from team to team. Immediate feedback was not possible in the game as functions were not automated as in a conventional computer game, however player-to-player and player-to-facilitator interaction substituted for automated support.

The control component of intrinsic motivation was designed into the digital game-based learning environment; players were not required to follow a pre-set course and were able to gather clues and information as individuals or as part of a team. Players could collaborate synchronously through voice or text chat, or asynchronously through messages left on the BrainBoard.

Collaboration

In earlier iterations of the game the designer had planned for the team collaboration to take place outside of the game space on a discussion forum in a course set up in a learning management system (LMS). Discussions with an expert instructional designer, and reflections on the research design, led the designer to choose a MUVE-based collaboration solution. Keeping players in the gaming environment was an attempt to reduce confusion, and also facilitated the research goal of capturing player-to-player interaction as it occurred within the MUVE. But as will be seen in the comments of players in the next section the in-world collaboration tool was not always that easy to use.

Reflection

The original design of the game included numerous opportunities for players to reflect:

- Collecting notes and reflections related to their expert stream.
- Sharing knowledge with and asking questions of teammates (e.g. formal and informal meetings).
- Participating in a town hall meeting with all teams and content experts.
- Commenting on their experiences as players and in their roles as experts during a debriefing session following the evaluation session.

The debriefing was a particularly rich source of player feedback. Players liked some elements of the environment such as the ability "to move around as I wanted and … not feel restricted". Others were less comfortable, especially with some of the tools (e.g.

BrainBoard) and with modes of travel and communication used in the game.

> *The Board was not a good place to collaborate as the information could not be seen at times and at other times it was difficult to fix things. Unlike a Word document that is much easier.*

Player reflections provided guidance on when to introduce real world experts into the environment, after they had developed "a sense of what was there" (i.e. became more knowledgeable of the relevant content in their expert stream).

> *I can see the utility of having an expert after users have had an opportunity to read/learn/interpret the existing information.*

Support

Learner support features were designed to provide novice users of the MUVE with an ability to effectively use the built-in communication tools, move (e.g. walk, fly, and teleport) in the environment, navigate the town site, and use the collaboration tools. The orientation session and the features in the environment such as the teleport-enabled town site maps, user guides (e.g. BrainBoard), and instructions on media playback options were intended to reduce the cognitive load that players experienced during the actual evaluation session.

Teleport-enabled maps were modelled on the conventions used in maps in other environments in Second Life. Players still experienced difficulty navigating the environment, and using the various teleports (e.g. interactive maps, teleport pads) and some players requested that others who had gone ahead teleport them to the player's present location.

The user guide to the BrainBoard contained information on how to add notes to the board, insert line breaks, change the color of a note and move notes to another position on the board. Players were visually cued that an object was a scripted object or contained specific information through the presence of floating text.

Importance of Narrative

The fantasy aspect of digital game-based learning was seen as essential by educational researchers such as Gunter, Kenny & Vick (2008). The primary narrative of this game was associated with the mayor's mission. The secondary narrative was related to a mystery around the perpetrator of a crime at a local industrial sequestration facility. The primary and secondary narratives overlapped at certain points and information related to both narratives were dispersed throughout the environment. Players searching for information in a particular expert stream were brought into contact with clues related to the crime. Westera, Nadolski, Hummel and Wopereis (2008) suggested that serious games need "a pre-structured complexity based on a narrative or scenario covering the dynamics of the game" (p. 422). The open-ended problem that players were expected to address provided this complexity.

Articulation

The term articulation referred to the sharing of ideas, thoughts, and information. In order to be competent professional scientists or even informed amateurs players need to develop skills that will help them tackle open-ended problems, that is, problems with no clear solution (e.g. multiple variables, subject to complex system interactions). Players were expected to articulate their reasoning process to their teammates and other players and experts (at a final town hall meeting).

The components of the game that support articulation are the communication and collaboration tools. Communication options ranged from text, voice, and non-verbal gestures. Text communication options included text chat and instant messaging. Voice communication was possible through use of a headset or built-in microphone however the designer chose not to use voice chat in the context of the evaluation session because the players were working in the same setting and the resulting noise would be quite distracting.

CONCLUSIONS

This design case demonstrated to the design team that the digital game-based learning environment we used had the capacity to support the development of scientific literacy through collaborative activities and individual game play. Evidence of improved scientific literacy specifically in relation to climate change and water issues was evident in the kinds of notes that players posted to the BrainBoard and entered in the chat. Some players entered information pretty much as it was originally presented however other players reflected on their findings and tried to make connections between the knowledge they gained in their own expert stream and their teammates' findings. One player in particular was able to make a connection between the patient history of an infant with diarrhea and the impact of climate change on water quality (i.e. increased microbial contamination).

Future iterations of the game will require some changes in the tools that players use to collaborate given the difficulties that players experienced with the BrainBoard. Although it would be desirable to have most of the communication and collaboration in the MUVE the collaboration tools in that environment were limited in terms of their features and usability. What was nice about the BrainBoard was that it, along with the chat entries, helped to make player thought processes more transparent to the designer. However, there are a large number of collaboration tools available for free. Having students share their documents outside the virtual world (e.g. through Google Docs) may also provide insights when paired with direct observation of players in the environment as well as analysis of text and voice chat.

The designer spent a great deal of time ensuring that there were visual parallels between the virtual environment of the town site and the real world. While this was a 'nice to have element' it was likely not essential. Future iterations of the game while making visual references to the real world would not focus so much on fidelity.

One of the suggestions made by players had particular merit – re-designing the game so that clues to the mystery are clearly demarcated. Players were also interested in having more interaction with local residents, that is, NPCs or live actors assuming the identities of characters. This kind of change would require a considerable amount of coordination and commitment from volunteers, a commitment that might wane over time. A compromise may be to include more NPCs and provide them with detailed back-stories and more frequent interactions with players (e.g. messages from the characters, artifacts associated with the characters). Greater participation by real world experts as mentors of students in expert streams could also foster improved engagement and understanding of the science.

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