RumbleBlocks: Teaching Science Concepts to Young Children through a Unity Game

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***Abstract*—RumbleBlocks was developed at the Entertainment Technology Center (ETC) to teach engineering principles of tower stability to children ages 4-7. The game features tower construction, tower piece removal, and tower comparison levels which were designed with feedback from early childhood educators and learning researchers, and iteratively improved with feedback from child play tests. This paper emphasizes the development process, and initial formative play tests with children. It was developed using the Unity3D game engine, allowing for export as a stand-alone application, web player, or to mobile devices. First results are promising in terms of educational effectiveness, with more studies planned for the future.**

Educational game, early childhood science education, game development process, Unity game engine

I. Introduction

Young children have inquisitive minds, often asking their family members and teachers questions about science. Through thoughtful interactions, families and early childhood professionals can foster a child's scientific thinking, stimulate curiosity, and establish a foundation for a lifelong interest in science [1]. Through powerful interactions of being present, connecting with the child, and offering opportunities to extend learning, an educator can foster a child's ability to explore, think, and communicate [2]. The RumbleBlocks development team began with the challenge of producing a game for children ages 4-7 that would teach science concepts in ways that can be tracked by educational researchers, with all the positive aspects of a game promoting curiosity and engagement. Can a game offer powerful interactions to the child, while fostering measurable scientific learning?

RumbleBlocks is a collaborative development between two departments at Carnegie Mellon University: the Entertainment Technology Center (ETC), and the Human-Computer Interaction Institute (HCII), with HCII faculty also a part of the Pittsburgh Science of Learning. This paper discusses design decisions for RumbleBlocks made by the ETC and HCII, the iterative development process involving child playtesters, some very early formative evaluation work, and concludes with the next steps for the project as it heads toward more formal educational evaluation. The template presented here can guide other game development teams interested in early childhood science education.

The ETC addressed game development (discussed in this paper) through two semester-long projects, with the HCII focused on educational evaluation (including much planned future work). In the Fall 2011, RumbleBlocks began with the ETC *Illuminate* project. In Spring 2012, the ETC *Sci-Fri* project continued RumbleBlocks work as well as other science game efforts. Both projects detailed their weekly progress in online newsletters, with download links for RumbleBlocks as a web version, stand-alone PC, Mac, or Android game nested within the *Illuminate* pages [3]. The interested reader can search out the newsletters and play the game for greater detail and insight behind the points made in this paper.

II. Science Principles Underlying the Game

The game developers began with a review of various United States government and educational advisory board standards, guidelines, and documents addressing science education for pre-school, kindergarten, and grades 1-3 (ages 4-9). They interviewed teachers in this class range, and worked closely with additional evaluation experts from the Pittsburgh Science of Learning so that the domain choice would be one where children's advances in science learning (or lack thereof) could be adequately tracked during game play. They visited classrooms for this age range, seeing what the children used for science learning and play. Brainstorming sessions produced a number of candidates, including machine repair, levers, states of matter, day/night and seasonal cycles, causal reasoning, and electric circuits.

The ideas were collapsed down to a subset that seemed fruitful to teachers, viable to educational researchers, and with potential to appeal to both girls and boys in a slightly narrower ages 4-7 demographic, a potential tested repeatedly in follow-up interactions with children. In the end, the idea that won out was a tower-building game. The underlying engineering principles being taught by the game include the following:

- Expanded base: the base should be wider than the top of the structure. Towers built more in the shape of a pyramid tend to be more stable, so that when upper pieces shift, they have room to do so.

- Symmetry: the structure should be symmetrical in at least one dimension around the central axis; structures aligned with equal distribution of weight tend to be more stable.
- Closed gaps: Blocks in the same story of the building should be touching each other rather than spaced apart.

Interviews with 5-6 year olds that used contrasting cases showed that these principles are not universally understood already, i.e., the children made mistakes. Two towers were shown on paper to a child and he or she was asked which is more likely to fall. Children's answers were recorded and later analyzed to uncover misconceptions that may be used to produce instructional sequences with contrasting cases. The use of contrasting cases designed to help students notice information they might otherwise overlook dates to the 1950s and perceptual learning, while also providing an opportunity to maintain instructional fidelity and experimental control [4]. The contrasting cases helped to confirm the appropriateness of the science concepts to be addressed by the game.

III. DEVELOPMENT PROCESS

The ETC offers a two-year professional degree, the Masters of Entertainment Technology. In pursuit of this degree, students spend their first semester with four core courses, including "Building Virtual Worlds" (BVW), followed by three semesters in which students tackle studio projects like *Illuminate* with a small team of artists, game and audio designers, and programmers. Courses like BVW and the studio projects teach the value of rapid prototyping and iteration [5]. BVW groups students in teams of four that create 5 separate prototypes over the course of the semester, all taking no longer than three weeks from start to finish. This class embodies the idea that the quicker you get a game fielded, the quicker you can fail and discover where your initial ideas were ill-conceived which lessens the impact of course corrections. The ETC emphasizes the importance of early and frequent iteration in game design, and the majority of semester studio projects follow the Agile development process with weekly sprints that break down tasks into small increments.

RumbleBlocks benefited greatly from iteration. First designs were communicated through paper prototypes, leading to insights that guided subsequent work. For example, the first towers were constructed of a playful mix of lollipops, candy corn, and chocolate bars, chosen for a strong candy theme with rich color and variety of shapes. This early idea, loved by the artists, met with skepticism from educators concerned about promoting bad eating habits. After a number of follow-up sketches and ideas, a space theme featuring stranded aliens was adopted, once additional tests with boys and girls found acceptance across both genders with a cute, non-threatening, nurturing art style.

The award-winning Unity 3D game engine [6] was chosen for delivering RumbleBlocks, in part because it supported deployment to a variety of platforms found in the schools and homes of the target demographic, as well as having a built-in physics engine useful for animating tower building activity. A related early playtest focused on whether 4 to 5-year-olds were comfortable with 3D blocks manipulation (in three-dimensional space) using a mouse as an input device. Many of the art assets in RumbleBlocks are three-dimensional (the spaceship, alien, blocks) for physics engine consideration, but children had difficulty in maneuvering 3D objects, doing much better in manipulating the objects when constrained to a single perspective view along the z axis. While the blocks are boxes and cubes, in such a view they appear as rectangles and squares. Figure 1 shows the perspective view as seen by the child players (left), with the assets constructing the view shown at right in a top-down view in the Unity development environment illustrating their three-dimensional nature.

Figure 1. RumbleBlocks screen shot (left), a single perspective along the z-axis built with a mix of planar and 3D assets as shown in Unity Scene View from a high angle looking down (right).

Additional playtest iterations refined the tower-building levels, but the HCII team members expressed concern over the evaluation of a sandbox exercise like that illustrated in Fig. 1: when the player places a block, is it a good or bad move showing understanding of the principles of Section 2? Specifically, can game mechanics be introduced that offer discrete moves, where each move can be analyzed for correctness? Discussion on such measurement of player activity led to two additional activities being introduced into RumbleBlocks: tower block removal (Fig. 2 left), and contrasting cases (Fig. 2 right). In tower removal, the player's mouse cursor is a sledgehammer that is clicked over blocks to remove them (or finger-tapped, on touch devices), with the goal of removing a set number of blocks without disturbing the flying saucer (i.e., the "unidentified flying object" or UFO for short; most often called "spaceship" by the players). In contrasting cases, the player selects the more stable tower, with a subsequent earthquake knocking down the less stable tower after the player's selection (the UFO then lands on the more stable structure).

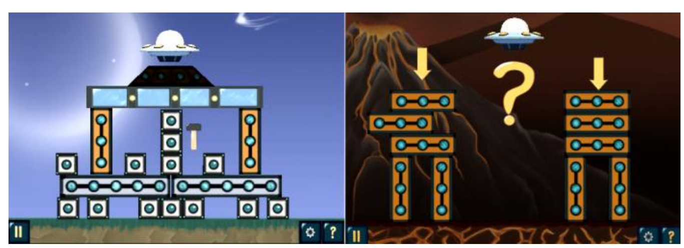

Figure 2. Screen shots of Tower Removal (left) and Contrasting Cases.

Formative playtesting occurred throughout the game design process. RumbleBlocks was designed toward achieving an ideal "flow" [7], with a balanced challenge level to let the student enjoy a rewarding enough experience to remain engaged and feel a sense of achievement without undue frustration or resignation. The development team knew that proper level sequencing would take time, so rather than hard-code a particular sequence of levels, the level progression was set through an xml configuration file. Each level's art assets could be laid out and tested by the development team using Unity's development environment and Scene and Game views.

Children could test different sequences of the game by varying the configuration file. Through frequent playtesting, RumbleBlocks has evolved, with the goal of driving children toward achieving high levels of understanding of the science principles of Section 2, through appropriate challenges in advancing levels. Such iterative playtesting is a staple of ETC project studio development processes [5]. Specific "lenses" for game design are useful to focus playtesting from the palette presented by Schell [8]. For example, the Lens of Flow addresses the challenge progression in levels and a play test might focus on flow. The Lens of Surprise addresses appealing surprises in the game, and a play test might focus on reactions to embedded surprises like the alien having a protective shield with audio and animation effects when the player tries to hit it with a block.

IV. RumbleBlocks Story Narrative and Game Mechanics

First versions of RumbleBlocks lacked a narrative framework: children were prompted to build towers up to a star top block. ETC faculty encouraged the students to incorporate a story premise that would help give young children a concrete explanation of the goal and motivation to move through the game successfully. Over many weeks the story developed with a series of play tests with groups of 1-7 children, who noted in actions and words which story elements worked and which were still confusing. The last of the *Illuminate* project's play tests with 11 children (7 boys and 4 girls, ages 6-8) confirmed that the implemented story was presented clearly, understood, and helped drive the player to success. Comments like "I want to help the alien" peppered the videotaped interviews.

The Unity game includes opening and ending victory videos, illustrated in part by the storyboards in Fig. 3. The player is introduced to a mother ship in space which is hit by a comet, with a number of UFOs then evacuating the damaged ship for a variety of planets. The different planets serve as backdrops for the levels the players work through: an ice world, a volcano world, etc. In each planet the UFO crashes, damaging the ship but depositing the alien safely on a ledge. An energy tower must be built to raise the ship to a level where the alien can be rescued from the ledge, and the ship is energized if the tower's blocks are placed properly over the blue energy balls. While the tower energizes, an earthquake shakes the terrain, knocking down unstable towers but allowing good structures to save the alien.

The energy balls (3 are shown in Fig. 1, with two properly covered by blocks) are a means of giving the players scaffolding in the task. If the level is teaching the wider base concept with a high degree of scaffolding, the energy balls will give strong cueing that a pyramidal form with wide base and narrowing top is the solution. Levels with less scaffolding will show fewer energy balls and allow for more degrees of freedom in block placement. To complete a level, the player moves and rotates the crashed UFO to the top of the built tower. The tower energizes the UFO, and it flies away with the alien and a cheer on success. The player then is presented with the next level. On successful completion of all levels covering the principles of Section 2, the player sees a video of the UFOs flying back out to a rescue ship, where they then are presented together on a congratulations screen (right panel of Figure 3).

Figure 3. Storyboard panes for left Intro sequence (mother ship damaged; UFOs crash land; friendly aliens need help) and right Victory sequence (UFOs return to rescue ship; aliens all dance happily and wave following player helping them all back to their UFOs).

V. Additional Lessons Learned From Playtesting

The target age range is broad, and more formal tests may eventually narrow the optimal target to say first-graders (ages 5-6). Younger children found levels challenging, and tower-stability principles confusing if too many were presented at once. Careful design of levels introducing complexity over time, with scaffolding provided through the energy balls, helped the players. Experienced older players worked through the easy levels quickly without complaint as they focused on the narrative of helping the alien. Younger players made use of the energy balls to guide block placement.

The game designers paid careful attention to the Lens of Pleasure and Lens of Juiciness from Schell [8], rewarding the player's actions in many ways at once with audio and visual cues. Through tests with children, decisions were made on how to increase the pleasure and juiciness of the game. The 48 levels of the game are distributed across four different planet worlds, each with its own alien to be rescued, audio background track, and visual style. The blocks were picked up from an inventory shelf (via mouse or touch interactions) and made to interact with the alien world, rather than float in front of it. The block being moved by the player can crash into other blocks, turn the spaceship, or even interact with the alien's force shield, accompanied with playful sound and visual effects. The alien fidgets and babbles on the ledge for the player's amusement. The earthquake challenges the player's tower with audio rumbles and shakes that produce shifting and clanging of blocks that move according to Unity's physics engine. The energy balls light up and via lightning effects energize the UFO on successful survival of the earthquake test, as shown in Fig. 4. Children's reactions to various particle effects, from level completion to UFO energizing, as well as to the above-mentioned effects, were monitored in numerous playtest sessions. Their smiles, focus on the screen interactions, immediate discussion with other child players, and follow-up interview comments confirmed their pleasure with the interface modifications and underscored the importance of juicy interfaces in science games for young children.

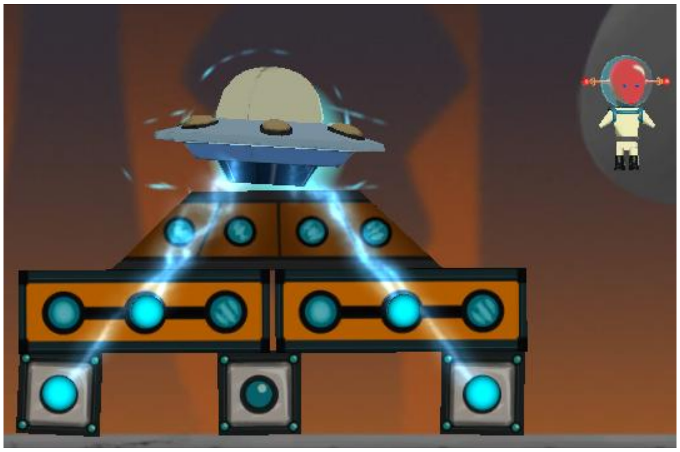

Figure 4. Zoomed-in view of the UFO becoming energized on successful construction of a tower that survives the test earthquake; a follow-up animation shows the alien and UFO fly off before proceeding to the next level.

There was concern about whether the children would understand how to move the blocks, using the mouse on a personal computer, or a touch screen on phones or tablets. Visual and audio cues were added and tested to provide interactive feedback. A tutorial heavy in symbols was added to the very first level that a child performed. If he or she repeated the action asked for in the tutorial, it would move on; if not, it repeated the instruction with more detail. One playtest examined the utility of the tutorial, and found that even without voice-over accompaniment (in English) describing the actions, the illustrated action storyboard was good enough to communicate how to move and rotate blocks and the UFO to help the alien.

Children are familiar with real-world blocks and their interactions. An early playtest with a few children examined whether a picked up block should float over and through all other objects until it is released into the world (and presumably made a part of a tower). An alternate system was tested whereby a selected block moved with the mouse but with physics and colliders working on it so that if it banged other blocks, they would move, if it banged the cliff it would stop, if it banged the UFO it might rotate, all under realistic control of the Unity physics engine. This sandbox of block actions that behave like real blocks was found to be much more intuitive and appealing.

Children did not react negatively to the mix of tower building, tower block removal, and contrasting case judgment levels in the game. They did notice a disconnect in that early versions of contrasting cases had single block structures, rather than towers constructed of pieces as shown in Fig. 2. For this age group, a strong narrative and consistency were found to be important.

For consistency, the *Sci-Fri* team made the changes to contrasting cases interface as shown in Fig. 2, i.e., replacing monolithic single block towers with towers constructed from multiple blocks. The team then tested the work to look toward educational effectiveness in the spring of 2012. A test with six 6-7 year olds began with six contrasting cases, then a mix of tower construction and tower block removal levels (up to 33 levels, up to 30 minutes of play time), then once either the time limit or all levels were reached a final set of six different tower-pair contrasting cases. The results are shown in Fig. 5. Students scored 42% on the pre-test and 67% on the post-test. This difference suggests that the game produced substantial learning. We believe it to be unlikely, but we cannot exclude the possibility that differences in the pre- and post-test forms produced or contributed to this difference. Hence, we will follow up with more formal testing with many more subjects.

Specifically, we acknowledge that the results from Fig. 5 are from a very small sample set. Evaluation plans include testing with students ages 4-9 to determine if there are differences across these ages with respect to the engineering principles being taught in the tower building, tower deconstruction, and tower contrasting levels. There will be pre-tests and post-tests given bracketing the game as was done here, to establish whether the game promotes learning outside of the game itself. Of course, the game will be instrumented as well with robust logging and in-game assessments that will document the achievements that take place within the game.

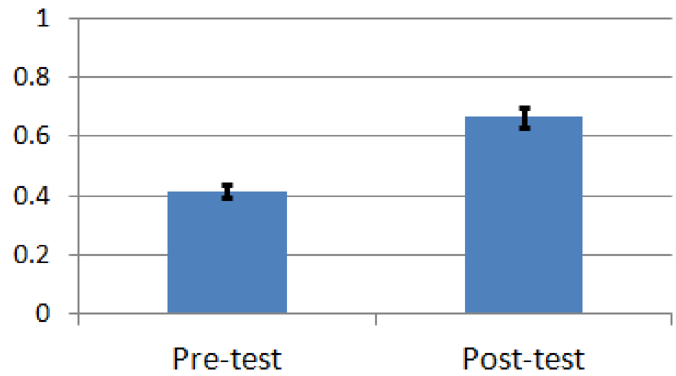

Figure 5. Results from six children on educational assessment of RumbleBlocks, showing 95% confidence bars and accuracy scores on contrasting cases pre- and post-tests.

VI. Conclusion and Future Work

The results of Fig. 5 suggest that thirty minutes with a game may change understanding of scientific principles regarding tower stability as measured by contrasting cases. (It is important to note though that results from such a small number of students do not always generalize to large segments of the student population. Stronger evidence will come from larger-scale studies on which we have embarked.) Obviously, the work is early in the formative stages. Will these results hold for thousands of students? What is the role of the tower construction activity found to be so appealing by the students that they will stay with the game for a full 45 minutes? The role of tower piece removal? The influence of a varying number of contrasting cases interspersed with the other types of levels? The role of showing center of mass perhaps visually on the screen as a point that changes with each block placement? The role of showing which tower falls due to being less stable during an earthquake in the contrasting case pairings? These and other questions will be considered by the HCII learning researchers using classrooms of tens of students and making use of DataShop logging that has served well for intelligent tutor evaluations [9]. Eventually, a number of varying configurations of RumbleBlocks will be deployed widely through the web to fine-tune level choices, much like the game Refraction has tested play time, progress, and return rate across varying versions of their game [10]. Such broad deployment across the web is facilitated by Unity's web player. Testing various level compositions and sequencing is facilitated by game logic that makes use of configuration files.

This paper has emphasized the early design decisions, prototypes, and quick play tests with small sets of children which led to the development of RumbleBlocks. From the choice of art style to the inclusion of a narrative, from the need for symbolic communication of a tutorial to target 4-7 year-olds (who may not yet know how to read) to tweaking game elements of fun and surprise to keep the players engaged, the paper has overviewed the improvement of the game over time. The interested reader is welcome to see more background on the reported work and play RumbleBlocks via links from the ETC [3]. RumbleBlocks appears to have measurable educational effectiveness for children and is a fun game. Future work will scale the evidence, field test more broadly, and report modifications made based on such testing.

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