Martian Boneyards: Scientific Inquiry in an MMO Game

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ABSTRACT

This paper reports on research of a game designed for scientific inquiry in a new and publically available massively multiplayer online environment (MMO). Educators and game designers worked together to create a highly immersive environment, a compelling storyline, and research-grounded tools for scientific inquiry within the game. The designers also played characters within the game that allowed them to deliver an evolving and responsive game narrative while also serving as participant observers for the research. Researchers integrated these observations with survey data, log data, artifact review, and interviews to provide a composite picture of the player experience and the gaming environment. This study shows evidence that sustained scientific inquiry can be nurtured in an MMO game and that gamers relationship with characters in the game and other players may help facilitate that inquiry.

Keywords: Gaming, Virtual Learning Environments, Scientific Inquiry

1. INTRODUCTION

The authors are looking beyond today's schools toward learning environments that transcend formal and informal boundaries, leveraging the learning that takes place in peoples' everyday lives. Internet-based free-choice environments are becoming a major source of science learning and social activity for an increasing portion of the population (Falk & Dierking, 2010; Ito et al., 2008; Lenhart, 2010). This research examines if and how a combination of commercial-quality game design and well-grounded models for science learning is able to harness the passion, inquisitiveness, and "blissful productivity" (McGonigal, 2011, p.53) in a community of gamers and engage them in sustained and productive scientific inquiry.

2. STATEMENT OF THE RESEARCH PROBLEM

Youth and adults, both male and female, are spending increasing amounts of time playing computer games (Ito et al., 2008; Lenhart, 2010). These games often use very high-end graphical engines, creating realistic and spectacular imagery. Massively multi-player online environments (MMOs) where players use avatars to represent themselves in online communities are becoming a huge new venue for socializing (Castronova, 2007; Gartner, 2008).

A growing body of research is examining innovative ways of learning that may occur in social digital gaming environments (Gee, 2003; DeFreitas et al., 2010). In many popular role-playing games (e.g., *World of Warcraft*), practices such as peer-review, collaboration, sharing and analysis of data, and evidence-based reasoning take place among the players (Steinkeuhler & Duncan, 2008). These gaming activities are similar to the habits of practicing scientists in professional communities who share data and observations, challenge and confirm each others claims, and work together to build theories through a well-recognized and explicit peer-review system (Dunbar, 2000).

Gamers' activities are also suggestive of well-established situated learning models such as communities of practice. In a community of practice, people work together on domain-specific knowledge building using common habits, language, and communally-accepted rules of engagement (Lave, 1988; Lave & Wenger, 1991). Vygotsky (1978) recognized the mediating affects of a community and tools, and the inextricability of environment and community as they mediate the learning process. Vygotsky also described a zone of proximal development (ZPD) that is the difference between what a learner can do individually and what s/he could do with assistance from others. Interestingly, a similar tenet of many game-design models is that tasks must be just outside the current grasp of a player—doable, yet challenging—and often requiring the assistance of other players and/or tools within the game (McGonigal, 2011). A good social game always has a new task to be accomplished and a group of people to help.

> *In a good computer or video game you're always playing on the very edge of your skill level, always on the brink of falling off. When you do fall off, you feel the urge to climb back on. That's because there is virtually nothing as engaging as this state of working at the very limits of your ability.* (McGonigal, 2011, p. 24)

3. DESIGN AND IMPLEMENTATION OF *MARTIAN BONEYARDS*

In summer 2010, the authors launched a social game of scientific mystery called *Martian Boneyards* with the goals of steering gamers' voluntary activity towards meaningful science knowledge building experiences. Paramount to the design of *Martian Boneyards* was that it be appealing to experienced gamers, which requires a certain level of polish (Isbister, XX). The authors partnered with a top-end designer in the high definition MMO, *Blue Mars*. *Blue Mars* uses the CryEngine2 gaming engine, the same used in state-of-the-art first-person shooter video games in 2009.

The authors and their team created the land of *Arcadia* to host a prototype game called *Martian Boneyards*. *Arcadia* is a city[1] in *Blue Mars* that contains an abandoned Science Center and extensive grounds around the Center (see Figure 1).

Figure 1: The Boneyards outside the Science Center in Arcadia

A very brief initial storyline introduced a team of explorers who came to *Arcadia* and found the Science Center abandoned. The explorers had also found a gruesome discovery—there were bones scattered all over the surrounding outside area. That is when the explorers recruited players from the rest of *Blue Mars* to help them figure out what had happened in *Arcadia*. The designers also created many different types of bones, modeled after real specimens from humans, Neanderthal, chimpanzees and other animals. The designers placed these bones and other artifacts within the environment to provide evidence of an intricate storyline that designers had documented. Once the game started, however, the players were allowed to take the story in any direction for which the community agreed was evidence-based. For example, a femur bone from a nearly full skeleton may have been found some distance away. It was near a stream and there were lemur bones nearby. Was it moved from their original location by scavengers or water or other means? Did a skeleton wind up at the base of a cliff due to being pushed or having fallen, or just dying in that place?

This game design approach is responsive to the participatory culture found in virtual environments where creation and knowledge building is becoming more decentralized and distributed throughout the public community (Castronova, 2007; Jenkins, 2006). The game industry is turning more and more to games without instructions, relying on the user to figure nearly everything out on their own (McGonigal, 2011).

Designers played characters in the game allowing the interactions with players that were necessary to facilitate this dynamic and evolving storyline (see Figure 2). The designer's involvement was critical for engagement of players and also for the ability of the design team to respond to what they were learning from the player community. It also required close attention and constant facilitation by the designers' characters during the implementation period.

Figure 2 – Laurel (in white coat) is facilitating a session in Martian Boneyards

3.1 Supporting and Measuring Scientific Inquiry

The authors used a framework to design and study scientific inquiry in *Martian Boneyards* that is rooted in a theory of argumentation from Toulmin (1958). This frame centers on data or evidence, and claims (or warrants). As players work together to solve the mystery, game tools help scaffold their coordination of claims and evidence. Kuhn (2005) describes how scientists carry out this coordination with conscious control and explicit and consistent criteria. In developing scientific understanding, *learners* must also test ideas against evidence and continuously revise theories (Harlen, 2005). This process is inherently collaborative as learners must compare and contrast their claims and evidence with those of others to advance the knowledge-building process (Scardamalia & Bereiter, 1996).

The designers used a simple structure of evidence-based scientific inquiry to design tools for *Martian Boneyards*. When players first came to *Arcadia*, they would typically take some time to explore the area. To encourage exploration that led to questions related to the mystery, designers placed posters and non-clickable artifacts around the Science Center. There were posters and examples of skulls and skeletons of various animals and a few posters that resembled conference submissions from groups of researchers. The posters' titles related to terraforming practices and genetic research, but the text itself was very small and in a language that would be very unfamiliar to nearly all players. This allowed designers to create an "effect" without having to provide too much specific content.

From the Science Center, players could teleport to the Boneyards where they used their virtual PDAs to gather data by scanning bones and artifacts, collecting pictures and information (see Figure 3). This required players to move their avatars around the Boneyards, zooming in to scan for very small pieces of bones sometimes obscured by bushes or sand. Designers strived to make discovery of artifacts simple enough to not be frustrating or lose players but also challenging enough to keep players engaged, just within their ZPDs. The PDA allowed them to see two different views of each artifact, review all their findings, and take notes about them.

Figure 3: Players scan bones with their virtual PDA

Players used the analysis workstations in the Science Center to share and analyze data (see Figure 4). They compared multiple views of each bone, used a measurement tool to collect length and width data, and compared their measurements and tags with those found by other players. An artifact would show up on a player's table only if they, themselves, had found it and it could be used for community evidence only if at least 20 people had scanned (verified) it. Not only was this constraint meant to foster collaboration, but it was also intended to slow-the pace of early players to allow for the community to grow. Moreover, it also mirrors a peer-review process in science where data are not taken seriously until replicated in some manner by colleagues.

Figure 4: Players use the analysis workstations to share data and make measurements

As players generated evidence from their findings, they were intended to use the theory-building board in the Science Center. The theory-building board allowed them to enter claims about the mystery requiring that each claim be substantiated with evidence from the analysis databases. Players' evidence was coordinated with other players' claims, building towards explanatory, peer-reviewed theories. Players were also able to comment, add evidence, and rate each others' claims. These tools were designed for constant iterations within and among phases of scientific inquiry.

The theory-building game tool was not functional very early in the game and was never the medium of choice for players who wanted to share text along with images and URLs to Internet resources (this was still awkward to do in *Blue Mars*). Players predominantly used a web-forum (hosted for the *Blue Mars* community) to share information about the game instead. Some players posted their entire inventory of artifacts, along with descriptions of where they were found, to help other players. Observers noted that even as the players moved to the less-structured discussion area, those who started their claims on the theory board continued in the practice of posting evidence with their claims.

3.2 Minimal Instruction and Directions

A goal of *Martian Boneyards* was to learn what types of instructional scaffolding might support scientific inquiry in games. To do this, the designers felt that they should start minimalist and not presume that these scaffolds would be similar to those used in formal or informal structured learning settings. Professional game designers suggest that this minimalist scaffolding is, in fact, a choice of many gamers (McGonigal, 2011). The designers took advantage of this opportunity to help researchers understand the nature of scientific inquiry that occurs naturally in games. The culture of participation and decentralization of knowledge encouraged in social digital games may provide its own emergent structures.

For this reason, the designers did not provide any content delivery of scientific information and provided very little written instructions for tools. The posters around the Center showed only enough scientific content to seed the idea that the Center may have been used to study comparative anatomy, genetic engineering, and ways of survival on the (newly terraformed) Martian planet of *Blue Mars*. The inquiry tools had no instructions or manuals. Players learned their operation mostly by working with other players. When technical glitches in the tools occurred (typically due to the beta-test nature of the *Blue Mars* environment), designers used screens in the Center to stream in a flash video from an external web site with fixes and workarounds.

The design of *Martian Boneyards* strived to use the enticement of the beautiful 3D graphical environment, a compelling mystery storyline, and well-crafted inquiry collaboration tools to sustain inquiry among the beta test population of *Blue Mars*

4. RESEARCH STUDY

Martian Boneyards was implemented for four months in summer 2010 to study if and how elements of the initial and evolving design were able to promote the desired high quality, productive sustained inquiry among the player community. In particular, the research looks to see if the game helped players move to analysis and theory-building phases, those that were underrepresented in earlier research in online inquiry such as studies using the CoI model (Garrison & Cleveland-Innis, 2005). The research examines the nature of the community who took part in the game and the nature of their scientific inquiry activities. The research of the design and implementation of Martian Boneyards uses mixed methods to examine:

- Who came to play Martian Boneyards? Who became involved in sustained scientific inquiry in the game?
- What is the nature and quality of players' scientific inquiry in *Martian Boneyards*?
- What types of design elements and implementation strategies were seen to support sustained scientific inquiry in *Martian Boneyards*?

4.1 Methods

This research study uses methods borrowing from ethnography to study the context within which players act and from phenomenology to study how players' experience the gaming environment. This multiple viewpoint addresses the interdependency of environment design, players' activity, and players' progress by representing the game as a distributed system of players, knowledge, and scientific tools and resources in *Arcadia*. Netnography, also referred to as virtual ethnography, blends analysis of digital records from Internet-supported interactions with ethnographic methods used when the researcher is immersed in the community of study (Hine, 2000; Kozinets, 2002). Netnographic methods used in this research include analysis of electronic records of avatar motions and actions as well as surveys, interviews, and participant observations to provide a well-rounded picture of participants' behaviors and culture in the environment.

4.2 Sample

The overall player population for this study is all entrants (N=613) to *Arcadia*, which includes anyone (ages 18+) who took the registration survey between June 1, 2010 and Sept. 30, 2010, by which they also consented to be included in the digital data sample. The player community was recruited primarily from the current beta-test community of *Blue Mars* so it was primarily composed of experienced virtual world users dedicated to exploring and seeking activity in the new virtual world.

4.3 Measures

The design and implementation study examined the nature of and the relationship among game design, the player community, and the nature and quality of players' scientific inquiry in *Martian Boneyards*.

Game Design

The measure of game design focuses on the designers' decisions and facilitation strategies intended to support and sustain scientific inquiry. These are extracted from the logs kept by designers throughout development and implementation, and the participant observation reports that summarized the facilitation strategies used during the game.

Players' Inquiry Activity

Players' scientific inquiry activity in *Arcadia* is measured two ways: a) the frequency of the interactions with the inquiry tools and b) the duration of time in *Arcadia*.

The frequency of interactions with the inquiry tools is also disaggregated by phase of inquiry. The number of scans each player conducts with the data collection device, the PDA, is a measure of their *data gathering* activity. The extent of players' *analysis* activity is recorded as the number of their interactions (tagging/measuring/comparing) with the analysis workstations, and their extent of *theory building* is the number of interactions with the theory-building board. (This measure is actually an underestimate because it only counts the theory-building activity that took place within *Arcadia*, excluding the substantive activity on the a web-based discussion board that players chose to use outside the gaming environment.)

The measure for overall duration of time spent in *Arcadia* is relevant in this study because observers found that nearly all of the players' time was spent "on task" in the game activity, as opposed to purely socializing. The avatar activity logs recorded each avatar's entry and exit into each room or outside area in *Arcadia*. To avoid including the idle players in the research data, the records that were greater than one hour in duration were removed if there was no other subsequent activity recorded by that avatar.

Quality of Scientific Knowledge Building

To measure the quality of science content and scientific knowledge building demonstrated by the players, a team of three scientists in paleo-anthropology and biology reviewed a set of user-generated materials using a rubric and process modified from previous research to review the quality of materials from online science courses (author, 2008).

The *Martian Boneyards* materials included postings from the theory-building board (with supporting evidence), postings from the *Blue Mars* web forum that players used for supplemental discussion, and one excerpt from in-game chat (over 200 text entries in total2). The materials reviewed include all entries collected that contained scientific content.

The panel of scientists used a rubric to rate: a) the extent of the scientific inquiry, b) the sophistication of the scientific inquiry, c) the accuracy of core ideas in comparative anatomy, and d) the depth of core ideas in comparative anatomy. The scientists rated the quality of the materials along each dimension on a 5-point scale (poor, fair, good, very good, excellent) as compared to the discussion related to a project conducted in an introductory undergraduate science class for non-science majors. These measures were applied to the set of materials as a whole, looking at the group knowledge-building outcomes, as opposed to individual learning.

4.4 Data Sources

The netnographic techniques used by the researchers examine a variety of digital sources to get a broad and deep look at the context that is mediating the game play, the environment and the community, and the player's experience within that context. The data sources include surveys, digital records, observations, and interviews.

Surveys

When providing consent for entrance to *Martian Boneyards*, players were asked their gender, race, age, science involvement, and virtual-world experience. All survey responses were tagged with an anonymous ID allowing them to be linked with the other digital data collected.

Avatar Log

Each time a player clicked on any tool in the Science Center, the interaction was recorded with a time stamp and the anonymous player ID. Each tool was associated with one phase of the inquiry cycle: data gathering, analysis, or theory-building.

Participant observations

The team of three designers played avatar-based characters in the game and served as participant observers. They recorded their own facilitation actions during each 2-hour event (at least twice per week), as well as the players' activities. Observations focused on storyline, social dynamics, and how designers supported scientific inquiry. Two additional members of the research team, who were not designers or regular participants in the game, co-observed and reviewed an event report for validation.

Design Documents

Researchers' review of the design teams' documents focused on the scaffolding of evidence-based inquiry in the design of the tools, storyline, and environment.

Interviews

Researchers used a semi-structured interview protocol to conduct avatar-to-avatar interviews, situating the interview in the studied environment (Turkle, 2005). Players were asked what attracted them to *Arcadia*, what they felt contributed to the value of the game for enjoyment and science learning, and how their experience in *Martian Boneyards* changed the way they think about science.

4.5 Limitations of the Research

There are several limitations that restrict the ability to generalize this research to broader applications. The audience of *Blue Mars* was a highly selective group of early adopters of virtual worlds. They likely do not represent the experience of a typical student or learner. Another limitation (and strength) is the close relationship between the design team and researchers in the study. The participant observers were the designers themselves as they were the facilitators of the game. Two independent reviewers each approved the

interpretations of an observation session for validation of the reporting. Finally, the interviews that provide the bulk of players' interpretation are only from three top tier players. Their views should not be generalized to the entire player population.

5. RESULTS

The results from the *Martian Boneyards* implementation study are reported in response the three research questions, reporting on:

1) The player community in *Martian Boneyards*
2) The nature and quality of the scientific knowledge building in the game
3) The game design strategies used to support sustained scientific inquiry and promote high quality knowledge building.

5.1 The Player Community

The demographics of the *Martian Boneyards* community are reported in Tables 1 and 2 in terms of 3 nested sub-samples. *All Players* (N=228) are those who interacted at least once with an inquiry tool in *Arcadia*. *Core Players* (N=66) are those who used the inquiry tools > 20 times and *Top Tier Players* (N=18) are those who used the inquiry tools > 100 times. Nearly 400 subjects who took the initial survey did not become a player (by clicking on a tool). They may have come on cursory tour of *Blue Mars,* having entered to see *Arcadia,* but never came back to play the game. Although never published, players and designers estimated that the number of regular users of *Blue Mars* was about 50-100 during the study period.

Table 1
Sex, Race, and Age of Martian Boneyards Players

	All entrants (N=613)	All players (N=228)	Core players (N=66)	Top players (N=18)
Sex				
Female	29%	29%	32%	50%
Male	66%	66%	60%	50%
No Answer	5%	6%	8%	0%
Race				
White	74%	78%	76%	83%
Non-white	26%	22%	24%	17%
Age (yrs)				
18-27	31%	32%	35%	39%
28-37	27%	27%	27%	33%
38-47	23%	20%	15%	11%
48-57	13%	13%	12%	11%
58-67	5%	7%	9%	6%
68+	1%	1%	2%	0%
Mean age	36.00	36.16	35.71	33.00

Note. Core players had >20 tool interactions, top players had >100 tool interactions

The typical *Martian Boneyards* entrant and player was a 36-year old white male who is not involved in a science career but may read or watch TV about science. He spends a lot of time in virtual worlds.

The typical top tier player was of the same age and other attributes as the entrants, but notably – the top tier was 50% female. (See Table 2)

Table 2
Science and Virtual World Interest of Martian Boneyards Players

	All entrants (N=613)	All players (N=228)	Core players (N=66)	Top players (N=18)
Science in daily life				
Not involved	26%	22%	33%	28%
Interested	48%	51%	44%	44%
Involved	25%	27%	23%	28%
Time spent in virtual world				
Nearly all	12%	9%	9%	0%
A lot	55%	58%	54%	50%
A little	20%	21%	26%	39%
First time	14%	12%	11%	11%

Note. Core players had >20 tool interactions, top players had >100 tool interactions

5.2 Players' Activity

The players' activities are described in terms of:
a) A quantitative description of the extent of their scientific inquiry
b) A qualitative description of the nature of the inquiry.

The extent of the scientific inquiry is measured by the frequency of interactions with inquiry tools and duration of play in the game.

Table 3 shows the frequency of inquiry tools used by core players in the game, overall and disaggregated by participant characteristics. Overall, approximately 74% of players' interactions were in the data-gathering phase of inquiry, leaving 15% of the interactions in analysis and another 11% in theory building.

Table 3
Distribution of Inquiry Phases by Demographics for Core Players (N=62)

Player Variable	Total tools	Data gathering	Analysis	Theory building
Total	118.27	87.00	17.95	13.32
Sex				
Male (n=41)	91.78*	71.41	12.49*	7.88*
Female (n=21)	170.00*	117.43	28.62*	23.95*
Race				
Non-white (n=13)	79.31	68.69	6.69	3.92
White (n=49)	128.61	91.86	20.94	15.82
Science in Daily Life				
Non-career (n=48)	123.42	94.60	15.94	12.88
Career (n=14)	100.64	60.93	24.86	14.86
Time spent in Virtual Worlds				
high (n=42)	98.38	71.83	15.02	11.52
low(n=20)	160.05	118.85	24.10	17.10

Note. N=62 because the 4 players who chose not to identify sex are not included in analyses.
*p < .05

Figure 5 shows a histogram of the frequency of inquiry tools used for all core players and disaggregated by males and females. The average participation with the inquiry tools is higher for females than males in the core group ($F(1, 60)=5.209$, $p<0.05$). Females also have higher participation in analysis ($F(1, 60)=6.156$, $p<0.05$) and theory building ($F(1, 60)=4.674$, $p<0.05$) activities. The only inquiry phase where activity is not significantly different between males and females is in data gathering.

Figure 5 goes about here

Table 4 shows the duration of play, in hours, of players, overall and disaggregated by player characteristics. The 66 core players spent an average of nearly 28 hours in *Martian Boneyards*. A large extent of players spent less than 20 hours in *Arcadia*, but some players spent upwards of 200 hours in the game. Because of the skew, particularly among the top tier players, the apparent large difference in means between males and females is not significant (See Figure 6 for histogram).

Table 4
Time Spent in Game by Core Player Types (N=66)

Player Type	Mean Duration (hrs)
Overall	27.68
Sex	
Male (n=40)	20.80
Female (n=21)	40.78
Race	
Nonwhite (n=13)	13.70
White (n=49)	30.15
Science in Daily Life	
Non-career (n=51)	26.19
Career (n=15)	26.00
Time spent in Virtual Worlds	
high (n=42)	23.28
low(n=24)	31.20

Figure 6 goes about here

Observers noted the inquiry among players was highly collaborative and overall, the activity within the game was highly on task. The inquiry is described here as four phases: exploration, data gathering, analysis, and theory-building, though it is important to remember that these are not so much separate phases—and are certainly not linear—when they take place in the game.

Exploration

The players typically explored the Science Center before discovering the teleporter to the Boneyards. In the beginning, it was the designers who gave the players tours of *Arcadia* and the tools, but that task was quickly taken over by other players. The environment supported players' desire to explore by providing many surprises and continually opening new regions throughout the game.

Data Gathering

Players were given a PDA upon entrance that was viewable by clicking a tab in their screen. Players found this easily and quickly trained new players on the correct and most efficient way to use it. At no time were players observed trying to hide their inventory. They all readily shared their data with each other. The community depended

on several players to scan and "verify" artifacts before those artifacts were considered valid evidence so players were eager to have others locating artifacts and contributing their findings. The players found ways of showing the location of bones to each other even those their avatars could not point.

Hey - right here by my right foot. There are 4 or 5 of them and they are really small. I'll stand here if you can scan around me. Let me know when everyone's got it.

Players were quick to pick up on any (often spurious) pieces of information that characters dropped that could be taken as a clue. For example, early in the game Laurel (with no particular goal in mind) mentioned that the bones seemed hard to see in the river when the sand has buried them. That provoked a group of players to form into a search party spontaneously to comb the river. They spread out in a line and sent row by row over the grounds to search for bones (see figure 7).

Figure 7: Players self-organized to comb the river for bones

Sharing and Analysis

Players used the workstations to identify and tag the bones, but there was not as much discussion as designers anticipated about the tags themselves. There was, however, substantive collaboration around the measurement of bones, as that became important in the players' identification of the bones. As players continued to discuss how they measured bones, it became clear that there was no standard among the players. Players chatted about standardizing measurement but did not use the tools to create a formalized system. For example, on participant observer noted:

Francie brought up how to tell male from female again re: using pelvis as well as ratios of bones….Does that make it a male shoe or female shoe, consensus was that it is too big for female, therefore Scully is male. They are linking shoe and bones by shoe to Scully, that is good but they need to do some more comparison/measurements to link the bones to each other via a theory….

Players brought in resources from the Internet, their own background knowledge, and sometimes real-life research trips were suggested. A player, Kalw, posted on the discussion board:

Hi! We have come a long way baby! Ok now I do not know if you guys have found this site or not it is http://www.whyevolution.com/chimps.html and I forgot all about Pittsburgh's Carnegie museum of Natural History!!! May take a road trip also)) You would not believe what they have in that museum!! Oh Notail's noticed on the sign in the

work station area that it says btw jj - checkout arcadiashare did it always say that about jj ? love and hugs kalw 

To which another player, Jespau, replied:

Hi kalw –
Nice work on chimps. I spent ages today researching them after your idea and you are right. They are our closest primate relative. Only 1 chromosome different. That's what's on the painting i think. – Jespau

Soon the measurements became very detailed and players began to compare their measurements to outside information. Jespau posted the following (this is one short example of dozens of such measurements)

[Note: The headings B-11-XXX refer to the artifact IDs used by the game tools.]
FEMUR: Thigh bone
The average adult male femur is 48 centimeters (18.9 in) in length and 2.34 cm (0.92 in) in diameter. This is the longest bone in the human body and a quarter of the body length. (Brothwell 1981: 35). 5 Femur bones have been found. A persons height can be calculated from these measurements.
These two bones match in size and could be from the same living thing. This is short for a Mature HUMAN but could still be a younger person.
B-11-HQ1: 35.82 cms x 8.55 cms (width) 2.73 (mid width) (14.10 inches x 1.07 inches)
B-11-UE1: 35.82 cms x 8.73 cms (width) 2.91 (mid width) (14.10 inches x 1.14 inches)
Colour: Beige and the other a bit more sandy but close match.
Height: 143.28 cms or 4 feet 7 inches.
These two bones match closely in size, are close to HUMAN length and could be from the same HUMAN of short stature.
B-12-DW1: 41.36 cms x 2.64 (mid width) (16.28 inches x 1.03 inches)
B-12-QG1: 41.64 cms x 2,27 (mid width) (16.39 inches x 0.89 inches)
Height: (averaged) 166 cms or 5 feet 5 inches.
Colour: DW is ancient looking and white with tan blotches. QG1 is more grey with no tan blotches. So not a great match for colour but both found in Cave 12. These last two bones are not verified yet so no picture evidence available. See your workstation for examples.

Evidence-Based Theory Building

The players never converged on one substantiated set of claims that could emerge into one theory. Rather, they had various related and overlapping claims, some having much more detail (depending mostly on time and imagination expended by the player) than others.

The theory-building area in the Science Center allowed posting of text-based claims with evidence from the workstations. The players wanted to include images and URL's in their posts, which were not allowable in *Blue Mars* at the time. Upon the players' request, the designers opened a discussion area on the *Blue Mars* web-based

forum where players continued the bulk of the theory-building in the game easily integrating images, links, and text.

Participant observers noted that players quickly adopted the "rules" of the inquiry tools, and the scientific language and behaviors promoted by the game were enculturated within the community. Even as players moved to using web-based theory boards, they still used language suggesting that they were trying to form evidence-based arguments.

Players often used phrases such as "we can't use it as evidence until it has been verified," "before we can post a claim we have to find evidence to support it." Players were using this language as one might explain the rules of a game to a new player, but later speaking about the need for evidence to substantiate theory-building became commonplace in the community.

Quality of Scientific Knowledge Building

The quality of the scientific knowledge building was measured through a review of player-generated artifacts by a panel of three independent scientists from related fields. The scientists concluded that substantive scientific inquiry took place in the game. The materials touched on other topics such as evolution, genetics, and botany but the scientists identified that the deepest inquiry was in the area of comparative anatomy. The reviewers judged that the player community engaged in sustained scientific inquiry—questions, making claims, substantiating claims with evidence—to an extent that would be considered very good in an undergraduate introductory science course. The content generated in comparative anatomy was rated very good on accuracy and good on depth. Reviewers noted that the game motivated a level of inquiry among some players that was similar to top students in a class who took a lesson much farther than required out of personal interest. One reviewer commented "Those top players reminded me of those students you get once in a while that just have a burning desire to learn." Reviewers also noted that nearly all Internet resources used by players were from reasonable scientific websites, including Wikipedia and accredited sites from universities and national labs. Reviewers agreed that nearly all of the content in comparative anatomy was accurate and players' arguments in these areas were scientifically valid.

5.3 Design Features for Sustained Scientific Inquiry

The designers of *Martian Boneyards* began with several hypotheses about how to sustain inquiry based on theory from game design and learning sciences. As the game unfolded, many more design strategies emerged and were used. These include:

a) A compelling and evolving storyline in an aesthetically-pleasing environment
b) Facilitation (but not-content delivery) by designer characters in the game.
c) Well-crafted tools to scaffold collaborative inquiry
d) A game reward system that recognizes players' contribution to communal knowledge building

From observations and interviews it was clear that the environment and the mystery storyline were forefront in players' reasons for coming. In addition, designers

learned that the relationships players established with the characters in the game were a strong motivator for players. Overall, researchers found that it was players' desire to solve the challenging quest laid out for them that drove them to continue.

The three top tier players who were interviewed explained that they were motivated to play the game by the beauty of *Arcadia*, the social community with the players, and the *need* to solve the mystery that was laid out in front of them. They found *Arcadia*, the environment in which the game was embedded, to be an exemplar of what could be found on *Blue Mars* and said many came to explore its beauty and intrigue before they got caught up in the story,

KalW, a top player, enjoyed learning the science and talking with her husband (who did not play the game) about the questions she had. When asked what compelled her to spend over 200 hours in the game, she explained that she loved *Martian Boneyards* for the layout, the idea, the learning. She and others referred to their need *as a gamer* to solve the mystery of *Martian Boneyards*.

Another female top player, Jespau, who also spent over 200 hours in *Arcadia* and said she spent many more days collecting information and organizing files for *Martian Boneyards*.

Jespau explained that she spends over 50 hours per month in playing *Martian Boneyards* because:

Arcadia allows me to learn and play...I have a folder with over 200 things in it!...It was a matter of getting to the conclusion by whatever means. If it be science, then that's fine…I am a gamer. We never give up!

Observers noted that players were drawn to the subtlest detail in the environment that may lead to a clue, often fabricating intricate stories even where designers had no intention of leading them. They wanted to know more about the characters' back-story and their "lives" in *Arcadia*. The mystery storyline focused on skeletons of dead characters who also became objects of interest and intrigue for the players. The players also noted that their affinity for the game grew as they got to know the player community and the characters. EcoDude, a male top player, said about his interest in the game:

Well the mystery would have to be interesting to me. And on the other hand I wouldn't be interested without other people being involved.

An Evolving Mystery Storyline in an Aesthetic Environment

The designers had a very intricate back-story in mind when they laid out the evidence, however once the game started they allowed players to come up with their own interpretation of the evidence they found. This dynamic and evolving storyline was critical for engagement of players and also for the ability of the design team to respond to what they were learning from the player community. It also required close attention and constant facilitation by the designers' characters during the implementation period.

It was clear very early to the designers that intrigue and mystery were paramount to several of the players. When core players arrived at the center, they typically started hunting for bones or analyzing data that they had already collected, and they discussed

the storyline. The amount of non-game related discussion in the game was remarkably little. Players were there to solve the mystery.

While everyone enjoyed the quest of hunting, those who came back night after night wanted more information about the back-story. Top players, mostly female, asked many questions about the (fictional) lives of the explorer characters. The characters that designers used in the storyline were useful in holding players' interest and motivating further scientific inquiry.

Occasionally the environment "distracted" players from the storyline and science that designers anticipated, but brought in completely unintended lines of inquiry. For example, the large Baobab tree sparked very early discussion, even before *Arcadia* was launched. A *Blue Mars* user happened to try to enter *Arcadia* during a few hours of open testing before the game began. He recorded and posted a machinima video and images of *Arcadia* on his blog and included paragraphs from Wikipedia about the regions where Baobab trees grow and what their fruits are used for. He was already trying to piece together a back-story for the environment before the game had even begun!

Some players became very interested in posters on the wall that designers had purposely made difficult to read since making them scientifically accurate was not a priority for time and resources. The posters were just meant to create an ambience. Players spent hours, sometimes days, translating the microscopic text, discovering that it was a combination of Welsh and Esperanto—translating to lyrics of a David Bowie song "Life on Mars" and a chapter from *War of the World* by H.G. Wells. Later, designers rewarded their hard labor by spinning the lyrics into clues that led to a key to a journal that would play an important role in wrapping up the storyline.

Facilitation and Implementation Features

The design team credits several implementation decisions and activities to their ability to sustain scientific inquiry in the game. A phased roll out of the game allowed designers to build suspense and reward activity with more of the environment to explore. Having designers play characters in the game was also vital, as they were able to deliver the evolving storyline and also able to receive and respond to input from the players. They also found that players were highly invested in finding pertinent information from external website (such as eSkeleton) so they did not rely on designers for content delivery.

The designers opened *Arcadia* in stages. At first players only saw the Science Center and proximate surroundings with other terrain visible, but not accessible. Every few weeks, a new region was opened (with new spectacular scenery and clues to the mystery). Designers also decided to leave the bones and other artifacts in place so that other players could discover them even after the early players had been through the Boneyards in order to extend the game for a large number of players.

The game was implemented in 5 phases started on Jun 1, 2010 and ended October 7, 2010. Each phase corresponds to the opening of a new area of the Boneyards. Phase one lasted about 7 weeks while the other four phases were each closer to 3 weeks. The staged roll out of *Arcadia* allowed designers to schedule the opening of each new phase at the right time for the community. Designer characters timed the phase releases with progress in the storyline. They told players the funds from the new phase came from an

anonymous donor as a result of the players' hard work and progress. They told players that their donors would pledge more money to open new areas when they could see progress on the theory board (or the forum) in the form of solid evidenced-based reasoning about what had happened in the Boneyards. This inspired players to follow a model of evidence-based theory building with peer review and knowledge building that was expected by the council of scientists. Designers also observed that each new phase spurred on a new wave of activity in the community.

Since designers were playing characters in the game, and serving as participant observers for the research study, they were highly engaged with the players and were constantly strategizing about what to do next with the storyline, facilitation, and roll-out of the game. The designers communicated nearly daily between the game sessions and they were also connected by Skype during the game to be able to simultaneously deliver an improvised storyline. The storyline was an ongoing discussion among the designers as they played their characters and responded to the ideas and activities of the players.

The team constantly sought a balance in how to deliver a compelling and evolving storyline, how much instructional design to include in the game, and how to help the players organize their evolving ideas while also providing a community-centered entertaining game. The designers made very few informational sources available to players in the Science Center. There were a few posters that showed bones of various species and posters that gave inklings about genetic engineering and terraforming, but there was no actually content delivery through assets in the game.

The role of designer character was crucial in the absence of direct instruction because it enabled the designers to have unique opportunities for facilitation and participant observations. The designers played explorers in *Arcadia* who had found the abandoned Science Center and knew no more than the players about what had happened. As non-experts, they were able to ask questions in a natural fashion that facilitated "think-alouds" to both support players' inquiry and also to produce valuable opportunities for participant observations. It was a perfectly natural part of the storyline for the designers' characters to be asking "Why do you think that? What is your evidence?" when a player offered an idea – both scaffolding the players' articulation of their evidence-based arguments, and also prompting impromptu "think-alouds" and enabling researchers to see the players' explanations of their scientific thinking in text as they respond in the chat box.

Tools and Resources

Designers focused their initial design priorities on well-crafted tools to support evidence-based reasoning and providing compelling and accurate scientific artifacts to stimulate inquiry. The symbiosis of the game tools and the inquiry model became essential for the design of the game and research study. By having each tool match with one and only one phase of inquiry, designers were very clear about the priorities for functional design for the tool. Researchers, meanwhile, had a natural way to measure the extent of players' activity in each of the different phases in the science inquiry framework.

Collaboration was also a main driver for the design of the scientific inquiry tools and thus was build into their operation and the storyline. For example, one designer explains:

The data verification process was specifically designed for collaboration – players needed to have 20 people having also found the artifact to be able to use it in a claim. That made the community work together to make sure people found bones so that they could analyze them together.

Designers did not instruct players on how to use the tools or on scientific content in approaching ways to solve the mystery. It was left open to the community to decide. This was visible in the measurement of bones for identification, a prominent analysis activity among players. Observers noted that players chatted about standardizing measurement, but did not establish a formalized system of standardization. The designers suggested ways to work with others but did not give instruction of any kind. A player posted on the discussion board:

I was measuring the femurs, like I say my measurements maybe different form yours, I took the average Numbers! Area 11 femurs - HQ1 is 31.27, UE1-20.99 hmmm! Area 12 femurs - DW1is 35.33, QG1-34.64! Area 13 femurs- OB1 is 31.27, UF1-31.23. Area 24 I have not found any but LF1 could possibly be the end of the other sawed of one in area 25!!! Area 25 femurs TF1 is 37.63, UE1-37.68!!! Okay now there is another femur that I found in Area 25- OC1 measuring at 37.82, and the other sawed off bone which is the end of a femur PI1-11.4 so if they fit then that bone would be 44.99(?)!!! Now if u look at view 2 on the Area 25 - PI1 the sawed off one at the sawed ended there is a red dot, I cannot get a good view of it, could it be like the transmitter on the bracelet!!! love and hugs – KalW

In the end, the players used ratios of the width to length of bones from their measurements to identity species. An excerpt from an example post reads:

I may have identified the Skully 2 skull. it is 22.73 cms length by 19.45cms wide. An adult skull is 21-22 cm. long (8.6 in) (from forehead to occiput) and 17-18 cm (7.08 in) wide. That means it is a bit longer and a bit wider than modern humans but the picture scan shows it is not like us and might be HOMO SAPIENS IDALTU - the earliest known homo genus like us to be found dated 160,000 years ago in Ethiopia. Has extended brow, long shallow cranium and vertical alignment of brow, nose, front teeth, An older but close version of homo sapiens sapiens! Ref: http://www.abc.net.au/science/news/stories/s877478.htm

From these types of analysis, measurements, Internet searching, and discussion the community of players was able to correctly identify and distinguish the (sometimes incomplete) skeletons of a chimpanzee, a male and female human, a male Neanderthal, and a lemur.

Building Community and Identity through Rewards

Initially, EdGE used an informal reward system that relied on the designers' characters to give out awards to recognize players' activities. The nimbleness of this approach allowed designers to respond to the players' stated desires and designers'

observations of what seemed to motivate productive game play. EdGE commissioned a clothes designer in *Blue Mars* to make t-shirts, cargo pants and vest (with lots of pockets for collecting bones), and a water bottle – all items one might need on an archeology dig (see Figure 8).

Figure 8: Top players and designer characters in their Arcadia *t-shirts*

Later in the game, the designers thought an award ceremony would be a way to wrap up the storyline. When Laurel announced that an award ceremony was going to be held in the *Arcadia* Science Center, creating much excitement among the players. One observe commented about how the announcement of the award ceremony spurred on further collaboration towards a solution:

They were invested communally – they weren't just going to go off to work alone, they were going to MEET and do it!

Figure 9: Screenshot from the theory-building room on awards night

Each of the design strategies described above contributed to the tone and culture of *Martian Boneyards*, without which players and designers both predict there not be the same rich and sustained scientific inquiry.

6. CONCLUSION

The designer of *Martian Boneyards* took a step in a new direction in designing a professional quality, voluntary MMO game dedicated to fostering scientific inquiry within the community. Designers predicted that a highly aesthetic environment and compelling storyline could engage the MMO audience and that tools with minimal scaffolding along with facilitation by designers could support the community in productive and sustained scientific knowledge building.

The research found that the core members of the MMO did come to play Martian Boneyards and engaged in high levels of inquiry, including analysis and theory-building. These phases are similar to the synthesis and resolutions phases of the Community of Inquiry model used to study inquiry in online educational environments (Garrison et al., 2003). Those researchers, however, found inquiry lacking in these later phases in online communities of inquiry (Garrison et al., 2005). This finding suggests that MMO games such as *Martian Boneyards* might be better at scaffolding inquiry in these phases and/or that netnographic methods are more able to capture this type of inquiry.

Martian Boneyards initially attracted an audience that was predominantly male, but the top players include 50% females and females conducted more of the analysis and theory building in the community.

The design features seen by players and designers as useful for fostering inquiry include the storyline and environment as predicted initially, but also extend to the relationships between players and the characters in the game. Top players intertwined their sharing of data and theory building with rich narrative about the characters involved in the mystery. The strong presence of the designers in the game also allowed them to be very responsive to players needs and developing narrative, making the game-play even more immersive for the players.

As the designers look ahead to next steps in the research they are designing transmedia games using tools from multiple platforms (web, handhelds, and MMOs) to provide a wider access for a broader population of players. They are continuing to use the approach of an evolving storyline with dynamic roll out and facilitation, but for the long term are also looking for ways to make that facilitation come from the player community itself. The research team is eager to continue working in social digital games to look more deeply at how quality scientific knowledge is built, diffused, and adopted within gaming communities—and how this new way of looking at learning can transfer to classroom applications.

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Footnotes

1 Each region rented and developed on *Blue Mars* is called a city. *Arcadia* is a city and has its own entry point on the *Blue Mars* launch page. All *Martian Boneyards* activity happened within the city, *Arcadia*.

2. One inquiry topic, which was one of the most interesting from the view of the participant observers, was only addressed in chat (and nowhere else in the reviewers' materials) so researchers included that one piece of chat log with the materials.

Table 1

Gender, Race, and Age of Martian Boneyards *Players*

	All Entrants (N=613)	All Players (N=228)	Core Players (N=66)	Top Tier Players (N=18)
Gender				
Female	29%	29%	32%	50%
Male	66%	66%	60%	50%
No Answer	5%	6%	8%	0%
Race				
White	74%	78%	76%	83%
Non-white	26%	22%	24%	17%
Age (yrs)				
18-27	31%	32%	35%	39%
28-37	27%	27%	27%	33%
38-47	23%	20%	15%	11%
48-57	13%	13%	12%	11%
58-67	5%	7%	9%	6%
68+	1%	1%	2%	0%
Mean age	36.00	36.16	35.71	33.00

Note. Core players had >20 tool interactions, top players had >100 tool interactions

Table 2

Science and Virtual World Interest of Martian Boneyards *Players*

	All entrants (N=613)	All players (N=228)	Core players (N=66)	Top players (N=18)
Science in daily life				
Not involved	26%	22%	33%	28%
Interested	48%	51%	44%	44%
Involved	25%	27%	23%	28%
Time spent in virtual world				
Nearly all	12%	9%	9%	0%
A lot	55%	58%	54%	50%
A little	20%	21%	26%	39%
First time	14%	12%	11%	11%

Note. Core players had >20 tool interactions, top players had >100 tool interactions.

Table 3

Distribution of Inquiry Phases by Demographics

	Core players (N=62)			
Player Variable	Total tools	Data gathering	Analysis	Theory building
Total	118.27	87.00	17.95	13.32
Gender				
Male (n=41)	91.78*	71.41	12.49*	7.88*
Female (n=21)	170.00*	117.43	28.62*	23.95*
Race				
Non-white (n=13)	79.31	68.69	6.69	3.92
White (n=49)	128.61	91.86	20.94	15.82
Science in Daily Life				
Non-career (n=48)	123.42	94.60	15.94	12.88
Career (n=14)	100.64	60.93	24.86	14.86
Time spent in Virtual Worlds				
high (n=42)	98.38	71.83	15.02	11.52
low(n=20)	160.05	118.85	24.10	17.10

Note. N=62 because the 4 players who chose not to identify their gender are not included in the analyses.
*$p < .05$

Table 4.

Time Spent in Game by Core Player Types (N=66)

Player Type	Mean Duration (hrs)
Overall	27.68
Gender	
Male (n=40)	20.80
Female (n=21)	40.78
Race	
Nonwhite (n=13)	13.70
White (n=49)	30.15
Science in Daily Life	
Non-career (n=51)	26.19
Career (n=15)	26.00
Time spent in Virtual Worlds	
high (n=42)	23.28
low(n=24)	31.20

Figure Captions

Figure 1: The Land of *Arcadia* in the MMO *Blue Mars*

Figure 2: A player uses the PDA to collect data in *Martian Boneyards*

Figure 3. Players using the workstations that allowed measurement and comparison of artifacts

Figure 4: Theory board where players post evidence-based claims and reasoning

Figure 5: Players organize in a search party to hunt for bones

Figure 6: An excerpt from JJ's journal

Figure 7: Players were fully decked out in evening wear for the awards ceremony

Figure 8: Histogram of the frequency of inquiry tools used by core players, total and by gender

Figure 9: Histogram of duration of play, overall and by gender