The Game of Curiosity: Using Videogames to Cultivate Future Scientists

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INTRODUCTION: USING VIDEOGAMES IN SCIENCE EDUCATION

According to a report from the National Research Council (NRC, 2011), children have an innate curiosity about the natural world, yet many students loose interest in science after elementary school. A national survey of middle- and high-school students reports that only 20% of the students surveyed expressed an interest in science as a career (Project Tomorrow, and PASCO Scientific, 2008). Mayo (2009) suggests one way to increase the number of students interested in science is through videogames. Her initial work indicates learning through videogames can yield a 7%–40% positive learning increase over standard learning through lectures.

A key component inherently built into videogames is trying something, failing, and then unabashedly trying again. This "we will all fail" concept is counter to the "everyone is a winner" perception that is proliferating in our culture, where sporting events issue medals and trophies to anyone who participates, the suburbs are littered with "My child is an honor student" bumper stickers, and high-schools have not one but multiple valedictorians (Best, 2011). Most videogames, to the contrary, are considered boring if everyone wins all the time. Similarly, scientists rarely excel if they do not experience failure to some degree. A recent article by Gerber (2012) posits that to prepare our future scientists, we need to teach them how to experience failure, over and over again, and to teach them how to learn from their failure. Gerber claims today's science educators are doing the opposite, conveying that failing at science, even a little, is unacceptable.

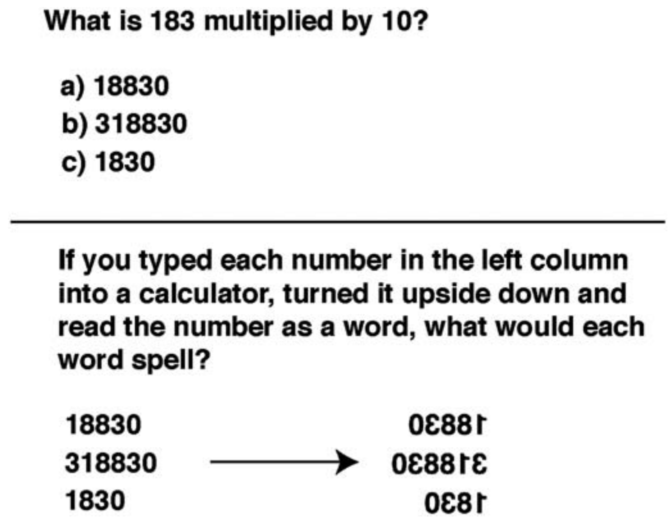
Although conclusive evidence is not yet in place, research suggests that using gaming to present scientific concepts can engage our younger generation of science learners and get them interested in learning (Wang and Hannafin, 2005; Federation of American Scientists [FAS], 2006; Kirriemuir and MacFarlane, 2006; Kiili and Lainema, 2008; Hines *et al.*, 2009; Mayo, 2009; NRC, 2009, 2011; Rideout *et al.*, 2010; Entertainment Software Association [ESA], 2013). Given the proper learning environment there can be an increase in student engagement, scientific inquiry, and scientific learning (e.g., Moher *et al.*, 2005, 2010; Dede, 2009; Ouyang *et al.*, 2009; Coyne *et al.*, 2010; Kilb *et al.*, 2012; Kilb, 2013). Based on our experience, we believe that using videogames as an educational tool increases our chance to engage students who experience frustration because of learning difficulties and/or students who lack the self-confidence to excel and ask questions. The gaming platform also allows the student to be in charge of their education, which is often the key to increase motivation and potential (e.g., Mayo, 2009; Hess *et al.*, 2011). We expect this type of learning is particularly important for students who do not excel in traditional learning environments.

There are a growing number of schools, museums, and science centers that use gaming as part of their exhibits and programs (Beale, 2001; FAS, 2006; Kirriemuir and MacFarlane, 2006; Honey and Hilton, 2011; ESA, 2013; Gewin, 2013). For example, opening in 2009 the noncharter, public *Quest to Learn School* in Manhattan, New York, uses strictly a game-based curriculum. This school, which started with only sixth graders, is now expanding to include both middle- and high-school students. In 2011, the Tech Museum of Innovation in San Jose, California, opened the Tech Test Zone Gallery, which is a 1000-square-foot space of innovative game prototypes that showcase emerging technologies. The relatively new field of educational gaming is also of interest to the White House. In the fall of 2011, Constance Steinkuehler was hired as a senior policy analyst for the White House Office of Science and Technology Policy (OSTP) and assigned the task of studying the impact of videogames and how play relates to learning (Steinkuehler, 2013). Steinkuehler's job was to advise on national initiatives related to games for impact.

Currently over 97% of children play videogames (Irvine, 2008); yet, in spite of this clear trend, there is a vast divide between videogames and science education. Videogames are primarily reserved for after dinner, after homework, and after chores. Because videogames are commonly used and accepted in popular cultures, especially by today's youth, we want to leverage that excitement in science education. Here, we investigate to what extent videogames can be used to entice someone to continually play, learn, and explore (Fig. 1). The videogame we developed merges socially relevant topics (what to do when a large earthquake strikes) with scientific topics (how do seismologists study earthquakes).

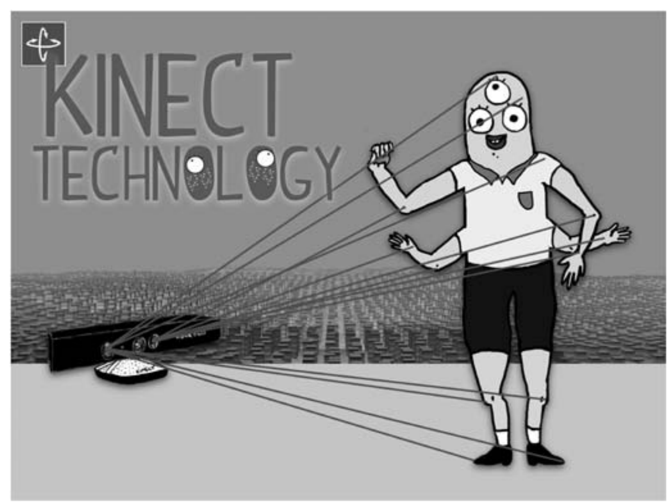
In this work, our team (Fig. 2) uses the Microsoft Kinect technology to explore whether or not a fast-paced zany seismology videogame can be used to entice a student to play and

doi: 10.1785/0220130182



▲ **Figure 1.** Videogames should avoid requiring players to memorize facts and instead encourage players to explore. (Top) Traditional quiz questions, such as this one, are not that interesting to today's gamers. (Bottom) Tasks that challenge the player to think in unusual ways are more apt to keep the players attention. The curious player would figure out the answer to this question is "Debbie," spelled in different ways.

▲ **Figure 2.** Our project team includes people from different disciplines.



▲ **Figure 3.** The Kinect technology tracks the players' skeletal motions using near-infrared lights (indicated by the lines in this cartoon). In this way, the players use their bodies to control game play. Many people prefer this type of controller-free environment, especially those who find traditional game controllers intimidating.

learn. We target 8- to 12-year-old players because research indicates early exposure to science is an effective way to refute protests of "science is hard and boring" (Eshach and Fried, 2005). Our goal is to get the player to look at failure as a challenge, not a stigma, and to provoke their curiosity in exploring scientific unknowns. The player plays the role of a scientist, making decisions about seismic station deployment strategies similar to decisions made by today's seismologist. The game also allows the player to participate in the immediacy of deploying seismic sensors as quickly as possible to record aftershocks. Pretending to be a seismologist and making decisions about station deployment strategies at first sounds very boring to some students, but we have found that almost all students who play our game at some point during the game will smile, laugh, or giggle.

GAME OVERVIEW

Our game is based on the Quake Catcher Network citizen science project (Cochran *et al.*, 2009, 2011; Chung *et al.*, 2011; Lawrence *et al.*, 2014). In general, citizen science projects are projects that enlist the help of the general population to assimilate, examine, and/or collect scientific data (Cohn, 2008). Citizen science projects are typically designed so anyone can participate, requiring minimal setup time to become operational. The citizen science project that our videogame emulates, the Quake-Catcher Network (QCN) project, is a collaborative initiative for developing a large, low-cost, strong-motion seismic network. This network is made up of small (about the size of a matchbook) $50 seismic sensors that attach via a USB connection to internet-connected computers. The price of the sensor drops from $50 to $5 for sensors that will be deployed in schools (QCN, 2013). Currently, there are over 2700 QCN seismic sensors installed globally in homes, schools, and offices. Our game promotes the QCN citizen science project, highlighting the network logistics and its unexpected challenges.

Our game uses the Microsoft Kinect, which allows for controller-free gameplay (Fig. 3). The Kinect is a motion-sensing device that can respond to the players' motions. The Kinect can calculate if the player has one or two hands raised above their head and if the player is crouching or standing. The Kinect works through a camera that transmits invisible near-infrared light and measures its time of flight to reflect off an object, allowing it to distinguish objects within 1 cm in depth and 3 mm in height and width. This controller-free environment is an inexpensive tool for informal education (i.e., no controller to secure or sanitize) that makes the game accessible to players of all ages and is user friendly to those who do not have experience with videogames. Requirements to setup the gameplay in your local environment include obtaining (1) the Kinect hardware ($150), (2) a computer with a Windows operating system (Mac users can use a Windows emulator), and (3) our game software (available for free download, SIO Games, 2014).

The player in our game is a seismologist responding to a large earthquake. Similar to today's seismologists, when the player becomes aware that an earthquake just occurred in their city, they must act quickly to deploy seismic sensors in buildings to record the impending aftershocks (Fig. 4). When gameplay begins, players first select a building where they want to deploy a seismic sensor. At this point, the main gameplay is paused, and the player is asked to complete one of several science-based minigames that are designed to interactively teach the players about geoscience-related concepts (Table 1). These minigames communicate ideas such as safety themes, seismic station deployment techniques, seismogram reading instructions, and basic concepts of plate tectonics among others. To learn about these concepts, the player has to actively participate in the testing and safety procedures by, for example, ducking under a sturdy table, correctly securing a seismic sensor to the ground, and gathering items for an earthquake survival pack. This type of active gameplay not only has health benefits (Maddison *et al.*, 2013), but findings show learning is most effective when players are tasked with both physical and intellectual challenges (e.g., Mayo, 2009). If the player successfully completes the minigame challenge, the sensor is installed in the chosen building. If not, the sensor is not installed, and they return to select another building. Gameplay continues in this way, where the player repeatedly selects different building locations and is then challenged to complete a minigame with the aim of setting up as many sensors as possible. The game ends after the first aftershock, at which point the player's score is calculated according to sensor placement. Sensors placed closer to the epicenter of the aftershock score more points than do more distant sensors.

▲ **Figure 4.** Our videogame begins with an earthquake, and the player is assigned the role of a seismologist who needs to quickly deploy seismic sensors throughout the city. The player picks any building in the city, and a seismic sensor is installed at that location if the player successfully completes a minigame. The game ends after the first aftershock.

FINDINGS

Players ranging in age from 5 to 85 years old have played our videogame at a number of different venues, including demos for school groups, science camps, scientific meetings, and outreach programs. At these events some of the tween (ages 10–12) and teen (ages 13–19) students seemed put-off by the game because, we assume, that playing it might potentially lower their "cool" status because, as they see it, science is not cool (Ruben, 2012). Also shying away from gameplay were those who appeared selfconscious about their bodies and did not like the game format in which one person stands up to

Table 1
Description of Minigames

	Minigame Name	Description*
1.	Clean	Remove dirt and debris from the surface where the seismic sensor will be installed. {Use both arms in large sweeping motions to clean the floor.}
2.	Compass	Align the arrow on a compass to north. {Arms out to the right/left until alignment is correct.}
3.	Convection	Track mantle convection currents until molten rock reaches the surface. {Quickly move both hands in a circular motion in the direction of mantel convection until the tectonic plates above become separated and molten rock flows to the Earth's surface.}
4.	Emergency	Identify items that belong in an emergency kit. {Selection of items using one hand.}
5.	Epicenter	Locate a given a longitude and latitude coordinate on a map. {Place star at correct location on a map using one hand.}
6.	Magnitude	Reproduce the logarithmic magnitude scaling law by producing 10 times more motion for a magnitude 4 earthquake than a magnitude 3 earthquake. {Full body motion including arms, legs, and head.}
7.	Maze	To assist someone with their seismic station installation, drive your car through a maze of streets to their designated location. {Navigate using arm motions to turn your car right and left.}
8.	*P* wave	Identify the *P*-wave component of a seismogram. {Place missing puzzle piece in correct location using one hand.}
9.	Permission	Ask for permission to install a seismic sensor in a home, office, or school. {Using two hands knock robustly on doors.}
10.	Plates	Given a map that shows the largest seven tectonic plates, select a particular one. {Use one hand to hover over the correct plate.}
11.	Power	Avert a power outage problem by hooking up a generator. {Search in the dark for the generator using a flashlight that is controlled by one hand.}
12.	Safety	Practice "Drop, Cover, and Hold On" by crouching down under a sturdy table. {Drop, cover, and hold on.}
13.	Steal	Someone has stolen your seismic sensor, and you must run to catch them. {Running in place with knees high.}
14.	Tape	Secure your seismic sensor to the ground using Velcro tape. {With one hand, grab the tape and place it at the designated location, then grab the seismic sensor and secure it in place.}
15.	Test	Test that the seismic sensor is working by jumping and confirming the data shows a wiggle record of your jump. {Jumping up and down as high as possible; to successfully complete the game, both feet must be over six inches off the ground for at least three jumps.}
16.	Travel	In preparation to respond to a large earthquake, pack 200 seismic sensors in your suitcase. {Use either your left or right hand to select the seismic sensors from a bookshelf and move them into your suitcase.}
17.	Trilateration†	Locate an earthquake using the concept of trilateration by placing a marker at the intersection point of three or more circles. {Use one hand to place a marker on a map.}
18.	Speed†	Estimate how long it will take a seismic *P* wave (which travels at ~11,000 miles per hour) to travel from one famous landmark to another. Two locations are displayed on a map, and the player sets a stopwatch to their estimated time. {Use one hand to set the stopwatch to the desired time; repeat as needed until the correct value has been reached.}

Minigames are listed here alphabetically, but during gameplay the minigame order is chosen at random. The minigame design is modular so improvements and augmentations can be easily incorporated.
*Type of motion required to complete the game is indicated in curly brackets.
†This minigame is being considered for development and is not in the current release of the software.

play the game while the others watch. People in both of these groups, however, often participated in the audience banter by yelling out suggestions and answers to assist the players.

The goals of our game are to engage players in activities related to seismic station deployment techniques and safety measures and to introduce scientific concepts in a lighthearted environment so the player can begin to understand what it is that seismologists do and to grasp the broadscale idea that science is about exploring. During internal testing events in our lab with a select group of students of various ages, we found many players would hypothesize how to receive the most points (Fig. 5). Some suggested deploying all their sensors in a clump in the hopes that the first aftershock occurred near the clump (i.e., relying on luck not scientific strategy). Others recommended distributing the seismic sensors uniformly throughout the city to increase the probability of having a deployed sensor close to the first aftershock location. As the players figured out, both methods have pros and cons.

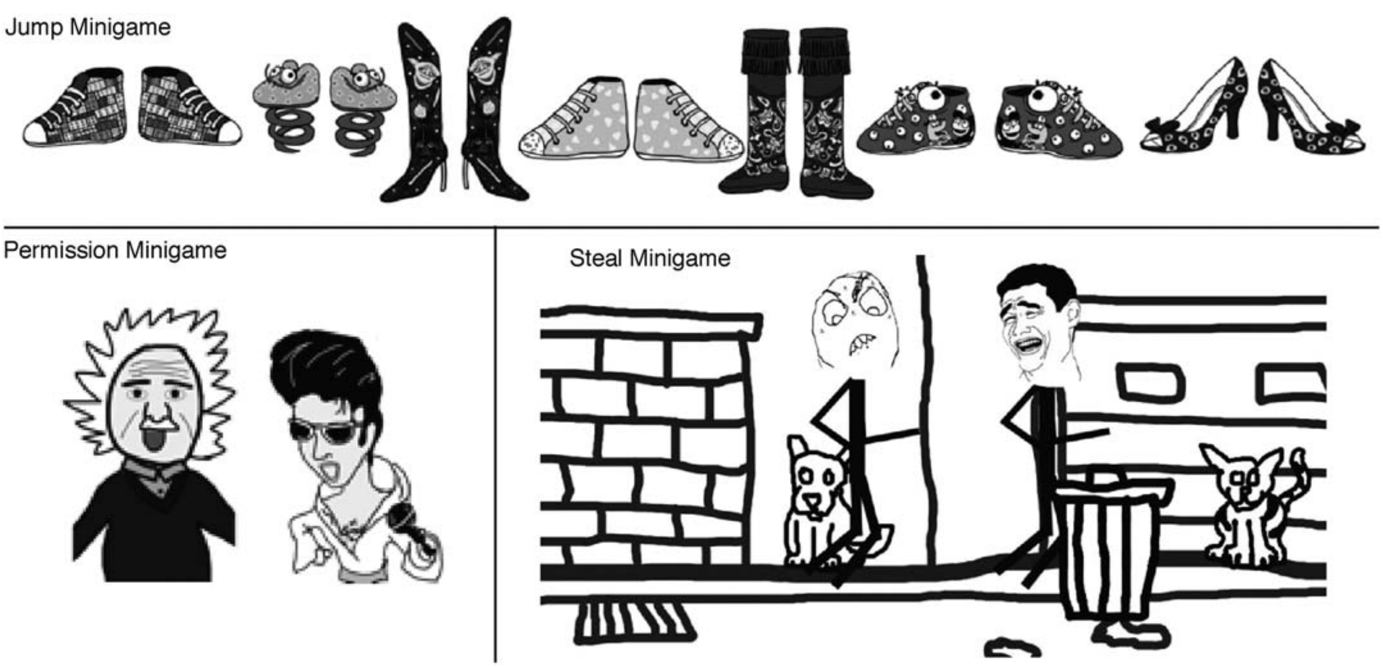
▲ **Figure 5.** To allow the players to be in charge of their education, we do not dictate what the best game strategy is to successfully complete the game. Instead, the players themselves must determine the best game strategy by trial and error. This format of learning mimics the methods of advanced scientists.

Although earthquakes can cause horrible tragedies, the focus of our game is on learning and safety. To inform rather than scare the players, we use a unique art style in the form of zany cartoon characters and other brightly colored visuals for our game. These range from the bizarre to the ridiculous and help maintain a very positive and exciting mood during gameplay that is conducive to learning. These visuals complement the fast-paced game. The 2D images within the minigames each have their own unique art style (Fig. 6) to help keep player's attention and interest. The cartoon animations (Fig. 7) and video scenes that help explain the details of the seismic topics are also comedic and fun to watch. With this wide variety of visual media, our game's fast pace competes well with non-educational videogames.

Photos taken by the Kinect are shown to the player after each minigame, often capturing the players' look of determination and enjoyment; and, because the game requires so much physical agility, the photos often catch the player in unique and amusing positions. Using a small portable photo printer, players have the opportunity to print their action photos on glossy photo paper to take home as a souvenir. Printing a photo is not required, but because the player typically has 4–5 action photos to choose from, almost all students find at least one photo that they want to print.

WHAT PLAYERS ARE SAYING

In the spring of 2013, we demonstrated our game for sixth-grade students (one teacher, four different science classes) at a middle school in San Diego, California. In each of four different class periods, the teacher identified a set of ~5–8 students who had completed their homework. Throughout the class, we would randomly chose one student from the list to play the game. The remaining ~20 students not playing the game were encouraged to help the player by shouting out suggestions: "The Antarctic plate is that one at the bottom that is red!" or "The *P*-wave is the first arrival!" At the end of each class, the students (a total of 102 students) took a written survey about what they thought of the videogame, the Kinect technology, and science in general (Table 2). The majority (84%) of the students reported enjoying using the Kinect, with 97% of

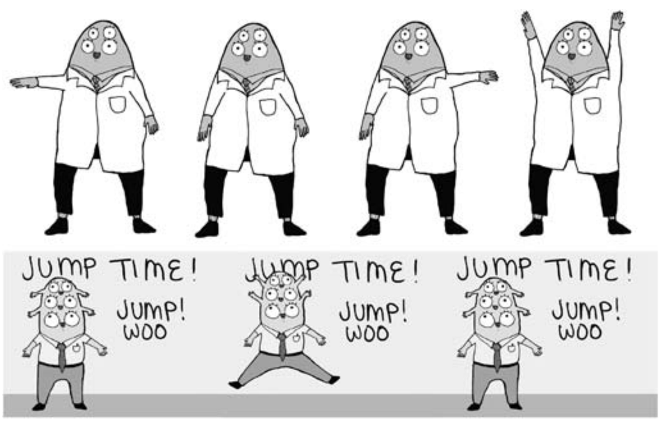


▲ **Figure 6.** The artistic "fun and whimsical" theme remains constant throughout our videogame, yet each minigame has a unique style.

Table 2
Select Survey Results from Sixth-Grade Students (Ages ∼11–12) Who Tested Our Game in April 2013

Question	Total Number of Responses	Yes	Maybe/Sometimes	No
Do you like the Kinect technology where your body is a controller?	100	84 (84%)	–	16 (16%)
Do you think the videogame we are showing you today is fun?	93	53 (57%)	37 (40%)	3 (3%)
Would you like to play this game again?	99	54 (55%)	40 (40%)	5 (5%)

Listed are the total number of responses and tallies of how the students responded to the questions. Associated percentages are shown in parentheses. The total number for each response is not the same for each question because some students did not answer all questions.



▲ **Figure 7.** Cartoon images are animated to instruct the player (top) how to navigate the scene and (bottom) how to test the seismic sensor.

students reporting that the game was fun, and 95% reporting an interest in playing the game again. These findings are consistent with verbal feedback we received at other game demonstrations in our lab, at the Birch Aquarium at Scripps Institution of Oceanography, and at the American Geophysical Union's Exploration Station.

CONCLUSIONS

Engaging players in an urgent time-sensitive response to earthquakes using a videogame with brightly colored cartoon characters is a novel approach to teaching seismology. We found that the Kinect motion sensor provides a unique game experience by incorporating body gestures and movements (such as ducking low, jumping high, running in place) and using arm motions to complete game challenges such as location selection. These physical demands depart from standard educational electronic games that involve only a traditional game controller. Emerging research suggests this type of gameplay learning is more appealing to the majority of children in our 8- to 12-year-old target age range than teaching methods that focus on memorization of facts and formulas (NRC, 2011). The gaming platform also allows the student to independently choose where to go and what to do, which increases motivation and potential. This type of learning is particularly important to students who do not excel in traditional learning environments (Mayo, 2009).

The structure of videogames strongly encourages imagination (e.g., in our game, the players imagine they are seismologists) and the fortitude to try again if something did not work as expected. The core commonalities between the format of videogames and how scientists at the top of their field conduct science are the concepts of exploration, curiosity, and the idea that failure, to some extent, is okay and expected. We think that the more educational video games can help highlight these similarities, either directly or indirectly, the more appealing scientific studies and careers will be to our younger generation.

ACKNOWLEDGMENTS

We thank Alan Kafka and an anonymous reviewer for feedback and suggestions that improved this manuscript. We also thank Judy Gaukel and Jennifer Matthews for their editorial and graphical assistance, respectively. We are grateful to the many students and teachers who provided feedback on our educational videogame. This work was funded by the National Science Foundation (NSF) DRL Grant Number 1222541, "ISE Pathways: Earthquake!" and NSF EAR Grant Number 1027807, "Collaborative Research: CDI-Type II: From Data to Knowledge: The Quake-Catcher Network."

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