Using microgenetic methods to investigate problem solving in video games

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ABSTRACT

As formative research for the development of a suite of middle school life science video games, we are adapting microgenetic research methods [15] that use repeated, small-scale task-based sessions with participants to document how reasoning and understanding can develop and change in short periods of time. In this study, we are working with students between the ages of 9 and 12, examining the development of their strategic thinking as they play commercial games that focus on problem solving tasks (*World of Goo, Auditorium, Crayon Physics, Portal).* The purpose of this paper is to illustrate the methods we are using and to discuss how they may help to illuminate how game mechanics, narrative context and instructional design can be utilized to create developmentally appropriate games.

Author Keywords

Video games, students, strategy, problem solving, microgenetic

OVERVIEW OF RESEARCH AND DEVELOPMENT

The Center for Children and Technology and the Center for Science Education of the Education Development Center, Inc. are developing a suite of game modules that include Nintendo DS mini-games and web-based activities for middle school life science classes. This five-year research and development project is funded through the U.S. Department of Education's Institute of Education Sciences. These games are intended to help students overcome common science misconceptions and develop scientific reasoning skills by enabling them to experience science in a different way. The research we are conducting to inform the game development carefully examines how video games can be designed to support sustained, engaged exploration of complex science content, skills and concepts.

Titled *Possible Worlds* to reflect our thinking about what digital games can contribute to education and the teaching of science in particular, the end product of this work will be four game modules, an accompanying website, and teacher professional development and support materials. The *Possible Worlds* game will be comprised of individual and group game play facilitated by the teacher. The game is meant to supplement, rather than replace, existing science curricula, and target some of the concepts that research shows students have the most difficulty understanding and some of the skills students have difficulty acquiring.

The length of this research project allows us to conduct a series of related studies to help us better understand how developmental issues need to be accommodated in the instructional design of games, and how strategic thinking can best be supported through game design. Over the first year of the project we conducted formative research with middle school students, looking at the interplay between game play and the evolution of their problem solving strategies. Findings from this study, as well as the methods we developed, will inform the game design for the *Possible*

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Worlds modules and our approach to the field test of games in classrooms.

Games provide distinctive advantages over other curriculum extras as supports for middle school science learning. Video games can be designed to engage students with a complex environment, a set of variables to manipulate, and opportunities to explore and influence that environment. They can save multiple versions of that world for comparison over time, and support comparison of one students' version of that world with another's. In short, a videogame can allow a student to elaborate at length upon a possible world in which some particular set of propositions can be made true. In the hands of a prepared teacher, a well-designed videogame can stand in contrast to the immediate physical world and function as a rich, dynamic alternative world in which scientific phenomena can be examined and explored.

In addition to providing rich, evocative environments to explore, videogames for science learning must also provide carefully-structured feedback that can align reliably with students' modes of exploration. To learn more about how to create effective feedback to inform students' scientific thinking, we conducted the study presented here. In this, we are explore how students use feedback to revise their strategies and game play methods. We observed 22 middle school aged students as they played four commercial video games: *World of Goo, Auditorium, Portal,* and *Crayon Physics.* In this paper we will discuss our method of analyzing date from participants' play in *World of Goo*. The work is exploratory and we are continuing to revise our methods for investigating children's problem solving strategies in games and their relation to the feedback the games provide.

SUPPORTING THE DEVELOPMENT OF SCIENTIFIC THINKING SKILLS

The *Possible Worlds* game aims to address students' scientific misconceptions while supporting the development of scientific reasoning skills through game play and teacher support. There is considerable evidence to suggest that adolescents begin to develop these and related skills as they enter into a more adult world and are asked to reason in school and in their life outside of school, but that it is difficult for students to gain a stable, explicit set of scientific reasoning skills and apply them appropriately [7]. There is also mounting evidence to suggest that some video games can promote the practice of scientific thinking skills in players as they solve problems, seek answers, and work collaboratively [20, 22]. While most studies of this nature have looked for evidence of these skills, few have examined how these skills develop through game play over a period of time. As summarized below, these questions of development, emergence and change are rich for study in many domains.

Broadly, this investigation is informed by recent cognitive research on how these skills emerge and develop over time by psychologists including Kuhn [6], Klahr [2], Lehrer and Schauble [10, 11], Siegler [17, 18, 19] and Zimmerman [23]. Key principles from this literature that guide this project include the following:

- **The components of scientific reasoning emerge incrementally, iteratively, and in fragmented form.** Practice, articulation, and reflection are critical activities that facilitate the gradual emergence, rehearsal, refinement, and alignment of the component skills.
- **Students' ability to draw upon and articulate scientific reasoning skills is highly contextual.** Students respond more successfully to highly constrained tasks and show less evidence of scientific reasoning in response to less well-defined problem areas. Their success is also shaped by whether they are working alone or together, with peers or with experts, and by whether or not they are accustomed to being asked to solve novel problems or to explain their thinking aloud.
- **Even adults rarely demonstrate a solid mastery of the skills of scientific reasoning.** While this may seem evident in the everyday discourse of non-specialist adults, these skills are targeted as learning standards for middle and high school students in many states in the U.S.

The skills of scientific inquiry are a significant component of the *National Science Education Standards* in the United States, which were created to promote scientific literacy among American students [12, 13]. Inquiry activities include identifying problems and forming questions with which to investigate them; proposing investigations and gathering evidence to address the questions; interpreting evidence, drawing conclusions, and putting forward arguments that explain the phenomena [13]. Klahr [2] and Klahr and Dunbar [3] described inquiry and scientific reasoning practices as forms of problem solving characterized by systematic searches in "problem spaces" for solutions to problems.

We are guided by Kuhn and Pease's [8] "strategic competence in inquiry" model, which specifies the following steps:

1. Recognizing that there is something to find out, or recognizing that some problem exists;
2. Designing investigations that will yield evidence germane to the problem;
3. Interpreting the evidence;
4. Justifying conclusions based on the evidence;
5. Revising theories based on the evidence when necessary;

6. Generating predictions consistent with newfound understandings; and
7. Sharing claims with a community in order to contribute to scientific discourse.

The ability to engage in the kind of reasoning represented in this model does not come naturally. Rather, these are a set of disciplinary skills that need to be learned and practiced. The development of these skills is particularly challenging for adolescents and requires repeated exposure to the concepts and processes, and extensive practice over time. Scientific reasoning applies both to formal experiments as they might be conducted in labs and schools and to informal experiences such as video game play, in which players must hypothesize solutions to game problems and interpret feedback in order to determine how to overcome obstacles. Regardless of the setting, the development of inquiry skills—of which the ability to coordinate theory with evidence is paramount—is critical both to "doing science" and to becoming citizens capable of engaging in reflection, weighing the merits of arguments, and engaging in informed, effective debate about issues [6].

Consistent with other studies of changes in children's scientific reasoning strategies [4, 14, 17], Kuhn and Pease [8] found that variability in children's strategy selection for investigating causality persisted even after they learned newer, more effective strategies. Schauble [14] found that adults tended to be more systematic in their inquiry and their "plan structures" for investigation tended to be more comprehensive by considering the overall problem space and the variables within. More comprehensive plan structures tended to lead to higher levels of valid inferences about causality in her study of two physics problems. Schauble also found that children tended to duplicate their efforts inadvertently—that is, they did not replicate an earlier experiment in order validate it. Rather, they tended to forget they had done it.

A number of developmentalists now argue that strategy change is not an "all or nothing affair"—effective and ineffective strategies coexist over time [4]. Siegler's [16] "overlapping waves theory" explains how children develop and employ a range of strategies for problem solving and that development includes an increasing ability to choose more selectively among those strategies. Kuhn [4, 5] characterized strategy choice as "metastrategic thinking," and has suggested that its development is a greater developmental challenge than is learning individual strategies.

Finally, a number of researchers have characterized scientific reasoning as "problem solving in two spaces" [2, 3, 9, 14, 23]. Klahr and Dunbar's *scientific discovery as dual search* (SDDS) model posits scientific reasoning as coordinated problem solving in two related spaces:

- the hypothesis (or content) space and
- the experiment (or strategy) space.

Schauble [14] and Kuhn, Schauble, and Garcia-Mila [9] suggested that changes in understanding in both spaces bootstrap one another. In summarizing research on the development of children's scientific reasoning skills, Zimmerman [23] noted that, in general, the research in her review found that the children in these studies tended to generate uninformative experiments, arrive at conclusions based on insufficient evidence, and to be unsystematic in their investigations. With practice, however, children exhibit co-development of knowledge and strategies.

Though some researchers have argued that video games may offer more authentic spaces in which children can develop the skills of scientific reasoning [22, 20, 21], two significant considerations are missing from these studies. First, they say little about developmental factors that can affect players' abilities to learn these skills from video games. Second, they do not address specific components of the games that explicitly enable players to gain exposure to and practice these skills. Children at different stages of development have different capacities to consider multiple alternatives and variables in a systematic way. It is crucial that these developmental issues be taken into account when designing games for younger players. It is equally crucial that designers who seek to support the development of scientific reasoning provide informal and formal opportunities for players to engage in the different steps of the reasoning process. Our research and development is intended to explore how young people's experimentation in games may help them gain some emergent understanding of the components of scientific reasoning, and identify when and where they need more support and structure to solidify and formalize their understanding.

FORMATIVE RESEARCH: GAMES AND METHODS

This exploratory study investigates how twenty-two preadolescent children (ages 9–12) engaged in problem solving and strategy development in the *World of Goo* video game. We are interested in observing relationships that may exist among inputs (player actions), feedback from the game, players' responses to feedback, and in investigating how they solve game-based problems. As this work is a piece of the formative phase of a larger game development effort, it will also help us create a methodological framework we will use to conduct research on the games we design. The framework we are proposing will help us achieve greater insight into how young people understand game feedback within the context of problems and strategies and whether and how developmental differences inform problem solving in games. Such insight will lead to a better understanding of how to scaffold learning with video games.

As this is not an investigation into the development of scientific reasoning and inquiry skills in the classical sense in which we might provide participants with problem spaces and a number of variables to be investigated, we are not specifically looking for "evidence of scientific reasoning in video game play." Rather, we are attempting to discover whether the game play activities (including thinking) in which adolescents engage while playing *World of Goo* mirror any aspects of "strategic components of inquiry" delineated by Kuhn and Pease [8]. Specifically, we ask the following questions:

1. How do children use game feedback to revise game play strategies?
2. Are children systematic in their efforts to solve game-related problems?

In the next sections of this paper we describe our data collection methods and how we plan to analyze the data and address these questions.

DATA COLLECTION

We selected four commercial, computer video games: *World of Goo, Auditorium, Portal,* and *Crayon Physics.* From the perspective of research design, these games afforded us a number of advantages in terms of observing game play. First, none of these games are explicitly educational, yet they adhere to many physics-like principles that encourage players to draw upon their understanding of "folk science." None of the titles are "twitch" games that require players to move around quickly or to attend to multiple game events—such as being fired upon by enemies—on the screen, making it difficult for players to think aloud and answer our questions about their play. Similarly, players do not race against the clock in these games, though there are levels in all of them that require quick action and thinking on the player's part. The relatively slow pace of all four games enabled us to stop players frequently and ask them questions about what they were planning on doing and to reflect on game feedback after they executed a move. Finally, as "puzzle" games with a fairly limited (though by no means easy) set of solutions, the games all contain relatively well-defined problems that do not require narrative frameworks, multiple players, or external resources such as cheats or walkthroughs (though we did eventually learn that one 6th grader did refer to a walkthrough on his own time) in order to advance through levels. Given our limited time with the players, we chose games that would allow us to begin to focus relatively quickly on how players framed problems and how they responded to feedback.

World of Goo was the first game we played with participants and is also the first for which we have started to code game play. Our work with *Goo* will help us to refine our coding practices, as well as our methods of observation. *World of Goo* is a game in which the player builds structures, such as bridges or towers, with small balls that connect with one another to reach the goal, a pipe (see Figure 1). Players progress through levels by building structures to the goal and having the required amount of extra balls to go into the pipe. The tools in the game are primarily small balls, called "goo balls," that connect with one another to form structures. Different types of goo balls have different properties; for example, most form triangular supports with other goo balls, while others can connect to four or five other goo balls. While the structures have many properties similar to real life, the goo balls are not static and they move along the structure. This can cause the structure to sway and bounce, giving the player feedback on how strong or sturdy their structure is. On each screen player can click on signs that give them cryptic advice on how to solve the level or on the future challenges in the game.

Figure 1: Screenshot of *World of Goo*.

Participants and Research Sites

We selected participants and research sites for this exploratory study using convenience-sampling methods, though we did limit the ages of the boys and girls to late elementary through middle school, as that is the age range of the students for whom we will be developing life science mini-games beginning in the second year of this study.

We worked with two research sites: a private elementary/middle school affiliated with a large university in New York City and a computer clubhouse affiliated with a Manhattan community-based organization. We observed twenty-two students once a week for four months: fifteen students (13 boys, 2 girls) in the elementary/middle school and seven students (6 boys, 1 girl) in the computer clubhouse. The majority of students in the elementary/middle school were in the 4th grade, though we did observe one 6th grade boy. All of them were participating in an after school program in which they were making video games with *Scratch* and *Gamestar Mechanic*, two software environments for introducing young people to game design concepts and elementary computer programming skills. The students in the clubhouse were all 11 or 12 years old, mostly in the 7th grade, and attended local middle schools.

The disparity between the numbers of boys and girls we observed for this study is clearly an issue, particularly given earlier work that addresses differences in the ways boys and girls play games [1]. This is exploratory research, however, from which we make no general claims about how boys and girls play and problem solve problems in video games. Rather, the study has provided us with an opportunity to begin to craft and refine methods for observing game play that we will employ in future work, while also allowing us to explore how different children solve game problems differently.

Methodological Framework and Interview Methods

In this study we are investigating changes in game players' strategies, their interpretation of feedback, and their understanding of game problems. Because video game play can be so rich in terms of the frequency of player inputs (i.e., actions in the game space), game feedback, and changes in players' thinking about game problems, we needed a way to focus on specific moments in which players appeared to reconsider or alter their strategies or their understanding of a problem. Microgenetic research methods were the framework we adopted to help us focus on changes in thinking as we observed game play.

Microgenetic methods have traditionally been employed by developmentalists to study the process of change as it occurs, as opposed to focusing strictly on the outcomes of change [4, 14, 15]. Whereas pre/post research designs typically only illustrate change in some phenomenon after an intervention, microgenetic methods enable researchers to explore change as it is occurring. Siegler and Crowley [15] described three essential aspects of the method:

> (a) Observations span the entire period from the beginning of the change to the time at which it reaches a relatively stable state. (b) The density of observations is high relative to the rate of change of the phenomenon. (c) Observed behavior is subjected to intensive trial-by-trial analysis, with the goal of inferring the processes that give rise to both quantitative and qualitative aspects of change. (p. 606)

Through this fine-grained study of change, small shifts in thinking can be exposed and examined in relation to prior action, thinking or task challenge to express patterns of individual change. Furthermore, the dynamic nature of these skills cannot be captured in one assessment. Rather, many small assessments administered over a period of time exposes the intra-individual variability in thinking skills [7].

As Siegler and Crowley noted, microgenetic studies are most successful when previous research has identified assessment methods, age ranges and a general description of development, for which to place findings in a context [15]. For this study, we are relying on what is known about the development of scientific thinking and its high rate of change during adolescence. However, our assessment methods, playing video games while thinking aloud in response to researcher prompts, are untested and pose the greatest challenge for adopting this methodology.

Despite its methodological promise, our research has yielded three possible issues. First, it is difficult, and somewhat arbitrary, to define a "trial" in game play. Levels within the games ask the player to use previous knowledge and build on what he already knows. However, this limits the number of similar tasks that can be looked at, as each level requires new skill. Second, we are relying on verbal and visual data to map out thinking. Unlike other studies which use a notebook or worksheets for students to record their work, this study requires no such stopping for recording purposes. And finally, multiple strategies might be employed in solving game problems at the same time or in rapid succession. Players must use both game play strategies (such as speed) and thinking strategies (collecting pieces of information to gain an answer).

At the computer clubhouse participants played alone for up to 45 minutes at a time, while at the school-based afterschool program participants played in pairs for no more than 20 minutes at a time. Flip Cameras were mounted on tripods, aimed towards the screen and used to capture game play and audio during each observation. At both sites participants played Nintendo DSs when they were not being interviewed.

Researchers, working in pairs, sat with participants and observed their game play. One researcher was responsible for implementing the protocol (prompting participants to think aloud as they played), while the other researcher was responsible for making sure the camera was aimed at the screen and taking notes on significant moments during game play. At the beginning of each game level, before the participant began game play, the researcher asked the participant to verbalize his/her initial reactions to what he/she saw with questions such as: What do you think you are going to have to do to beat this level? What do you think the goal of this level is? Depending on the participants' responses, researchers asked follow-up questions, including but not exclusive to: How do you know? What do you see that tells you that?

After the initial questioning, the researcher told the participant to begin game play, reminding him or her to think out loud during play. Researchers were looking for how participants initially engaged with the game environment: did they explore first, and if so, how? Did they play around on the screen, what drew their attention? Or did they immediately set about beating the level? During game play, researchers looked for "Aha" moments: moments during game play when game feedback led the participant to figure something out about how the game works. Researchers were interested in capturing what the participants learned, what game feedback led them to figure it out (how they learned it), and how this new piece of information (about the game) changed the way they played the game (their strategy).

CODING AND ANALYSIS

Student game play was roughly between 20-40 minutes long per session, so our first task was to divide up the play into a meaningful unit of analysis. For each player on each level of the game we created four levels of codes. This multi-layered approach was designed to capture both macro (what has happened over the entire level) and micro (what happened in that moment) levels of players' thinking and activity.

The smallest unit of analysis is a twenty second clip of game play, wherein discrete codes are assigned to get a count of what happens, both player-initiated and game-initiated, in that time frame. What we consider actions are organized into three categories: game actions (e.g., building a structure, testing), information seeking (e.g., reading a sign, or level statistics), and feedback (e.g., structure wobbles, gooball dies). Over the course of the level, these actions can then be examined for their frequency and, later, how these are associated with what players learn about the game.

Next, a longer interval of one minute is coded for types of play and verbal statements. These codes are descriptions of game play strategies based on player actions and statements the player has made about what he or she is doing and why. Coding provides us with a means to describe game play, feedback, players' thinking about how to complete levels, and how their thinking might change based on feedback. The length of one minute allows the codes to encompass individual actions into a larger context of play activity. In other words, the sequence of actions can be taken together to make a determination about what the player is trying to accomplish and how that relates to the underlying principles of the game. These codes can therefore describe general game strategies, such as building with speed, as well as content- or game-specific play, such as building a structure by bracing (a key strategy in many levels of *World of Goo*).

We also code individual statements made by players that describe what they are doing, their plans and strategies. Statements made by the players provide evidence about what they understand about the game, and how they interpret the feedback they receive.

Finally, the game level as a whole is coded with a description of what has been learned by the player. These codes are broad enough to describe the development of players' understanding of the game principles during that level of play. These codes track if the player has:

- understood a concept and applied it,
- if they are approaching an understanding, and/or
- if they are applying a previously learned game principle or
- if there is no new game principle understood.

Taken together, these four levels of codes comprise a systematic documentation of how often targeted actions occur with qualitative assessment of how the player acts and responds within levels. The patterns within these codes will allow us to map out individual learning trajectories within games. Additionally, as actions are coded in these categories we will be able to map player behavior against the seven components of strategic competence of inquiry, as described by Kuhn and Pease [8]. While we do not expect to see all seven components in any one game, as each game demands different skills, we do expect to be able to map some play behaviors against this model and begin to contribute to the work on the development of strategic thinking by offering data from the field of video game play.

FUTURE WORK

The *Possible Worlds* games are intended to be used in a classroom with support, scaffolding and prompts from the teacher. Future studies might explore what kinds of supports players need in order to further their understanding. In this study, researchers consciously avoided giving prompts, suggestions or in any way manipulating game play to aid or change player behavior. However, there were instances that might have naturally led to an adult in any other role than researcher to offer a suggestion or demonstration.

In examining this data we are interested in what game factors inhibit or facilitate relationships between inputs, feedback and change in player strategies. The data described here, while culled from a small population, will begin to inform the instructional design of the *Possible Worlds* game modules. We hope that if this coding and analysis methodology is successful in yielding patterns of individual learning trajectories, the future research phases of this project will provide more data from which to reveal more broad findings about adolescent game play and strategy change.

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