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Combining Video Games and Constructionist Design to Support Deep Learning in Play

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Abstract: In recent years much research has explored the potential of using video games in education. This effort has produced many interesting games though it is unclear if "educational video games" have achieved their promise. Similarly, for many years constructionists have engaged children in learning across a variety of contexts, including game design. While these programs have been successful, their exploratory nature leads to concerns about content coverage. In this symposium we discuss the potential of blending these two design traditions. Constructionist video games infuse traditional game structures with constructionist ideals to create gaming experiences that encourage exploration while ensuring engagement with desired content. This symposium presents the constructionist video games construct and showcases empirical research on the use of such games in both formal and informal contexts.

Session Summary

In this symposium we bring together researchers from the educational games and constructionist design communities to discuss empirical work highlighting the value and challenges of merging these two design traditions.

Recent data suggests 97% of all children play video games daily (Lenhart et al., 2008). As a nearly universal experience for American youth, video games offer an exciting design opportunity with the potential of having immense impact. In the past decade there has been a large influx of effort and money to take advantage of this opportunity and design video games that offer powerful educational experiences. This effort has produced many interesting products that wrap school-sanctioned content inside traditional game mechanics and structures allowing learners to interact with targeted lessons in a highly engaging format. While there has been considerable enthusiasm for this program of research and the results suggest learners improve on metrics directly aligned to in-game action, learners often fail to acquire a deep understanding of embedded content that they can apply in alternate contexts (Annetta, 2008; Barab et al., 2007; Clark & Martinez-Garza, 2012).

At the same time, researchers firmly rooted in the constructionist design tradition (Harel & Papert, 1991; Papert, 1980) have produced a host of environments that allow children to create games of their own design (Caperton, 2010; Kafai, 1995). This work has proven successful at achieving deep learning in a wide variety of domains, but is often hampered by its own commitment to openness when attempting to focus learners on specific ideas or content. The challenge, referred to by Noss and Hoyles (1996) as the "play paradox," is to create an effective balance between designs that force learners to confront targeted content (which in turn may reduce the feeling of play), versus those that provide complete freedom in exploration (sacrificing assurances that learners will *always* encounter the targeted content).

The blended genre of constructionist video games has been proposed as an approach that can overcome the challenges faced by each design perspective in isolation. Constructionist video games (Weintrop, Holbert, Wilensky, & Horn, 2012) infuse traditional video game structures with constructionist ideals and mechanics to create gaming experience that encourage exploration and experimentation while ensuring players' engagement with prescribed ideas and content. This design approach is particularly suited to deepen learners' experiences with mechanics in educational video games though it also shows potential for streamlining exploration in fully constructionist spaces. In this symposium we present the constructionist video games construct, discussing both its historical roots as well as areas were we believe the construct forges new territory, and showcases empirical research on the use and potential of such games in both formal and informal contexts.

The symposium will consist of four presentations. Nathan Holbert, David Weintrop, and Uri Wilensky will open the session by presenting the constructionist video games construct. This talk will highlight the various principles important to the design of constructionist video games and showcase findings from two such games, *RoboBuilder* and *Particles!*, that highlight the potential of this design for producing powerful play experiences that result in deep learning. Pratim Sengupta, Stephen Killingsworth, Kara Krinks, Corey Brady, and Douglas Clark will present SURGE, a game for exploring Newtonian Mechanics that blends the important practice of scientific modeling with video game play. This talk reports findings from a study of 7th graders playing SURGE to show how interactions with the constructionist designs in the game supported students as they made sense of Newton's 1st and 2nd laws. In the third talk, Eric Klopfer presents a new massively multiplayer constructionist game, *Radix*, for learning science and math and shows how the open nature of *Radix* supports learners as they engage in authentic science inquiry. In the final presentation of the symposium, R. Benjamin Shapiro and Rosemary S. Russ, describe how cognitive clinical interviews enabled an evaluation of the design of a constructionist video game designed to engage players with issues of sustainability. Shapiro and Russ present evidence from a series of clinical interviews conducted with game players showing that participants often reevaluated their assumptions about sustainable framing practices through the new perspective acquired from game mechanics. Finally, acting as the session discussant, Yasmin Kafai will bring her expertise both as a leading constructionist theorist and designer as well as her many years studying how children learn while playing and making games to review some of the overlapping issues brought up by session presentations and to highlight the potential advantages and disadvantages of this design approach.

Constructionist Video Games: Creating Educational Video Games that Empower Players to Construct New Knowledge

Nathan Holbert, David Weintrop, & Uri Wilensky

Objective

This talk will lay the theoretical groundwork for the design genre of constructionist video games and, using environments of the authors' designs, discuss the major features and principles of this class of learning environment. As described in the session summary, constructionist video games merge features of video game design with educational theory and design principles from the constructionist tradition to form a medium that supports meaningful exploration and learning while also providing a motivating, structured learning context (Weintrop, Holbert, Wilensky, & Horn, 2012). By blending these two design traditions we address what Noss & Hoyles (1996) call the 'play paradox'; the tension between allowing open, learner-directed exploration and the desire on the part of the designer for the learner to engage with the content designed into the environment.

We define constructionist video games as: *Designed computational environments in which players construct personally meaningful and shareable artifacts to overcome artificial conflict or obstacles resulting in a quantifiable outcome.* To aid in the construction of these games, we offer four key design principles:

1. Constructionist video games include sufficiently expressive construction tools with which players can engage in personally meaningful ways.
2. Game goals and construction tools encourage exploration and discovery during play.
3. Constructionist video games provide a public forum for players to share constructed artifacts with others.
4. Learners engage with and employ one or more powerful ideas to advance through the game.

We have been motivated by the sense that traditional educational video games often focus too intently on *delivering* content, and not enough on *empowering* players to construct new knowledge that they find personally meaningful. As knowledge construction is a strength of the constructionist program, we have worked to find innovative ways to bring constructionist principles to the design of educational video games. In this talk, we present two such attempts: *RoboBuilder* and *Particles!* (Figure 1.). Using these games as "objects-to-think-with" (Papert, 1980) we will elaborate on the four design principles central to creating constructions video games. We will then briefly report findings from two empirical studies to show how these principles provided opportunities for learners to engage deeply with target concepts intentionally embedded in the games as well as evidence indicating that players gained new knowledge resources for thinking and reasoning outside of the game.

(a) (b)

Figure 1. In *Particles!* (a) players design molecules for blocks that can be added throughout the game to change the emergent physical properties of objects in the game world. In *RoboBuilder* (b) players construct a robot strategy in a block-based language then watch their robot enact it in competition.

Theoretical Framework

The constructionist video game construct is rooted in the constructionist design approach (Harel & Papert, 1991; Papert, 1980) and engages players in the construction of personally meaningful artifacts. This construction process facilitates the development of internal cognitive structures and brings learners into a closer relationship with explored ideas, phenomena, and systems (Papert & Harel, 1991; Wilensky, 1991). We also draw from the growing literature on the use of video games as contexts for learning, including their potential as motivating environments, their alignment with youth identity and norms, and their potential to enable new, interactive engagement with concepts (Annetta, 2008; Barab et al., 2007; Gee, 2003). To evaluate the formation and character of constructed knowledge structures, we draw heavily from the knowledge-in-pieces theory of cognition which views cognition as an emergent process heavily determined by the tools, resources, and implied perspectives provided by the situational context (diSessa, 1993).

Methods and Data

This talk will incorporate data from two separate studies of participants playing an author-designed constructionist video game. In the first study, we draw on data collected from a study of 15 programming novices playing *RoboBuilder* (Weintrop & Wilensky, 2013). In *RoboBuilder*, players write small programs using a domain-specific, visual programming language to control an in-game character as it does battle. During gameplay, subjects were instructed to think-aloud and were asked summative questions by the researcher about their experience at the conclusion of game play. Additionally, artifacts constructed in-game were collected for later analysis. Data from the study in the form of vignettes, programs constructed, and post gameplay interviews will be presented to show how RoboBuilder's construction primitives allowed players to externalize their design ideas for further evaluation and debugging.

In the second study we present data from nine children, ages 11-4 playing *Particles!* (Holbert & Wilensky, 2012). *Particles!* is a platformer game intended to help players see how the properties of objects in the world emerge from the arrangements and structures of atoms and molecules. In *Particiles!* players are given the opportunity to modify game levels as they play through them by dynamically designing the molecular-level structures that make up game blocks which in turn leads to blocks with new emergent properties. Players were interviewed before and after playing the game about the properties of real world objects. An analysis of player responses will be used to show how *Particles!* players drew on in-game representations to provide more precise and complex explanations for the causes of material properties.

Results

In our presentation we will outline the central characteristics of the constructionist video game genre and show how each feature was incorporated into *RoboBuilder* and *Particles!*. We will then show how these features became the central mechanism by which players encountered targeted concepts and used these concepts both in and outside of the game to think and reason about related phenomena.

In the case of RoboBuilder, this takes the form of players developing an understanding of central programming concepts through their iterative development of in-game robot strategies. Over the course of gameplay, data shows the novice programmers constructing strategies of increasing size and sophistication as they progressed through the game. Further, in analyzing the interviews, we find evidence of players engaging with the concepts designed into the game, including the relationship between the programs and the resulting behavior, and the ways conditional logic, iteration, and state can be used to create desired in-game behaviors.

For *Particles!*, pre- and post-game interviews reveal players shifting from attributing object properties to the identity of the substance the object is made of to descriptions that attend to the arrangement and structure of the particles that make up each object. These more complex and precise descriptions of the cause of object properties were paired with references to in-game construction tools indicating these shifts were likely due to interactions with the constructionist features of the game.

Significance

Given the prevalence and popularity of video games in youth culture, the potential impact of fun, engaging, and most importantly, effective educational video games grows. Built off a firm theoretical grounding and backed by evidence of the successes of environments designed in this genre, the spread of constructionist video games has great potential for influencing the designers of learning environments and enabling deep, meaningful learning to happen through the increasingly popular act of playing video games.

Integrating Modeling with Games for Learning Newtonian Mechanics

Pratim Sengupta, Stephen Killingsworth, Kara Krinks, Corey Brady, & Doug Clark

Introduction

Modeling is the language of science, and development of scientific expertise is inseparably intertwined with the development of epistemic and representational practices such as modeling and graphing (Giere, 1988; Lehrer & Schauble, 2006; Nersessian, 1992). In this paper, we focus on the integration of modeling with digital games for learning physics. We show how the integration of graphing and modeling with SURGE as core gaming activities positively effects students‘ learning of concepts related to Newton’s first and second laws that have been traditionally challenging for novices to learn (Halloun & Hestenes, 1985; Larkin et al., 1980; Dykstra & Sweet, 2009).

Modeling and Graphing in SURGE

SURGE (Figure 2) supports students’ game play as an iterative process of modeling. In order to make Surge move along a path, the learner creates a predictive model of the trajectory, by placing impulses along the target path. The learner then deploys his or her model by playing the level, which simulates the behavior of Surge on-screen. Feedback enables learners to refine and revise their initial models.

In addition, a graphing environment enables real-time construction of representations based on periodic sampling of measures of SURGE's motion (including total displacement; signed x- and y-component displacements; total velocity; and signed x- and y- component velocities). A slider-bar on the x-axis allows the student to rewind and replay the completed level.

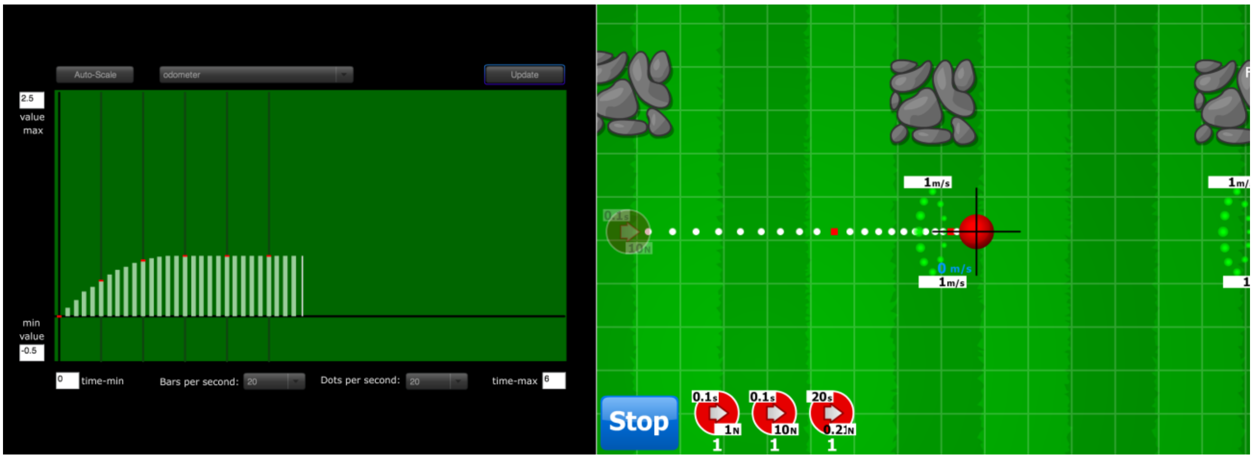

Figure 2: SURGE’s world (on the right) and the graphing environment (on the left)

The Study and Findings

We conducted a study in which four sections of 7th grade students in a public school in Nashville interacted with SURGE. Students within each class were randomly assigned to one of two graphing conditions (grapher vs. no grapher) and one of two collaboration conditions (collaborative vs. non-collaborative). Repeated-measures ANOVAs were conducted for each of three question groups (Newton's 1st Law Questions, Newton's 2nd Law Questions, and Graphing Questions). Across the between-subjects conditions, the analysis showed significant pre-post gains for the Newton's 1st Law, $F(1, 96) = 87.42$, $p < .0001$, $= .47$, and for the Newton's 2nd Law questions, $F(1, 96) = 6.05$, $p = .02$, $= .06$. There were not significant gains overall for the graphing questions, F(1, 96) = .51, p = .48, = .01, but there was a marginal interaction between graphing condition and test administration for questions on Newton’s 2nd Law questions, F(1, 96) = 2.87, p = .09,= .03. This interaction suggests that the graphing activity may have allowed students to perform better on 2nd Law questions (M_{gain} = 11.1%, SD_{gain} = 25.3) than without the grapher (M_{gain} = 3.1%, SD_{gain} = 27.0). We will also present qualitative case studies of students based on video data, which illustrate the process through which this improvement may have occurred.

Scholarly Significance

Given that models and modeling are central to informal game play (Gee, 2006), we present a pedagogical approach in which modeling and graphing can be integrated as core game-playing activities to support conceptual development in physics. Our findings highlight the importance of supporting the development of students’ representational competence central to Newtonian mechanics in order to support their conceptual development.

Constructivism, Constructionism and The Radix Endeavor

Eric Klopfer

Objective

For years the Scheller Teacher Education Program (STEP) has been developing constructionist environments to promote STEM learning. These environments have included tools for developing 3D games and simulations (StarLogo TNG). In recent years work has focused on combining game development and simulation use (Klopfer et al. 2009). However, these open-ended tasks often face an implementation challenges in classrooms. In parallel STEP has been developing educational games that embody some of these same characteristics. The latest game, The Radix Endeavor (Radix), is a Massively Multiplayer Online Roleplaying Game (MMO), which allows players to be self-directed, while bounding their actions and focusing them on mastery of science and math concepts.

Perspective

A radical constructionist (Papert & Harel 1991) game is hard to conceive, at least by many definitions of games that imply particular goals and constraints. But different games can include components of constructionist design in interesting ways. MMOs, in which players explore a large world, obtain a variety of quests that they can complete in increasingly more complex chains, and center around tool use allow for a great deal of player choice and customization. This design is consistent with Experiential Learning (Kolb 1984) in which learners/players have experiences (engage in game play), reflect on those experiences (often through lulls in the game between increasingly challenging quests – sometimes with other players in the world), abstract those ideas (in order to be able to apply them in new situations) and test them (through the next task).

Methods

Players in Radix choose a character that either pursues the biology line or the mathematics line. The premise of the world is that in a renaissance era earth-like world, math and science are being kept from the people by an evil ruler. The player takes on the role of an apprentice in an underground society attempting to bring this knowledge back to the people to help with a variety of world issues. Players obtain quests in the world, which require no previous knowledge but relate to core concepts in each of the associated domains. The key “weapons” that players have are scientific tools associated with each of the quest lines. Advancing in quest lines provides players with more sophisticated tools. In many of the quests they are changing the world through environmental improvement or constructing buildings.

Data Sources

As players proceed through quests in the world, data is tracked from each of their tasks, noting how often they try a task, and diagnosing where they succeed and fail. The game provides feedback to the players about where they are struggling, but does not provide direct instruction. In this study, data is obtained from both in game data, and external content assessments aligned with state standards.

Results and Significance

Players in Radix have shown a propensity for exploring many of the more open-ended areas of the world, even when the game provides little to no direction in that exploration. The quest design and tool use have successfully embodied the experiential learning approach.

Cognitive Clinical Interviews for Studying Thinking in Constructionist Video Games

R. Benjamin Shapiro & Rosemary S. Russ

Supporting the development of robust, multi-faceted understandings of sustainability along with the system-level dynamics and individual-level choices that give rise to it is a difficult design research problem (Goh et al., 2012; Eberbach et al., 2012). One element of this challenge is that sustainability is a compound outcome; it can be quantified as a weighted sum of environmental, social, and economic sustainability, measures that themselves exist at both local and global levels of scale (Gratton, 2011). Additionally, the measures are interdependent; an individual farm that minimizes adverse environmental impact cannot be said to be sustainable if the means through which it does so render it economically insolvent.

Role-playing video games, essentially participatory simulations (Wilensky & Stroup, 1999) with a playful, role-based twist, provide opportunities for players to learn interconnections between individual choices and local/global sustainability processes and outcomes. We created a multi-player video game in which participants role-play as farmers by making choices about what biofuel crops to plant in their fields over time given shifting market conditions (Figure 3 shows a screen shot of the most current version of the game). Throughout multiple "years" (rounds) of play, farmers design and tinker with their fields based on their understanding of how the global system works and how to succeed in that system. That is, they make decisions on how to construct their overall farm (i.e. the ways that particular fields are planted, fertilized, or left fallow) based on their interpretations of the external, shared representations of the global environmental and economic system. It is in this sense that the game reflects the principles of constructionism (Papert, 1990; Shaw, 1996).

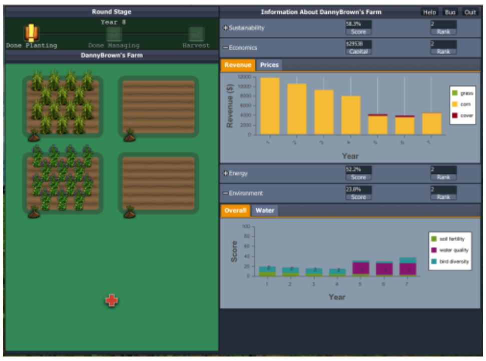

Figure 3. Screen shot of player "DannyBrown"'s farm after 7 "years" of playing the game.

We conducted game-play sessions in undergraduate classrooms to investigate how game play, combined with peer and whole class discussions enabled learners to reason about the system dynamics of the simulated game world, and how individual's choices could respond to or shape them. These sessions mirrored how we expect the game will typically be used in schools, and so were of 1-2 hours in duration. Consequently, students were only able to play through a limited number of scenarios, limiting our ability to observe how students might reason about and respond to important conditions.

Therefore, play sessions were followed by cognitive clinical interviews (Ginsburg, 1997) that asked participants to explain how individual choices or aggregate patterns cause various non-game-based scenarios, or to explain what they would do in various scenarios, and why. Our choice to use cognitive clinical interviews to assess learning was deliberate; they offer the opportunity to probe the structure and robustness of learners' conceptual models developed through constructionist game play.

Analyses of these interviews revealed that participants generally understood causal mechanisms embedded in the game's simulation, connecting soil health, short- and long-term profit, the impacts of bioenergy producing crops, supply and demand, and how individual values shape choices. Some participants explained ways in which their own beliefs about those value-laden priorities shifted as a result of game play and discussion, and how those shifts were operationalized in their game play choices. Finally, participants successfully transferred their newly developed understanding of bioenergy farming sustainability dynamics to hypothetical scenarios outside of the game context. Many of these nuanced understandings were not apparent during the limited time that game play was possible in a classroom setting, and so could not be observed through play alone. By using cognitive clinical interviews we were able to develop insights into student thinking that would otherwise have been invisible.

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