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 publicly 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 broad picture of the player experience and the gaming environment. This study provides evidence that sustained scientific inquiry can be nurtured in an MMO game and that gamers' relationships with characters in the game and other players may help facilitate that inquiry.

Keywords: *Gaming, Martian Boneyards, Massively-Multiplayer Online (MMO) Environment, Scientific Inquiry, Virtual Learning Environments*

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, Purcell, Smith, & Zickuhr, 2010). This research examines if and how a combination of professional-quality game design and well-grounded models for science learning is able to harness the passion, inquisitiveness, and "blissful productivity" (McGonigal, 2011, p.53) that some gamers exhibit, to engage a player community in sustained and productive scientific inquiry.

The authors have designed and studied a prototype game in a massively-multiplayer

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online (MMO) environment using tools for scientific inquiry in an immersive, aesthetically-pleasing environment, with designers playing game characters to facilitate the game. This paper reports on the theory behind the game design and the findings of what types of players were attracted to the game and what types of design features were important to support sustained inquiry among those players. The paper also considers what design strategies might carry over to new games and where further research is recommended.

THE POTENTIAL FOR SCIENTIFIC INQUIRY IN SOCIAL GAMES

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 high-end graphical engines, creating realistic and spectacular imagery. MMO environments, where players use avatars to represent themselves in online communities, are becoming a popular 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 (Barab, Arcici, & Jackson, 2005; de Freitas, Rebolledo-Mendez, Liarokapis, Magoulas, & Poulovassilis, 2010; Gee, 2003; Ketelhut, 2007). 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 (Steinkuehler & Duncan, 2008). These gaming activities appear 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; Scardamalia & Bereiter, 1996). 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)

In game design there is a constant tension between what is enough scaffolding to get players motivated and able to pursue the mystery and how much can be left open-ended for players to learn on their own. Too much scaffolding can easily feel "school-like" and procedural, taking away from players' initiative to tinker around to discover things on their own. Too little scaffolding may leave players lost and disengaged.

Reaching out to a gaming audience may open up opportunities for people who do not consider themselves as science-oriented to engage in scientific inquiry through a different venue. Nearly all youth and 67% heads of households play electronic games (Ito et al., 2008; McGonigal, 2011). Though the typical video gamer is often reported to be a 37-year old white male (Entertainment Software Association, 2011), market research commissioned by

Pop Cap Games shows that adult women are playing social games online more frequently than men (Information Solutions Group, 2010). There is less research on race and ethnicity of game players, but studies show that Latinos and African-Americans use their mobile phones to access the Internet more frequently than their white counterparts (Lenhart, 2010). This trend might be used to help decrease a digital divide if rich learning opportunities are attractive and accessible over mobile phones.

MMOs have been reported to help people nurture new facets of identity and agency (Turkle, 2005). This is may be an important aspect of science learners (Carlone & Johnson, 2007; Carlone et al., 2008) and may be particularly important factors to consider for typically excluded members in science, whether they are women, minorities or both (Brickhouse et al., 2000; Brickhouse & Potter, 2001; Shanahan, 2009). MMO games may be particularly interesting in this aspect because the use of avatars may create social presence and immersion for players who are coming together to form a community in which identities may be established (Dalgarno & Lee, 2010).

In summer 2010, the authors launched an MMO game of scientific mystery called *Martian Boneyards* with the goal of steering gamers' voluntary activity towards meaningful science knowledge-building experiences.

DESIGNING *MARTIAN BONEYARDS* FOR SCIENTIFIC INQUIRY

Dunbar (2000) describes scientific practice as a social process as scientists exchange and evaluate claims and evidence within a community. To operationalize this practice with game tools, the authors used a framework rooted in theories of knowledge building and argumentation. Knowledge building in a community of practice is inherently collaborative as learners must compare and contrast their claims and evidence with those of others to advance the knowledge of the community (Scardamalia & Bereiter, 1996). Toulmin (1958) introduced a model for argumentation that centers on data or evidence, and claims (or warrants) as a learner moves towards the adoption of principles. This model is expanded upon by Kuhn (2005) who describes how scientists, in particular, 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 within a community (Harlen, 2005).

With this theoretical framework in mind, designers developed the prototype game *Martian Boneyards* to enlist and support a community of scientific inquiry. Players and designers worked together in a carefully crafted game environment to solve an open-ended mystery. Players' game activity and progress fed back into the game narrative, as designers folded emerging evidence and interpretation back into an evolving storyline. Designers focused on elements that would (a) draw players into the gaming experience and sustain their engagement, and (b) tools that scaffold player data gathering, analysis, and evidence-based theory building,

ATTRACTING AND RETAINING AN AUDIENCE OF GAMERS

The goal for *Martian Boneyards* was to attract an audience of adults who were already playing social games and to direct their play towards measurable scientific inquiry. It was not the intent of the designers to create new gamers but rather to make use of current gamers' time. Designers took three approaches to attracting and retaining gamers: (1) building the game using a state-of-the-art game environment; (2) implementing a dynamic, evolving storyline responsive to player activity; and (3) facilitating game play, not science content learning.

State-of-the-Art Gaming Environment

Games for a gaming audience require a certain level of polish (Isbister, Flanagan, & Hash, 2010) so the authors partnered with a top-end

Figure 1. The analysis room of the Arcadia Science Center in the MMO Blue Mars

designer in the high-definition MMO, *Blue Mars*. *Blue Mars* uses the CryEngine2 gaming engine, the same used in current first-person shooter video games in 2009. In *Blue Mars,* avatar representations of the players could walk and run, use a chat window, and use embedded tools that were activated by clicking on a heads-up display or by clicking directly on an object that activated Flash game elements in a new window. The avatars had limited mobility with their arms so they could not pick objects up or point to places. The authors and their team created the land of *Arcadia* in the *Blue Mars* MMO to host a prototype game called *Martian Boneyards.*

Dynamic, Evolving Storyline

Arcadia is a city in *Blue Mars* that contains an abandoned Science Center and extensive grounds around the Center (Figure 1). *Blue Mars* itself has a vague backstory of being a terraformed Martian planet in the year 2150. Although other areas of the virtual world were not using this storyline, the designers used this as the backstory of *Arcadia.* Three explorers of this new planet had found an abandoned science center in *Arcadia* with tools that seemed to be used for scientific inquiry but it was unclear what science the researchers were studying. There were a few clues such as posters on terraforming and human evolution on the walls.

The Science Center was surrounded by beautiful grounds and a gruesome mystery. The designers had placed bones from humans, Neanderthals, chimpanzees, and other animals around *Arcadia* in ways that could seed a variety of storylines. The explorers (played by the designers) told players they had discovered the bones, cordoned off different areas to protect them from damage, reactivated some of the tools, and then called upon the *Blue Mars* community to help them figure out what had happened in the boneyards.

Designers had placed the skeleton of a female human in the remains of a large Baobab tree that was in the fifth and final area released to players. The designers planned for a dramatic release of her grave by introducing clues (including the journal) of a female scientist, JJ Cleat, who had gone missing during the early settlement of *Blue Mars*. There was also a skeleton of a male Neanderthal found in an earlier phase that JJ Cleat had journaled about. Chimpanzee bones were scattered around to serve as both distractors (making the game more challenging) and also to support a possible story of genetic engineering. Lemur bones were placed to support evidence of why bones might be scattered around, and a male human skeleton was placed both for storyline and to make identifying the sex of the human skeletons necessary. These bones were modeled after real specimens and hidden amongst the bushes and caves in *Arcadia.*

Players were allowed to take the story in any direction for which the community agreed was evidence-based. For example, a skull was found some distance away from a nearly full skeleton. It was near a stream and there were lemur bones nearby. Was it moved from its 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? These types of questions and the subsequent scientific topics of inquiry were left open for the players to investigate (or not).

Facilitating Game Play

Although the designers were not teaching, they were intricately involved with facilitation of the game play. They each played several characters, some who had roles in the storyline (the explorers and a few characters who had an interest in the mystery such as JJ Cleat's brother) and they also sometimes played avatars who represented typical players in the game so that they could interact with other players from that perspective.

The designers had several modes of communication with players. They used live chat, discussion boards in a web-based environment outside the MMO, and poster boards in the science center where designers could easily add new content. Designers started by playing the game every day. They quickly found times when many of the new players could meet in world and established regular meeting hours, called events. These were typically Tuesday and Thursday evenings for an hour or two. Players could come to the game anytime, but they knew a group would be gathering at those times.

During events, the designers would welcome new players and help them understand the current status of the game—what the community had already established about the mystery. Often times other players stepped in and did the facilitating themselves. Designers used the poster boards to let players know about new parts of the game that were open and storyline updates needed to keep momentum in the game, as well as fixes for broken tools at times.

Players found a brief note upon entry to the game explaining the initial storyline of *Arcadia* and introducing the three explorers: Laurel, Fischer, and Tieaun. The designers used their characters to facilitate the dynamic and evolving storyline. As players presented evidence from their inquiry, designer-players then used this as fodder for asking such questions as "How were you able to find that out?" or "That doesn't seem to agree with what (another player) said, what could be the difference?" In this way, the designers facilitated the inquiry, but did not add scientific content. The information and the analysis processes players used to identify the bones came entirely from the player community (and the Internet resources they cited).

During players' scientific inquiry, the designers also tried to keep the bulk of the players within their ZPD. The designers continuously estimated how much the players' activity was being stimulated and mediated by new artifacts and discoveries and the increased knowledge and interactions among the players in the community. When designers saw that players' analysis and theory-building became stalled, the designers would offer a new set of clues or open a new area to stimulate new discovery. The designers were able to ask them questions such as "how hard was that to find?" and "was it worth the effort?" to know when the players were enjoying the "grinding" of hunting for bones and searching for identifying information, and when they were frustrated at not having enough information. Designers used this information to know when to release a new area of the boneyards (with new artifacts to find) or when to add a storyline element to stimulate or cohere activity. For example, when the players had found most of the artifacts in an area and were spending a lot of time spinning out many different possible storyline elements, the designers announced the disappearance of scientists in the area and an award that was going to be given to the Science Center who presented evidence of what might have happened to them. This was intended to spur the players on to organize their claims by asking them to present them for an external audience.

When designers saw a player who was not connecting with the group right away or was not up to speed with the storyline, the designers (or another player) would often take the "newbie" aside and fill them on how to use the tools or what other players were working on. The designers also 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 gameplay.

The designers also added several game elements "on-the-fly" in response to players' activity and interests. For example, designers played characters such as Cameron Cleat, JJ's brother who is searching for answers to why she disappeared, but is not forthcoming because he is suspicious of foul play. Cameron piqued the interest of players and players starting asking many question about JJ. Designers used this opportunity to leave a journal from JJ further refining the story that the players' themselves were unfolding. The journal became essential in tying story elements together for players. In addition, the designers were able to commission 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. These clothes were used as prizes each week for players' contributions (either in quantity or importance in the eyes of the designers). Finally, to bring the game to a close once players had discovered all of the artifacts and had pieced together most of a storyline, the designers held an award ceremony at the end of the game to recognize all the top players who contributed to the theory building. This ceremony was attended by over 40 players who had spent all week preparing, both by posting their final claims and evidence and also dressing up in evening wear (Figure 2).

Tools for Scientific Inquiry

Professional game designers suggest that minimalist scaffolding is a choice of many gamers (McGonigal, 2011) so the designers took advantage of this opportunity to understand the nature of scientific inquiry players can generate on their own in games. The designers created tools for scientific inquiry including data gathering, analysis, and theory-building. Each player's click on any tool was associated with one of the three phases of inquiry so that the extent of activity in each of the phases could be examined in the research. This simple quantification of the extent of activity with the inquiry tools accompanies the participant observations conducted by the designers and a review of the scientific content in players' postings for a larger picture of the scientific inquiry in the game.

The designers provided very little written instructions for tools. Players learned how to use the tools mostly by chatting with other players when they were searching for bones and trying to identify them. Upon entering the game, players were given a virtual Personal Digital Assistant (PDA) that remained viewable no matter where they roamed within *Arcadia*. They were also able to click on glowing analysis workstations in one room and the theory-building board in another room in the Science Center.

Data gathering with PDAs 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 (Figure 3). The number of scans each player conducted with the data collection device, the PDA, is a measure of their *data gathering* activity.

Players used the analysis workstations in the Science Center to share and analyze data (Figure 4). The workstations allowed players to identify and label the artifacts by either choosing a label another player had entered or entering their own. The most common labels rose to the top of the list so that some crowdsourcing was possible. Players could compare multiple views of each bone, use a free-form drag and measure tool to collect length and width data, compare their measurements and

Figure 2. The final award ceremony in the Arcadia Science Center

tags with those found by other players, note which area in *Arcadia* the bone was found, review all data collected, and take notes about each artifact. The extent of players' *analysis* activity was recorded as the number of their interactions (tagging/measuring/comparing) with the analysis workstations.

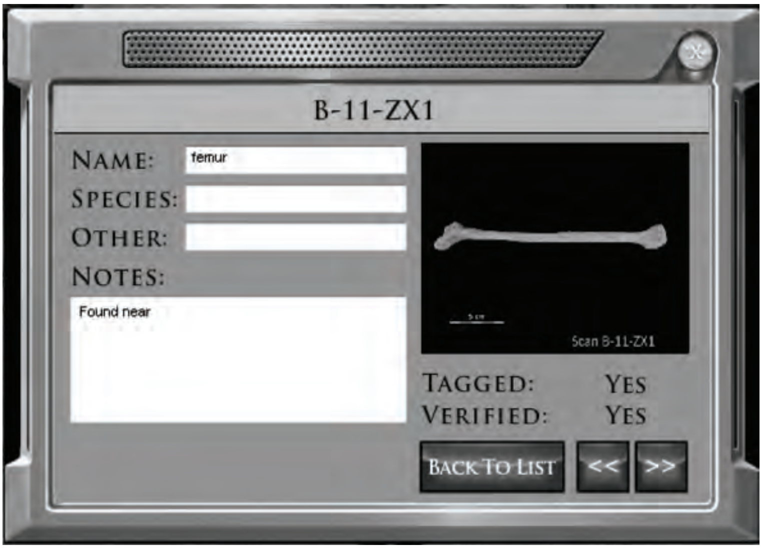
The theory-building board in the Science Center tool allowed players to post claims about the mystery as well as comment, add evidence, and rate each other's claims. Each claim had to be substantiated with evidence from the analysis databases, meaning players had to explicitly tag artifacts as relevant to a particular claim. Players were intended to coordinate their evidence with other players' claims by comparing findings from different measurements and different Internet sites to find ways to identify the bones. Their amalgamation of data and techniques and the challenging of each others' ideas were intended to build towards explanatory, peer-reviewed theories.

The measure of player's *theory building* is the number of interactions with the theory-building board. The theory-building 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*). Instead, players predominantly used a web-forum (hosted for the *Blue Mars* community) to share information about the game. Some players posted their entire inventory of artifacts, along with descriptions of where they were found, to help other players. So, this measure is actually an underestimate because it only counts the theory-building activity that took place within *Arcadia*, excluding the substantive activity on a web-based discussion board that players chose to use outside the gaming environment.

All tools were designed to foster collaboration among players and reflect the practices of a professional science community. When players synchronized their PDAs with the analysis workstations in the Science Center, they could see the observations and notes from other players. Each artifact had to be scanned by at least 20 people's PDAs before it could be used as evidence in claims and theory-building, just as professional scientists often do not take scientific data seriously until they are replicated in some manner. All claims and revisions posted on the theory-building board required evidence from the analysis workstations (or information from outside sources) to model evidence-based argumentation among players. These constraints that are best practices in science were treated as rules of the game to players, in the hope that they would adopt the language and behaviors of science as they progressed in the game.

In summary, the design features used to support scientific inquiry in *Martian Boneyards* include a) an aesthetic environment and mys-

Figure 3. The PDA data gathering tool with a scanned bone and personal notes



tery storyline to engage players, facilitation by designers to unfold a responsive storyline, and c) tools that support data gathering, analysis, and evidence-based theory-building.

STUDYING SCIENTIFIC INQUIRY IN *MARTIAN BONEYARDS*

Martian Boneyards was implemented May–Sept 2010 to investigate the extent to which designers were able to promote high-quality, productive, and sustained inquiry among the player community. This study examines the background and demographics of the community that took part in the game, the nature and quality of players' scientific inquiry activities, and what types of design elements and implementation strategies were seen to support sustained scientific inquiry in *Martian Boneyards*.

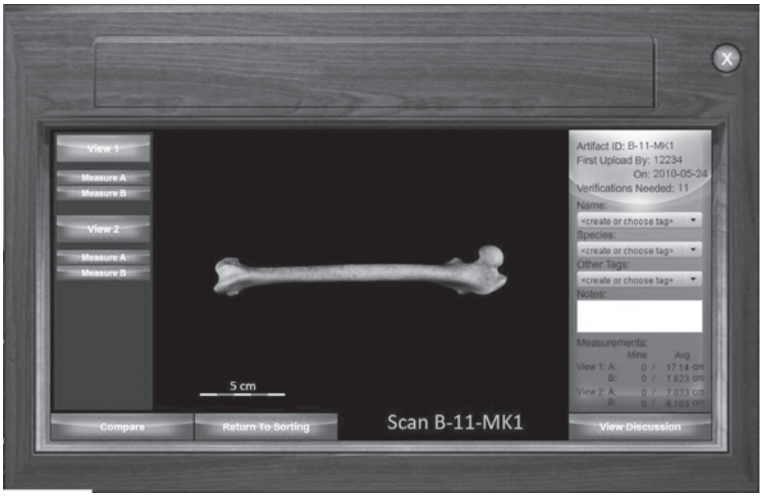
A total of 613 players entered *Arcadia*. Players were recruited primarily from the current beta-test community of *Blue Mars*. The audience of *Blue Mars* was a highly selective group of early adopters of virtual worlds. These players probably have the economic resources to access high-end technologies which are likely not available in public settings. Thus, these results are not generalizable to typical learners.

The study uses ethnographic methods to study the context within which players act and how players' experience the gaming environment. Digital records from Internet-supported interactions were combined with ethnographic methods (Hine, 2000; Kozinets, 2002) to provide a well-rounded picture of participants' behaviors and culture in the environment. These multiple viewpoints address 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*.

MEASURES AND DATA SOURCES

The methods used by the researchers examine a variety of quantitative and qualitative data sources to get a broad and deep look at the context that is mediating the gameplay, the environment and the community, and the player's experience within that context.

Figure 4. The analysis workstation tool with scanned bone and the area for measurement and community tagging for identification



Surveys

When providing consent for entrance to *Martian Boneyards*, players were asked about their real-life identity, including their gender, race, and age. They were also asked to describe the role science plays in their life, choosing as many as apply:

A. I am not very involved in science in my daily life.
B. I choose to watch science shows or read about science for pleasure.
C. I work as a technician in a science-related field.
D. I teach science.
E. I am a professional scientist (researcher).
F. I am studying to be a professional scientist.
G. Other.

These responses were later grouped into (A) *Not Involved*, (B) *Interested*, and (C-F) *Involved*, the latter being an amalgamation of all the science career responses. The final question asked respondents to describe their experience in virtual worlds choosing one of the following responses:

A. This is one of the first times I've been in a virtual world.
B. I've spent a little time in virtual worlds.
C. I have a lot of time in virtual worlds.
D. I spend nearly all my time in virtual worlds.

These responses were later grouped into (A, B) *Low* and (C, D) *High* for purposes of analysis. All survey responses were tagged with an anonymous ID allowing them to be linked with the other digital data collected.

Avatar Log

Players' scientific inquiry activity in *Arcadia* was measured two ways: a) the frequency of the interactions with the inquiry tools and b) the duration of time in *Arcadia*. 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. This measure treats clicks of tools as synonymous with the cognitive activity underlying a specific phase of scientific inquiry, more clicks means more inquiry. While observational data and game artifacts support the connection between clicks and activity in many cases, more clicks could be associated with difficulty using the tool or some other unknown factor meaning the amount of inquiry may be overestimated. This measure needs further validation and refinement.

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.

Participant Observations

Observations were recorded for 33 unique events, at least twice per week and each about 2 hours long. 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 event, 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 read through the near 100 pages of design documents to gain insight to what design features and implementation decisions were made specifically to scaffold evidence-based inquiry in the game. Researchers focused on the design of the tools, the crafting and methods of delivery of the storyline, and general features of the game environment that designers used to promote and sustain scientific inquiry.

Interviews

Researchers used a semi-structured interview protocol to conduct three 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.

Interviews that provide the bulk of players' interpretation are only from three top tier players. These players were highly engaged in the activities and were thus eager to help the designers with their research (although even one of them was hesitant to divulge any information about her outside life). Though researchers recruited other players, including those who had dropped out of the game, none would consent to meet with an interviewer (her avatar in the game) to be interviewed. In-game prizes were offered as incentives, but players chose to earn their prizes through gameplay. This limits the usefulness of the interviews.

Expert Ratings

A team of three scientists in paleo-anthropology and biology reviewed a set of player-generated materials using a rubric and process modified from previous research to review the quality of materials from online science courses (Author, 2008).

Researchers reviewed the entire corpus of player postings to the theory-building area, an associated *Blue Mars* web-based discussion board, and the rare excerpt of chat that designers were able to capture from the gameplay. Designers filtered this for the expert review to include all segments that contained any science related discussion. The posts that were excluded contained only social dialogue or pure storyline/mystery gameplay that had no scientific content. The majority of players' postings were included in the sample. Reviewers examined over 200 text entries in total.

The panel of scientists used a rubric intended to help the reviewers come to agreement on the quality of science content and scientific inquiry demonstrated by the players in the sample of user-generated artifacts. They rated 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 (1=poor, 2=fair, 3=good, 4=very good, 5=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. The reviewers were instructed to rate the highest level for which they saw evidence instead of what was typical across all the materials.

NATURE OF SCIENTIFIC INQUIRY IN *MARTIAN BONEYARDS*

Researchers examined who typically came to play *Martian Boneyards* and who engaged in sustained inquiry. The analysis focused on the duration of play, what the players did with the inquiry tools, and the quality of the discussion and postings generated by the players.

Who Played *Martian Boneyards*?

Roughly a third of those who entered *Arcadia*, 228 of 613 players, interacted at least once with an inquiry tool. A third of the players who used at least one tool, 66 players, clicked on an inquiry tool at least 20 times. This group is labeled the core group of players. A quarter of the core group, 18 players, used an inquiry tool at least 100 times. These players are referred to as the top-tier.

The typical *Martian Boneyards* player was a 36-year old white male who is not involved in a science career but may be interested in science. He spends a lot of time in virtual worlds. The typical top-tier (N=18) player was of the same age and other attributes as the general player population, with one exception. Half of the top-tier players were female and the two most active players were both female. Thus, science and virtual world background did not seem to impact persistence in the game. Details are reported in Tables 1 and 2.

Why did top players continue playing? From observations and interviews with three top-tier players, it was clear that the environment and the mystery storyline were forefront in their reasons for coming. In addition, designers learned that their relationships with the players in the game were a strong motivator for players' sustained inquiry. Overall, researchers found that it was these players' desire to solve the challenging quest laid out for them that drove them to continue.

The players 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 presented to 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 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, and the learning. She and others referred to their need *as gamers* to solve the mystery of *Martian Boneyards*.

Another player, Jespau, spent over 200 hours in *Arcadia* and said she spent many more days collecting information and organizing files for *Martian Boneyards*. She explained that she spent over 50 hours per month 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!"

Jespau had started the game by avidly gathering information and communicating with the designers' characters, but she often minimalized her own work saying, "Oh these are just all my notes, I don't know why anyone else would want to read them." Later in the game, her expertise was recognized by other players, and they started calling her "Doc" and going to her for updates on the mystery findings. She increasingly posted her information publically and often on behalf of the community. When Jespau won the top award at the final ceremony, there were many comments from other players saying how much she deserved it.

What did Scientific Inquiry Activity look like in *Martian Boneyards*?

Scientific inquiry is described here in three phases of the design framework corresponding to the tools: data gathering, analysis, and theory building, though it is important to remember that these are not separate phases—and are certainly not linear—when they take place in the game.

Table 3 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*. Most players spent less than 20 hours in *Arcadia*, but some players spent upwards of 200 hours in the game (Figure 5).

Table 4 shows the average frequency of inquiry tools used by core 66 players in the game, for all players and disaggregated by participant characteristics. Approximately 74% of players' tool interactions involved gathering data, leaving 15% of the interactions with the analysis and another 11% in theory building.

Figure 6 shows a histogram of the average 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 (170.00) than males (91.78) in the core group ($F(1, 60)=5.21$, $p<.05$). Females also have higher participation in analysis ($F(1, 60)=6.16$, $p<.05$) and theory building ($F(1, 60)=4.67$, $p<.05$) activities. There was no significant difference between males and females in the frequency of data gathering.

Data Gathering

Players spent most of their time hunting for bones and using the PDA to scan them. Early players found the PDA easily and quickly trained new players on the correct and most efficient way to use it. Some of the bones were quite difficult to find and scan because of their small size. Certain players became known for their expertise, one even earning the title "eagle-eye," and other players knew to ask them for help.

At no time were players observed trying to hide their inventory from each other or treating the quest as a competition. They all readily shared their data with each other. This may be because the advancement of 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 though their avatars could not point, such as:

"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 which could be taken as clues. They wanted to know more about the characters' backstories and their "lives" in *Arcadia*. Players interviewed also reported having spent a large amount of time on the Internet finding information about bones and techniques for identification.

Table 1. Demographics of players

	All Entrants	All Players	Core Players	Top Tier Players
	(N=613)	(N=228)	(N=66)	(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 experience of players

	All entrants	All players	Core players	Top players
	(N=613)	(N=228)	(N=66)	(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.				

Sharing and Analysis

There was 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, one player posts:

"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

Table 3. Duration

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

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(?)!!!

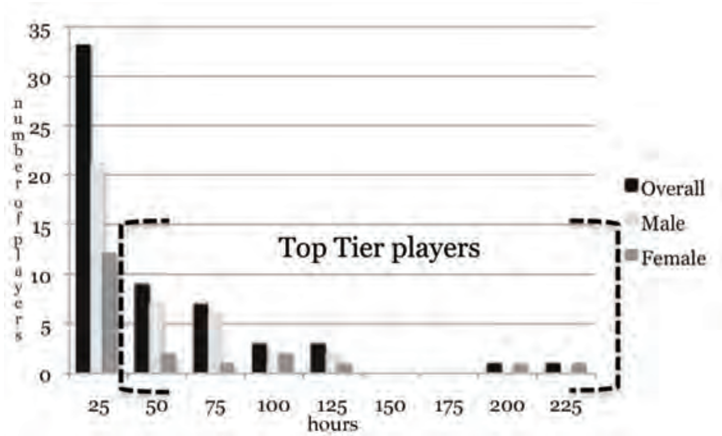
Now if u look at view 2 on the Area 25 - PI1 the sawed off one at the sawed ended there is a red dot, I cannot get a good view of it, could it be like the transmitter on the bracelet!!!

love and hugs – KalW"

Several players had found information on the Internet that led them to use ratios of the width to length of bones from their measurements to identity species, an appropriate method from comparative anatomy. Players used these measurements to identify the origin of the skeletons. 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.

Figure 5. Histogram of the average frequency of inquiry tools used by all core players and by gender



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 analyses, measurements, Internet searches, 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.

Evidence-Based Theory Building

The theory-building area in the Science Center allowed posting of text-based claims with evidence from the workstations. Because the theory-building game tool was not functional very early in the game, players predominantly used a web-forum (hosted for the *Blue Mars* community) instead to share information about the game. Some players posted their entire inventory of artifacts, along with descriptions of where they were found, to help other players.

Players posted resources from the Internet as well as 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!

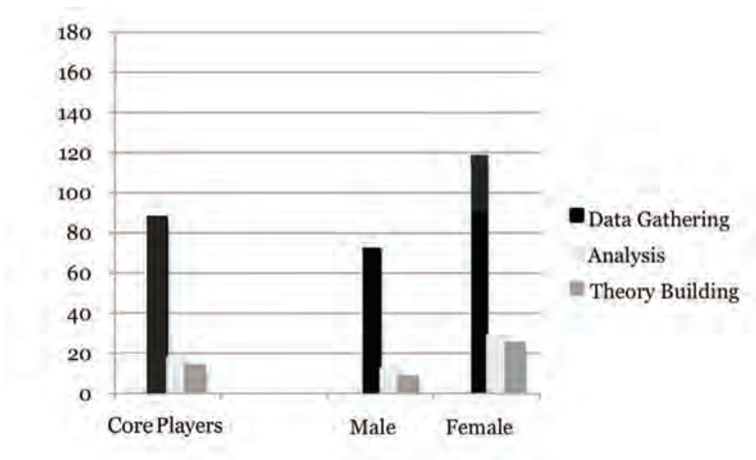
Ok now I do not know if you guys have found this site or not it is http://www.whyevolution.com/chimps.htmland I forgot all about Pittsburgh's Carnegie museum of Natural History!!! May take a road trip also))

You would not believe what they have in that museum!!

Table 4. Frequency of tools

		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				

Figure 6. Histogram of duration of play, for all core players and by gender



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"

Discussion about the measurement of bones became very detailed as players began to compare their measurements to outside information. Jespau posted the following (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, p. 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."

This type of detailed posting was common (and sometimes very long) among a few of the top tier players. Participant observers noted that core 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. In the chat sessions within the game, players often used phrases such as "we can't use it as evidence until it has been verified" and "before we can post a claim we have to find evidence to support it." Players were using this language initially 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.

The player community never converged on one substantiated set of claims that could emerge into one theory. Designers used storyline elements such as a potential award for the Science Center and an awards ceremony to prompt the community to cohere their ideas and organize their findings into a solution to the mystery. The top players had a series of posting at the end culminating in a long post from Jespau's detailing a story quite similar to the one the designers had imagined. In her posting, Jespau credits other team members and describes it as *The Story of Arcadia*. Her writing, however, is a culmination of her own evidence and interpretation and does not explicitly refer to the findings of others.

Quality of Scientific Content

The quality of the scientific content was measured through a review of player-generated artifacts by a panel of three independent scientists from related fields.

The materials touched on several 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 (rating of 4 out of 5) in an undergraduate introductory science course. The content generated in comparative anatomy was rated very good (4) on accuracy and good (3) 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 accredited sites from universities, national labs, and museums. Reviewers agreed that nearly all of the content in comparative anatomy was accurate and players' arguments in these areas were scientifically valid. They noted that the mystery storyline only required them to identify bones and that players did not get into much deeper content about comparative anatomy or human evolution. Since this was a prototype game, designers did not have the resources to continue the game so that players might dig deeper, but one can imagine an evolving storyline that incorporates players' new knowledge into further challenges requiring deeper content learning.

LESSONS LEARNED FROM *MARTIAN BONEYARDS*

These results provide proof-of-concept evidence that it is possible to sustain scientific inquiry within a free-choice, social game like *Martian Boneyards.* This study demonstrates that a player community can produce science knowledge with accuracy and depth comparable to what is found in undergraduate science courses for non-science majors. Researchers found that use of the avatar activity logs to look at the frequency of players usage of each of the inquiry tools and combined with the view of the participant observers and science content reviewers helped create a multi-perspective picture of scientific inquiry in this prototype game, *Martian Boneyards*. The extent to which these findings can be interpreted as demonstrating the types of scientific inquiry that is found in scientific communities of practice or is desired in formal science learning environments is still open to study.

Researchers found that the core players of *Martian Boneyards* used the inquiry tools, including the analysis and theory building tools, extensively during game play. The analysis and theory-building 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) where researchers found the inquiry lacking in these later phases inquiry (Garrison & Cleveland-Innes, 2005). This finding suggests that MMO games such as *Martian Boneyards* might be better at scaffolding inquiry in these phases and/or offer methods are better able to capture this type of inquiry, but it is yet to be seen if this measure of inquiry can be validated against other sources of science assessments.

The results also show that females were more frequent users of analysis and theory-building tools than males, and that the proportion of females was higher in the top-tier players than the core players or entrants. This may be explained, as other research is finding, because females are more attracted to social games (Information Solutions Group, 2010). The female players interviewed were motivated to sustain inquiry by their relationships with the characters which supports findings about socially connected ways of learning attributed to females by some researchers (Belenky, Clinchy, Goldberger, & Tarule, 1986). This requires further study to understand what further design features might entice more women to participate in scientific inquiry though social games.

Designers had 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. These hypotheses were supported by analysis of participant observations, player interviews, and game artifacts.

There were also emergent findings that may help designers scaffold scientific inquiry in new games. As the game unfolded, designers used their roles as characters in the game to learn about what players were doing and to facilitate their inquiry. Having designers in the game allowed an evolving storyline that was responsive the knowledge generated by the community. This type of responsive learning environment may be essential in future participative online communities, where authority and knowledge are seen as increasingly decentralized (Jenkins, Clinton, Purushotma, Robison, & Weigel, 2006). Rather than prescribing a storyline with designated content learning and sequence through materials, social games may provide a way for educators to work within players' interests and own path of inquiry while supporting the inquiry with high quality resources, tools for evidence-based reasoning, and a community for peer review. In the near future, the investigators will continue to use designer characters in their game both to serve this function of responsive designers and also as participant observers for the research. In the long term, designers will study ways to "wean" the games off of designers so that games can become self-sustaining.

The designers responded to the community's needs with "on-the-fly" game elements such as JJ's journal, community awards for player's participation, and an awards ceremony to motivate players to converge and document their theory building. Instead of designing these before the game started, the designers built these as the activities, questions, and knowledge of the player community was developing. In this way, the designers could take the players' lead on where the story should go, and also provide clues to players for new information just at the time that they were looking for it. Although in *Martian Boneyards*, this dynamic development was focused on storyline elements, this technique may also be useful for content delivery. One can imagine a design process resources "chunked" so that there can be waves of development to serve an ongoing player community. One phase of a game would be launched with the first chapter of the storyline. As players generate knowledge and questions through the first chapter, designers can be gathering tools and resources to provide in the second chapter, with the content dependent on the community's directions of inquiry.

The designers were disappointed that budget and timeline for this project did not allow a formal advancement structure where players can monitor their advancements both as a community and as individual players. They felt that this would have added to the motivation for more players to participate in sustained inquiry and also for the community to cohere their inquiry to fewer, more organized claims. In future games, the investigators will use a variety of advancement systems (e.g., points, visible achievement badges, titles, privileges, and prizes) to study which types motivate for different types of players in social games of scientific inquiry. The authors are most interested in looking at community-based rewards, such as status and titles, because they may be most influential on players' identity. Identity is often defined by a reflection of one's position in a community, but can also be seen as one's sense of self as having behaviors as that of a type of person (such as mother, athlete, or scientist) (Fraser, 2009; Shanahan, 2009). By building on the natural opportunities that social games afford to create roles and status within communities, developers may be able to bridge what some players see as gamer identity into what science educators hope to build in learners, science identity.

IMPLICATIONS FOR FUTURE GAME DESIGN

The research on *Martian Boneyards* provides guidance for designing a new type of voluntary MMO game dedicated to fostering scientific inquiry within a community. The research team is eager to continue studying inquiry 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. In addition to drawing upon the lessons of design discussed in the previous section, designers are also seeking ways to extend the audience to wider range of social game players, find models to make inquiry gaming environments ongoing and self-sustaining, and find ways to deepen and measure the content and inquiry learning that takes place in the games.

The audience for *Martian Boneyards* was limited mostly to avid virtual world enthusiasts and tended to be mostly white. The top players interviewed came to *Arcadia* because it was a new place to explore in the MMO. It remains to be seen the amount of wide appeal a game of scientific inquiry will have among gamers. Though the entrants were predominantly self-reported males, female players were equally represented among the top players and conducted more of the analysis and theory building in the community. As educators look ahead to next steps in the research, they might consider transmedia games using tools from multiple platforms (web, handhelds, and MMOs) to provide a wider access for a broader population of players. For example, African Americans and Latinos use handhelds to access the Internet at a higher proportion than whites (Shuler, 2009) so developing mobile apps may be a way to reach a more diverse audience. The investigators are working with informal and formal education partners to recruit a more diverse population for upcoming games.

The investigators are continuing to use the approach of an evolving storyline with facilitation by characters to keep the storyline responsive and also to keep the level of play within players' ZPD, but as this was very taxing on the designers' time, they are looking for ways to make that facilitation come from the player community itself. The top-tier players were responsible for bringing in much of the content that led to the high quality scientific inquiry found in the player community. The facilitation that was done by the game designers could come from anyone skilled with general game leadership skills and that transition would be necessary to achieve a self-sustaining gaming environment for many people. More research is needed to understand what facets of the facilitation is required from game designers in a responsive development process and what roles can be taken over by top players in the game or maybe discarded altogether once a community becomes mature.

In terms of measuring science learning that takes place in social games, *Martian Boneyards* took a first step at looking at how tools could be used to both support and measure the extent of scientific inquiry. The accompanying procedure of reviewing the scientific content and the participant observations conducted by designers were essential for examining the nature of the scientific inquiry that occurred in the game. The process of building knowledge through scientific inquiry is much more complex, however, than can be adequately measured with these types of methods. In order to impact educational systems, game-based learning will need to include measures that can be validated for constructs outlined in national science standards and/or state frameworks. This will require extensive work with classroom teachers and students within the game to define effective assessments that do not break the gameplay.

Another interesting avenue of study for games is identity, in particular how to bridge gaming identity and behaviors with science identity. When some of the top players, who were not involved in science in their daily lives, said they engaged in the inquiry to solve the mystery, they further explained they were "gamers" and that is what gamers do—persist and tackle each challenge, whatever it takes. They adopt an identity of a gamer when describing the reasons for their efforts in the game. Their persistence, along with their curiosity about the mystery is part of what scientists practice in their investigations (Dunbar, 2000). Bridging these gaming behaviors and identity with science identity could be a powerful educational tool afforded by social games. Social structures that emerge within the community of the game, such as relationships among players and characters, may be a promising place to start because these have been identified by researchers as important to building science identity (Shanahan, 2009) and reported by the *Martian Boneyards* players as important to their sustained inquiry.

Questions that are driving further research in studying social games as learning environments include: How can the dynamic, responsive and character-driven storylines be made to embed science learning including content learning goals and fostering science identity? How can these games be made self-sustainable? How can learning in these social games be measured in a way that is of value to the educational community?

As the investigators move ahead towards these goals, they build on several lessons from the *Martian Boneyards* study. These include the importance of an aesthetically pleasing environment, an intriguing and compelling narrative, characters that players can bond with, and a reward system that focuses on community recognition. They also seek to reach a broader audience, develop self-sustaining facilitation models, and further their supports for measurable science learning and the emergence of science identity among gamers.

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