Possible Worlds Year 2 Formative Research

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Introduction

This report summarizes the goals, procedures, and outcomes of research activities conducted in fall 2009 by EDC's Center for Children and Technology (EDC/CCT). Funded through the U.S. Department of Education's Institute of Education Sciences (PR/Award #R305C080022), this five-year program of research and development focuses primarily on the development of educational games that make use of portable game systems (Nintendo DS and DSi) to support science and literacy learning among middle-school age students.

The program, now referred to as *Possible Worlds*, began in July of 2008 when EDC/CCT was named one of two National Research and Development Centers on Instructional Technology. The goals of the first year were to create a common base of shared knowledge about relevant games, curricula, and research, and to develop the first module of *Possible Worlds* game prototypes.

We currently are in the middle of Year 2, the goal of which is to conduct formative research with middle-school students and teachers in afterschool settings in order to evaluate and revise these Module 1 prototypes. We completed the first round of formative research in fall 2009. Our primary concerns this fall were to evaluate the playability and comprehensibility of the DSi games, as well as to get a sense of teachers' needs if they are to integrate them into classroom instruction. A secondary goal was to begin to assess the extent to which the games engage students with the content and concepts the games are intended to address. Systematically studying learning outcomes will become a central concern in future stages of the project.

The information gathered through formative research in fall 2009 is being used to inform the revision of the Module 1 DSi games. We will return to the afterschool settings in spring 2010 to assess the appeal and potential instructional value of the revised games. The information gathered during those sessions will inform the revision of other elements of Module 1, including the professional development materials for teachers who will field test Module 1 in their classrooms. Module 1 wil then be field tested in 7th grade science classrooms in fall 2010.

Year 4 will involve a more rigorous impact study to assess the impact of the games on students' understanding of science concepts. Over the next three years, we will also continue to conduct formative research to test the appeal and comprehensibility of newly produced games and associated materials for Modules 2-4 in afterschool programs similar to the one described in this report, as well as field testing those Modules in science classrooms.

Developmental Considerations

Early adolescents are working through developmental transitions that are likely to shape their engagement with electronic games. An ongoing focus of our work is to understand the influence of these factors on students' gameplay and their readiness to master difficult scientific concepts, and to design games that support students' development as thinkers and problem-solvers. Below we briefly outline some relevant developmental factors that we believe impact how 7th grade students interact with and learn from games. In the What We Learned section of this report, we cautiously point to ways in which the prototypes for the Module 1 games were more or less effective at accommodating these factors.

From a socioemotional perspective, 7th graders are in a transitional period, moving toward the challenges and opportunities of adolescence but not fully prepared to act as independently as older teenagers. They are likely to move back and forth between the preoccupations and perspectives of late childhood and more aspirational activities that model the social practices of older adolescents. Consequently, they are likely to be engaged by multiple forms of play, but may be very sensitive to the cues of their peers in the public choices they make about game-play. The complex but still fundamentally imaginary play of late childhood is still meaningful to them, but they are more prepared to step back from fictional narratives, name them as "not real," and to assert the greater importance of "real life." The notion that fiction or imaginary experience is "just for fun," and consciously identifying these experiences as opportunities for social interaction—as opposed to a primary form of experience of the world—is a major shift youth are working through at this age.

From a cognitive perspective, twelve year-olds are likely moving through a similarly gradual and complex shift from late childhood to early adolescence. The core cognitive task involved in this process is perspective-taking—the ability not only to consider the point of view or experiences of someone else, but to incorporate that other point of view, or multiple points of view, into a sustained analysis or reflection on a situation. While research suggests that younger children are able to do this kind of perspective-taking in short bursts or under well-defined conditions (Sobel, Yoachim, Gopnik, Meltzoff, & Blumenthal, 2007), mastering these skills and integrating them into the day-to-day work of engaging with family, schoolwork, and social networks is now becoming possible and, in the school context, expected. Furthermore, their ability to manage and manipulate abstract ideas, to organize evidence logically, to follow chains of reasoning, to attend to detail for sustained periods of time– all of these are abilities that change over time and can be accommodated and stimulated in learning environments that give them opportunities to practice those skills.

Implications for game design

To accommodate these socioemotional and cognitive developmental factors, Module 1 games seek to engage adolescents in multiple forms of play that provide opportunities for independent and collaborative exploration. Furthermore, the games aim to absorb students in a narrative that has both fictitious and scientific elements. The narrative premise of the final game module will be that a group of teens are exploring a fantastic cavernous region that harbors vampire-like creatures and other mysteries. While the characters' search for vampires requires players to engage with a fictional narrative, success in the games is requires students to engage with and manipulate processes that directly parallel concepts and processes they are encountering in science class.

The activities in the Module 1 game prototype were also designed to inspire questioning, probing, and reflection among students as they develop and revise theories about the scientific processes under investigation. In this way, *Possible Worlds* games are designed to engage students in direct exploration of scientific concepts and process, rather than to deliver information about scientific topics. Our work responds to a host of recent findings and policy voices that point to the need for academic interventions for adolescents that emphasize inquiry-based instruction, reading in and across the subject domains, the integration of higher-order thinking skills with content-area knowledge, and added motivation for struggling students.

Adolescent development and scientific misconceptions

While adolescents are ripe for the types of developmental and cognitive changes outlined above, their preexisting beliefs about how the world works can act as obstacles to learning . Students enter science classrooms with a variety of ideas about the world; some are correct but others are incomplete or faulty. Students hold onto their pre- or misconceptions tenaciously (as do adults), which often clouds their thinking about science concepts they encounter in school. *Possible Worlds* games focus on the aspects of scientific topics that are often the subject of misconceptions, which are difficult to displace because of their apparent explanatory power and parsimony. The goal of the instructional design of the DSi games is to encourage and prepare young people to look critically at the theories they hold, to immerse them in direct, if virtual, experiences that engage them directly with alternative explanations of the phenomenon under study, and to motivate them to evaluate and reconsider how they make sense of that phenomenon.

These guiding principles will drive the development of four modules, each addressing a different scientific concept that is the subject of misconceptions. The remainder of this paper describes formative research conducted to inform the development of our first module, which will address the photosynthetic process.

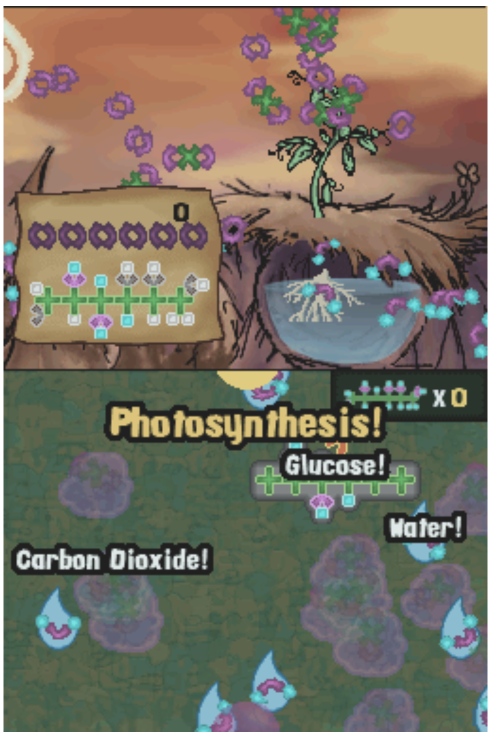
Possible Worlds Game Prototypes

The game prototypes described in this report were the result of a development process that unfolded between fall 2008 and summer 2009. The primary focus of this process was to find a balance of scientific accuracy, developmentally appropriate content, and compelling game-play that could work together to produce games that were compelling while also achieving our instructional goals . Our emphasis on promoting exploration of concepts rather than delivery of information required striking this balance, but led to thorny design challenges. For instance, the development team struggled to determine how to give players a role in manipulating or participating in a self-regulating system (photosynthesis in plants) or the ability to view invisible particles in order to play with them. The prototype development team spent pursued multiple iterations of game mechanics that could exploit the unique features of the Nintendo DS, present appropriate visualizations, reinforce science concepts and not inadvertently introduce misconceptions..

Below is a brief description of the Module 1 game prototypes that were tested in fall 2009, in the order in which they were piloted. These games currently are undergoing significant revisions as a result of our observations of game-play and feedback we received from adolescents and teachers, which are also presented below.

Photosynthesis Game

This game employs a shooter mechanic, in which the player makes photosynthesis and respiration happen. During daylight, the player “shoots” energy at molecules and if the energy hits a molecule, it breaks apart and atoms bond with others to form glucose molecules. During respiration, at night or during the day, oxygen molecules are shot into glucose molecules and when the sixth oxygen molecule hits, the glucose breaks up, energy is released, and the plant grows. The educational goal of the game is to provide students with the experience of enacting the processes of photosynthesis and respiration by interacting with the particles associated with the process.

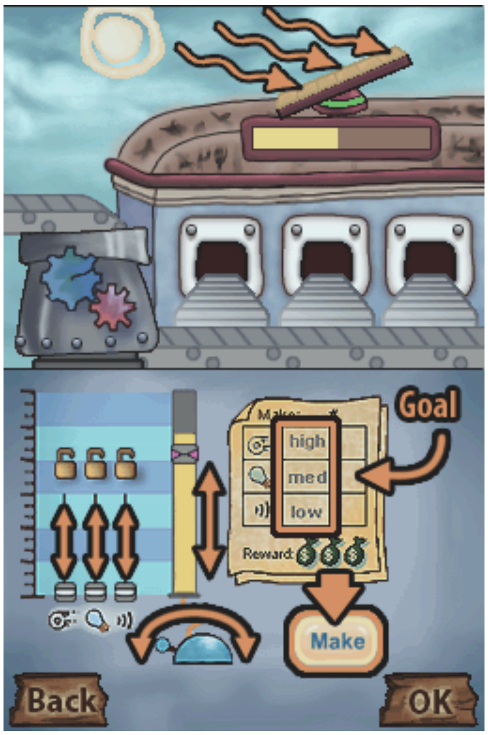


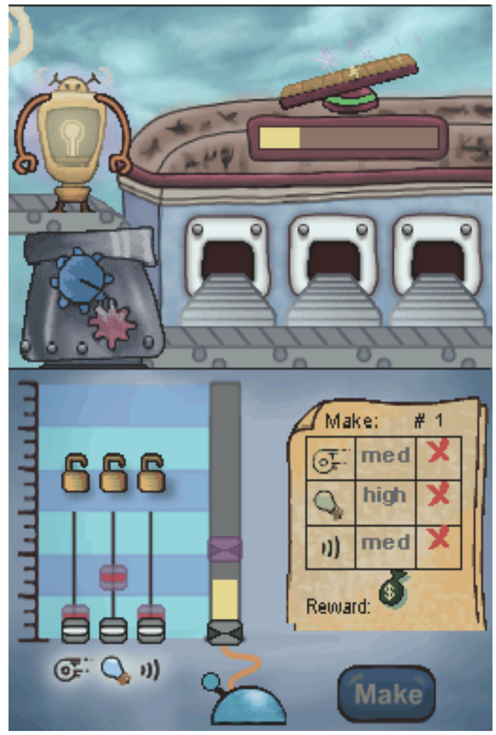
Methanol Game

This game allows players to explore another energy transformation phenomenon: artificial photosynthesis. It employs the same shooter mechanic as the Photosynthesis Game, but the player's goal in this context is to make a robot come to life and move by producing and burning methanol molecules via artificial photosynthesis and combustion. The learning goal is to have students understand that, like natural photosynthesis, an artificial photosynthesis process uses light energy to transform matter and ultimately create a new form of energy.

Systems Game

The learning goal of this game is to help students play with the notion that in a closed system, things have to stay in balance in order to work; having more of one component of the system means having less of something else, and different balances of major variables create different conditions. During game-play, the player receives orders that dictate the energy requirements (light, motion, and sound) to make a functional robot. The player must then adjust the levels of energy in order to balance the system according to the specified criteria. Their goal is to fulfill as many orders in the time allowed in order to make robots and earn money.





Literacy Game

The learning goal of this game is to have students consider the use of words in different contexts. The game mechanic aids comprehension by presenting written sentences with words that have synonyms and variations in usage. Players manipulate the meaning of the words and the sentences by selecting definitions from a word bank. Although the player is rewarded for selecting the correct usage, there is an alternate reward for exploring all the different meanings. When players choose the incorrect answer, they get to see the humorous animations illustrating the sentences. This gives struggling readers the opportunity to be playful with words. The game is intended primarily as a literacy support for struggling readers, but because vocabulary is a central concern of science teachers of this age group, it also aims to support more general vocabulary learning.

The Classroom Game

The fourth game in Module 1 involves two activities designed to be played in the classroom rather than on the Nintendo DS. In the first activity, players evaluate the conditions of a fictitious cave to determine if vampires are present. This open-ended sense-making activity requires them to use limited evidence to make a reasonable argument about whether a group of kids should enter the cave. The second activity gives students the opportunity to use their understanding about energy transformation to try to solve a puzzle about how vampires might transform into bats. The fictional process of "Vampirosynthesis" is similar to that of photosynthesis and artificial photosynthesis. The activity is intended to aid the development and identification of students' ability to decode and articulate those real-world scientific processes.

Information the robot probes sent back from the cave:

CAVE ATMOSPHERE	DATA	What it means:
Humidity	80 %	
Oxygen	25 %	
Carbon Dioxide	12 %	
Light	0.15 lux	
Temperature	20° F	
Sound	60 decibels	
Blood	35 %	
Living Things	bats, moss & algae	

Methods

Throughout our formative research efforts we are focused on gaining insight into how teachers and students make sense of the games or other instructional materials presented to them. This examination of the Module 1 game prototypes required us to attend to students' and teachers' interactions with each of the following dimensions of the games:

- *Game mechanics:* How do students interact with the game, including both physical manipulations and symbolic engagement (e.g., use of a shooting mechanic to convey energy transfer)? How does their understanding of and interaction with the game align with or come into conflict with the conceptual understandings the game is aiming to address?
- *Narrative*: How do students and teachers make sense of the narrative provided to them, and how does it support or impede students' analysis of evidence or consideration of alternative explanations for phenomena?
- *Relation to instruction*: How do teachers make sense of the game content and structures relative to their current instructional practices? What kinds of guidance or support do students seek out?

Because the narrative content of Module 1 was not fully produced for fall 2009, questions about narrative played a secondary role in this round of formative research.

<u>Research sites and procedures</u>

Fall 2009 formative research took place in four afterschool settings- three in New York City and one in a New Jersey suburb. Afterschool sessions were held twice weekly, with 10-12 sessions occurring at each site. Sixth and 7th graders were recruited to the program and told that they would play a series of educational games that are in development, and would be asked to critique the game prototypes in order to inform revisions. During the first session, the teacher delivered a PowerPoint presentation developed by EDC/CCT that introduced students to strategies for critiquing video games and other media. Researchers often referred to elements of this presentation when eliciting feedback from students during and after game-play.

During afterschool sessions, students and teachers played the *Possible Worlds* game prototypes. Students also played some commercial games, including *Diner Dash, Line Rider,* and *Scribblenauts* when extra time was available or when researchers were working with other students. During all instances of game-play with the Module 1 prototypes, researchers observed and recorded students playing and followed protocols designed to identify their thinking about the problems they perceived in the games, the cues they identified to overcome obstacles, and the decisions they made to solve those problems. Typically, game-play was followed by a whole-group discussion, for which protocols were designed to give students opportunities to reflect on the game and articulate their theories relating to underlying scientific processes (See Appendix for protocols).

At several points in the session sequence, teachers presented content about photosynthesis to students, using PowerPoint presentations developed by our team. The purpose of these activities was to allow us to observe whether and how students made connections between the concepts and processes they had been exposed to in the games and the processes of photosynthesis and methanol production, and to observe how teachers chose to make connections between the game content and the content they were presenting.

The first of these presentations described the processes of photosynthesis and respiration and was presented after students played the photosynthesis game. During initial play, students were asked to keep track of their theories about what happened in the game. Following the presentation, students had the opportunity to ask questions and play the game again with labels turned on that identified various game elements (e.g., carbon dioxide, water, glucose). The Methanol Game was also accompanied by a PowerPoint presentation outlining the underlying processes of methanol production and combustion. This presentation, however, was given before game-play. These were the only sessions that were accompanied by explicit instruction about the scientific processes depicted in the games.

In addition to observing game play and interactions among teachers and students, debrief interviews with teachers were conducted at the end of each session, and all teachers participated in an interview at the end of the program (See Appendix for the interview protocol).

What We Learned from the Formative Research

The fall 2009 formative research was designed to inform revisions to the game prototypes, instructional sequencing, the creation of teacher support materials, and the development of instruments and procedures to evaluate classroom implementation and the more rigorous field trials to take place in Years 3 and 4. Because our research questions and approaches were largely open-ended throughout this phase of the project, the "findings" we present below should not be misconstrued as clear evidence of how students learn from games of this kind or how those games should be implemented in the classroom to support teaching and learning. Instead, we present our initial observations and theories, which will be examined systematically in the coming years.

Below we present our initial findings in six sections, corresponding to 1) the Photosynthesis Game, 2) the Methanol Game, and 3) the Systems Game, 4) the Literacy Game, and 5) the Classroom Game. In the sixth section, we present feedback from teachers relating to the classroom applicability of the game prototypes.

<u>Photosynthesis Game</u>

The emerging sophistication of 7th graders' understanding of narrative led us to make more ambitious use of ambiguity in the look and feel of these games, as well as in game mechanics. We asked students to play the Photosynthesis Game without offering instructions, guidance, or insight into the scientific processes represented. Students' responses to this open-endedness varied widely.

Lack of Instructions

Many students, especially the younger ones, complained about the lack of instructions during game-play and said they wanted an explanation or tutorial. Some, however, appreciated the ambiguity and enjoyed figuring out how to become good at the game. According to one kid, "I think it's cool once you understand how to play and what you need to do to get the points. Even before I knew how to play, I thought it was cool because I like to figure it out by myself." Another kid echoed, "I liked that nobody had to teach me, the video game taught me stuff."

The Setting

Some students wished for more clarity regarding the game setting. While some insisted that it took place inside a leaf and offered reasons to support that interpretation, others stated they did not know where the game was supposed to be taking place. As one kid stated, “In real life, photosynthesis happens in the leaves and in the game it wasn’t clear where it was happening.” The ambiguity of the game setting may have interfered with the ability of some students to build theories about what was going on in the game.

The Topic

Students differed greatly in their opinions of what the game was actually about. Some students incorrectly guessed that it was about “viruses,” “the water cycle,” and “making steam.” Others put forth more accurate interpretations, theorizing that it was about “photosynthesis,” “growing plants,” “building and breaking branches,” and “breaking things up.” A boy justified his theory that the game was about plant growth by explaining, “I see the clouds and rain is turning into the clouds. Water vapor makes the clouds and then when it hits the clouds, more things go into the plant, which makes it grow.” A girl explained that the game was about photosynthesis “because you are the sun and you’re shooting at these green plus signs and once you get a full one you shoot with the purple ball thing at the bottom and it explodes and your plant grows.”

Goals & Strategy Perceptions

The goal of the Photosynthesis Game was a source of debate among students. Most understood that they had to make the plant healthy, but disagreed about what was involved in fulfilling that goal. The strategies they developed to win may have resulted from their efforts to achieve the perceived goals of the game. One kid said that the way to win was to “Keep shooting and don’t stop even when the sun is down.” While this method of play may in fact lead to a healthy plant, it does not reflect any strategic thinking about how to use time or resources most effectively. Another kid explained that his strategy was to “get six of the things together and then shoot the teardrops to get the nutrients. Then you feed the plant the nutrients with the sun and you have to get water to keep the plant from drying out.” This description acknowledges that there is an ideal order in which to complete game tasks, and reflects an understanding that plants rely on atmospheric elements to grow. However, the claim that water is used merely to provide moisture to the plant rather than to aid in its growth is a misconception. Finally, a kid explains, “You should wait to break the plus sign strands at night because that’s the only thing you can do at night; you can’t break them during the day.” Here, the student acknowledges that, to win the game, it’s best to focus on different activities at different times of the day to use one’s time and resources most effectively.

Object Identification

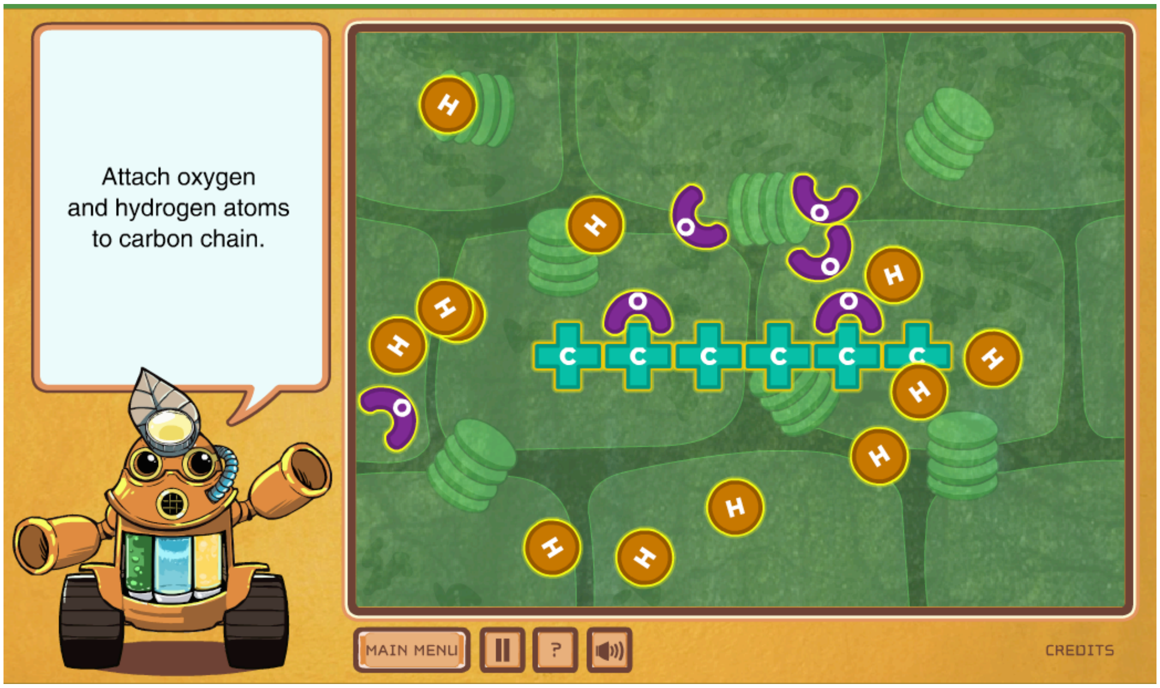
When asked to identify objects that appeared in the game, students confidently identified the yellow orb as the sun. They disagreed, however, about what was represented by the purple orb at the bottom of the screen. They identified it as “the moon,” “a different sun,” “water,” “a robot,” “the purple ball thing,” “the plant root,” “something that makes energy for plants,” and “something that shoots nutrients.” The moon interpretation was by far dominant among students and, in many cases, it persisted even after they played with the labels turned on. Their tenacity with this interpretation suggests that the game failed to prompt some students to reflect on and correctly apply the information presented in the PowerPoint to the identification of game elements. The proper transfer of information may have made it clear to students that the moon is not related to the processes of photosynthesis and respiration.

Game Mechanics

Despite the multiple sources of ambiguity and differences of opinion among students, almost all of them picked up on the mechanics of the game and seemed to master them within a short period of time. On one hand, this is a positive finding because repeated instances of failure often lead to student frustration and disengagement. On the other hand, a game that is too easy can lead to disinterest and, more importantly, low levels of learning. Our observations suggest that the shooting mechanic enabled players to adopt a careless scattershot approach to interacting with the particles, and that this made the prototype Photosynthesis Game too easy for students. Some students began playing at the hardest level and succeeded there, giving them little incentive to play slowly and pick up more subtle strategies. On one occasion, a girl demonstrated that she could win the game with her eyes closed. Despite the inclusion of an accuracy score, clicking as fast as possible and shooting everything in sight was an effective strategy to win. However, this approach undermines any inquiry or problem-solving aspects the game may offer. Revisions to the game currently under way aim to require students to play more strategically and make use of multiple thinking skills.

Content Comprehension

Students played the game with the labels turned on (see below) after their teacher delivered a PowerPoint presentation describing photosynthesis and respiration. The PowerPoint underscored the idea that, during photosynthesis, water and carbon dioxide molecules are disassembled and rearranged into sugar, and the sun's energy is stored in glucose molecules. During the second round of game-play, students were asked to reflect on the information from the PowerPoint and articulate the ways in which they thought the scientific process was (or was not) represented in the game. During game-play, for instance, one girl said she was "breaking apart CO2 to make glucose." Another student explained that the sun's rays "make things split." Finally, another student explained, "The game shows you that you have to make the glucose and it shows you that you have to piece it together in the right way." These comments contrast to the conceptions of many students of this age group, who believe that molecules (rather than atoms) are basic, simple, indivisible entities (Griffiths & Preston, 1992), and do not understand that new substances can be formed by the recombination of atoms in the original substances (Andersson, 1990). The comments above, which reflect an understanding that molecules can be divided and recombined, suggest that the game, coupled with the PowerPoint, may help students develop a more accurate understanding of energy, matter, and the nature of chemical change. Future research will continue to examine the aspects of game-play that most effectively support conceptual mastery of this kind, and how supplementary instruction can contribute to this understanding.



Methanol Game

Likely due to the similar mechanics and level of guidance for mastering the game, the Methanol Game brought on disagreements among students comparable to the Photosynthesis Game. A difference in this case is that the PowerPoint presentation detailing the scientific processes preceded game-play. This may account for students' greater accuracy when identifying objects in the game, as well as their more consistent interpretations of the game's goals. After students saw the PowerPoint and played the Methanol Game, researchers asked them about the goal of the game. Most students correctly theorized that the goal was to "make methanol." One student elaborated by saying, "We were trying to gather up certain molecules until they made a methanol molecule and then break it."

When asked about the strategies they used to win the game, most students reiterated the strategies they mentioned when playing the Photosynthesis Game. One student stated explicitly, "I used the same strategy as I used for the other game." Students pointed out that the goal of both games was to make a molecule, and both games required shooting. Game revisions aim to instill an understanding of both processes without being overly redundant in terms of the game mechanics and ideal strategies.

Systems Game

We expected the Systems Game to be the most difficult *Possible Worlds* game for students to master. It required students to attend to multiple variables while applying knowledge of systems to create the balance necessary for success. We predicted that, due to the game's open-endedness and the precision required, students might become frustrated or lose interest in the game.

Game Mechanics

Much to our surprise, a number of students began "making profits" after a few minutes of play, suggesting that they quickly caught on to the mechanics of the game. A few students, however, never made sense of the mechanics on their own. When paired with another student who was able to explain the game to them, these students were able to begin playing independently. The "student-teaching-student" dynamic was more common in this game than the previous games.

Rising to Challenges

The most common complaint about the Systems Game was that it lacked instructions and a narrative context to help students understand what they had to do. One girl said, "Without instructions, you fail at first. And failing is not fun. If there were instructions, you would know how to play the game." The majority of students, however, said they preferred this game to the previous games. They said they liked that, in order to win, "You have to be exact," "You have to pay attention," "It's harder to figure out," "You can't just shoot to win," and "You have to put everything in the right place." These comments suggest that the Systems Game required students to use reasoning and problem-solving skills that were not required in the previous games. Their feedback also reveals what we already suspected from students of this age group—they *like* to think and engage with difficult problems that require various approaches. As one kid articulated, "I like hard games because when you lose it makes it more fun and you keep doing it. It gets addicting." Comparing this game to the Photosynthesis Game, another kid said, "This is harder but better because it's challenging. You have to figure out what you have to do. In the plant game you just had to shoot randomly. In this you have to get everything in the right position." The revised games will incorporate more challenging tasks to satisfy their desire to reason and to aid the development of target thinking skills.

Content Comprehension

Feedback from several students revealed an understanding that the system components had to remain balanced to function properly. According to one girl, the game was about "using energy to create balance." Another student explained that you "have to strike a balance" and subtle differences lead to system overload. While these are promising insights, other students did not seem to recognize that balancing inputs was a central component of the game. Reflecting on the game, one girl remarked, "The only thing I can understand about this game is the money." Another student said the game was about "making robots. I don't get how it relates to science." Having played the game unsuccessfully a number of times, resulting in a "machine overload," one boy commented, "It keeps not working and I don't get it." Currently, we are developing assessments for use in Year 3 that will enable us to evaluate the extent to which a game of this kind may contribute more effectively to students' understanding of systems.

Literacy Game

Ease of Play

This game was developed with struggling readers in mind. Unfortunately, struggling readers comprised a small subset of the students that participated in the afterschool programs. Most participants were high achieving students with average or above average literacy skills. As a result, they played through the game quickly and many reported that they found the game to be "easy" or "boring." After viewing the different word meanings, students quickly toggled to the correct meaning to complete the sentences. Many completed all of the sentences in less than 10-15 minutes and made few, if any, mistakes. Several students said they knew all of the words and suspected that the game was designed for younger students; one boy said "common sense" led him to the right answers.

Game Narrative

The vampire narrative was introduced more explicitly during this game, and seemed to appeal to students who previously criticized the other games for lacking a clear story. Because this game featured pictures and sentences relating to vampires, students had the beginning of a story to latch onto. They responded positively to this even though the narrative remained vague and fragmented. At times, it seemed that students constructed a cohesive narrative to make sense of the activity. One kid insisted, "It's about vampires and bats and caves." Another students said, "You kind of have to build sentences and you're working your way through the cave." According to another student, "They are smart to make it about vampires because everyone's in love with vampires right now."

Replayability

Some students criticized the Literacy Game for its lack of replayability. One kid said, "Once you play once, you're done. You can't go back and replay it like the other games." This complaint may reflect adolescents' common liking for complexity, exploration, and alternative approaches in contexts where they do not have to be concerned about the consequences of their decisions. We will seek to incorporate opportunities for repeated exploration into future iterations of the game.

Classroom Game

Engaging Narrative

More than in any other of the Module 1 game prototypes, the Classroom Game absorbed students in a clear narrative. They were told that a group of students had to figure out whether vampires were present in a cave they wanted to explore. In Part I, the players were told that a robot probe was sent into the cave to gather information about the cave atmosphere. Their job was to evaluate the data and thereby draw conclusions about whether vampires were present. A list of "facts" about vampires was also provided to students for use in their analysis. Students responded positively to the narrative and said almost uniformly that vampires are interesting to them. Their feedback also suggested that the mystery of the story and the imagined danger were appealing and engaged them in the activity. Several students requested more narrative information and wanted to know how the characters had found the cave in the first place.

Interpreting Data

The fictitious cave data were presented to students as a series of graphs. We anticipated that making sense of the graphs would pose a challenge for many students. However, most students who attended to the graphs read them accurately and were able to justify their conclusions about the cave atmosphere. Almost all students agreed that there were probably vampires in the cave and that the characters should not enter if they sought to avoid them. A teacher told us that the data were more straightforward than the data they typically have to interpret out of a textbook or for a standardized test. Future iterations of the game could make use of more complicated presentations of data to pose greater challenges to students and promote more varied conclusions to stimulate debate. However, student readiness to work with this type of data is likely to vary widely, and we will need to be sure to provide a range of data types to accommodate variations in how prepared students are to make sense of data displays.

Drawing from Prior Knowledge

Adolescents' prior knowledge often clouds their ability to make sense of new and conflicting information. This developmental challenge manifested itself in some students' tendency to ignore the cave data and, instead, make initial conclusions based on their pre-held theories about vampires. For example, when asked to interpret the level of light on the cave, one boy wrote, "vampires are killed by light." When asked how he knew this, he said, "I just knew that naturally." This boy later looked at the vampire facts and changed his response to "vampires are blinded by light." Other students said they used "common sense," rather than evidence, to interpret the data from the robot probes. However, there were a number of occasions when students' "common sense" interpretations were contradicted by the evidence. In these cases it was clear that some students were prepared to set aside their expectations and engage with the data presented, while others chose to ignore the data and maintain their prior beliefs. This disparity is consistent with developmental and learning theory, which suggests that students at this age are *able* to set aside prior beliefs to consider alternative evidence and explanations, but that their ability to do so is largely dependent on the opportunities available to them for rehearsing this practice.

Appeal of Science Fiction

Students made it clear that they recognized this game as a science fiction narrative that integrated fictional and factual evidence. Students said that, with this activity, the talk about vampires made more sense than it did in the Literacy Game and seemed more relevant to science class. One student said this was because "now we have facts that show that vampires can live." The structure of the activity and the nature of the task (with charts, data to interpret, etc.) were similar to what they would see in a classroom context, which made the experience feel more authentic to them. A girl said, "I like the vampire thing. It makes it cooler. At first when we were talking about vampires, it wasn't sciency at all, but doing this sci-fi stuff and figuring out the science behind vampires was really cool." A boy echoed this notion by saying that science fiction is a good way to teach about science "if it's based in facts and builds on facts. If they have something rooted in them, if you start with something science and you grow on it without changing any of the real facts."

While the vampire narrative was generally appealing, we also observed several students who did not understand why they were asked to consider the existence of vampires within the context of a school science game. For example, one student said, "This doesn't make sense. Vampires aren't real. It's not like they're real or anything. You can't find evidence that they exist." Other students in the class disagreed. One insisted, "No, this stuff is real," while another asked, "Why would somebody make an educational game if it's not teaching you something? The idea of it is not an educational game, but how you do stuff is educational." This comment is interesting for two reasons. First, it suggests that at least one student distinguished between logical processes of inquiry, though she did not refer to them as such, and scientific content and realized the former might not require the latter in order to function. Second, it reveals a distinction between "educational games" and "other games"—in this framework, games branded as "educational" have something to teach and therefore must be educationally valid. From the perspective of instructional design, that authority can be useful in terms of pushing students to solve problems if they know there are solutions to be found in school-based activities, but it might also be problematic if students view content as valid without question.

Some student feedback revealed confusion as to whether real-world logic can apply to game-based fantasies and vice versa. One student commented, "You have a bunch of facts here about vampires, but I don't know if vampires are even real," to which another student responded, "But maybe in the game they do exist." These comments reflect a potentially productive tension between real-world logic and facts and game-based fantasy – a tension that is familiar in children's media but that will take on some new implications for students in a formal instructional setting. We understand the skeptical comments above, about the relevance of considering the existence of vampires in science class, as a sign of some students' powerful expectation that scientific reasoning skills would or could only be expressed in the context of content that is already established and known (though not necessarily by the student themselves). We will work carefully to develop strategies for teachers to use to frame the vampire aspect of this module in a way that allows students, and teachers as well, to consider the vampires as a thought experiment – a case around which they can master and make use of their understanding of the principles of energy transfer and chemical transformation that are central to this module.

Student Discussions

Part I of the Classroom Game served as a springboard to other conversations among students that seemed to be thought-provoking for them, and at times were philosophical in nature. For example, during a whole-group discussion following the activity, students launched into a debate about whether, based on the characteristics of vampires, one should concluce that they are dead or alive. Supporters of each conclusion argued and listed reasons for their belief. At another site, students explored ideas about whether vampires are more like humans or more like other animals. At yet another site, the discussion led students to debate the difference between things that are "living" as opposed to things that are "alive." They talked about whether those words have different meanings and where vampires fit in that distinction. These discussions also suggest to use that while the introduction of science fiction or fantasy features into these modules will need to be framed and introduced carefully, that it is a fruitful avenue for stimulating exactly the kind of motivated engagement with the details of abstract processes (such as chemical change) and the kind of argumentation drawing on evidence that we are seeking to support.

Transfer Task

Part II of the Classroom Game gave students the opportunity to use the principles of energy transformation that they had been exposed to in the game prototypes to try to solve a puzzle about how vampires might transform into bats. They were given various diagrams and were first asked to decode a series of pictures that described the steps of photosynthesis and artificial photosynthesis. Next, they were presented with a diagram depicting the fictional transformational process of “vampirosynthesis” and were asked to detail that process in a similar manner.

Students identified vampirosynthesis as the process by which a vampire turns into a bat. According to one kid, “It shows the process that it goes through to turn from a vampire into a bat, what’s needed, stuff like that.” Some students explained that vampires cannot do this on their own; like the other scientific processes, they require substances from elsewhere to aid the transformation. One student articulated, “It’s trying to explain that when vampires take in blood, they have more energy to turn into a bat.” When students were presented with a second diagram, in which a vampire is transformed into a bat and then back into a vampire, some students recognized the similarities with the previous processes they encountered in the Module 1 game prototypes. In describing vampirosynthesis, a boy said, “It’s a cycle, like photosynthesis and artificial photosynthesis.” Some students counted the different molecules at different stages of the transformation process, seemingly to make sense of the information in front of them and keep track of the various molecules. In his efforts to make sense of a vampirosynthesis diagram, one boy stated, “I need to know where he got the carbons...He needs two more Os and one C, but I need to know where he gets the Cs.” In some instances, counting seemed to reflect a basic understanding that the molecules from one part of the process are the same ones, though rearranged, at another part of the process. One boy, counting the oxygen molecules at various stages and noting that the number of “Os” remained the same, concluded that “at the end of the process, it just goes back to normal.” Comments like these suggest that the activity may have aided the development of knowledge that can be applied to contexts other than the specific content area in which they initially were used.

Classroom Connections

Most teachers participated in debrief interviews after each session and all participated in interviews at the end of the program. These were conducted to get their feedback on how these games might be implemented in classrooms, what obstacles and challenges teachers would encounter when implementing them, and what kinds of training and materials they would need to implement the games successfully.

Teachers listed various ways in which these Module 1 prototype games could benefit teaching and learning. First, they felt that the games provided a good way to introduce a science topic. They explained that the open exploration the games invited requires no prior knowledge, but it sets the stage for a deeper understanding of the content. According to one teacher, “Particularly for visual learners, actually seeing the molecules separating and coming back together, there’s nothing I could do on PowerPoint, or even on the board…to show those bonds. That’s helpful.” One teacher said that, in this way, the games serve the same purpose as the multimedia resources and simulations she already uses frequently in her classes.

Several teachers also said that they believe the games promote independent thinking and persistence, which they feel are difficult to inspire in science classrooms. The format allows students to relax and explore without worrying about the "right" way to do something or whether they would be successful. Rather than asking for more instructions, as they often do in science class, students enjoyed the freedom to explore and make independent decisions when playing the games. One teacher said that, in contrast, students tend to freeze in place during traditional classroom activities as soon as they don't understand something. She referred to the Classroom Game activities as "gray activities" because there is no right or wrong and many approaches are possible. In 7th grade, she said students typically dislike these activities because they are concerned with getting the answer right: "They usually have a million questions during gray assignments because they want to validate their answers with me before they write them down. They don't want to make a mistake. In science, if they're afraid that their answer is wrong, they won't write it. They don't feel comfortable enough to take a risk." Throughout the Classroom Game, this teacher noticed that students were engaged, motivated, and unconcerned about right and wrong answers. She is eager to use the games in her classroom if it will make students more receptive to the type of thinking activities presented to them. She said, "One of the biggest weaknesses in science class is students' ability to work something out they don't understand independently, to problem-solve like that. So I could really see using [the games] for that." One teacher expressed concern, however, that students' persistence was less due to the games than due to the afterschool setting, where there were no grades and students were in a mindset that was more conducive to play and exploration.

The teachers did have specific critiques of these game prototypes. While most teachers thought that playing the games prior to instruction provided a good introduction to the content, one teacher suggesting prefacing game-play with animations or videos featuring the focal scientific processes. He thought the games were too fast-paced to allow kids to focus on the content and process what was going on; by exposing students to scientific content prior to game-play, he felt, students would be better prepared to learn from the games. He suggested that these preparatory resources include images from the game.

Echoing a common criticism among students, teachers pointed out that players can do well in the games without much thought and without reflecting on the underlying scientific processes. Teachers thought students should have to show that they understand something in order to do well in the games. They suggested that having different levels of difficulty would be inspiring for students and give them a reason to play more thoughtfully and strategically. They also proposed breaking the games down into smaller pieces to highlight different aspects of the scientific processes. When teaching systems, in particular, they said it is necessary to be explicit and name each component in order for students to understand the mechanics of a given system.

While most teachers felt that the games had the potential to be educationally valuable, they had trouble identifying anything specific that students learned from the games. One teacher thought the photosynthesis game, if adapted, could help students understand the chemistry behind the process. In its current state, though, he did not think this was a realistic learning outcome and he felt it represented a missed opportunity. According to this teacher, "It's such a tease talking about oxygen, carbon, and glucose, but it never really addresses that these individual atoms are connected with bonds, that bonds break, and that new bonds form again. This is the backbone of everything. Establishing that in the beginning would be huge. It's not represented in the games now, but it could be." Another teacher stated, "I do think hopefully that they got that molecules break down and reform during a process, but I don't know if that's true." These kinds of comments are useful in guiding our development of additional resources and activities to help teachers use the games in relation to traditional instruction that will provide much of the explanation of content that is not intended to be captured in the games.

A few teachers responded negatively to the fact that students in all but one site preferred independent game-play, and felt their alienation from the social environment was unfortunate given how much there is to learn from group discussion and hearing other students' thinking. In the school in which collaboration did take place, students sat at two tables and talked throughout game-play, asking questions of one another, sharing scores, and even working together to investigate effective strategies. The teacher suspected that group conversation may have come easily to these students because many of them were already friendly and the school encourages collaborative work and conversation in class. Teachers in the other sites were disappointed by the lack of communication and cooperation between students while they played the games. On a positive note, they did notice that the reflection discussions were very participatory, and attributed this to the high levels of student engagement during game-play.

Teachers said that the Classroom Game is most similar to the types of activities they conduct in their science classrooms. They stressed the importance of analyzing data and using evidence to support conclusions. The vampirosynthesis component of the game, in which students break down the process into smaller steps, uses a familiar activity structure even though it focuses on unique content. One teacher explained, as a point of comparison, that she has students write out each stage of the rock cycle process. She said simplifying the process is essential, and she likes this activity because it breaks down a complicated process into small steps. Another teacher said the Classroom Activity was a successful way for students to learn about the concepts of balance and energy conservation. She thought students picked up on these concepts because she saw and heard them counting the number of different molecules from one picture to another in order to track how the molecules were transformed and to make sure that all components were all accounted for.

Implications and Next Steps

The insights described above have various implications for game revisions and the development of teacher supports. Below we discuss implications for students and game-play, followed by implications for professional development and supplemental materials.

Students and Game Play

Our research suggests that students responded more positively when games engaged them with relatively complex challenges, and also seemed to attend more carefully to the content-relevant features of the game when they were being challenged. For example, students in the pilot study preferred the Systems Game to the other prototypes, seemingly because it required them to balance multiple variables and manage them strategically. They enjoyed playing the game multiple times in order to master its intricacies. In contrast, students quickly grew bored with the prototypes in which they could win by shooting indiscriminately, with little thought to the processes or intended constraints of the games. In light of our goal to make fun and educationally valuable learning experiences, the revised versions of the Module 1 prototype games will pose greater challenges for students. They will require students to engage in diverse activities that tap multiple skills. Among other challenges, the revised games will require students to identify problems and form questions with which to investigate them, analyze data, and use evidence to support their theories. Additionally, in order to succeed in the game, students must engage in the underlying scientific processes represented in the games.

Narrative richness was also an important motivator and drew students into careful consideration of the content being presented. In the revised Module 1 games, a storyline will serve as a bridge throughout the games across all of the Module resources. In light of students' positive responses to the science fiction aspect of the original narrative, the games will continue to be grounded a fantastical plot with rules and activities governed by scientific principles.

We continue to grapple with implications of some other findings relating to students and game-play. For example, we struggle with how to deal with the difficulty some students had with the ambiguities in the games. If we offer clear instructions during game-play, it may inhibit the inquiry process that these games aim to promote. However, if we overlook students' requests for explicit guidance, we risk losing their interest and thereby hindering the learning process altogether. In our formative research in spring 2010, we will consider methods to tailor the level of guidance to the unique needs of individuals, such as by integrating just-in-time support to those who need it.

We are also grappling with how to deal with students' preference for individual rather than collaborative game-play. The benefits of collaborative work are well documented. Among other advantages, it enables students to build on each other's ideas in order to make joint decisions, as well as make their ideas explicit and, in doing so, draw attention to discrepancies in understanding (Rogoff, 1990; Chi, 1997). We are eager to leverage these and other benefits in future versions of Possible Worlds games by capitalizing on the DS's built in networking capability to promote interaction throughout game-play. In all afterschool sites, however, students opted to play alone, and in all but one site, there was almost no interaction among students as they played the games. Our occasional efforts to have students share a DS were met with strong resistance from them. The only evidence of collaboration occurred in one site, in which students played individually but maintained an ongoing conversation with peers about game strategies and what they thought was going on in the game. In the spring, we will enhance our efforts to promote collaborative practices of this kind and identify how those types of interactions influence learning.

Teacher Professional Development and Support Materials

Teachers in this study consistently commented on how focused and persistent students were when they were playing these games. They feared, however, that students' tendency to give up and ask for support – behaviors they considered to be more typical in the classroom - would surface if these games were implemented in a science classroom rather than an afterschool program. Teachers told us that their students are highly concerned with grades and high school placement exams. For this reason, they prefer well-structured tasks with clear procedures and "right/wrong" answers. They tend to shy away from the “gray activities” mentioned earlier, which allow for multiple approaches and theory development. Clearly, these responses are particular to the relatively high-achieving school contexts in which we were working. But to some extent this desire for clear answers and clear guidance are also developmentally predictable if students believe they are being asked to perform according to some public, formal set of standards. Preserving the playfulness of the module resources (not only in the DS games themselves) may be particularly important if these resources are to invite students into a creative process of reconsidering and re-examining their tacit beliefs about scientific processes. To prepare teachers to implement these games in their science classrooms, we will develop training and support materials that will help them foster the same levels of playfulness, motivation and eagerness to explore that students exhibited in the afterschool program.

Mastering the mechanics of the *Possible Worlds* games was much easier for students than it was for most teachers in the study. Some teachers said it was a new situation for them to be a novice at something while their students quickly became experts. While some teachers enjoyed this role reversal and saw it as an opportunity to learn from their students and help them build confidence, one teacher felt it could result in an uncomfortable situation in her science class. In the coming months, we will develop training and support materials to help familiarize teachers with the games and to prepare them to implement them in their classroom. In designing training sessions, we will heed one teacher’s advice to have teachers play collaboratively prior to instruction so they can figure out the game mechanics as they identify the scientific processes represented in the games. Support materials also will incorporate resources and tips to help them manage any role reversal that may occur.

Some students who played the Classroom Game tended to draw from prior knowledge about vampires rather than attending to the data we provided. As a result, they often came to faulty conclusions about the cave atmosphere. That it is a developmental challenge for students to sideline preexisting notions has been well documented (e.g., Kuhn, 2009). With proper guidance and opportunities to practice, students can develop the habits of mind to interpret new information and integrate it into their evolving belief system. In spring 2010, we will explore methods to prepare students to confront this developmental challenge.

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Appendix I

Session Observations

The Teacher

Throughout the session, describe the teacher's use of the protocol/materials, deviations from the protocol, instructional strategies, and challenges. Read through the post-session reflection questions because they can help guide your observations.

Students

Describe students' reactions to the content, and their participation, questions, challenges, and interactions. Most importantly, we want to know how they're interpreting what's going on in the game and how it relates to scientific processes addressed during the session. Look for ways in which students differ in their interpretations. Throughout the session, keep an eye on struggling readers.

General Observations

Note any other observations or issues that you think we should discuss.

Appendix II

Student Game Observation Protocol

This protocol will be administered during the game-play periods in each session, and is designed to be applicable to any of the games scheduled to be played throughout the scope of the intervention.

One researcher will observe students one at a time as they play the game. The researcher will record the observation using a Flip Video Camera aimed at the DS screen.

Protocol

Explain to the student that you are trying to learn from them how he/she plays the game. As he/she plays, ask the following questions, as appropriate:

1. What do you think the game COULD be about?
2. What about the game tells you that?

Next, remind them that the reason you are watching them play is to see how THEY figure out how to play the game. As they play, reiterate that they should talk to you about what they are doing and why they are doing it.

During game-play, the researcher should prompt the student to describe specific actions if the student is not already doing so. For example:

3. What are you doing now?
4. What did you just do?
5. Oh. I see. How come?

After the student has finished a level, the researcher should ask the following questions, as appropriate:

6. How do YOU play this game?
7. How do you win?
8. How do you know how to do that? What about the game tells you that?
9. How did you figure that out?
10. What is challenging or frustrating about the game? Why?
11. How do you know if you are winning or losing?
12. What do you have to do to be good at this game?
13. What do you have to do to win this game?
14. How do you know?

Appendix III

***Possible Worlds* After-School**
Teacher Debrief Protocol

Observer name		**Date**	
Teacher Code		**Session #**	
School Code		**Session length**	

Note to the researcher: These interview questions are intended to be open-ended so that teachers can share their thoughts about the experience of using *Possible Worlds* games and curricular materials with their students. Encourage them to be as honest and critical as possible in order to help the *Possible Worlds* team to revise the materials.

1. How did today go?
    a. What was challenging about leading/teaching this session?
    b. Were there any moments when you had difficulty responding to your students or answering questions they had? If so, what would you change about the materials we provided that might have helped you?
2. What did you notice or hear about what students were doing today with the game?
    a. What kind of questions did they ask?
    b. Was there anything you noticed that was different from what you normally see or hear from students in your classes?
3. Which aspects of the game and materials have you noticed engage or motivate your students the most? The least? Why do you think that is? [Use specific examples from the session of low/high engagement]
4. Did you notice students having trouble reading or understanding any terms used in your teaching or in the game? [Ask about any students who are known to have reading difficulties.] Was this student able to engage with the game as well as other students?
5. What do you think students learned today?
    a. Did they learn anything about how to play or win the game?
    b. Did they learn anything about science?

Appendix IV

Possible Worlds After-School
Teacher Interview: End of Program Protocol

Note: Researchers will use this protocol with teachers who participate in the after-school program at the end of teaching all 4 mini-games.

Interviewer name		**Date**	
Teacher Code			
School Code			

Note to the researcher: These interview questions are intended to be open-ended so that teachers can share their thoughts about the experience of using *Possible Worlds* games and curricular materials with their students. Encourage them to be as honest and critical as possible in order to help the *Possible Worlds* team to revise the materials.

Interview questions:

Game Implementation and Teacher Materials

1. In general, how has the experience of using this *Possible Worlds* mini-game and curricular materials been for you?

2. From the perspective of instruction and your own teaching style and needs, which aspects of the game and materials have you found useful? Why? Which were not useful? Why?

3. What was difficult for you about teaching with a game? If not much, what might be difficult for other teachers?

    a. What were some of the challenges in referring back to the games during discussions
        i. E.g. photosynthesis, artificial photosynthesis, classroom game,
        ii. What might make that easier

4. Having finished using this game module and materials, how could you imagine making use of them in your classroom teaching?

5. What kind of professional development or support would have been helpful for you?

6. Having spent some time using the games and materials with your students, what advice would you give to another teacher who has not used games in her or his classroom before?

7. Having worked with these games, what do you see as some benefits or affordances of using a game in the classroom? What do you see as some downsides to using a game?

8. Would you ever consider assigning games for homework? Would you be opposed?

Student Experience

9. Which aspects of the game and materials have you noticed engage or motivate your students the most? The least? Why do you think that is?

10. What have student interactions during game-play been like? Have you noticed any changes in the ways that students were asking questions or talking with one another about the content? Was anyone left out?

    a. Different games, different types of interaction?

11. Do the paper-based supplementary materials help or hinder student discussion and participation in group work? Does the use of the Nintendo DS help or hinder student discussion and participation in group work?

12. What do you think students got out of this experience?

13. What misconceptions if any do you think students might have walked away with from these games?

    a. How would you address them?

14. What skills or concepts do you think students might have walked away with from these games?

    a. How might you capitalize upon?

15. What did you notice students struggling with?