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Michail N. Giannakos
Old Dominion University

David Jones
Old Dominion University

Helen Crompton
Old Dominion University, crompton@odu.edu

Nikos Chrisochoides
Old Dominion University, nchrisoc@odu.edu

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Designing Playful Games and Applications to Support Science Centers Learning Activities

Michail N. Giannakos[1,2], David Jones[1], Helen Crompton[1], and Nikos Chrisochoides[1]

[1] Old Dominion University
Norfolk, VA, USA
[2] Norwegian University of Science and Technology, Trondheim, Norway
{mgiannak,nikos}@cs.odu.edu, {djone564,crompton}@odu.edu

Abstract. In recent years there has been a renewed interest on science, technology, engineering, and mathematics (STEM) education. Following this interest, science centers' staff started providing technology enhanced informal STEM education experiences. The use of well-designed mobile and ubiquitous forms of technology to enrich informal STEM education activities is an essential success factor. The goal of our research is to investigate how technology applications can be better used and developed for taking full advantage of the opportunities and challenges they provide for students learning about STEM concepts. In our approach, we have conducted a series of interviews with experts from science center curating and outdoor learning activities development, with the final goal of exploring and improving current learning environments and practices. This paper presents the development of set of design considerations for the development of STEM games and applications of young students. An initial set of best practices was first developed through semi-structures interviews with experts; and afterwards, by employing content analysis, a revised set of considerations was obtained. These results are useful for STEM education teachers, curriculum designers, curators and developers for K-12 education environments.

Keywords: Design Guidelines, Considerations, STEM Education, Informal Learning, Technology Enhanced Learning, Design for All, Best Practice, Field Trips, Science Centers.

1 Introduction

In recent years there has been a renewed focus on science, technology, engineering, and mathematics (STEM) education [19]. According to the Association of Science-Technology Centers (ASTC), which represents 353 U.S. science centers and museums, science centers and museums see nearly 63 million visits each year. In addition, young generations are growing up in a digital age and are often familiar with various forms of technology, especially mobile and ubiquitous technology. Using these forms of technology via playful applications can promote and enhance students' mental exercise, fantasy, creativity, and communication [2], [7]; however,

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the introduction of technology applications in informal learning activities and science centers is often complex, and students do not always use them as expected [9], [27]. Additionally, students do not perform as expected when they are using them [11].

Based on these conditions, the opportunity to improve technology enhanced learning within the context of science centers is to learn how to design games and application in order to engage students and optimize informal outdoor learning. In our efforts to investigate how interactive games and applications could be better designed in order to motivate students during a museum visit, we conducted a series of semi-structures interviews with experts in order to capture their ideas and experiences with regard to the development of informal STEM activity. Next, we employed a content analysis technique [15] in order to organize the data. As the final step of the process we used the structured data and derived guidelines for improving the design of STEM games and applications focusing on young students.

2 Related Work

Dale [6] indicated that rather than learning through abstract thinking, students should learn from concrete experience, such as direct experiences (real-life experiences), contrived experiences (interactive models), and dramatic participation (role plays). Outdoor education often provides learners with first-hand and concrete experience, which connects the learner with real people and real issues [10]. Woodhouse & Knapp [26] postulated that outdoor education aims to provide learners with meaningful contextual experiences by using both natural and constructed environments. This method further gives teachers and students an opportunity to complement and expand classroom instruction with print and electronic media. The outdoor environment, although extremely beneficial, is often neglected by teachers, curriculum developers, and researchers [17]. Moreover, when carrying out outdoor education, teachers must consider using limited teaching materials, which often impede effective instruction [28].

Informal learning is becoming increasingly popular, and mobile technology in particular has opened up a vast range of possibilities concerning learner feedback [16], context awareness opportunities, and reinforcement [16] [4]. Prior research on interactivity in learning has shown that the interactivity of the devices can improve students' learning [14]. The success of handhelds as museum guidebooks and learning systems [24] [25] is apparent from the growing interest in the use of interactive devises as learning tools in informal learning contexts. Previous research [12] has revealed the benefits of certain properties of mobile technologies (i.e., portability, environment, sensitivity) in informal learning. Although there has been much research on how mobile devices can support and enhanced learning [23] [5], limited empirical work currently exists focusing on students' needs and how the current design and development can reinforce and enhance learning. In this study, we focus on design practices for the successful development and use of technology devices to support learning within informal settings (with particular focus on STEM disciplines).

Gaming activities provide structure for collaboration and promote students engagement through rewards. It also provides a context to these activities (e.g., with materials in the aquarium). As such, students are motivated to interact and be engaged throughout the learning process in a way that is meaningful for them [21]. Learning by playing encourages interactions and stimulates collaboration [22]. Collaborative playing requires different skills to be deployed simultaneously [12]. Evidence of students' performance of learning by playing has been shown to leverage their experience with the learning context and increase the educational effectiveness [18]. In addition, learning by playing has been successfully applied in history [1], arts [12], cultural heritage [3], and mathematics [25]. In all cases, gaming elements (e.g., co-operation, competition, score, time limits) can motivate and attract students [16]. In this study, by extracting knowledge from experts, we identify effective design patterns to support the development of technology applications to support STEM learning.

In particular, our research is intended to shed light in the area of how games and applications could be designed to motivate students for informal learning activities, especially in STEM disciplines. We conducted field studies, collected empirical data and provide insights that enable scholars and educators to efficiently design and develop applications to support STEM field trips. Our research follows a three-step process (Figure 1). In the three consecutive steps, we proceed with the data collection, data analysis and ending up with the design considerations.

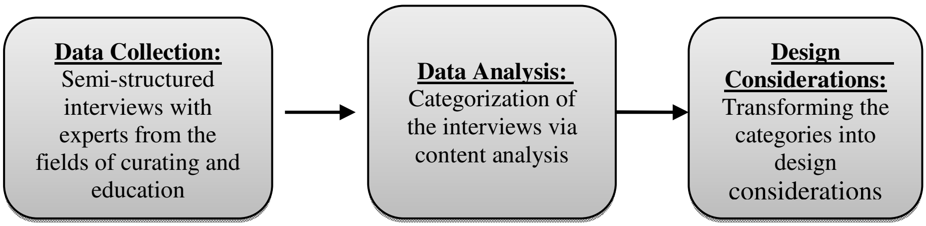

Fig. 1. Overview of the research process

3 Methodology

3.1 Procedures and Participants

During the initial research phase we contacted experts from the area of science center curating and informal learning activities development. In particular we arranged and implemented semi-structured interviews with the Director of Education and the Instructional Technology and Outreach Specialist of the Virginia Aquarium & Marine Science Center, as well as corresponded via email with a science education consultant for the aquarium.

We chose to conduct semi-structured interviews to gain insight in preconditions, practical implications, and success factors of K-12 informal learning activity in science centers. We started the interview by asking the interviewees to identify some of the challenges of teaching high school students in informal learning settings, such as the Virginia Aquarium. Following we discussed best practices and recommendations for teaching high school students in informal learning settings. The interviews continued by addressing the main challenges of teaching high school students STEM curricula through an informal technology enhanced learning environment. The interviews lasted approximately 1 hour with the Director of Education and 45 minutes with the Outreach Specialist. The researcher recorded the interviews and kept notes.

3.2 Data Collection and Analysis

As aforementioned, these data collected were from interviews with experts. A semi-structured interview guide was used in the personal in-depth interviews. Interview questions were designed to probe for different aspects and difficulties of informal learning and designing materials to support field trips.

Following the interviews the material was transcribed and evaluated, then it became clear that the point of saturation was reached and interviewing more experts was not expected to provide radically different or more in depth material. After the interviews collection, we proceed with a content analysis. The researcher read all responses first, and coded important keywords until categories emerged from similar codes.

In particular, the researcher coded the answers and discussion reasoning from the expert into different categories of informal learning. Next, he coded these ideas and practices into design considerations. Content analysis is a technique used to categorize data (e.g., interviews, ideas) through a protocol. Content analysis enables the researchers to sift through large volumes of data and systematically identify properties, attributes and patterns embedded. The technique is considered useful for identifying and analyzing issues in gathered data [15].

4 Research Findings

Next, we present the extracted design guidelines by giving a brief description with some sample coded phrases and some illustrative examples.

1. The structure must be easy and understandable

Description: The gaming application should avoid overly complex operations and tasks, which can produce user frustration and disappointment. The user should be able to immediately understand any on-screen instructions, and promptly begin assigned tasks. As the experts noted, "The application must be user-friendly. Usually, the easiest systems are the best." They suggested that game creators should "start small" and build from that point.

Example: The game's control panel and format should be simple to understand, so the user can focus on game content while enjoying smooth operation.

2. Use Visual and Interactive Elements

Description: The majority of game material should be conveyed through visual and interactive means instead of written. According to the Instructional Technology and Outreach Specialist, "*75% of people are visual learners and would thus benefit more from visual elements*". The user very quickly will be overwhelmed from too much written material "*There is some data that shows only 13% of your guests really ever read written material that's there for interpretive purposes*," noted the Director of Education in regards to the aquarium's exhibits. "*There is plenty of information around, but they [students] don't take the time to read that because they are busy looking at things*." Written material should be kept to a minimum, with only the most important information being put in print or better the screen of a mobile device.

Example: Having an animated narrator provide gaming instructions would be one possible method. Using diagrams instead of writing to explain different parts of a system (e.g. the water cycle) is another possible way to convey information. For instance, when the game's key character is floating down a mountain stream, the game could visually show his vessel rocking in the current and the water rippling across rocks. The sounds of chirping birds and bubbling brooks could resonate in the background. This would create a realistic sensation for the user and promote engagement.

3. **Incorporate Entertaining Responses for On-Screen Actions**

Description: Game users enjoy receiving "cool" or surprising responses when they complete an action. The more they anticipate responses, the more they will experiment with different actions. "*Students find it engaging when they get an answer right and something 'cool' happens on-screen*" the Director of Education explained. "*Particularly when they can play around on their own cell phone – that is the type of thing that is appealing to that audience*" Both the experts emphasized about the importance of animation.

Example: When users complete the correct action, a pop-up congratulatory message could appear, perhaps with some cash or other reward. Conversely, when they commit an error, they receive a negative response. Their character could fall, be bitten by an animal, or loose valuable resources whenever mistakes are made. Surprising or humorous responses, when accompanied by special sound effects, can be especially entertaining.

4. Enhance Interaction with Large Touch-Screen

Description: Large touch-screens provide enhanced viewing and interaction. According to the science education consultant, improving interaction in games is critical. "*Teachers are looking for interesting ways to engage their students with [STEM material], so the more interactive the app can be, the better it will be received.*" Incorporating a large touch-screen is one way to promote more engaging interaction. The Instructional Technology and Outreach Specialist explained that in her experience, the most engaging and well-received applications are those performed on large touch screens. During the interview, she pulled out a tablet with a touch-screen and demonstrated how students can move through the on-screen environment by "scrolling" with their finger, select objects by touching the surface, and even use the camera function to take pictures. This encourages additional exploration. "*They are great for visual learners*," she said.

Example: Being able to physically touch objects of interest, as opposed to clicking them with a mouse or keyboard, also delights the game user. The large size of the touch-screen will be able to convey more realistic, entertaining images.

5. Apply Short-Term Scalable Design (Include Multiple, Short Stages)

Description: The game should consist of a series of stages, each of which can be completed within a minute or two. Spending too much time on a level may cause users to become restless. As stated earlier by one of the experts, user-friendliness is critical to a gaming applications success. Thus, anything that would frustrate users (such as game levels that take too much time to complete) should be avoided. In addition, the game should be in accordance with the field trip time limits; during the field trip (e.g., Virginia Aquarium) visitors usually spend a limited amount of time in any one area. After a few minutes or less, guests move on to other exhibits. The Director of Education explained that when educators try to teach guests in informal learning settings, "*we've got a 'one-shot-deal.' That interaction could last 5 seconds, it could be 5 minutes… We have to make people, in a very short period of time, feel like it's worth their time to give us 30 seconds or a couple minutes… to show them something, to show that it's worth doing this rather than going around the corner to see*" other exhibits. Thus, it is important that the game be divided into different segments that convey interesting material in short periods of time.

Example: Each stage of the game should correspond to a different exhibit area of the science center, progressing in the same order as the exhibits (e.g., see figure 2). The game could have short stages and allow users to track their progress with an animated map. The map would show the different parts of the river (representing stages) and identify the users' current location along the river (representing current status).

Fig. 2. The VAQ's "Journey of Water" exhibit series follows the course of water from a mountain stream to the ocean. The different exhibits represent different stages in the journey.

6. Direct Users' Attention to Specific Topics

Description: Student visitors often miss valuable material presented in informal learning settings unless someone or something directs their attention. "*With your average high school group, unless someone is directing their activities, they are going to be less apt to spend time in an exhibit where they need to look a little more closely or do a little more reading or spend a little more energy to see what is going on,*" the Director of Education explained. The game should direct the attention of its users to particular topics. Especially for institutions where tours are self-guided (such as the Virginia Aquarium), a mobile game can and should act as a guide or docent. According to the Director of Education, this consists of "*pushing somebody to get interested in something by giving them a tid-bit of information. This gets the guests to say 'Oh, that is kind of interesting,' and then they'll go read the material because they decide it's worth their time*".

Example: Each stage of the game should focus on a specific skill or concept, which users must master in order to complete that stage. If desired, the game could direct users to actual exhibits within the center that cover topics associated with that stage. As an illustrated example, the game could refer the user to the "Getting to the Bottom" station in the Chesapeake Bay Interactive Gallery in order to address how different types of sediment settle in water to form layers. This station shows how coarse-grain and fine-grain sediments settle at different speeds.

7. Support Cooperation and Competition among Users

Description: High school students tend to enjoy group problem-solving activities. Many of them also enjoy competing with one another. The Director of Education noted that planning and executing group activities, especially for high school students, is difficult due to logistics and time constraints. However, she said that "*Generally, in education, they [students] like to have group-based, problem-solving types of activities*". The game should allow and encourage cooperation and competition among its users.

Example: The gaming application could be arranged in such a way that users can send electronic messages to another. Users could be allowed to share resources (such as virtual cash or tools) with other users, encouraging cooperation. A scoreboard could be included on each user's device with a list of the highest-ranking players.

8. Connect the Activity with the School Curriculum Emphasize

Description: The game's material must be based on curriculum standards. "*The key thing right now is to identify what teachers need help with in terms of standards and STEM content. Then you can focus your game on that,*" explained the Director of Education. Hence it is important to actually contact teachers and science supervisors to hear what topics and needs must be addressed. She mentioned also that these topics will often depend on mandated academic standards such as the standards of learning (SOLs). "*We can guess and say, 'This would be a great thing to do,' but unless we meet their [teachers' and students'] needs, they're probably not going to use the game.*" The science education consultant also expressed the importance of basing the game's content on relevant SOLs. The game should prompt students to rigorously investigate these topics and develop a thorough understanding of them.

Example: Assuming that the game is directed to Virginia students, the game needs to address the Virginia Standards of Learning (SOL). As such, important earth science content, like ocean tides and currents can be addressed in conjunction with Virginia Beach the aquarium's "Ocean Gallery". Geometry and earth science material can be integrated in creative ways, like; locating points on a coordinate plane (Geometry SOL) and apply them to interpret latitude and longitude on a map (Earth Science SOL).

5 Discussion and Conclusions

This paper presents an initial attempt to exploit knowledge from experts in informal science learning and model this knowledge into useful guidelines for designers and developers who aim to address students as potential users of STEM games and applications. Our research is characterized by a close collaboration between designers, STEM educators, developers, HCI practitioners/researchers and Museum and Aquarium experts.

The study described in this paper has led to a set of research-derived guidelines for designing games and applications for Science museums. The guidelines were backed by addressed experts' best practices and has been exposed to several stages of validation and organization (semi-structured interviews, content analysis), which should provide some assurance of their validity. Based on this, eight design guidelines have been proposed to take advantage of STEM learning in contextualized environments outside the school context.

We want to emphasize that our findings are clearly preliminary with inevitably limitations. Probably the main limitation is the absence of students' in this work. Our future research will concentrate on further refinement of the proposed guidelines by applying and evaluating them on real conditions. In the next step of this ongoing project we will continue our research with evaluating these guidelines with a mixed methods approach, and aim to improve and optimize them. Furthermore, educators, practitioners and researchers in the area of technology-enhanced STEM learning can also evaluate the proposed guidelines in order to ensure their understanding and seek suggestions and extensions.

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