D.E.E.P. Learning: Promoting Informal STEM Learning through Ocean Research Videogames

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Abstract
Serious games are increasingly being recognized as effective tools for STEM learning in both formal and informal education settings. We have developed a serious game based on the popular Microsoft Xbox360 gaming platform, that engages Informal Science Education Institution (ISEI) visitors in the exploration and understanding of the deep-sea environment and advances in ocean sampling technologies. The game, based on NSF research initiatives (Ocean Observatories Initiative; Ridge 2000 Program), provides highly visual, interactive interfaces that allow visitors to explore STEM content and concepts in the context of a compelling and otherwise inaccessible environment. Results of these efforts provide new intellectual insights into the role of serious games in motivating STEM learning and conceptual understanding in informal education environments.

Key words – education, outreach, informal science education, video games

I. INTRODUCTION

Videogames are increasingly being developed and used in STEM education disciplines in both formal and informal educational settings. Research is beginning to reveal what serious video game developers have long assumed – that scientific concepts across a broad range of disciplines can, in some cases, be more readily learned or more fully appreciated via the gaming experience (Mayo, 2009). Coupled with the fact that increasingly, videogames have become an integral feature of modern American culture and family (Rideout *et al.,* 2010; ESA, 2011), the idea that interactive games can be used as effective tools for STEM education is rapidly growing.

Recent advances in the learning sciences suggest that games have great potential to support new approaches in science education (e.g., inquiry-based approaches) by advancing multiple science learning goals, including "… motivation to learn science, conceptual understanding science process skills, understanding of the nature of science, scientific discourse and argumentation, and identification with science and science learning." (NRC, 2011). It is generally recognized that games also have the potential to promote the development of specific, valuable learning and life skills, including data processing, decision-making, critical thinking, planning, communication and collaboration (Kirriemuir and MacFarlane, 2006). But the research and development of educational games, and the study of the educational value of serious games in general, have lagged far behind the same efforts for games created commercially for the purpose of entertainment.

In this project we have examined the efficacy of educational STEM video gaming within the specific context of informal science education. Although efforts to improve the understanding of gaming as an effective educational tool in the formal education environment have increased in recent years (e.g., Games for Learning Institute), less work has been done to explore the same application of videogames in informal learning settings, and in particular in informal science education institutions (ISEIs; e.g., aquariums, museums, science centers). The use of games in informal science learning presents an opportunity to improve the public's scientific literacy (Squire and Patterson, 2009). ISEIs are desirable settings for videogames because they:

- are regarded as venues for both entertainment and education,
- draw large audiences (tens of millions annually) that are culturally, socio-economically and generationally diverse,
- facilitate social learning experiences, and
- are largely free of the traditional pedagogical and logistical constraints and biases of classroom learning environments (NRC, 2011).

II. GAME DEVELOPMENT

Over the last ~5 years scientists and educators from the National Science Foundation (NSF) Ocean Observatories Initiative Cyberinfrastructure program (OOI CI), the Birch Aquarium at Scripps (BAS) and the NSF Centers for Ocean Sciences Education Excellence – California (COSEE–CA) have collaborated on developing and testing a game created for the Xbox360 platform titled Deep-sea Extreme Environment Pilot (D.E.E.P.; http://deep.ucsd.edu). In the game, the player assumes the realistic role of a remotely operated vehicle (ROV) pilot who is challenged to complete a scientific dive plan within a specified time-limit. The game play has three levels: a deep-sea hydrothermal vent environment, an

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underwater network of ocean observation instruments, and a deep ocean coral reef environment. The players must complete a series of tasks to collect points and advance to the next level of play. As players interact with the environment (e.g., a hydrothermal vent, an ocean-bottom seismometer, various organisms) they must use the ROV features to take samples, measurements, and photographs. If they choose, they also have the opportunity to learn about what they encounter via on-screen windows that are accompanied by embedded text, images, video and voice-over narration. The D.E.E.P. game design follows that proposed by Clark et al. (2009) and includes:

- targeted science learning goals (motivation and conceptual understanding),
- short duration (several minutes),
- participation via a virtual world (the deep-sea), and
- a purposeful curricular focus (i.e., game play is based on realistic scientific endeavors).

In this way, the D.E.E.P. player experience differs from standard learning simulations in that the player's actions and decisions within the game alter the game outcome, and player's are provided with continual feedback to help the player progress towards their goals.

The development of our game has also been guided by specific content-driven learning outcomes that include concepts such as:

- Exploration and discovery play an important role in the process of scientific research of the ocean.
- The deep-sea environment covers a significant part of the Earth's surface yet remains largely unexplored.
- The use of technology allows scientists to develop a better understanding of the ocean and the seafloor.
- Scientists are creating observatories, which are groups of different instruments that collect scientific measurements and samples both in and above the ocean.
- Observatories provide scientists with data on scales not previously available using traditional sampling and measuring techniques.

These outcomes have served as a starting point for the games, and it is anticipated that they will continue to be revised and refined based on additional progress and findings. More broadly, we anticipate that players will improve their understanding of the uniqueness and mystery of deep-sea ecosystems, the technologies that scientists are using to better sample and understand our global ocean, and the process of scientific research.

III. PROTOTYPE TESTING

Informal trials of the prototype games in the last two years with visitors at Birch Aquarium at Scripps (BAS) resulted in positive feedback regarding the use of the Xbox360 game platform in the Aquarium setting, as well as the focus on deep-sea exploration and technology content. A formal evaluation of the first generation game prototypes, including changes incorporated after the initial informal trials, was conducted with thirteen participants of various ages over a two-day period at BAS. Led by an evaluation team from the Lawrence Hall of Science (UC-Berkeley), these efforts proved to be most informative regarding the design and usability of the game (controller use, instructions, navigation, layout), and less insightful for assessing the impacts of the game on content knowledge or conceptual understanding. Perhaps not surprisingly, players were less inclined to pay attention to the science content of the games if their attention was diverted to understanding the basic elements of game play.

Players' reactions to the game prototypes were overwhelmingly positive, and the novelty of using a popular gaming platform in an ISEI environment generated excitement across all ages. Almost all players expressed an interest in playing the games again, and would recommend them to others. All but the youngest players were comfortable using the game controllers, which may be an artifact of relatively high fidelity among most console controller designs, regardless of brand (the Wii is an obvious exception). Although controller use may be a threshold for some segments of the informal audience, the use of a controller also realistically simulates how pilots actually control an ROV in the ocean. Controller expertise may ultimately become insignificant as consoles and games are increasingly employing 'natural user interfaces' that interpret body motions to control game play (e.g., Microsoft Kinect), and we are exploring the potential of this approach for broader audience appeal.

The design team has continued to implement changes to the game navigation and instructions based on the evaluation data, and to refine basic elements of game play, including increased interactivity, features, and background information. These changes have been guided and informally evaluated by periodic testing of the game in various informal learning venues (e.g., Birch Aquarium student summer camps, American Geophysical Union Meeting 'Exploration Station' public event, NOAA public events at the Aquarium of the Pacific). Progress has been promising, as evidenced by the selection of D.E.E.P. as a top-10 finalist in the 2011 NSF International Science and Engineering Visualization Challenge in the category of 'Interactive Games'. Currently, the game prototypes are fully functional and ready to be further refined through the proposed iterative design process.

Testing our games in museum settings, ISEIs, and classrooms has allowed us to qualitatively assess the educational gaming techniques that work and those that do not. We have discovered that elements such as audio

queues and voice-overs play a powerful role in holding a player's attention. We have also found that having learning built into the gameplay is often more effective than directly quizzing the player's knowledge. Players' engagement also increased when presented with unfamiliar and unexpected elements with which they could interact, and when experiencing game features such as controller vibration when colliding with objects or the seafloor. The duration of the game is another important factor and can lead either to overwhelming frustration if too short or boredom if the game stretches on too long. Finally, the players clearly expect high quality visuals (Figure 1).

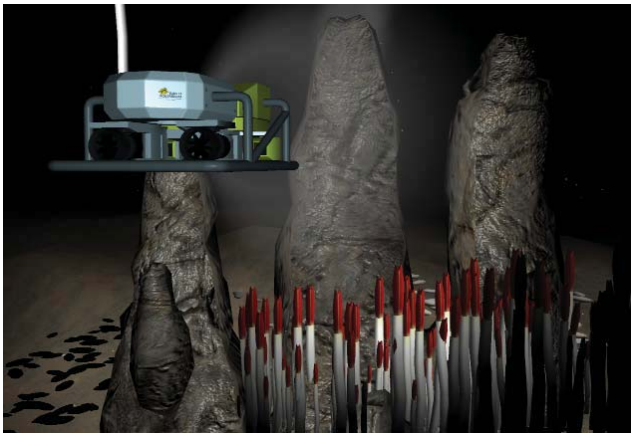

Figure 1: Snapshot of the D.E.E.P. videogame showing the ROV, tubeworms and a hydrothermal vent on the sea floor.

IV. FUTURE WORK

The challenge of creating a gaming experience that is both effective and efficient, and one that serves to inform the creation of other digital STEM education experiences, is at the core of this project. We intend to continue the development of the D.E.E.P. games with the benefit of rigorous evaluation efforts rooted in current findings of the learning sciences community. These efforts will help to inform several of the key challenges related to educational gaming collectively identified by the National Science Foundation, the Federation of American Scientists, and the video gaming industry, including:

- identifying the role of games and simulations in learning,
- designing the pedagogical process in games and simulations,
- identifying the best features of games to apply to learning,
- understanding how specific game features (e.g., challenges, stories/scenarios) support motivation and learning,
- determining the amount of learning that can take place over time (i.e., educational density)
- understanding the effect of immersion and engagement on learning motivation (FAS, 2006).

In particular, the learning goals of motivation and conceptual understanding will be considered relative to the characteristics associated with a learning experience in an ISEI setting (e.g., self-directed and diverse audiences with limited time availability and/or attention spans) (NRC, 2009). Few examples exist of research that has focused on determining the ability of games to motivate interest in science and improve conceptual understanding, and the findings that exist are inconclusive and have almost exclusively targeted classroom learning (NRC, 2011).

Guiding questions for assessing the learning outcomes of the project include:

- Can serious games motivate interest in STEM learning in an ISEI setting?
- How might motivation inspired by serious games differ among subpopulations of ISEI visitors (e.g., mutigenerational groups, adolescents, females, traditionally underrepresented minorities)
- Can serious games enhance conceptual understanding of science in an ISEI setting?
- Do serious games support learning outcomes differently depending on whether they are independent experiences, or employed in conjunction with other related ISEI resources and experiences (e.g., exhibits)?

V. SUMMARY

The D.E.E.P. project will contribute to the nascent body of knowledge regarding the use of serious digital gaming in informal science education institutions. Such work is critical to understanding how popular digital technologies, which have become omnipresent and familiar facets of daily life for most Americans, can serve as effective educational tools in support of STEM learning and literacy in informal environments. The D.E.E.P. project exploits high-quality, cost-effective resources (commercial gaming platforms and software) to inform the development of potentially transformative products and approaches to informal STEM education. Specifically, insights are being gained regarding how design elements and player engagement support informal learning through the use of digital games.

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