Terra Nova Toward Terra Firma: Data On Games For Science Learning

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Abstract. Much enthusiasm but less data has often accompanied games for science learning. This session brings together several researchers who investigate the potential of games for science learning and invites audience members to consider the evidence, raise their own questions and concerns, and form their own conclusions regarding several current projects. This interactive symposium will combine a structured poster session with a discussion session led by Yasmin Kafai. In particular, the session explores three questions. Does the data support the claims that the games can effectively support valuable science learning? What types of skills, concepts, and processes do the games and virtual worlds most effectively teach? What other data could and should be collected to support more definitive claims?

Session Overview

According to the National Research Council (2005) and international comparison studies (e.g., TIMSS), science is often taught at a superficial level of definitions. Digital games and virtual worlds offer a potential medium to allow students richer access to deeper authentic understandings of science. This session brings together researchers who investigate the potential of games for science learning and invites respondents and audience members to use the evidence to form their own conclusions. The goals of this symposium will be to shed light on the following issues in terms of several current projects:

- Do data support the claim that games can effectively support valuable science learning?
- What types of skills, concepts, and processes can video games and virtual worlds most effectively teach and what types prove more challenging?
- What other data could and should be collected to support more definitive claims?

The format of this interactive symposium will be in three parts. First, each of our poster teams will briefly introduce the major aspects of their projects to the audience. This will be followed by an open time for

attendees to explore each of the posters and interact with the presenters, focusing on discussing the major issues and evidence in their projects. This open time will be structured to move attendees in a semi-organized manner through a set of mini-sessions at the posters of their choosing. The final section of the symposium will be devoted to discussion led by Yasmin Kafai and a lively interaction between presenters and attendees focusing on issues of data collection and analysis in research on games for science learning.

The Role of Embodiment and Symbolization in Supporting Physics Learning with Games and Virtual Worlds for Young Children

Noel Enyedy, UCLA, Joshua Danish, Indiana University

Research Goals and Theoretical Framework. Newtonian mechanics is not typically taught to first and second grade students. In fact, these concepts are even difficult to teach to high school students (White, 1993). However, the Semiotic Pivots and Activity Spaces for Elementary Science Project (SPASES) overcame this barrier using technology to transition students from embodied games to scientific modeling. This transition was supported by the use of embodiment as a tool for representing students' ideas (Danish, 2009), and then helping students refine their ideas by progressively symbolizing them and then refining those symbols (Enyedy, 2005).

Game Context and Methods. SPASES was a 15 week, 2 days a week, force and motion unit piloted with children aged 6-9 (n=49). The curriculum leveraged embodiment and symbolization by using motion tracking technology to follow students as they physically enacted their ideas, and then feeding this information into computer simulation tools. Video case studies will be used to demonstrate the process through which the SPASES tools supported learning gains which will be presented using quantitative analyses of a pre- and post-test based on the FCI.

Data Results and Significance. First, we present analyses of the pre- and post-test gains which demonstrate significant improvement on the questions related to forces in 2-dimensions. For example, the proportion of students who accurately predicted the path of a puck that was moving and then struck by a force in a direction perpendicular to it's current motion increased from 0.10 to 0.69. The difference in proportions is significant,($\chi 2$ =24.61(1, N = 39), p<0.0001. We then present analysis of two game activities that supported students in making this shfit from common misconceptions about force to more normative scientific conceptions. In the first game, students used their physical orientation combined with a simple worksheet to refine their understanding of vector arithmetic in 1-dimension. In the second game, students modified their symbols and then used them in a computer simulation to refine and demonstrate their understanding of 2-dimensional motion. The results will demonstrate the role of embodiment and symbolization in supporting young children in engaging with complex science concepts.

Model Based Reasoning & Use in Massively Multiplayer Online Games

Constance Steinkuehler, UW-Madison

Research Goals and Theoretical Framework. (Massively) multiplayer online games (MMOs) have recently emerged as a technology with potential for science education. As simulations of complex systems, they allow participants to digitally inhabit a virtual world and engage in join activity with others. Innovative projects such as Quest Atlantis (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007) and River City (Ketelhut, Dede, Clarke, Nelson, & Bowman, 2007) offer proof of the concept that such technologies can foster powerful forms of science learning in formal instructional environments. What is even more surprising, however, is that commercial games with no intention to teach may have potential. In a cognitive ethnography of the MMO Lineage, Steinkuehler (2005) observed teens who decided to test every combination of resources available against a given problem, tabulated the results in Excel , created simple mathematical equations to explain them, and then argued with one another about whose model was most accurate. Subsequent studies found that such practices were more prevalent than first suspected: Across a random sample of MMO forum discussions posts, Steinkuehler and Duncan (2009) found that 86% of the discussions were social knowledge construction with 58% focused on complex systems, 11% providing models to explain those systems, and 28% providing evidence to support their claims. The goal of this study was to further this line of research by examining not the finished models that gamers posted to

discussion forums but rather the processes and resources they used in order to construct and justify them.

Game Context and Methods. This study was conducted in the context of an after school lab using the online game World of Warcraft to engage adolescent "at risk" males (n=25) in literacy practices. Participants were asked to construct and justify their best model (a "build") for how the in-game "priest" class could be specialized using the in-game "talent" system (Figure 1). Each was given a laptop to access any online game-related resource materials they chose and instructed to "think aloud" to reveal their problem-solving process. Researchers asked probing questions ("why did you do that?") during any lapses of thinking aloud and videotaped participants' activities (including computer use), took fieldnotes, and collected resulting artifacts. Participants also completed a simple pretest and posttest to measure reported prior experience (pretest), interest (pretest/posttest) and beliefs of success (posttest).

Data Results and Significance. Participants used a complex set of multimodal expository and procedural texts as the basis for their problem-solving and solution justification. In order to find the best-fit solution to then given problem of multiple constraints, they made heavy use of both commercially provided and user-generated online modeling tools that enable the individual to review the functional outcomes of various choices among resource allocations before committing to any one "build." Curiously, the main tools they chose to complete the problem were user-generated and multimodally complex, with concepts articulated not only through "technical verbal language but also mathematical, graphical, diagrammatic, pictorial, and a host of other modalities of representation" that, ironically, typically make reading comprehension in more traditional domains particularly challenging (Lemke, 1998, p.247).

Current Evidence of Engagement, Understanding, and Achievement in the *Taiga* Curriculum in Quest Atlantis.

Daniel T. Hickey, Eun Ju Kwon, & Michael K. Filsecker, Indiana University

Research Goals and Theoretical Framework. Prior annual design research cycles of a 13-hour ecological science curriculum refined the way students drafted and revised in-game assignments, and the way the game and the teacher provided formative feedback. Substantial incremental improvements in scientific discourse, conceptual understanding, and science achievement were obtained (Barab et al., 2007; Hickey, et al., 2009). In this most recent cycle, new insights about participatory assessment (Hickey & Anderson, 2007; Hickey et al., in press) led to new reflective prompts for the assignments, and a 30-screen formative feedback routine was reformulated as FAQs. These and other refinements were coordinated using new insights about consequential and critical engagement (Gresalfi et al., 2009).

Game Context and Methods. The Taiga virtual park is a world in the *Quest Atlantis* MUVE. Students play the role of field investigator, interacting with non-player characters, each other, and their teacher. Players draft and submit "quests" to the ranger/teacher while investigating declining fish populations. The same sixth grade teacher who had implemented Taiga in three previous cycles implemented it in all four of his classes. Impact was examined primarily by analyzing the discourse in submitting and refining quests, and secondarily using an open-ended performance assessment and a random sample of achievement items aligned to targeted standards.

Data Results and Significance. Analysis of initial and final quest submissions, feedback exchanges with the teacher, and log files of FAQ access showed impact of these refinements, and students enlisted more domain formalisms in their quests and did so more accurately. These and other refinements resulted in even larger gains on the performance assessment from the previous year (from 1.4 to 1.6, SD). While still statistically significant, the average achievement gain of 0.5 SD was smaller than the 1.0 SD gain the previous year; this was partly due to one anomalous class whose achievement scores actually declined. We concluded that (1) the new features were promising and worthy of further refinement, (2) the notions of consequential and critical engagement were helpful for coordinating such refinements and for game-based assessment more broadly, and (3) the performance assessment should be refined to more explicitly afford such engagement.

SURGE: Intended and Unintended Science Learning in Games

Douglas B. Clark, Mario Martinez-Garza, Vanderbilt University,
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Research Goals and Theoretical Framework. This poster considers data from two studies and highlights the potential for both intended and unintended student learning in games. School science, with its focus on explicit formalized knowledge structures, seldom connects to or builds upon students' tacit intuitive understandings. Well-designed commercial video games, however, are exceptionally successful at helping learners build accurate intuitive understandings of the concepts and processes embedded in the games due to the situated and enacted nature of good game play. Most commercial games fall short as platforms for learning, however, because they do not help students articulate and connect their evolving intuitive understandings to more explicit formalized structures that would support transfer of knowledge to other contexts. In *Thought and Language*, Vygotsky (1986) discusses the potential for leveraging intuitive understandings from everyday experience ("spontaneous concepts") with instructed scientific concepts to build robust understandings. The question remains whether or not the intuitive spontaneous concepts developed in games can be successfully leveraged into robust instructed concepts in the format and terminology of academic assessment and across domains recognized as central by the scientific disciplines themselves.

Game Context and Methods. SURGE (Scaffolding Understanding by Redesigning Games for Education) focuses on design principles for connecting students' intuitive "spontaneous concepts" about kinematics and Newtonian mechanics into formalized "instructed concepts." SURGE integrates research on conceptual change, cognitive processing-based design, and socio-cognitive scripting with design principles and mechanics of popular commercial video games such as Mario Galaxy, Switchball, Orbz, and Portal. Students' intuitive "spontaneous concepts" are measured in SURGE through their performance in actual game levels. Their understanding of formal "instructed concepts" is measured using items from the simplified Force Concept Inventory developed by physicist Hestenes and colleagues (e.g., Hestenes, Wells, & Swackhamer, 1992).

Data, Results, and Significance. Our first study analyzed 24 undergraduate and graduate students playing SURGE. The data strongly reinforce the potential of games to help students learn, but also underscore their potential to reinforce alternative conceptions as well as normative conceptions. The game actually resulted in a significant decrease ($\chi 2 = 4.75$, $p = .029$) in students who answered one question correctly by unintentionally focusing students' attention on another physics relationship (we had not yet added all of the intended functionality to the interface relevant to projectile motion and the independence of the x and y components of an object's velocity), but the students demonstrated significant ($p = .037$) gains on the concepts posttest when that question was excluded. The game therefore showed itself to be effective in changing how students thought about questions from the Force Concept Inventory, but care must be taken to ensure that the ideas that students take away from the game are the ones intended by the designers.

Learning Argumentation through a Role-playing Game-based Curriculum

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Research Goals. Argumentation plays a key social and intellectual role in the construction of knowledge, but how we may socialize students into the practice of argumentation in schools is less explored. To address this issue, this design-based research (Barab & Squire, 2004; Brown, 1992) project investigates three middle school students' experience and their argumentative discourse in a 10-day game-based learning curriculum designed for argumentation.

Theoretical Framework. To teach argumentation, I propose a situated argumentation design framework that foregrounds four aspect of argumentation design: epistemological, cognitive, social, and material. This design framework guides the conceptualization of game-based learning approaches, mainly role-playing simulation, open-ended challenges, authentic resources and tools, in creating a designed experience (Squire, 2006) for dialogic and collaborative arguments.

Game Context and Methods. We designed Saving Lake Wingra, a 10-day game-based learning curriculum for argumentation based on the situated argumentation design framework. The curriculum aims at restructuring classroom discourse for argumentation through three phases. The first phase (days 1- 4) aims at reconditioning classroom discourse patterns from a usually teacher-centered and turn-taking pattern to a student-centered, dialogic, and collaborative format. The second phase (days 5-8) engages students in extended practices of dialogic and collaborative arguments as teams of three professionals. In the last phase (days 9-10), students present arguments collaboratively and individually to argue for the best interest of Lake Wingra.

Data Results and Significance. The results indicate that all three middle school students participating in this study were socially and intellectually engaged in practicing and developing arguments about the future of Lake Wingra. Some constructed claims with supporting evidence and even countered claims proposed by peers, though the degree to which each participant was able to argue differed. Role-playing and open-ended knowledge representation empowered students to express personal opinions supported by evidence. The findings suggest that (1) conceptual understanding plays a key role in constructing evidence-based claims and (2) the situated argumentation design framework can be improved by foregrounding the importance of conceptual understanding in constructing arguments.

Virtual Environment-based Assessments of Science Content and Inquiry: The SAVE Science Project

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Research Goals and Theoretical Framework. The SAVE Science project is focused on creating, implementing, and evaluating assessment modules designed to capture evolving patterns of scientific understanding among middle-school students based on data collected from their interactions in a virtual environment. In this presentation, we report on findings from implementations of our first assessment module. In particular, we focus on how the module can reveal misconceptions held by students about scientific phenomena, and describe student perceptions of virtual environment-based activities designed primarily as assessments rather than as learning environments.

Game Context and Methods. In SAVE Science, students try to uncover likely contributors to a host of problems facing a virtual world. To accomplish this, students must apply knowledge and skills studied in their classroom-based science curricula through multiple assessment quests over the course of a school year. We are looking to see if learning outcomes on district and state assessments by learners in SAVE Science differ from those in control classes not participating in the project. The module in the current study assessing understanding of adaptations and structure/function asks students to investigate possible causes for poor survivability among a flock of sheep recently moved to the farm from a far-distant (and environmentally distinct) location. In completing the assessment task, students can interact with two computer-based characters (a farmer and his brother). For healthy indigenous or failing new sheep, students can measure legs, bodies, and can access weight, age, and gender data.

Data and Results. This presentation will focus on results from our pilot and first year of implementations. We conducted our pilot in spring 2009 with nineteen 7th grade science students who participated in the first *SAVE Science* assessment module, assessing understanding of adaptation of organisms to a local environment. Automatically collected data lends insight to student actions and understanding. For example, all students gathered data before reaching conclusions, indicating that students understand the concept of evidence-based inferences. Some students asked questions of the two non-player characters multiple times, and all observed sheep characteristics. Further, students used their observations to support their responses to questions from the farmer. The data also helped illustrate student misconceptions of inference versus observation and other science concepts. At the same time, students in the pilot study noted a strong sense of engagement while completing the assessment module activities. One student said, "[I] like how the people talk. [I] like the sound. [I] like how you can move yourself around. [IT'S] MORE FUN THAN A REGULAR TEST." This student's sensory experience in the virtual world made for an enjoyable, effective

learning experience.

Significance. Initial analysis indicates that we are able to differentiate between students who understood and used the appropriate methods in their inquiry from those with had misconceptions about the content or inquiry processes. Further, and perhaps not surprisingly, we found that students perceived the assessments as engaging and game-like (rather than stressful and test-like). The findings, while tentative, provided useful information for the redesign of the first assessment module that we are now implementing in multiple classrooms.

GameBuilder: Does Reduced Software Complexity Allow More Time on Task?

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Research Goals and Theoretical Framework. To allow for greater student engagement and learning as a result of involvement with augmented reality (AR) games, several programs are underway in which students, not teachers or researchers, develop their own AR games. Previous tools for developing AR games had very complex user interfaces. As a result, the team developed GameBuilder, an AR editor with a much simpler interface, under the assumption that such a tool would allow for more focus on the game to be built and learning components to be included in the game. This research is designed to test that assumption.

Game Context and Methods. A protocol was developed to test the abilities of middle-school aged children to engage with the game design and content of their games, as opposed to spending effort managing the software. Participants were randomly assigned to two groups, one that would use the more complicated AR game editor, and one that would use GameBuilder. Each group was asked to complete a tutorial on using the assigned software, and then asked to build a simple game, with a topic of their own choosing, using that software. A researcher observed each study participant through both the tutorial and the free design session, and participants were then asked to rate their satisfaction with the software and the experience overall.

Data Results and Significance. Results from the free-design period and surveys show that participants were equally able to use the two pieces of software to develop their own games, after completing the tutorial. It is interesting to note, however, that participants using the more complex game editor, which had a number of features in which they were not trained, did not take advantage of any of these more advanced features. In addition, though the surveys did not reflect any additional dissatisfaction with the tool, the researcher observing use of the more complex software saw that in a number of cases, users inadvertently opened parts of the software they did not mean to and were distracted for some period of time trying to get back to their planned task. This suggests that the simplified interface is beneficial. Further research should test the ability of users to complete basic tasks without the benefit of the initial tutorial.

MUVEs and Meta-Knowledge

Jody Clarke-Midura & Eugenia Garduno, Harvard University

Research Goals and Theoretical Framework. Numerous researchers have emphasized the role of metacognitive processes in inquiry learning (White & Frederiksen, 1998, 2005; Kuhn, Black, Keselman, & Kaplan, 2000; Kempler, 2006; Kuhn & Pease, 2008). As an example, White et al offer a framework for inquiry learning, the meta-knowledge framework, which contains four primary processes: theorizing, questioning and hypothesizing, investigating, analyzing and synthesizing (White & Frederiksen, 1998; White, Frederiksen, Collins, in press). As part of this framework, they claim there is a meta-processing level where one evaluates not only what process should be carried out but how well it is being carried out. Similarly, research on games and multi-user virtual environments (MUVEs) suggest curricula delivered via these technologies have the potential to offer more authentic science inquiry learning that reflect the processes in White et als framework (Gee, 2003; Dede, 2009, Clark et al, 2009). We are studying how curricula delivered via immersive technologies have the potential to create learning experiences that (1) allow for authentic inquiry learning (2) enable metacognitive processes laid out by White et al. The research questions we will address in this poster are: what aspects of learning influence students'

metacognitive processes? What aspects of MUVEs allow for students to engage in metacognitive processes?

Game Context and Methods. In order to answer our research questions, we conducted a series of studies in 2008. We used a MUVE-based science curriculum, River City, with 5218 middle school students within classes taught by 87 teachers. MUVEs are online digital contexts where multiple participants can communicate and collaborate on shared challenges. A participant takes on the identity of an avatar, one's digital persona in a 3-D virtual world, and communicates via text chat and non-verbal gestures. In this particular curriculum, students take on the role of a scientist and investigate a disease outbreak in a virtual city.

Specific instruments have been developed to measure metacognitive processes explicitly in the context of science inquiry (Kempler, 2006). The constructs measured by these instruments are often referred to as describing children's "thoughtfulness of inquiry" (Patrick et al, 2000; Fredricks, Blumenfeld & Paris, 2004). We used a scale developed by researchers at the University of Michigan to measure the extent to which students employ deep-level learning and self-regulatory strategies in inquiry-based science (Kempler, 2006). The University of Michigan studies reported an internal consistency reliability of .79 (Kempler, 2006). Students were administered surveys online prior to and after participating in the curriculum. The surveys contained two sections: (1) an affective sub-scale, which measured their thoughtfulness of inquiry (TOFI); and (2) a content sub-scale, which measured their inquiry and content knowledge. Multiple-choice were analyzed using multi-level regression. Open-end responses were first coded using open coding, allowing codes to emerge inductively from participants (Strauss & Corbin, 1998). A second round of coding was done to search for themes related to the research questions (Geertz, 1973).

Data Results and Significance. We found that students who felt like a scientist ($t(3625)=6.99$, $p=.0001$), felt like they were conducting an experiment ($t(3625)=6.28$, $p=.0001$), and enjoyed working as part of a team of scientists ($t(3625)=2.74$, $p=.001$) were more thoughtful of their inquiry. We found that teachers' self-identified teaching styles, in terms of the types of activities conducted in science class in general, had no significant effect on students' thoughtfulness of inquiry. Furthermore, a teacher's prior experience with teaching the *River City* curriculum showed no significant effect on students' thoughtfulness of inquiry. In this poster we will present more detailed results of our studies, including case studies of students who demonstrated high and low thoughtfulness of inquiry in the curriculum.

Metacognition is an important component of inquiry learning. As research on games and MUVEs in science education grows, it is important for researchers to understand what variables and design features help foster metacognitive and inquiry processes.

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