Building the next science generation through game-based learning in museums

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Abstract: In this chat, the American Museum of Natural History and The Field Museum highlighted different approaches to use museum-centered games-based learning programs to build a science-positive generation. The case studies cross a spectrum of technologies and museum goals, and speak to the diversity of techniques being used. Case studies were used to introduce broader questions about gaming and museum-based learning, such as: 1) Do games-based learning opportunities need to be centered in a museum's physical space? 2) How can museums use games-based learning to help youth develop a lifelong interest in science? 3) What are best practices for engaging youth and teens through games with museum collections? 4) What role can museums play in advancing games-based learning? Discussion themes included the importance of authenticity for engagement, the importance of games-based approaches for changing youth attitudes about museums, and the challenges and opportunities that museum collections present as source material.

Introduction

Within the field of education, it is well known that youth in the United States underperform in STEM and significantly trail their counterparts abroad with regard to STEM-related competencies. For example, in 2009, only 34% of 4th graders, 30% of 8th graders, and 21% of 12th graders performed at or above the proficient level in science (National Science Board, 2012). In order to address these shortcomings in STEM education, learning must not be limited to facts. Learners need to have an appreciation for science and to use science skills, such as problem-solving and critical thinking, to become educated consumers of science in both formal and informal learning spaces. This will make it more likely that they will be able to relate science to their everyday lives throughout their careers (National Research Council, 2012). Numerous studies have shown that providing opportunities for young people to participate in the scientific process is critical to their future enjoyment of and engagement with science (Lederman, 1992; Gibson and Chase, 2002). Despite these recommendations, the scientific process still largely remains inaccessible for youth.

Because of the way science is taught and presented, science is often perceived as a collection of obscure facts that are unrelated to daily life: science is not seen as a dynamic activity. However, at its most basic, science entails asking questions and making observations, two activities that youth practice regularly, if unknowingly, in both their daily and digital lives. Informal learning institutions such as zoos, aquaria, botanic gardens, and museums are particularly well-positioned to impact STEM learning, in part because they are not schools and are not burdened by the same preconceptions that learners ascribe to schools.

Informal learning institutions, specifically natural history museums, are uniquely positioned to engage youth in interest-driven learning that heavily leverages both digital media and science content. Past studies have demonstrated that informal learning institutions have characteristics that make them significant sites for inquiry-based learning (Paris, 2002); socially-mediated learning (Falk and Dierking, 2000); and constructivist learning (Hein, 1998). Given that young people today are already engaging with digital technologies, the challenge for informal learning institutions is how to support youth in the digital learning nodes and ecologies to which they belong and are already engaged (Goodlad, 1984; Brown, 1999). One way to support youth in their use of digital technologies is to expose them to content and future career paths that align with their interests. For the Field Museum of Natural History (FMNH) and the American Museum of Natural History (AMNH), informal learning institutions whose core research areas include anthropology, botany, geology, and zoology, this means leveraging digital technologies to engage interested youth in STEM careers. As discussed in this fireside chat, a games-based approach to learning has been well-received by youth, at-risk, and underserved audiences. These audiences can find the grand halls of a natural history museum off-putting and physically imposing. Gamifying learning within such a space can help to break down barriers between younger or underserved audiences and science. With extensive experience in developing and delivering games-based learning to youth and underserved audiences, FMNH and AMNH are poised to strengthen their presence in the digital sphere so that they may play a critical role in developing STEM-related competencies in young people.

Case Studies

Here we present brief summaries of some digital learning programs that illustrate the spectrum of current museum programming for youth and teens. Museum-based programs explore how young people can interact and learn in different ways within a research-focused science museum, often leveraging original research, data, exhibits, and/or collections. Our museums seek to gain a better understanding of how youth bring their own capacities in digital media to learning, how key concepts in science are conveyed in new game-type narratives, and how museums can extend this work. These examples were used to launch a broad discussion on the role that digital gaming experiences can play in museum-based learning, the obstacles that museums face when incorporating digital tools, and how efforts like this have the potential to transform museum-based learning in the digital age. We highlight 1) a serious game about paleontology that is in development for use remotely and within an exhibit (Game of Bones), 2) a virtual world simulation and suite of games that are based on museum research but have no presence within museum exhibits (WhyReef), 3) a program blending virtual worlds, engineering software, and data gleaned from museum exhibits and research (Virtual World Institutes), and 4) a day-long learning experience that integrated MineCraft with a temporary museum exhibit on food (FoodCraft).

Game of Bones

Games of Bones (GoB) is a video game being developed and piloted by FMNH to explore how we can use games to better engage museum visitors before and during their visit. The game seeks to enliven the "life through time" exhibits that are standard in most natural history museums. GoB is developed in the Unity 3D game engine for maximum flexibility and is intended for use both within museum exhibits and remotely. GoB game design and mechanics are targeted towards youth aged 9–13, but we expect the game will also appeal to family audiences. The game is web-based, thus playable remotely before or after a museum visit or on a kiosk within the museum. To date, the game has been played by focus groups of middle school students within a museum classroom (but not within an exhibit)

GoB aims to educate museum visitors and online learners about basic anatomy and evolution through ten game levels that map to seminal moments in Earth's history that are represented in almost all "life through time" exhibits. Each level will correspond to a different period in geologic time and will focus on an iconic fossils specimen. Gameplay replicates the activities of paleontologists, with players digging up fossils, re-assembling ancient animals and plants, using museum collections to test basic hypotheses about the organisms' ecology, and making virtual museum exhibits. The single-level game prototype focuses on *Edaphosaurus*, a fossil mammal relative from the Early Permian Period of Earth history (approximately 299 to 270 million years ago). GoB may provide a way for players to apply or improve science skills in context, making the scientific process more accessible and familiar. Gameplay may increase content knowledge, heighten interest in science, and engender positive attitudes toward science among players. Paleontology has a strong feeling of adventure and discovery that may help to draw in youthful players who might otherwise be reluctant to engage with science content. By making science accessible and increasing their content knowledge, GoB has the potential to provide youth players with a better understanding of paleontology and museum research.

FMNH has used an iterative development process, cycling design and development with focus groups of middle school students. Preliminary data gathered at focus groups shows areas where GoB can have a positive impact on learning. Gameplay helped players to understand 1) the realities of paleontology; 2) the tools and methods used by paleontologists; 3) the importance of museum collections for science; 4) basic anatomy; and gave players 5) the ability to evaluate anatomical function.

WhyReef

WhyReef is designed around the FMNH mission rather than around a particular physical collection or exhibit, as are most traditional outreach programs. Thus, it leverages the strengths of FMNH's collection and multi-investigator research programs on coral reefs. The charismatic interconnectedness of a reef ecosystem serves as an ideal platform for WhyReef's goals of increasing science literacy through awareness of and participation in conservation biology and ecosystem ecology. WhyReef allows players to be citizen scientists and also introduces the skills, such as critical thinking and problem-solving, necessary to understand the consequences of biodiversity loss.

WhyReef creates experiences and learning opportunities across channels--increasingly a requirement for the younger generation of learners. Digital media provides an unparalleled opportunity to link learning across the formal and informal spaces of home, school, after-school, and work (Ito et. al., 2008). WhyReef engages players in an array of activities, ranging from assessing coral reef biodiversity to affecting change in an unhealthy reef.

Players participate in activities that allow them to identify and monitor 50 unique reef species, observe who-eats-whom in the reef, and experiment to discern how human events can impact reefs. WhyReef contains two reefs, North and South, allowing players to compare reef appearance and condition. Periodically, one reef is degraded by a problem such as overfishing or coral bleaching. These damaging events are unannounced and progress over the course of weeks, worsening with time. Unlike the real world, reef damage in WhyReef is fixable within a matter of weeks through civic action and group intervention. WhyReef went live March 30, 2009 and received more than 40,000 visits in its first ten days. To date, WhyReef has had more than 175,000 unique players participate.

The scientific accuracy of WhyReef fosters an appreciation for coral reef ecosystems, engages youth in scientific methods and techniques (particularly hypothesis testing and collaborative problem-solving), and assists with science content knowledge of coral reefs. WhyReef 1) addresses the manner in which scientific accuracy in a learning-based virtual world simulates real-life scientific observations about and experiences in ecosystems 2) allows players to mimic scientific processes in order to inform solutions to real world questions, and 3) provides real-life "scientific discovery" moments and opportunities for "higher-level" engagement (Aronowsky et. al., 2011).

One key example of players practicing scientific skills can be found during the Save the Reef activities. During four different month-long occasions a perturbation was introduced into the North or South Reef, resulting in the degradation of that reef. In reaction, Whyvillians were asked to rally and find ways to bring the sick reef back to a healthy state and Save the Reef. The activities in Save the Reef gave Whyvillians several entry points for engagement. These options included: taking a survey to decide why the reef is sick and what is causing it; voting on a Reef Management Plan; making, buying and wearing reef-themed face parts (hats, shirts, signs, etc.) to raise awareness of the sick reef; donating clams to support the Reef Management Plan; and writing articles for the Whyville Times to inspire action. The Save the Reef activities were both highly engaging and popular with players with a total of 1,741 surveys and management plans completed, 218,811 faceparts worn, 5,350,825 clams donated and 92 articles written. By participating in "Save the Reef" activities, players practiced the problem-solving and critical thinking skills employed by marine biologists and scientists and gained invaluable practice in using data and structuring arguments to persuade others to take action.

FoodCraft

FoodCraft combined Minecraft with a temporary museum exhibit, Our Global Kitchen. The youth entered a modded version of MinecraftEdu where they learned they have settled a new community and are in the process of developing their food systems. Participants were challenged with figuring out the mechanics of farming and eating, and what crops they could successfully produce, process and trade. After the first gameplay the youth visited the food exhibit, met with one of its designers, and contrasted the food systems in the game with the real food systems depicted in the exhibit. A second visit to Minecraft introduced a global transportation system and industrial farming and challenged the youth to solve new problems using information learned from their visit to the exhibit.

The program was designed to achieve the following educational objectives. By the end of the day long program, youth were able to: (1) articulate the different elements of a food system, (2) identify some of the factors that influence the food system and their consequences, based on experiences within both FoodCraft and AMNH's Our Global Kitchen exhibit, (3) explain how a video game can create a "need to know" about content in a museum exhibit and how a museum exhibit can provide needed content for a video game, and (4) enhance their abilities to problem solve through collaboration in a digital environment.

Virtual Worlds Institutes

AMNH's new programs grow out of our recent work exploring the educational applications of virtual worlds. Virtual Worlds Institutes provides unparalleled access to the Museum's wealth of science resources, curatorial expertise, and collections, and utilizes a combination of digital sculpting software (Sculptris) and virtual worlds (Active Worlds). Learners use these digital platforms to bring to life their hands-on investigations of fossils, artifacts, gene sequences, and museum dioramas and exhibits.

The Institutes introduce students to the Museum's extensive and unique resources—fossil halls, paleontology collections, astronomy exhibits, science departments, and scientists—and tap into the continued evolution of scientists' use of technology to analyze, model, and communicate scientific data. Each institute culminates in students presenting their digital work, including the hypotheses and analyses behind it, to their families and the AMNH community, who acts as unique and essential resources in the development and execution of these scientific programs.

In 2012 students were enrolled in: (a) Cretaceous Oceans: students were placed in the role of paleontologist to "resurrect" an extinct ecosystem based on fossil evidence from the Museum's collections. This Institute was first offered Summer 2010 and highlights can be viewed in the this video: http://www.youtube.com/watch?v=ORO-pzDvYFNI and (b) What Happened to the Neanderthals?: students assumed the role of paleo-anthropologist to reconstruct the events that may have led to the extinction of Neanderthals and the predominance of modern humans as the only hominid left on Earth. Summer 2012 was the first offering of this Institute.

Discussion

We selected seven questions around which to center the discussion. These questions (Table 1) came from a lively pre-conference discussion among staff at both museums about the role of games-based learning in museums and the role of museums in the future of games-based learning. During the fireside chat, we used www.wheeldecide.com to randomly select a series of focal questions. Once a question was selected, each museum staff member answered the question using examples, data, or anecdotes from the case studies described above. Then the discussion was opened to all participants for comments about their own institutions and processes, as well as further questions. The conversation was both stimulating and informative, such that we only had time to address questions 2 and 3 of the seven questions in Table 1. Several participants tweeted from the fireside chat. The tweets are available in Barry Joseph's blog summary of the event: http://www.mooshme.org/2013/06/speaking-on-science-museums-and-games-at-gls/ Some of the compelling topics included collections-based games, games as a way to change youth mindsets about natural history museums, goals of museum-based programs, measuring impact, and the importance of authenticity for engagement.

Like most informal institutions, museums have to consider a diversity of stakeholders, audiences, and technologies when designing and implementing games-based learning experiences. Natural history museums (NHMs) engage learners from pre-Kindergarten through university to families. We engage learners both onsite and off, through channels including websites, virtual worlds, mobile devices, field trips, summer camps, and afterschool programs. The average museum visitor is a family with two children and two adults in their 30s (see Reach Advisors, 2010). An ongoing study conducted by the FMNH Exhibit Department (in collaboration with the evaluation firm Slover-Linett) to inform the museum's Grainger Digital Initiative, showed that the average museum visitor has a smartphone but wants a break from screens while in the museum. However, these same visitors think that an exhibit without technology and interactives is outdated. Given this diversity of audiences and contrary feedback, it can be challenging to design games-based experiences and museums must be thoughtful about when and how to utilize technology.

Number	Question
1	Do games-based learning opportunities need to be centered in a museum's physical space?
2	How can museums use games-based learning to help youth develop a lifelong interest in science?
3	What are best practices for engaging youth and teens through games with museum collections?
4	What role can museums play in advancing games-based learning?
5	Should museums produce games themselves, or should they serve as facilitators or content experts for game designers?
6	How can museums best offer opportunities for youth to remix content?
7	How can primary collections and research-based data be incorporated into gaming experiences?

Table 1: 7 discussion questions for Fireside Chat.

NHMs and science centers both have missions focused on raising awareness about and engaging the public with science, but typically they take different approaches to achieve these goals. Science centers generally base their exhibits and programming on experiences whereas NHMs base theirs on collections or objects. The centrality of collections to NHMs was highlighted by the first discussion question (best practices for games-based learning using museum collections). For museums and scientists, collections are a tool for actively solving problems and, as such, have great potential within games. But what are good practices for using collections within a game? In GoB, players must answer two simple questions about an unfamiliar extinct animal: what did it eat and how did it move? During gameplay, players use images from FMNH's collections to compare the extinct animal with more familiar living animals (e.g., wolves, ducks, turtles) to form and test hypotheses. Foodcraft is an example of games that create a need to know about objects. In Foodcraft, gameplay preceded the exhibit and potentially changed the way that learners saw and experienced the objects on display. Vanished was a nation-wide game launched in 2011 by MIT's Education Arcade and the Smithsonian Institution. Vanished was played in schools and informally for seven weeks. Gameplay took some players into their local NHMs to find clues in the objects on display. That information was shared broadly within the game to help solve the central mystery. The broader group discussion highlighted how augmented reality games (e.g., ARIS or TaleBlazer) on mobile devices can change the way that players interpret and interact with objects on display. Using AR, objects on display can become clues in a mystery or components of a game; trigger audio, text or video information about an object; or allow visitors to interact with objects in ways that would otherwise be impossible in a static display. An added benefit is that AR has the potential to provide tailored informational or gaming experiences for different audiences (e.g., children, adults) within in a single exhibit.

Most museum-designed games are educational and have explicit learning goals, but in some cases the most important thing a game can do is to change a players perception about the museum itself. When museums attempt to engage underserved, youth, and at-risk audiences, raising awareness of the museum and breaking down barriers (both real and perceived) between a learner and the museum is paramount. This came to the fore with the second focal question (helping youth to develop a lifelong interest in science). Both AMNH and FMNH have found that the games-based approach is a hook to engage younger and underserved audiences with a museum and with science. AMNH and FMNH are in historic, grand, and imposing buildings, but these structures can hinder approachability for young people. Gamifying learning within such a space can make a museum and its content more relatable. For youth who already have an interest in science, games can make them feel confident and capable, and encourage them to explore content more deeply. For youth who like games but are not interested in science, games can reveal the commonality in approach between games and science (solving problems, going on a quest), making science seem more interesting and relevant.

Increasingly, museums are using games to engage and educate younger audiences, but how are museums measuring the impact of games-based learning? Given the limited resources available to museums, most games-based learning experiences are evaluated internally, but not externally. Museums typically have to be selective about which experiences merit external evaluation and rarely have funding for longitudinal tracking. Smaller, intensive in-person experiences like FMNH's Conservation Connection (Aronowsky et al., 2012a) and the I Dig Science collaboration with Global Kids (Aronowsky et al., 2012b) have yielded very promising results on a small scale. External evaluation of I Dig Science (Childs and Peachey, in preparation; Steinkuehler et al., 2012) showed that the program encouraged participants to explore career landscapes and workplace literacies that they may not have previously considered, and created an enjoyable and highly engaging environment in which to acquire and practice science skills and learn science content.

Given that the vast majority of science engagement in the U.S. is informal (Bell et al., 2009; Falk and Dierking, 2010), participants raised the question of whether museums should be solely responsible for evaluating the impact of their games-based learning experiences. Most participants felt that the onus for evaluation lay equally with museums and with learning scientists. A commenter suggested that we need a new infrastructure and new, more stable partnerships between museums and academia to support formative, summative, and transformative evaluation. When museums have to select individual programs for evaluation and dissemination, valuable data on learning experiences are lost. As museum practitioners who believe in the importance of informal institutions for changing attitudes about and increasing competencies in science, we fully support such collaborations and encourage dialogs that would foster such partnerships.

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