Bringing Biome Exploration into the Classroom through Interactive Tablet Experiences

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Abstract. Through advances in game engines and tablet technology, experiences that formerly required a field trip can now be brought into the classroom. Two interactive experiences, "Hello Ocean" and “Arctic Stars: The Far North”, were developed to bring a swim-through exploration of a Caribbean reef and a walk-through experience of an Alaskan tundra to an elementary school located far from an ocean and far from Alaska. The experiences were tested for their appeal and whether they encouraged children ages 8-11 to learn more about the respective biomes. The paper reports on various formative playtests with children and documents how the experiences evolved over time as a result of those playtests, as well as the unique attributes of the two biomes which led to different interaction styles for the two experiences. The reef was navigated well using the gyroscope in tablets to change the virtual world camera view by manipulating the tablet position in physical space. The tundra used a virtual joystick to see the activity in a sparser landscape with less need for up/down movement. High navigational freedom was important to both experiences.

Keywords: Virtual field trip; playtesting; iterative game development; visual realism; navigational freedom; virtual reality game; educational game

1 Introduction

Computer and entertainment technologies today offer amazing capabilities that can be brought into the classroom to deliver experiential learning. Piaget noted that children develop cognitive structure through action and spontaneous activity [1]. Piaget's constructivism is rooted in stimulating interest, initiative, experimentation, discovery, play, and imagination as fundamental to the development of a child's capacity to learn. Decades later (in 2004), Roussou surveyed uses of virtual reality (VR) to immerse child learners in three-dimensional multisensory, immersive, interactive environments [2]. She noted the importance of interactivity: of letting children drive the experience. Today, technologies like Kinect for motion control, tablets for handheld delivery and Oculus Rift for head-mounted responsive immersion have let users drive and appreciate experiences with greater fidelity than ever before. A learner's senses

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can be brought in more completely. Rather than read about an experience, or watch one passively captured earlier, one can actually have the experience. Children can construct their learning in line with Piaget's theories as they make use of technologies to discover new worlds.

With technology advances, schools can offer virtual field trips opening up the world to students [3]. Companies like EducateVia360, Inc. [3] and Kolor [4] offer image stitching and virtual tours with 360 degree views. They often fold in new techniques like using the gyroscope in tablets to navigate through the imagery space by manipulating the tablet position in physical space. These techniques work well for historic settings and provide a strong sense of place. What may be lacking is a sense of life, e.g., of discovering animal behavior that is dynamic, not always in the same place at the same time. Modeling animals in natural ways is the subject of Omasa, a Unity3D game where learners observe and interact with animal agents to learn predator/prey roles [5]. Real life captured through webcams, e.g., activity at a bald eagle nest in Pennsylvania [6], can be followed with very rich real-world fidelity but low interactivity: the viewer cannot modify the situation or schedule events such as hatching or feeding. Similarly, very high resolution imagery through Gigapan technology could be explored to offer extreme visual fidelity [7], but here too the user changes the view, but not the world under study.

A study with Czech high school students found that higher visual fidelity was considered more authentic, more attractive, and a better source of information in an educational simulation [8]. Two design parameters, visual fidelity and navigational freedom, were studied carefully by Maria Harrington using a Virtual Trillium Trail experience through a forest populated with featured plants and animals [9]. Working with 8-11 year olds, Harrington found that high visual fidelity was significantly better than low visual fidelity with respect to learning activity. There was a positive interaction with navigation freedom: high visual fidelity and high navigational freedom produced the greatest impact on a knowledge-gained measure. This study concludes that the combination of realistic worlds and free navigation features improves learning [9].

This paper discusses the development of two experiences for mobile tablets that can be played by children to explore different nature biomes. The experiences were each developed using the Unity game engine supporting export to both iOS and Android tablets and phones. All reported playtesting was done with Android tablets. The first two authors are faculty instructors for the two semester-long projects developing these experiences. The paper opens with the design and development of *Hello Ocean*, for an underwater biome, produced by the authors listed third through eighth. It then discusses the design and development of *Arctic Stars: The Far North* which was delivered to the same school (produced by the six authors at the end). Both are available for free download on Google Play for use on current Android devices.

2 *Hello Ocean* Design and Development

A graduate student team of six students produced *Hello Ocean*, with two faculty instructors advising the project-based course during its 15-week semester. Weekly meetings to review decisions and progress were held with teachers and administrators at a West Virginia elementary school (students in grades K through 5, ages 4-11), who served as clients for the project. At this particular school, there is a broad range of backgrounds, from students who have never seen an ocean to the well-traveled, from different ethnicities and various income levels. The six students took on the various roles of producer, user experience designer, 2D/3D artist, animator, interaction programmer, and technology programmer.

The first weeks of the semester were devoted to exploring the use of various classroom technologies, with early pilot tests narrowing the candidate technology to the use of tablets. Tablets were attractive for their potential to be used for other classroom exercises, and based on their appeal to deliver an immersive first-person experience to the person holding the tablet. We began the semester with a visit to the client elementary school, meeting with students, teachers, and administrators to get a better sense of what was hoped for with the experience to be developed. The context data from the early investigative work led us to make the following choices:

1. The experience should open the children's awareness to other nature biomes not seen in the West Virginia Appalachian Mountains.
2. The experience should be very easy to use.
3. The experience should offer the opportunity to explore a rich environment, with "rich" playing off of visually rich with audio optionally turned off in classrooms.
4. The experience should be simple. Do something small well in the semester development timeframe, rather than do a vertical slice of a broader activity that might never get filled in due to time, staff, and budget constraints.
5. The experience should start a conversation. It does not need to provide the lesson: teachers can use it as motivation to delve deeper into topic areas in science and other subject areas. If the experience gets child players to want to learn more about the topic area, e.g., to check out relevant library books or be more attentive in follow-up work directed by the teacher, then it will be deemed a success.

With an emphasis on visuals, the team settled on Caribbean Sea coral reefs for their beauty, diversity of life within a small area, appeal to children, and positive reception by teachers at the school. The team integrated a marine biologist expert into development to improve on the experience fidelity. We focused on sea animals, as their movement in the world would attract the eye and interest of child users.

As for technology, the use of the tablet gyroscope to generate a dynamic view into the underwater world was received well by game design faculty in our school. We watched them operate a tablet where moving the tablet angled upward would look toward the surface of the water, downward to the sea floor, left and right in those directions, with a press on the tablet to propel forward. This interaction is an Oculus Rift-like view into a world controlled by the player, but using a tablet rather than a device worn over the eyes. Over time, the swim-through interaction was enhanced with multi-touch support to propel forward more quickly.

As you navigate anywhere through the space, with very high navigational freedom supporting discovery learning [2, 9], you can interact with the sea creatures. To keep interactions simple, we looked to games like Pokémon Snap where the player snaps pictures of the virtual world. In our world, the player snaps pictures of the shown view, dynamically manipulated by the player's tablet positioning, via a tap on the camera icon. This simple picture-taking is natural for children, and allows the world to be discussed further via the collected picture gallery after the interactive swim-through is completed. We also wanted the sea creatures to react to player touches.

Two artists worked to populate our underwater biome with a series of tools. One artist collected real-world imagery to aid in generating photo-realistic textures of the sea creatures. He continued to model the creatures and texture them using ZBrush, converting them to low-poly meshes in 3ds Max. A second artist then added rigging skeletons to the models in the Maya tool. She authored 3D animations using Maya, so that the creatures would move in natural ways, based on their model and rig. Programming comes into play in managing fish behavior in the world. Some creatures rarely move (starfish), some stay very close to seaweed (seahorses), some swim together in a dense pattern (boga fish) requiring a schooling behavior. Over time, the unique types grew from a set of three to five, then eight, ten, and finally fourteen different species; a few are seen in Fig. 1.

Fig. 1. *Hello Ocean* view with final artwork for terrain, coral, fish, and shader renderings

The terrain was modeled from actual terrain maps of Caribbean reef areas. We wanted the experience to have high visual fidelity, in agreement with prior work that such fidelity can result in more motivated users and enhanced learning opportunities [8, 9]. We carefully modeled reefs, rocks, and seaweed textures as background art so that the world would be rich and attractive. We made use of shaders with the Unity game engine for lighting and underwater effects.

The work was reviewed by the marine biologist and approved to be natural for this environment, with one notable exception. Throughout all playtests, the leading cause of frustration was straying from hot zones of activity for too long and being lost in the sands of the terrain with nothing to discover. We raised the terrain edges into sand walls that surrounded the experience, to bind the player in. When players are up against the sand wall they naturally turn around and go back to neighborhoods of activity. We did not reduce the navigation freedom beyond what we knew was necessary. We could not offer an endless sea swim in all directions: we did not have enough time to generate the art assets and dynamically populate such a world. We did, however, have the time to craft a rich reef biome, deep enough in the sea to not be repeatedly clouded by tidal effects, shallow enough to support pockets of plant and animal life. We kept the child player focused on our developed territory by bounding it with sand walls, with teachers happy that the children are much more likely to encounter sea creatures when using the tablets for bursts of minutes at a time.

We sought early feedback for the tablet gyroscope mechanic driving the experience, the snapshot feature, and the "touch to trigger reactions." For our first prototype, we deployed an interaction where the tapped fish would approach the player and indicate its species. We pilot-tested with six girls ages 12-14 using direct observation followed by interviews. Two playtesters were at first uncomfortable with the gyroscope effect as it was new for them and they were familiar with the traditional swipe mechanism, while four thought it was an excellent feature. We noted the value of a tutorial as needed future work, to introduce the navigation mechanism. All playtesters loved the snapshot feature and could easily take pictures in the world. All playtesters wanted more to discover in the world: it initially had only three types of fish, all finned. The testers suggested we add more variety and make the world more colorful.

Tapping added a text label to the fish identifying it, a label scaled within the 3D space. In this initial prototype, second and third touches would trigger additional animations in the fish and different avoid/seek behavior. The playtesters never discovered third touches, so we dropped third tap interactions completely. Second tap reactions were a surprising reward to players, so we kept that interaction, but varied it according to the type of sea creature and modified its timing to be a double tap.

After this first pilot test, we redesigned the terrain and added a variety of plants, weeds, rocks, corals to make it look more natural. Programmers improved the colliders in the world for more comfortable swim-throughs by players, and improved the fish artificial intelligence (AI, primarily path-tracking) for more natural fish movement. The next playtest offered 5 sharks, 3 eagle rays, 15 blue tangs, 15 angelfish and 2 jellyfish with a variety of environmental assets. It was conducted in the client elementary school with tens of children in kindergarten through fifth grade. Again, data collection was through direct observation of students using the tablet individually and in groups of two, with some follow-up interviews of randomly chosen children based on availability. The response was overwhelming: 90% of the students loved our world and navigating through it. They were shown how to navigate, as the tutorial was not yet in place. The remaining 10% were the kindergarten and 1st graders who were rather confused and found the technology very intimidating. Students in grades K-1 would tire quickly and rest the tablet on a flat surface rather than hold it and move it to drive navigation. Based on this playtest, we refined our target demographic to be students from third to fifth grades, i.e., ages 8-11. Comments from these students included “I want to live in this world”, “Am I a Mermaid?”, “Wow shark!” and other exclamations of curiosity and interest. The children ages 8-11 wanted more: they were eager to play longer, and asked us if they can download this application and play it at home. The children were also willing, active collaborators when paired with a single tablet. One child would drive, the other converse and suggest directions with the first. They would swap roles after a brief time. This collaboration surprised us, but was received well by teachers at the school. It could become an interesting future study: virtual field trips conducted in pairs with one tablet rather than individual usage.

The teachers and some school staff also played our game and were very happy with our progress. They did suggest some changes like adding more information about the fish and the environment. As a result, we developed a teacher resource with complete details on the virtual environment and operational instructions for the experience. We also incorporated "fun facts" about encountered sea creatures into the next prototype. We made the snapshot feature smoother and tweaked the fish AI to make it look more realistic. There were teacher concerns about focusing the exploration and discovery. To solve this, the team decided to work on a new feature: quests. The player will be directed to complete a stated quest through free-form exploration of the world.

For the next playtest, a single quest was presented to the user via a text directive in the tablet experience: find 5 different fish and take snapshots of them. A gallery icon would pop up upon quest completion and users could browse their collected picture set. When the user touches any fish, a name shows on top of the fish in the 3D space, along with a "fun fact" dialog box at the bottom of the screen in a 2D graphic overlay.

We tested with 30 people (22 female) in a broader age set of 8 to 16, using direct observation. One developer would watch the tablet interaction, and then ask a small set of questions afterward to the participant. We found that the given quest was interesting, but was shifting the focus completely away from free exploring to just solving the quest. Playtesters were ignoring the names of the sea creatures and their fun fact text overlays completely. They were navigating only to find something new to add to their set of five, i.e., taking pictures only to achieve the quest. When done with the quest, the playtesters were returning the tablet rather than free-form exploring on their own. The major design lesson from this playtest was that a "gamified" quest can diminish desire for navigational freedom and exploration. Also, a quest independent of information delivered through text resulted in the text being completely ignored.

Quests were hence redesigned in a number of ways. First, they could be turned on or off; if off, players were always in free-form exploration. Second, (if on) quests did not start immediately, but rather the player was free to explore for a few minutes before the first quest triggered and was shown. Third, if a quest went on for longer than two minutes, a dialog would ask the user if they wanted to continue the quest. Fourth, the current quest, if forgotten, could be shown again as a text block by tapping on a small "Quest" icon. The interface was minimized to only this icon and the camera icon to photograph the scene, to keep the virtual world emphasized in the view. Fifth, quests were tied to the sea creatures and fun facts about them presented as text overlays, drawing interest back to the text.

The user interface was also changed with respect to the names of the tapped sea creatures. Showing text within the water scene in 3D scaled to the creature could produce text that was difficult to read, and it made the underwater world less realistic. We moved the name of the creature into the 2D overlay, as shown in Fig. 2.

Taps on a creature produces the name and fun fact display. Double taps trigger movement toward the player if the creature is aggressive. If it is a community fish, it will move about. If it is a special animal like a puffer fish, it will puff up or otherwise play its special animation. In this way, we retained the surprises of double taps on discovered sea creatures. Providing player surprise, especially for experiences for children, is one of the lenses of good game design presented by Schell [10]. Notes on the fun facts, visuals on the sea creatures, and actions that are taken on taps are all documented for the teachers in their special teacher resources packet. Sea creature actions were all approved by the marine biologist for real-world fidelity.

Fig. 2. Fun fact text shown when player taps a blue tang (at middle right of Fig. 1)

We tested the revised prototype with 12 children (8 female) ages 8-14. As expected, the new quest system provided for more exploration in the game. The fun facts were read and successfully recalled in a follow-up questionnaire to the experience, showing that a quest can lead to increased attention on the fun facts. More importantly, quests were no longer central to the experience. Players explored, did quests when they came up, but continued exploring during and after quests.

The tested prototype was also the first by the team to present an in-game tutorial to learn how to have the Oculus-like VR experience through tablet movement. The children appreciated the tutorial and understood it, but the tested tutorial at this time was a screen-shot based sequence. Children instead expected an interactive tutorial: move tablet left and see the ocean world scroll accordingly, move up and see the water surface, and so on. As a result, the tutorial was revised in the final iteration to be an interactive experience where the player must succeed with a tablet orientation instruction in order to proceed. In less than a minute in the tutorial, the child player is now comfortable using the tablet to navigate the ocean reef. We saw the children enjoying the improved colliders. We revised the final terrain to include some swim pathways through tunnels and past rocks and coral. The settings button was revised based on both the past few playtests, and communication with teachers. Quests could be turned on or off in the settings as well.

An optimization of the entire project included baking of lights after multiple attempts to reach the best level of frame rate improvements with consideration for visual appeal. Occlusion culling was performed so that only a neighborhood of the VR world assets were rendered based on camera position, with a fog effect in place to hide the drop-off in the distance to absolute nothingness. These steps were taken to retain a high frame rate in playback on the tablets with the fully populated world.

The final playtest was conducted in classrooms for each grade from third through fifth in the presence of one teacher per class, one class at a time. Four teachers also went through the experience. The intention was to simulate the environment in which this app will be used in future.

83 students ages 8 to 11 tested the experience: 33 female, 42 male, and 8 not reporting a gender. We made use of direct observation as before, but in a crowded classroom environment rather than one-to-one. Given the volume of children playing, we also used a paper-based questionnaire to survey the 83 participants. We vetted the questionnaire with children during earlier tests, including iconography and a range of words, e.g., “bad – good” along with “frustrating – satisfying.” Children played either alone or in pairs on each of 16 identical Android tablets. As noted earlier, further study into paired use of the experience is warranted as we did not focus on this issue.

Overall, the students were thrilled to see all the new species of fish and the enriched terrain. The interactive tutorial was rated as easy or very easy to understand on a 5-point scale by 82% of the children; another 13% had no opinion. Asked afterward whether *Hello Ocean* helped them to know about the ocean and about sea creatures, the children were very positive, as shown in Fig. 3. 88% agreed or strongly agreed about learning more about the ocean environment, and 95% of those tested agreed or strongly agreed about knowing more about fish after the experience. The graph for response to the quests was not as positive. A significant fraction of the children self-reported quests as frustrating. There was a strong correlation between the age of the child and their frustration with quests. Three frustrated third graders also gave the lowest ratings to the other survey questions.

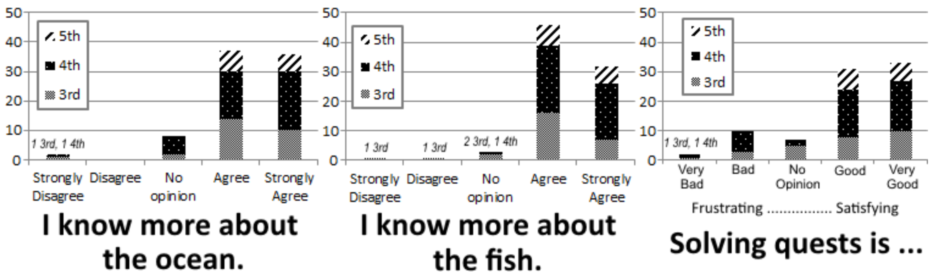

Fig. 3. Responses (N=83) to 3 survey questions by children in grades 3, 4, 5 (ages 8-11)

The Settings menu was noted as a means by which quests could be turned on or off. As teachers of 8-year olds wanted simpler quests than teachers of 11-year olds, in agreement with the data of Fig. 3, we produced two tiers of quests: simple and advanced. The simple quests play off a sea creature's name or strong visual characteristics, e.g., "take a picture of a sea creature that has 8 arms." The advanced quests make use of fun facts details. The teachers also encouraged the development of a "teacher resource page" where they could find additional information about the reef biome. The final deliverable to the West Virginia school included the revised experience supporting no quests, simple quests, or advanced quests along with the teacher resource page. In the final deployed version of *Hello Ocean*, there are 246 sea creatures created from the 14 types. The population counts for any creature range from two (for whales) to sixty (for boga fish divided into two schools).

3 *Arctic Stars* Design and Development

A graduate student team of six students produced *Arctic Stars*, with two faculty instructors advising the project-based course during its 15-week semester, the semester after the one producing *Hello Ocean*. The same West Virginia elementary school served as clients for the project, with this tundra biome running on the same Android tablets in the school. The six students took on the various art, design, programming, and production roles needed for the work. The goal was to bring a biome into the classroom that is not likely to be witnessed first-hand due to cost and distance: the Alaskan tundra. The student developers worked with the same 5 guidelines framing the *Hello Ocean* work (enumerated in Section 2), i.e., a simple small experience that promotes a conversation between students and teachers. The developers sought to emphasize the vastness of the arctic tundra, acknowledge its emptiness and extremes, while promoting a feeling of discovery. An Alaskan field researcher was recruited to review materials produced by the team for accuracy.

The tundra looks vastly different at day or night, and encourages a walkthrough exploration rather than a “go in any direction” as in *Hello Ocean*. We cycle through day/night to provide variety to the students’ tundra exploration, with night shown in Fig. 4. The virtual joystick shown at lower left with compass points moves the player, with slow “sneak” navigation when the joystick remains in the inner circle.

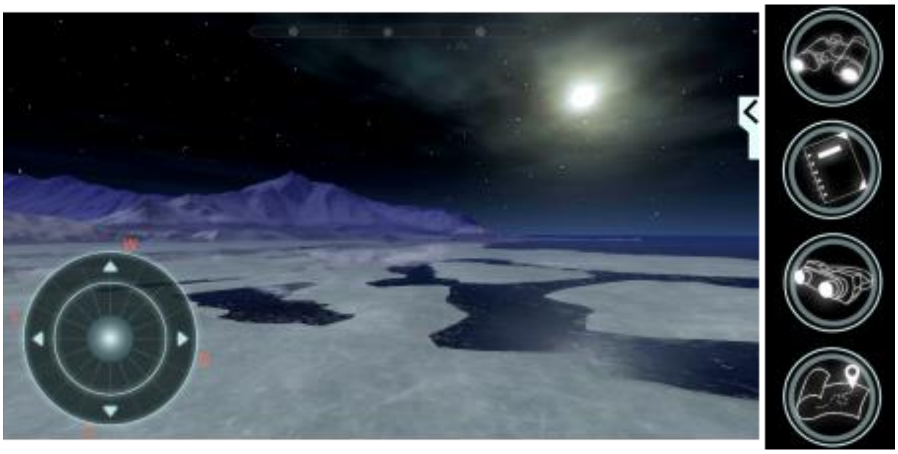

Fig. 4. At left, *Arctic Stars* view during night cycle, showing ice, mountains, and snow; at right, *Arctic Stars* toolbar icons for binoculars, scientist logbook, “thermal view” and map

The user interface arrow at the right of the screen expands out into a four-icon pane as shown in the right portion of Fig. 4. A series of playtests were conducted to iterate on the utility of the virtual joystick for navigation, the vastness of the terrain, and the complexity of the integrated logbook.

The first test one-third into development was done with Grade 3-5 students at the West Virginia client school, using observation, a post-test survey, and game logs. Our main goals were learning if players perceived objectives that aligned with what we intended, understood our mechanics, and retained information from the game. In a pre-test asking about arctic animals from 57 users, only 8 students mentioned wolves and 2 students mentioned caribou before playing. However, after playing, 46 students mentioned wolves and 25 students mentioned caribou, indicating that our format had some success for content retention immediately after playing. Player log data showed issues needing work: long periods with no player response or discovery, and confusion over visual "hints" in the scene such as antlers and scat. We changed the visual cueing from disruptive particle effects and glows to simple markers, such as the "i" to show information about the polar bear shown in the binoculars view of Fig. 5.

Fig. 5. Two *Arctic Stars* views: binoculars (to see far-away animals) and logbook (with food web; as animals are encountered, silhouettes are replaced with colored images and data)

Arctic Stars uses text "hints" as *Hello Ocean* uses "quests" but only to get the player introduced to filling out the food web in their scientist log (Fig. 5 right). After that, we hoped the player would take up the open-ended exploration and associated learning as found by Harrington [9]. In this first playtest, 55% of children noted the explicit goals we directly communicated to the player in-game, such as finding animals, with 48% noting implicit goals we hoped the player would take up, such as collecting data and investigating. The early test confirmed that players responded to provided objectives, understood tap interactions and the virtual joystick, and highlighted the excitement of children encountering animals. The terrain was too sparse or too vast, a separate button to trigger a "sneak up to animal to place tracker on them" did not work, and some expected interactions like pinching to zoom the binoculars view did not work. These lessons were folded into subsequent development.

Three significant playtests occurred in the final half of the semester: 14 children ages 8-11 outside of school, 71 students in 4 classrooms at the client school (2 classes who saw the earlier version and 2 fresh classes), and 20 students at the school who saw an earlier version for their commentary on the final release. Direct observation was used for the first two playtests, with surveys used for all three.

The playtests showed that visual appeal mattered: snow effects, the day/night cycle, water, and, most of all, the animals themselves rigged to move naturally and textured to look realistic were noted as high points of the experience by playtesters. As the interface was refined to that shown in Figs. 4 and 5, players had less failure in sneaking up on animals to track them, and greater success in filling out their logs with animals and information on various animals. The final experience features caribou, polar bears, king eider ducks, lemmings, ringed seals, arctic wolves and foxes, and arctic hares. The terrain itself was first expanded four-fold, but then users reported annoyance at the difficulty in finding anything of interest. As with *Hello Ocean*, the terrain was tweaked repeatedly to reduce sparse zones. It was shrunk back to original size but with ravines and water's edges providing well-marked activity areas while also giving visual interest as seen in Fig. 4. Child players needing help can turn on animal area overlays in their in-game map, and teachers can promote exploration routes by noting behavioral points, e.g., that polar bears are often on ice seeking seal breathing holes in a hunt for food. The final terrain was well-received by players, appearing to be both more vast and more interesting. The interest was fed by additional animations such as the polar bear breaking the ice to get to the seal, or the wolf pursuing a fleeing caribou. Surprise points such as animal vocalization in the logbook, 3D rotating of scat, and the richly colored thermal view increased player enthusiasm. Direct observation, teacher input, and surveys showed the students eagerly engaging with their game and with classmates ("Look what I found! It's over by…"), with natural pauses in the tundra exploration giving children the opportunity to share discoveries. As with *Hello Ocean*, there was much shared play seen with children using the tablets in a class at the same time, a usage context worth further study.

4 Discussion and Conclusion

The presented experiences *Hello Ocean* and *Arctic Stars* each grew from an iterative development process over 15 weeks, iteration as recommended in developing free-form experiences for children [11], centered on a series of playtests. Tutorials were added to provide practice with each experience's unique navigation through the virtual world, and to introduce more novel and playful elements. Teachers' abilities to turn on or off quests and quest complexity for *Hello Ocean*, and to give more or less context regarding food web and animal habitat for *Arctic Stars*, let both biomes be used for open-ended exploration across a grade range. For *Hello Ocean*, elements of gamification, i.e., being purely quest-driven, was found to stifle player exploration, much like too many rules stifles child open-ended play [11]. For *Arctic Stars*, animals were not surrounding you in 360 degrees as they were in the reef. A virtual joystick worked better for a walk-through experience in the tundra, while the gyroscope-based tablet motion to change the ocean view worked well for the reef. The logbook filled in shadowed slots as animals were encountered, using collection to entice students to continue their exploration. For both, clever terrain manipulation and visual clues in the biome are used to drive students toward appealing animal activity and keep them actively engaged.

Prior work showed the value of free-form navigation and visually rich worlds [2, 8, 9]. *Hello Ocean* and *Arctic Stars* were designed to allow such navigation throughout the respective biomes, discovering creatures that were vetted by experts to have realistic look and behavior, with children commenting positively on the visual appeal. We did not test the educational effectiveness of the experiences, only their appeal to child users and elementary school teachers who plan to use the experience in different ways. Follow-up pedagogical studies looking at particular usage cases are planned. One other shortcoming was in not using exclusively children ages 8-11 in iterative testing, as for some iterations we had easy access to broader groups. We confirmed choices made with such iterations by following up with tests with 8-11 year olds. In an ideal work flow, unique testers in the target demographic would be constantly available to run through every iteration of the open-ended play design process [11].

These biome experiences are not expected to stand in isolation with respect to resources for teachers in the classroom regarding coral reefs, tundra, or other biomes. Teachers can conduct a very rich and lively experience using multiple sources. For example, ultra high resolution stitched imagery such as a GigaPan coral reef [7] could be shown. Nature cams like [6] could be shared. 360 degree visits to aquariums or museums like a Smithsonian Institution Ocean Hall virtual visit are possible [3, 4]. All could be used by a teacher to "bring" the biome to a classroom. *Hello Ocean* fills the spot of a high fidelity very highly interactive swim-through experience in which children can tap the sea creatures and trigger additional reactions in the world. *Arctic Stars* presents a high fidelity very highly interactive tundra walk-through experience including day-night cycle and an emphasis on the arctic food web. Both were received well by children, and improved iteratively through a series of playtests. Next steps include working with teachers to determine whether these biome experiences meet goals of facilitating constructivist learning [1] in teacher-moderated classroom settings. The first stage has been completed: teachers now have released apps which bring the reef and the tundra into the classroom.

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