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Center For Children & Technology/Education Development Center, Inc.

96 Morton Street, 7th floor, New York, NY 10014

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Abstract: This paper provided the context for a workshop that introduced attendees to a distinctive approach to building games to support middle-grades science learning. This IES-funded project is creating Nintendo DSi games that combine familiar casual game genres, high quality production and careful instructional design. The games are played by students prior to instruction as homework or during other non-instructional time, and stimulate students to develop shared, novel visualizations of abstract phenomenon. Teachers are then supported in using that common visualization as an anchor for analogical thinking about counter-intuitive scientific concepts that are often the subject of scientific misconceptions. Attendees will be introduced to the project approach, and invited to play one of the games, which uses a Pokémon-style battle paradigm to introduce concepts about randomness and dominance that are fundamental to understanding genetic heredity, The session will include time to provide feedback and discuss the game approach with the developers and designers of the games.

Introduction

In recent years an increasing number of researchers and practitioners have embraced the notion that educational games can successfully support student learning. Examples of various approaches abound, from simple games that surround traditional “skill and drill” activities and can be used in one class period to complex immersive worlds that require weeks to implement. But many questions persist about how best to design and implement games that closely complement existing instruction and target particularly difficult topics. With the *Possible Worlds* project, we have attempted to develop innovative games with unique mechanics that utilize popular game genre conventions, integrate easily with traditional classroom practices, and target topics that teachers recognize as urgently in need of new instructional approaches.

Possible Worlds is a suite of digital games for the Nintendo DSi with accompanying classroom activities that are designed to help middle grade students master persistently difficult science concepts. The use model is based on “preparation for future learning” (Bransford & Schwartz, 1999), a pedagogical model in which students have an initial interaction with materials that they may not fully understand, but which prime them for later explanation from a teacher. In *Possible Worlds*, students play digital games outside of instructional time, as homework or during other non-instructional time in school. The games center on an instructional activity or interactive metaphor that teachers can draw upon during instruction to ground their explanation and help students conceptualize novel and counterintuitive phenomena.

Building on prior research on the development of scientific thinking (Kuhn, 2001), we theorize that part of the reason why naïve theories are so much more persuasive than counter-intuitive scientific theories, is that the scientific theory is much harder to imagine. They can be illustrated, but interpreting those illustrations often requires understanding the very process they are designed to illuminate. Providing students with an opportunity to construct a novel visual representation that has an analogical relationship to the complex concept at the heart of the misconception can help students make sense of new information about the target concept as they receive it. It may help them make sense of the scientific idea, provided it is followed by the teacher delivering the essential "tell," identifying the significance of the illustration and linking it to the curriculum.

Research Context

Two primary bodies of cognitive and developmental literature ground the development of the game modules. First, well-designed casual video games—that is, games that do not require players to invest long periods of time on game play and character development, or whose narrative developments are not strongly dependent on player game choices—can be effective tools for helping learners develop preconceptual mental models in targeted learning domains (Reese, 2007). Reese argues that game-based instructional design informed by *structure mapping theory* (Gentner, 1983) can promote the development and practice of analogical reasoning by providing learners with opportunities to have game-based experiences analogous to those in the targeted learning domain. Thus, educational games whose features are designed to map to conceptual features in a target domain can become metaphors for abstract concepts learners will encounter in their school classes.

Our second major point of reference is the idea that if students are to capitalize on games as "metaphor primers," teachers must provide them with the scaffolding and guidance they might require to make connections between game play and targeted learning concepts. Bransford and Schwartz's (1999) "preparation for future learning" (PFL) model effectively frames our thinking—educational interventions are followed by a form of direct instruction, which should increase the likelihood of transfer. In the PFL framework, activities "set the stage" for learning with direct instruction by providing students with experiences from which they can draw to make sense of subsequent material. In *Possible Worlds*, games are designed as analogs to abstract, scientific concepts, furnishing teachers and learners with experiences they can draw upon to frame and make sense of challenging concepts.

The PFL model does not adequately account for the quality of the direct instruction, however. That is, in order to increase the likelihood that learners make connections between the game as a metaphor and the targeted concepts, teachers will have to be prepared to help their students by clarifying features the two share and by discussing how the processes in both are alike (Cameron, 2002; Venville, 2008). Beyond the game, the additional materials we have developed are designed to assist teachers in helping students to make those connections. In addition to clarifying common features between metaphor and concepts, dynamic assessment methods such as "graduated prompting," which probe learners' understanding with a range of increasingly explicit prompts about the concepts, will also be used to promote student reflection and analogous reasoning (Bransford, Brown, & Cocking, 1999; Campione & Brown, 1987; Lidz, 1997).

Supporting teachers, not replacing them

Because our games do not carry the burden of teaching – of delivering accurate information or explanations of concepts - students are not expected to walk away from playing these digital games with a sense of how the visualization embedded in them relate to anything they encounter in their science class. They understand the visualization only within the context of the game.

We provide teachers with a range of support materials that constitute a bridge between the digital game play at home and the lesson in the classroom. We provide them with images and interactive puzzle activities they can project during lectures and discussions, and extension activities that use the visualization as an illustration of a scientific concept.

We also provide teachers with a consolidation activity, which does not require any technology, but supplies a guided way to help students align evidence with claims in complex non-fiction texts. The key concepts in this consolidation game-like classroom activity focus on the particular misconception we are trying to address.

These materials are designed to be used in a specific sequence, to support students in acquiring, extending, and applying new conceptual knowledge. But we deliberately ensure that each resource can also stand on its own, making clear that teachers could use any or all of them by "dropping" them into their curricula.

Using diverse expertise

While there are project members at CCT with game design experience, from the inception of the *Possible Worlds* project we knew we wanted to work with a dedicated game development company. 1st Playable is a commercial game shop with a proven track record of delivering successful games for the Nintendo DS. They also have a strong interest in educational games, hosting the Educational Games Symposium annually to help local educators become familiar with the potential for games in the classroom.

Partnering with 1st Playable has allowed us to divide up the game development process in a way that we believe builds on each partners' unique strengths. At CCT, our content experts and child development experts collaborate to define the educational goals of each game and decide on the core interactive metaphor with which players will engage. Then, throughout the game development process, our researchers work with students in afterschool programs and in classrooms to test game prototypes, ensuring that design decisions support the intended thinking.

Meanwhile, 1st Playable focuses on the larger design of the game including the game mechanics that will incorporate and surround our instructional activity. They also have skilled artists and designers who create the game's narrative, art, music, and level design. Their involvement ensures that the games feel like "real" games to kids, and offer familiar, fun, genre-based challenges that encourage students to play for sustained periods, extending their exposure to the core instructional experience.

Weekly meetings ensure that their game design efforts remain in line with the game's instructional goals, including age and gender appropriateness. At times, their suggestions to improve the fun of a game can conflict with or undermine the core metaphor, and at these points negotiations between organizations ensure that the games remain as enjoyable as possible, while being tightly focused on the key instructional idea. At other points, the educational value of a game may be firmly established, and 1st Playable is able to freely add to the game to improve playability.

Module 2: RoboGen

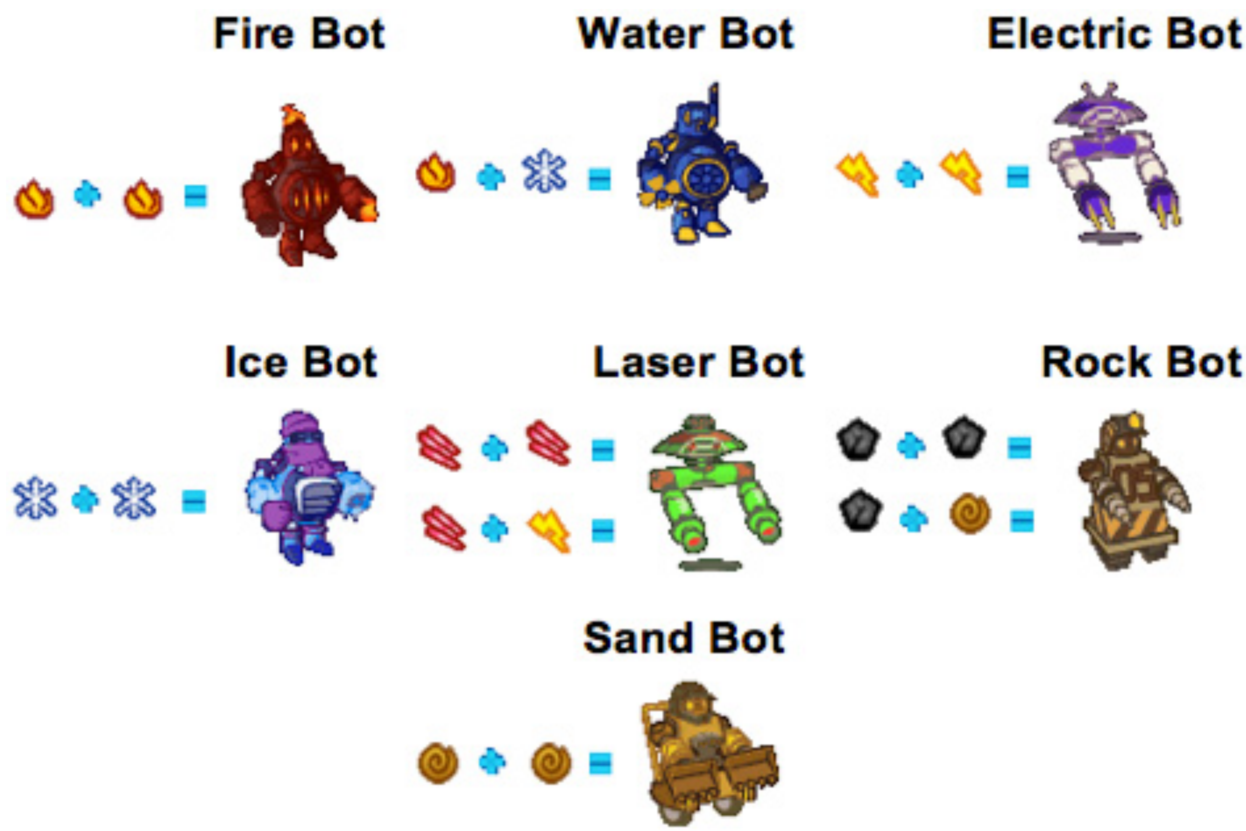
RoboGen is the second game in the *Possible Worlds* series and is designed to address two misconceptions in seventh graders' understanding of genetics. These have to do with the random nature of genetic inheritance and the genetic meaning of dominance.

The game is set in the world of Azalan where people depend on robots to do many tasks for them. As the story begins, many robots have become infected with a mysterious virus and have begun to behave in unpredictable and destructive ways. The player's character is a member of the Robot Rescue Squad and is charged with the task of repairing the infected robots. To do that, the player must use his or her own team of robots to disable the infected ones and install an anti-virus program.

There are a variety of different environments in Azalan, and in each place the robots have different "traits" that relate to the function the robot serves. For example, Rock Bots and Sand Bots are initially encountered at construction sites and do construction work, Ice Bots work in skating rinks, etc. Each type of robot is powerful against some types of robots, and weak against others. To win the game, players must create teams of robots with traits that match well against the weaknesses of the infected robots in a particular encounter.

If the player chooses the correct robots, his or her team will be able to disable the infected robots and the player can install the anti-virus software. The player does not start with a robot team, however. Instead, he or she must visit the Recycler and combine two broken robots to create one functional robot. Each robot's type is determined by two parts (analogues to allele pairs in genetics) that can either have complete dominance, or co-dominance. For example, Rock Bot can have two rock parts or one rock part and one sand part, while a Fire Bot must have two fire parts, an Ice Bot must have two ice parts, and a Water Bot has one fire and one ice part (see Figure 1).

Figure 1: **To Robot Parts**



In the Recycler, the player combines two robots, attempting to create one that will be successful against a specific infected robot. Which of the two robots' four parts that will combine is random, however. Thus, a player may combine two Water Bots to produce an Ice Bot, but a Fire Bot or another Water Bot, could also result. It may take multiple tries to produce the desired robot.

The science within the game

We used robots rather than biological creatures in this game because we wanted to avoid exacerbating already prevalent confusions among adolescents (and many adults) about hereditary traits and evolution. Many seventh grade students are confused about what an "evolutionary advantage" is. Instead of understanding that it means survival until procreation makes it possible to pass the trait along to the next generation, many students think it means having a characteristic that allows one to succeed in an environment. By using robots, which do not mate, have no life span, and exist to fulfill a single function, we sidestep those misconceptions.

Most seventh graders have a partial and concrete understanding of the word "random", understanding it as meaning "no pattern," "by chance," "arbitrary," or "unpredictable." However, they have a very hard time understanding that if a series of possible events is randomly generated, the next event has no relationship to the event that preceded it and will have no effect on what happens afterward. The notion that each event is *independent* even though there is an over-all distribution or pattern is deeply counter-intuitive.

The idea behind the Recycler in RoboGen is to help students visualize the randomness in heredity. They can watch how the random selection of one part (allele) happens within both "parents" and how the resulting robot is always a combination of the two parts. Randomness is in play, because sometimes it takes many attempts to get the combination that produces the robot the player wants for strategic reasons. The desire to get the right robots to win each encounter focuses the player's attention on the random nature of robot heredity, but without a teacher making the analogy to randomness in general, and biological heredity specifically, few kids would make any connection between the game mechanic and the material covered during class.

Dominance is another difficult aspect of genetics. Many seventh graders harbor a common misconception that dominant genes are stronger and better or carry traits that facilitate survival, while recessive traits are weaker and less useful. They may recognize that brown eyes are not really superior to blue eyes, but when it comes to other traits, the misconception that "dominant" means "more powerful" easily reasserts itself.

In this game, each robot has a single trait (*ice*, *water*, *fire*, *rock*, *sand*, *laser* or *electric*), which determines its phenotype. The central game mechanic asks players to consider how this trait empowers the robot in relation to other robots,. and dominance is clearly unrelated to power. In the Recycler, the rock part, for example, is dominant over the sand part, but when they meet, Sand Bots are stronger than Rock Bots. On the other hand, the laser part is dominant over the electric part, and Laser Bots are stronger than Electro Bots. Fire parts and ice parts are co-dominant, but Fire Bots are stronger than Ice Bots, and Water Bots, their "offspring," are stronger than Fire Bots and weaker than Ice Bots.

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