SANCTUARY: Asymmetric Interfaces for Game-Based Tablet Learning

by

Jason M. Haas
B.A. Film Studies, Wesleyan University, 2000

SUBMITTED TO THE PROGRAM IN MEDIA ARTS AND SCIENCES, SCHOOL OF
ARCHITECTURE AND PLANNING IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN MEDIA ARTS AND SCIENCES
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2013

© September 2013 Massachusetts Institute of Technology. All rights reserved.

Signature of Author: ______

Certified by: ______

Accepted by: ______

Department of Media Arts and Sciences
August 9th, 2013

Eric Klopfer
Professor, Director of the Scheller Teacher Education Program
Thesis Supervisor

Patricia Maes
Alex W. Dreyfoos Professor of Media Technology
Associate Academic Head, Program in Media Arts and Sciences
SANCTUARY: Asymmetric Interfaces for Game-Based Tablet Learning

by

Jason M. Haas

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning on August 9th, 2013 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Media Arts and Sciences

ABSTRACT

This thesis describes the production of Sanctuary, a multiplayer learning game to be played on two tablet computers. Sanctuary's principle innovation is the splitting of the user interface onto two tablets, separating player tools in separate roles and thus providing players with obtainable epistemologies. The designed intention of this interaction is to force communication and interaction and thus metacognition in players. By requiring players to express their beliefs about the game world to one another in language in order to be successful, the design of the game encourages players to formalize their intuitions and experiences. If this approach is successful, then it may be applied further to an increasing range of epistemological frames and better science education. This has the potential to build cooperative, thriving learning communities with shared experiences. The game was tested with a non-random stratified sample of high school students, suggesting new directions for the intervention, and demonstrating the value of co-design.

Thesis Supervisor: Eric Klopfer
Title: Professor of Urban Studies and Planning; Director, Scheller Teacher Education Program
SANCTUARY: Asymmetric Interfaces for Game-Based Tablet Learning

by

Jason M. Haas

Signature redacted

Professor Eric Klopfer
Director, The Scheller Teacher Education Program
Director, The Education Arcade
Massachusetts Institute of Technology

Signature redacted

Professor Mitchel Resnick
LEGO Papert Professor of Learning Research
Academic Head, Program in Media Arts and Sciences
Massachusetts Institute of Technology

Signature redacted

Professor T.L. Taylor
Associate Professor of Comparative Media Studies
Massachusetts Institute of Technology


**BIOGRAPHY**

Jason is a Research Assistant and PhD candidate in The Education Arcade and the Center for Mobile Learning through the MIT Media Lab. His research focuses on designing interesting multiplayer experiences (for learning and otherwise) and evaluating them in context. His interests include media, collaboration, learning, information flow, and the workings of organizations. He holds a B.A. in Film Studies from Wesleyan University and a M.Ed. from the Harvard Graduate School of Education’s Technology, Innovation and Education program.

**Eric:** Your class changed my life forever, and your lab further still. Your tireless and wise dedication to your collaborators and to the greater good are an inspiration. In particular, thank you for the example you provide with your deeply held belief that to abandon schools amounts to cowardice.

**Mitchel:** It would have been enough to be introduced to Kohn and Schon. You have opened up Papert for me and inspired me with your selfless dedication to creative learning and slow, purposeful, real change.

**TL:** Though we only just met through this process, in many ways I had to lean on you the most. Thank you so much for your wise and patient advice as you helped me become a real researcher. I am so glad you have joined us here, and greatly look forward to working with you in the future.

**Michael, Scott, and the students of Bedford High School:** Thank you so much for opening your doors, for your hospitality, for your dedicated play, and for your excellent ideas.

**Nick, Jordan, Nethanel:** I literally could not have done this without you. The success of this game and project is yours as well. Thank you so much - I hope we can work together in the future!

**Scot:** You were my thesis’ unofficial advisor. I can’t thank you enough.
**Jessica:** Well that certainly was a year! Thank you so much for your patience, understanding, and thoughtfulness, Dr. Monkey! Extra snuggles for you.

**Mom & Dad:** Thanks for all your love and support! I made it!

**Justin:** Thank you for teaching me so well that two is always better than one.

**Volcanic Kitties:** Without my immersion in your problem-solving ranks, and without the good-natured intelligence and collaboration of our little group, I probably couldn't have written this. Sorry I had to go on furlough to write it and then the guild died. LOK'TAR O'GAR!

**Education Arcade:** There are no better work environments, there is no better collection of smart, creative weirdos. I'll be back at the lunch table this year.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOGRAPHY</td>
<td>7</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>9</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>11</td>
</tr>
<tr>
<td>FOUNDATIONS</td>
<td>13</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>13</td>
</tr>
<tr>
<td>LEARNING SCIENCES</td>
<td>13</td>
</tr>
<tr>
<td>Understanding &amp; Pre-Existing Knowledge</td>
<td>14</td>
</tr>
<tr>
<td>Active Learning</td>
<td>15</td>
</tr>
<tr>
<td>Design of Learning Environments</td>
<td>15</td>
</tr>
<tr>
<td>Expertise</td>
<td>16</td>
</tr>
<tr>
<td>Learning and Transfer</td>
<td>16</td>
</tr>
<tr>
<td>Learning in STEM Disciplines</td>
<td>17</td>
</tr>
<tr>
<td>Wrapping Up</td>
<td>25</td>
</tr>
<tr>
<td>SCHOOLS</td>
<td>26</td>
</tr>
<tr>
<td>GAMES</td>
<td>30</td>
</tr>
<tr>
<td>GAMES AND LEARNING</td>
<td>34</td>
</tr>
<tr>
<td>PURSUING GAME-BASED LEARNING IN SCHOOLS</td>
<td>42</td>
</tr>
<tr>
<td>CONSTRUCTIONS</td>
<td>44</td>
</tr>
<tr>
<td>FEATURES OF SANCTUARY</td>
<td>44</td>
</tr>
<tr>
<td>A SAMPLE WALK THROUGH of SANCTUARY</td>
<td>53</td>
</tr>
<tr>
<td>CHARACTERISTICS OF SANCTUARY</td>
<td>55</td>
</tr>
<tr>
<td>Heuristics</td>
<td>55</td>
</tr>
<tr>
<td>Length of Play</td>
<td>56</td>
</tr>
<tr>
<td>Number of Players</td>
<td>57</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>59</td>
</tr>
<tr>
<td>Simulation/Systems</td>
<td>66</td>
</tr>
<tr>
<td>Player Effort</td>
<td>68</td>
</tr>
<tr>
<td>Superstructure</td>
<td>69</td>
</tr>
<tr>
<td>PROCESS</td>
<td>72</td>
</tr>
<tr>
<td>EXPLORATIONS</td>
<td>74</td>
</tr>
<tr>
<td>FRAMEWORK</td>
<td>74</td>
</tr>
<tr>
<td>RESEARCH DESIGN</td>
<td>78</td>
</tr>
<tr>
<td>STUDY DESIGN</td>
<td>79</td>
</tr>
<tr>
<td>Population &amp; Sampling</td>
<td>80</td>
</tr>
<tr>
<td>Data Collection</td>
<td>81</td>
</tr>
<tr>
<td>Operationalized Concepts (Observation)</td>
<td>81</td>
</tr>
<tr>
<td>Operationalized Concepts (Interview)</td>
<td>82</td>
</tr>
<tr>
<td>Analysis</td>
<td>83</td>
</tr>
<tr>
<td>SITE DESCRIPTION</td>
<td>83</td>
</tr>
<tr>
<td>About Bedford</td>
<td>83</td>
</tr>
<tr>
<td>Bedford High School By The Numbers</td>
<td>84</td>
</tr>
<tr>
<td>Experiencing Bedford High</td>
<td>85</td>
</tr>
<tr>
<td>RESEARCH</td>
<td>86</td>
</tr>
<tr>
<td>A THEMATIC EXAMINATION</td>
<td>99</td>
</tr>
<tr>
<td>Fun/Engagement</td>
<td>99</td>
</tr>
<tr>
<td>Usability</td>
<td>101</td>
</tr>
<tr>
<td>Role/Expertise Differentiation</td>
<td>102</td>
</tr>
<tr>
<td>Conceptual Understanding/Learning</td>
<td>103</td>
</tr>
<tr>
<td>Co-Design</td>
<td>103</td>
</tr>
<tr>
<td>REFLECTIONS &amp; PROJECTIONS</td>
<td>106</td>
</tr>
</tbody>
</table>
INTRODUCTION

“You’re not competing with World of Warcraft; you’re competing with jail.”

David Dockterman (attrib.)

Science, Technology, Engineering, and Mathematics (STEM) learning in the United States faces a crisis. Two of the most dire consequences of this crisis are 1) a citizenry lacking the science literacy necessary to engage in topics relevant to everyday life (ranging from stem cell research to the nature of x-rays) and 2) a shortage of young people preparing for careers in STEM disciplines and fields. One of the primary goals of science education is to prepare scientifically literate citizens (AAAS 1990, 1993, Millar and Osborne 1998). According to Miller (1998), scientific civic literacy requires: 1) An understanding of critical scientific concepts and constructs 2) An understanding of the nature and process of scientific inquiry 3) A pattern of regular information consumption and 4) A disposition toward taking action to make change in one’s lifestyle as necessary (adapted from Miller, 1998 by Squire and Patterson, 2009). Yet science literacy rates in the U.S. struggle to reach 20% (Miller, Pardo, Niwa, 1997). With regard to STEM careers and science identity, young people (particularly women and minorities) have difficulty imagining themselves as scientists, engineers, technologists or mathematicians. These careers seem out of reach or foreign to them and inconsistent with their interests (Lowell & Salzman, 2007).

My project is to question is whether, by providing players with two points of view on a shared scientific problem via asymmetric interfaces, under the conditions of play, that the challenges of epistemological pluralism can be made into a virtue for science learning, forcing quality communication, arguments, coordination, and co-strategization amongst participants. By provoking these behaviors, I expect that the game will overcome a chief challenge of experiential learning activities—the creation of tacit, unformalized experience and knowledge. To this end, I am building Sanctuary, an ecological simulation with one biology-themed and one mathematics-themed interface.
for two players. By requiring players to express their beliefs about the game world to one another in language in order to be successful, the design of the game encourages players to formalize their intuitions and experiences. This is an advance over existing learning game experiences, in which players are rarely required to formalize their strategies. This is also a naturalistic advance over other metacognitive interventions in which a play experience is literally halted in order to solicit formalized thoughts from players. If this approach is successful, then it may be applied further to an increasing range of epistemological frames and better science education. This has the potential to build cooperative, thriving learning communities with shared experiences.

The purpose of creating this work is to a) advance the understanding of teaching science (biology) and mathematics in existing scholarly and institutional context and b) understand the challenges of getting games into the classroom. The latter point has three smaller sub-questions: i) Does this game offer value to teachers? ii) Does this game offer value to students iii) Does this particular type of game play fit within an existing institutional structure? Much has been made about creative and play-based learning in extracurricular learning settings, but there is an argument for play-directed learning in schools.

How do you make a study of this sort of thing? I will be beginning with the learning sciences discipline of Design Based Research, a combination of formative evaluation and experimental psychology. My research in this thesis replaces psychological experiments looking to expose a new learning theory with a phronetic attempt to make sense of the culture around the game. Phronesis demands that we ask where we are going, who wins and who loses, and by what mechanisms, is it desirable, and what is to be done? I believe this makes sense as DBR demands continual iterative improvement to learning interventions.

Asymmetric interfaces potentially offer a solution to some of the problems with learning and game-based learning in particular, but it also introduces problems of power and control. This experiment pays close attention to the effects of power - students are age-graded, MCAS-taking, and given letter grades to evaluate and rank them in traditional school settings. The system may demand they contend with each other, but they can potentially work out their values locally. Another hoped for benefit is that the frame of play and the transgressive nature of the game helps them to pierce or be temporarily liberated from the top down space of school.
INTRODUCTION
In order to adequately describe and situate Sanctuary, it is necessary to provide an account of developments in the disciplines of the learning sciences and of game studies and design. These are, of course, interdisciplinary domains themselves, so care will be taken to be as clear and comprehensive as possible while minimizing exposition. This section of the thesis will first describe current thinking about learning and learning in math and science in particular. Because much of the recent thinking about learning indicates that much of learning is contextual, and because in the United States and much of the world, a great deal of learning is viewed as the domain of schools, it is important to discuss schools as a site of learning. Next, I will address thinking about games and then games and play as sites for learning. Finally, I will address the idea of game-based learning in schools.

LEARNING SCIENCES
Considerable advances have been made in recent years in the field of the learning sciences. The National Research Council (NRC)'s How People Learn (2000), published at the turn of the century, provides a stable bedrock for contemporary research and theories about learning. The major lessons of that work establish several important points about learning:

- Learning happens best if students understand the material, not just memorize it.
- Students have pre-existing knowledge and understandings, so teachers must meet their students where they are.
- Students learn best when they take active control of their learning.
- Learning environments are designed to focus on the learners, the knowledge to be conveyed, the creation of community, and on the useful feedback of formative assessments.

The work also delineates an effective explanation of expertise, an explanation of the controversial concept of transfer, and differing ways in which knowledge is constructed in different domains. Recent research into the structure and function of the brain is
explored, and the authors also establish an agenda for future research in learning science. This work collected and codified the state of the art in learning, and steered a course for research-based perspectives on learning in the 21st century. Below, I will address the topics key to the development of Sanctuary, as well as update these ideas with more contemporary research where appropriate. This perspective may sometimes be historical, but may be useful for understanding suggested innovations or new directions suggested by this research. Further, the book’s organization and focus may be read as a means of organizing the field.

**Understanding & Pre-Existing Knowledge**

For experts, those who have mastered a subject area, knowledge is usable because it is “conditionalized” - connected and situated in usable ways. In an example, the authors indicate that, “[b]ecause they understand relationships between the structure and function of veins and arteries, knowledgeable individuals are more likely to be able to use what they have learned to solve novel problems—to show evidence of transfer” (pg. 9). The authors suggest that these knowledgeable individuals are better suited to design an artificial artery, considering properties like elasticity, for instance. They caution that this understanding, “does not guarantee an answer to this design question, but it does support thinking about alternatives that are not readily available if one only memorizes facts (Bransford and Stein, 1993)” (pg. 9).

The authors then reflect a “constructivist” approach to learning, expressing that people, “construct new knowledge and understandings based on what they already know and believe (e.g. Cobb, 1994; Piaget, 1952, 1973a,b, 1977, 1978; Vygotsky, 1962, 1978)” (pg. 10). The authors report that in particular, an inquiry approach to science learning for younger students resulted in better understandings of conceptual and fundamental physics than older students in conventional educational settings (White and Frederickson, 1997, 1998). These and other innovative curricula are believed to work because the instructors are able to pay attention to learners’ existing mental models and using these models as a starting point for further instruction. The authors also point out that constructivism does not necessarily mean that students must do all of their learning in a hands on manner. They indicate that learners, “usually after people have first grappled with issues on their own, ...‘teaching by telling’ can work extremely well (e.g. Schwartz and Bransford, 1998)” (pg. 11). Sanctuary’s model aids in the development of constructivist learning environments by making students’ thinking visible and available to one another and to learning mentors.
Active Learning
The authors also emphasize the importance of learners taking control of their own learning - they, “must learn when to recognize when they understand and when they need more understanding” (pg. 12). This is achieved through “metacognition,” which, “refers to people’s abilities to predict their performances on various tasks (e.g. how well they will be able to remember various stimuli) and to monitor their current levels of mastery and understanding (e.g., Brown, 1975; Flavell, 1973)” (pg. 12). In other words, developing skills in thinking about their thinking. This can be encouraged by a teaching approach that focuses on, “sense-making, self-assessment, and reflection on what worked and what needs improving” (pg. 12). A teacher with such an approach would, “assume responsibility for what the students are learning as they carry out their activities,” but also, “continually turn...more of the learning process over to the students” (pp. 12 – 13). Sanctuary demands that students be given more control in the classroom, and the collaborative, goal-driven activity requires metacognition.

Design of Learning Environments
The authors understand that the research can generate a lot of questions about how to actually make decisions in the classroom. They relate that, “[a]sking which teaching technique is best is analogous to asking which tool is best—a hammer, a screwdriver, a knife, or pliers” (pg. 22). Instead of simply ranking “books and lectures” versus “hands-on experiments,” or declaring a, “universal best teaching practice,” (pg. 22), they recommend that a balance of facts and skills is important. Moreover, they, “posit four interrelated attributes of learning environments that need cultivation” (pg. 24). These attributes are:

- “Schools and classrooms must be learner centered” (pp. 23 – 24).
- “To provide a knowledge-centered classroom environment, attention must be given to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like” (pg. 24).
- “Formative assessments—ongoing assessments designed to make students’ thinking visible to both teachers and students—are essential. They permit the teacher to grasp the students’ preconceptions, understand where the students are in the “developmental corridor” from informal to formal thinking, and design instruction accordingly. In the assessment-centered classroom environment, formative assessments help both teachers and students monitor progress” (pg. 24).
• “Learning is influenced in fundamental ways by the context in which it takes place. A community-centered approach requires the development of norms for the classroom and school, as well as connections to the outside world, that support core learning values” (pg. 25).

As I will discuss, Sanctuary calls for a very deliberate replacement of traditional, broadcast forms of teaching with a community-of-learners approach in which students are given control of their learning and the curriculum must be reconsidered. Sanctuary is also entirely premised on the notion of the developmental corridor.

**Expertise**

One view of learning is that it is the transition from having naive conceptions of a topic to expert conceptions. The NRC delineates the following important points:

- “Experts notice features and meaningful patterns of information that are not noticed by novices.”
- “Experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter.”
- “Experts’ knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects contexts of applicability: that is, the knowledge is ‘conditionalized’ on a set of circumstances.”
- “Experts are able to flexibly retrieve important aspects of their knowledge with little attentional effort.”
- “Though experts know their disciplines thoroughly, this does not guarantee that they are able to teach others.”
- “Experts have varying levels of flexibility in their approach to new situations” (pg. 31).

To understand the value of Sanctuary, it is important to understand what expertise looks like in its scientifically-described state. Sanctuary’s key connection to expertise is that, because of the hands on, activated, and social nature of the activity, players should develop a flexible ability to problem solve instead of a series of “isolated facts or propositions.”

**Learning and Transfer**

Transfer is a complicated and divisive topic, which will be addressed contextually at the end of this chapter. Transfer is the idea that any idea or skill that has been learned can be said to have been learned if the learner can then transfer that skill to a different context. The NRC frame the topic in this way:
- "Initial learning is necessary for transfer, and a considerable amount is known about the kinds of learning experiences that support transfer."
- "Knowledge that is overly contextualized can reduce transfer; abstract representations of knowledge can help promote transfer."
- "Transfer is best viewed as an active, dynamic process rather than a passive end-product of a particular set of learning experiences."
- "All new learning involves transfer based on previous learning, and this fact has important implications for the design of instruction that helps students learn" (pg. 53).

Sanctuary closely resembles other learning experiences that enable transfer (if transfer actually exists – more on this later).

**Learning in STEM Disciplines**
The NRC relates that in order to examine the differences and similarities between the disciplines, one must examine how they produce and organize knowledge. They do this in part because, "[t]o use Shulman’s (1987) language, effective teachers need pedagogical content knowledge (knowledge about how to teach in particular disciplines) rather than only knowledge of a particular subject matter." (pg. 155). To clarify, the authors quote McDonald and Naso: "[teachers] must not only know their own way around a discipline, but must know the ‘conceptual barriers’ likely to hinder others" (McDonald and Naso, 1986:8). The authors then focus on three disciplines, history, mathematics, and science. As the scope of this thesis is limited to STEM, I will only relate the discussions of learning in mathematics and science, and even then, I will only highlight the most relevant aspects of the discussion.

**Mathematics**
The authors begin by relating the efforts of Magdalene Lampert, a teacher-researcher working with fourth graders. In addition to her deep understanding of multiplication, the authors praise her because, "her goals for the lessons included not only those related to students’ understanding of mathematics, but also those related to students’ development as independent, thoughtful problem solvers" (pg. 165). They quote her at length, and I find it valuable to repeat it here:

> My role was to bring students’ ideas about how to solve or analyze problems into the public forum of the classroom, to referee arguments about whether those ideas were reasonable, and to sanction students’ intuitive use of mathematical principles as legitimate. I also taught new information in the form of symbolic structures and emphasized the connection between symbols and operations on quantities, but I made it a classroom requirement that students use their own ways of deciding whether something was mathematically reasonable in doing the work. If one
conceives of the teacher’s role in this way, it is difficult to separate instruction in mathematics content from building a culture of sense-making in the classroom, wherein teacher and students have a view of themselves as responsible for ascertaining the legitimacy of procedures by reference to known mathematical principles. On the part of the teacher, the principles might be known as a more formal abstract system, whereas on the part of the learners, they are known in relation to familiar experiential contexts. But what seems most important is that teachers and students together are disposed toward a particular way of viewing and doing mathematics in the classroom (Lampert 1986:339 in NRC, 2000).

This theme of refereeing student discussions and asking students to take responsibility for their understandings and problem-solving identities in groups while the teacher guides them based on expert knowledge of the domain is repeated in two more discussions. The first centers on Deborah Ball’s work in teaching negative numbers, where choosing the correct model to discuss is an important responsibility on the part of the instructor (Ball, 1993). They also relate that, “her goals related to developing students’ mathematical authority, and a sense of community also came into play. Like Lampert, Ball wanted her students to accept the responsibility of deciding when a solution is reasonable and likely to be correct, rather than depending on text or teacher for confirmation of correctness” (pg. 168). The second centers on Annie Keith’s work in guided instruction, which further emphasizes the use of discussion, particularly of word problems in groups, as means to understand students’ initial concepts. There is also an active role for the teacher to listen and pick the work of particular students in order to bring interesting or relevant ideas to the rest of the class (pp. 168-169). This idea is a key inspiration to Sanctuary, ensuring that it is not just a group activity with roles, but an intervention that aims to transform classrooms into collaborative learning communities.

Finally, the NRC addresses the importance of “model-based reasoning.” Where this other research was conducted with elementary school students, the authors here explicitly state, “Work on modeling can be done from kindergarten through twelfth grade (K-12)” (pg. 170). According to the authors, modeling:

…involves cycles of model construction, model evaluation, and model revision. It is central to professional practice in many disciplines, such as mathematics and science, but it is largely missing from school instruction. Modeling practices are ubiquitous and diverse, ranging from the construction of physical models, such as a planetarium or a model of the human vascular system, to the development of abstract symbol systems, exemplified by the mathematics of algebra, geometry, and calculus. The ubiquity and diversity of models in these disciplines suggest that modeling can help students develop understanding about a wide range of important ideas.
Modeling practices can and should be fostered at every age and grade level (Clement, 1989; Hestenes, 1992; Lehrer and Romberg, 1996a, b; Schauble et al., 1995).

Taking a model-based approach to a problem entails inventing (or selecting) a model, exploring the qualities of the model, and then applying the model to answer a question of interest. For example, the geometry of triangles has an internal logic and also has predictive power for phenomena ranging from optics to wayfinding (as in navigational systems) to laying floor tile. Modeling emphasizes a need for forms of mathematics that are typically underrepresented in the standard curriculum, such as spatial visualization and geometry, data structure, measurement, and uncertainty. For example, the scientific study of animal behavior, like bird foraging, is severely limited unless one also has access to such mathematical concepts as variability and uncertainty. Hence, the practice of modeling introduces the further explorations of important “big ideas” in disciplines.

Much of the work here focuses on the responsibilities of the teacher as a content knowledge expert and as a creator of a collaborative classroom in which learners take ownership of their own knowledge. This is important, but there are limitations on what a designed artifact or intervention can do to improve a school setting (this will be discussed later, in the Constructions section). The modeling described in Ball’s work and in the segment above though, provides the beginnings of how to think about designed interventions in the classroom.

A full curriculum replacement program like the National Science Foundation and National Council on the Teaching of Mathematics’ Interactive Mathematics Program (IMP) is one way to go. It has made tremendous gains over ten years, claiming that their difference from traditional curricula is that:

- It is problem-centered.
- It is integrated.
- It expands the content scope of high school mathematics.
- It focuses on developing understanding.
- It includes long-term, open-ended investigations.
- It can serve students of varied mathematical backgrounds in heterogeneous classrooms.” (It’s About Time Interactive, 2012)

The program has a combination of collaborative and individual problem-based problems that whose “long term, open-ended investigations” connect to real world problems and models, including making predictions and decisions around running a baseball team based on player statistics, for instance. IMP students have demonstrated gains on the
National Assessment of Educational Progress and are otherwise equivalently skilled in traditional measures while having spent twenty-five percent of their time in conceptual wilds that their traditional-curriculum counterparts had not (Kramer, 2003; Webb & Dowling, 1997). Of course, IMP has faced the traditional political difficulties in being implemented, which will be addressed below.

Of course, there still remain many difficulties to iron out. For instance, in a recent editorial piece in the New York Times, the executive director of the Consortium for Mathematics and Its Applications and an emeritus mathematics professor from Brown University recommend even more contextual and less abstract mathematics than the IMP might suggest. They write:

Imagine replacing the sequence of algebra, geometry and calculus with a sequence of finance, data and basic engineering. In the finance course, students would learn the exponential function, use formulas in spreadsheets and study the budgets of people, companies and governments. In the data course, students would gather their own data sets and learn how, in fields as diverse as sports and medicine, larger samples give better estimates of averages. In the basic engineering course, students would learn the workings of engines, sound waves, TV signals and computers. Science and math were originally discovered together, and they are best learned together now.

Traditionalists will object that the standard curriculum teaches valuable abstract reasoning, even if the specific skills acquired are not immediately useful in later life. A generation ago, traditionalists were also arguing that studying Latin, though it had no practical application, helped students develop unique linguistic skills. We believe that studying applied math, like learning living languages, provides both useable knowledge and abstract skills.

In math, what we need is "quantitative literacy," the ability to make quantitative connections whenever life requires (as when we are confronted with conflicting medical test results but need to decide whether to undergo a further procedure) and "mathematical modeling," the ability to move practically between everyday problems and mathematical formulations (as when we decide whether it is better to buy or lease a new car). (Garfunkel & Mumford, 2011)

Despite disagreements about whether or not mathematics should be taught in methods that lean towards more abstract manipulations or towards more concrete, contextual examples, it is plain to see that these approaches are at the very least no worse than our current offerings. More likely though, they are they are an improvement, and a means of deeper engagement. Sanctuary attempts to give estimation, proportion, and other mathematical ideas weight by embedding these abstract concepts in concrete concepts and particular problems.
The authors begin by describing how educational research can improve designing interventions for learning outcomes. They describe two physics learning interventions that focus learners on the “hierarchical analysis” of problems. The benefits of hierarchical analysis are that students are capable of focusing on and categorizing problems based on fundamental principles and procedures, not surface features. The interventions also had students performing deliberate practice of “appropriate practices” (pg. 178) in computer tutoring environments. Finally, another strategy that can improve student outcomes is creating qualitative strategies before tackling problems, focusing on the major principle to be applied, the justification for using that principle, and the procedures to be used in solving that problem. Finally, these interventions illuminate the benefit of having a “coach” that helps efficiently solve problems. They say, “[s]tudents might get stuck for minutes, or even hours, in attempting a solution to a problem and either give up or waste lots of time...[L]earners profit from errors and...making mistakes is not always time wasted” (pg. 177). Through coaching and deliberate practice, students can make the best use of their time. Sanctuary does not provide particular mechanisms for coaching, but its entire development is premised on the existence of skilled coaches that can help students through such an intervention in a classroom with others having the same experience.

Four subheadings then call out critical subdomains of research-driven improvements to science learning: Conceptual Change, Teaching as Coaching, Interactive Instruction in Large Classes, and Scientific Thinking for All Children. Conceptual Change is an important concept because students often have misconceptions about what they are learning, and as discussed above, new knowledge is built on foundations, regardless of the quality of that knowledge. The authors put forth two strategies for dealing with misconceptions. The first, “bridging,” “attempts to bridge from students’ correct beliefs (called anchoring conceptions) to their misconceptions through a series of intermediate analogous situations” (pg. 179). The students’ beliefs can be accessed through, “dynamic probing” (pg. 179), and by helping students resolve their conflicting views, “students can be guided into constructing a coherent view that is applicable across a wide range of contexts” (pg. 179). Interactive demonstrations, on the other hand, provide opportunities for students to make predictions and receive feedback on those predictions. Like bridging, this seems to also help students overcome their misconceptions, and both seem to have the potential to permanently eradicate misconceptions. Sanctuary can be seen as a classroom-wide dynamic probe.
In Teaching as Coaching, the authors focus on Minstrell’s work on teaching physics for understanding. Minstrell’s ideas can be understood through the quote below:

Students’ initial ideas about mechanics are like strands of yarn, some un-connected, some loosely interwoven. The act of instruction can be viewed as helping the students unravel individual strands of belief, label them, and then weave them into a fabric of more complete understanding. An important point is that later understanding can be constructed, to a considerable extent, from earlier beliefs. Sometimes new strands of belief are introduced, but rarely is an earlier belief pulled out and replaced. Rather than denying the relevancy of a belief, teachers might do better by helping students differentiate their present ideas from and integrate them into conceptual beliefs more like those of scientists. (1989: 130 – 131)

During individual work, Minstrell coaches by asking students questions such as, “How do you know?” “How did you decide?” and “Why do you believe that?” (pg. 181). He uses the term ‘facet’ to describe individual pieces of student thinking. Facets can relate to conceptual knowledge, strategic knowledge, or generic reasoning, and allow Minstrell to identify the erroneous aspects of student thinking and to then revise his own strategies for instruction (pp. 181 – 182).

While the Interactive Instruction in Large Classes section, on the face of it, seemed an unlikely match for Sanctuary—it discusses Classtalk, a hardware/software intervention for polling students in large lecture classes. The polling of students on questions during the lecture results in anonymous histograms that allows the lecturer and the class to see a snapshot of current understanding in the classroom, creating, “an interactive learning environment in the lectures...This technology makes students’ thinking visible and promotes critical listening, evaluation, and argumentation in the class” (pg. 170). Once again, the teacher is a coach here, supporting the students as they work through these problems.

The examples described above are all targeted at high school and college students. Finally, the section on Science Learning for All Children section describes work by Roseberry et al. (1992) with Chèche Konnen (or “Search for Knowledge”), a methodology for teaching science with Haitian Creole children. The program’s, “‘[c]urriculum’ emerges in these classrooms from the students’ questions and beliefs and is shaped in ongoing interactions that include both the teacher and students,” (pg. 171) reflecting the programs underlying principle that, “discourse is an primary means
for the search for knowledge and scientific sense-making” (pg. 171). In the principle activities of the program, “[s]tudents constructed scientific understandings through an iterative process of theory building, criticism and refinement based on their own questions, hypotheses, and data analysis activities. Question posing, theorizing, and argumentation formed the structure of the students’ scientific activity” (pg. 171). By undertaking this activity, the classroom becomes a “community of practice”:

The emphasis on establishing communities of scientific practice builds on the fact that robust knowledge and understandings are socially constructed through talk, activity, and interaction around meaningful problems and tools (Vygotsky, 1978). The teacher guides and supports students as they explore problems and define questions that are of interest to them. A community of practice also provides direct cognitive and social support for the efforts of the group’s individual members. Students share the responsibility for thinking and doing: they distribute their intellectual activity so that the burden of managing the whole process does not fall to any one individual. In addition, a community of practice can be a powerful context for constructing scientific meanings. In challenging one another’s thoughts and beliefs, students must be explicit about their meanings; they must negotiate conflicts in belief or evidence; and they must share and synthesize their knowledge to achieve understanding (Brown and Palincsar, 1989; Inagaki and Hatano, 1987) (pg. 184).

This leads to a change in the students’ conceptual knowledge and scientific thinking, demonstrating this through using more precise vocabulary, demonstrating facility with larger explanatory frames, advancing chains of hypotheses to explain phenomena, and, instead of relying solely on their experience for evidence, proposing experiments to answer questions.

The above sections paint a clear but complex picture of how we might better teach science. Some major takeaways highlighted by the authors include focusing on principles first before focusing on the nuances of equations and arithmetic, allowing students to perform deliberate practice with their new skills and provide supportive coaching along the way, and to work with your students to understand their current thinking while building a community of practice around sense making.

While much of the subsequent work in science education becomes narrowly focused on particular topics (as one might expect), there is at least one generalized framework that extends and frames how we might think about science learning as a whole. If focuses on fostering an understanding and potentially a love of the nature of science in students. “Nature of science” refers to the epistemology of science, or the study of how scientific
knowledge is constructed, such as how it is distinct from other types of knowledge and the beliefs and values that influence its construction (Lederman, 1992). While the field is still in discussions about what precisely constitutes the nature of science, I will be focusing on the following generally agreed upon components of the nature of scientific knowledge development:

- Scientific knowledge is reliable; however, it may be abandoned or modified in light of new evidence or re-conceptualization of existing evidence and knowledge.
- Science is based on observation and inference, which are guided by scientists' prior knowledge and perspectives of current science. Multiple perspectives can lead to multiple valid inferences.
- Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher themselves.
- Scientific knowledge is created from human imaginations and logical reasoning, based on observations and inferences of the natural world.
- As a human endeavor, science is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
- Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws.
- There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is constructed and developed in a variety of ways including observation, analysis, speculation, library investigation and experimentation. (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Liang, Chen, Chen, Kaya, Adams, Macklin and Ebenezer, 2008 as derived from AAAS, 1990, 1993; Aikenhead & Ryan, 1992; Chen, 2006; Kuhn, 1970; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman, 2004; McComas & Olson, 1998; National Science Teachers Association, 2000)

Understanding the nature of science is potentially the backbone of scientific literacy (AAAS 1990, 1993; NSTA 1982) as well as developing the emotional connection to
science necessary for increased science identity. Specifically, “when people know how scientists go about their work and reach scientific conclusions, and what the limitations of such conclusions are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically” (AAAS 1990). While ideally a scientifically literate person should be intellectually equipped to judge the truth for him or herself, this is often impractical in light of the increasing expertise required to understand firsthand evidence. Thus, it is crucial that students gain a “rational trust” of experts through understanding how scientific knowledge is constructed (Norris, 1992). Lederman has also argued that without understanding the nature of science, students have an image of science as a collection of isolated facts devoid of context (Lederman, 1998; also see Schwab, 1962). In spite of the strong recommendations from AAAS, NRC, and NSTA, some students and teachers still lack a basic understanding of nature of science (Abd-El-Khalick and Lederman, 2000). Studies show that some teachers do not even value the inclusion of nature of science elements in instruction (Bell, Lederman, and Abd-El-Khalick 1997), reflecting the NRC’s issues in developing knowledge-centered environments where teachers are focused on. This must not deter the advancement of nature of science education, but it establishes a need for interventions like Sanctuary to be well supported with professional development and ongoing support as in Barab (2009).

Wrapping Up
We know a great deal about how people learn. It is worth noting that there is not necessarily a great deal of change in the field since this report. For instance, technology has drawn a great deal of interest in the learning sciences almost from their inception, but the MacArthur Foundation’s Connected Learning report (Ito et al, 2013), does not have a lot to improve on the fundamentals of learning. They describe a connected learning context as “peer-supported,” “Interest-powered,” and “Academically oriented.” This might be understood as exactly the properties at the core of the Chèche Konnen environment described in the previous section, for instance. The Connected Learning report describes connected experiences as, “production-centered,” “shared purpose,” and, “openly networked.” The connected dimension here may have added a media-production element and a focus on online tools, but here again there is a great similarity to the ideas of How People Learn. The shared goals and production focus can be seen in a number of the constructivist learning environments where students build their understanding together throughout this volume. Connected Learning’s design principles state that, “everyone can participate,” that, “learning happens by doing,” that, “challenge
is constant,” and, “everything is connected.” These principles can be seen in the
description of the types of learning environments described by the NRC, however they
are extended into a networked culture.

It is worth noting that I mention this comparison not in order to denigrate the work of the
Connected Learning report's authors. It is a testament rather to the work of the field that
the core tenets and ideas remain robust. In fact, many of the ideas in the Connected
Learning report are there because great learning phenomena were found in informal
learning environments, including those around the internet and other technological
hubs. If informal learning spaces are thriving with these sorts of practices, one might
expect that the nation that funded How People Learn might have made considerable
progress in their formal learning settings.

Sadly, this is not so.

SCHOOLS
In 2001, just after the publication of How People Learn, the United States' federal
government passed the No Child Left Behind Act. This Act of Congress requires that
schools that receive federal Title I funding to administer standardized tests every year in
order to demonstrate Adequate Yearly Progress (AYP). The intent was to ensure that
schools and teachers were held accountable for their student outcomes. Much has been
made about the effects of this law (and its subsequent “replacement,” Race to the Top)
on schools, teachers, and curricula, but a key focus of this research is understanding
how introducing a game into the context of schools might be interpreted by the students
in particular. I have established that learning is highly contextual and will establish that
games are highly contextual as well. It is important then to establish the broader context
of public schooling in the U.S. in order to establish a baseline for making sense of
features and events in my qualitative work onsite in schools. In particular, because
Sanctuary is a game and a suggested reform, it is important to acknowledge and focus
on the history of reform and on certain aspects of schooling that may become entangled
or intertwined in game play.

Public schooling in the U.S., according to Tyack and Cuban (1995), has had a key place
in American discourse, and their book highlights, “the tension between Americans’
intense faith in education—almost a secular religion—and the gradualness of changes
in educational practices” (pg. 1). The authors relate that education’s history in America
has held a number of rhetorical positions over time from one of nation-building through the creation of citizens to the pathway to prosperity and social mobility for all citizens or the pathway to international competitiveness in an increasingly globalized world. This “utopian” language creates tensions though when education is unable to overcome recurring social ills such as widespread economic inequality, the poverty that tends to attend an increase in single parent families, teenage pregnancy, minority unemployment, soaring arrest rates, and widespread drug abuse. After rattling off this list, the authors cite educational psychologist as saying, “the public school system of the United States has actually done remarkably well as it receives, instructs, and nurtures children who are poor, without healthcare, and from families and neighborhoods that barely function.” More to the point, the authors detail a number of measures that might be interpreted as progressive or regressive, depending on one’s point of view, like district consolidation, affirmative action, or the banning of prayer.

Thus, being an epicenter of controversy and “faith,” it has been difficult to engender much change in schools. In particular, Tyack and Cuban focus on the persistent “Grammar of Schooling” that seems to resist amendment by reformers. They describe this grammar as features that most Americans would recognize as constituent features of schooling:

People are accustomed to elementary schools that are divided into self-contained classrooms called, ‘grades.’ In these rooms individual teachers instruct pupils of about the same age in a variety of subjects. High school students are organized quite differently. Every hour, students shift from one subject to another, one teacher to another, Teachers belong to specialized departments and instruct about one hundred and fifty pupils a day—in five classes of perhaps thirty each—in their particular fields. When students complete these courses, they are rewarded with Carnegie units. In secondary schools, but generally not in elementary classes, students have some degree of choice of what to study.

Under these institutional arrangements, teachers have been expected to monitor and control students, assign tasks to them, and ensure that they have accomplished the work. Over the past century, there has been a good deal of continuity in how teachers taught. (pp. 85 – 86)

This continuity, they argue, “is a product of history, not some primordial creation.” Indeed, features like age grading and Carnegie units were cemented into law by efficiency-seeking reformers and a wealthy industrialist respectively because they were enacted at the right moment in history (the arrival of the widespread elementary school and the development of the secondary school here) and supported because of their organizational efficiency and their legibility to colleges, for instance. Meanwhile, other
reforms and structural interventions, like the Dalton Plan, the Eight-Year Study, and the High Schools of Tomorrow failed to take hold. The Dalton Plan, derived from the work of Maria Montessori (among others), required teachers to make time to negotiate monthly learning contracts with their students, allowing students to take ownership of their learning. Some topics were required, and group projects were encouraged, but students could learn at their own pace. “No fifty minute periods. No bells. No teachers lecturing or listening to students reciting lessons in large classes” (Pg. 95). The Eight Year Study refers to an experiment conducted between 1933-1941 in which schools were allowed to create experimental collaborative (both teachers and students), interdisciplinary schools within their schools. Colleges waived the necessity to participate in Carnegie units for those in the experiment (in part because of the Depression-related drop in applications), allowing schools the freedom to manipulate their curricula. Tyack and Cuban say:

As time went by, reforms in the schools settle into certain common patterns. Teachers developed more core programs that crossed departmental boundaries and varied the time periods and sizes of their classes. Students spent less time on mainline academic subjects and more on art, music, and drama. The distinction between the formal and informal curriculum began to dissolve as students participated in community service, artistic productions, publications, and decision-making in school affairs. Teachers spent much time with each other and students in planning these activities. In short, the grammar of instruction became more individualized and student-centered, de-emphasizing batch-processing. (Pg. 99)

When these students were evaluated, they did, “about as well as” their peers in their classes, but, “were more active in collegiate social, artistic, and political life.” The graduates of the most progressive schools did the best in college as well. When the program ended, the reforms stayed for a time, but subsequent follow-ups found that the reforms faded over time. Educators said that the collegiality remained, but as national events like the end of World War II and the rise of the Cold War appeared, schools found themselves under more pressure to conform. Students needed to compete for slots in college again. Parents and communities were not always willing to embrace these reforms, culturally.

The High Schools of the Future refers to similar interventions that arose in the 1960s and early 1970s. Tyack and Cuban characterize these programs on a spectrum, ranging from, “radical reformers...[r]einventing the Rousseauean notion that people are born free but are everywhere in chains,” (pg. 102) to, “those more moderate in outlook and aspiration” (pg. 103). These reformers pushed on the grammar of schooling along an
similar spectrum, from, “reject[ing] the institutional form of the public school out right...” to, “propos[ing] major organizational changes within the walls of the public school” (pp. 102-103). The radicals advocated for, “free schools' and 'schools without walls’” and even, “the 'deschooling' of society,” following Ivan Illich (pg. 102). The more moderate reformers attempted to edit the existing schools, attempting to make the schedule more flexible, to integrate and refine the curriculum, to making teaching a team activity, and to transform the classroom spaces into resources, customizable teaching venues, and social spaces (pg. 103). These reforms were successful to various degrees, but most of these communities returned to the traditional grammar of schooling by the end of the 1970s. Parents were concerned that their children weren't working hard enough. Administrators felt that a great deal of autonomy benefited students who were already self-directed, but poorly served the students who, “had trouble budgeting time” (pg. 106). Teachers found themselves at the center of the classrooms still, and while they enjoyed the collegiality of team teaching, found themselves exhausted by the demands of their new classrooms (pp. 105 – 106). Tyack and Cuban write, “The experiment left behind here and there some new forms of flexibility and the memory that the grammar of schooling was mutable. But in most districts, the Carnegie Unit, not the flexible schedule, remained the normal pattern” (pg. 107). In reflecting on the failure of reform, the authors highlight two principal problems with that the reforms faced. First, the reforms end up being too “intramural” - “leaders lost some of their political savvy and lost touch with the opinions of citizens who were not educators. Concentrating on convincing their professional peers, they did not cultivate the kind of broader social movement that might nourish educational and social change” (pg. 108). The second problem was, “burnout among reformers” (pg. 108). They quote Milbrey W. McLaughlin, saying that practitioners, “contemplating a change in classroom organization...might be confronting a complicated innovation that shows no clear advantage over existing practices—at least in ways that often matter most to school boards, voters, and anxious parents” (pg. 108). If one is to make an effective change in education then, the authors suggest that reform can’t necessarily happen via “basic” changes. They say, “almost any blueprint for basic reform will be altered during implementation, so powerful is the hold of the public's cultural construction of what constitutes a 'real school' and so common is teachers’ habit of hybridizing reforms to fit local circumstances and public expectations” (pg. 109). For instance, David Cohen highlights that technological innovations are often condemned, co-opted, or marginalized by teachers (Collins and Halverson, pp. 36 – 37). Ultimately, the authors assert that, “in a democracy, fundamental reforms that seek to alter the cultural constructions of a ‘real school’ cannot
succeed without lengthy and searching public dialogue about the ends and means of schooling" (pg. 109).

Tyack and Cuban wrote these ideas in 1995, and of course the national policy discussion has produced the accountability regime that began with No Child Left Behind and continues with Race to the Top. Begun with the desire to normalize the educational experience of children across the nation and to increase the accountability of administrators and teachers, these policies have created learning environments with qualities quite opposite to those espoused by How People Learn. The environments are more teacher-centered than learner-centered, and the focus on assessment of teachers and students based on students’ performances on standardized tests. This results in “teaching to the test,” which often leaves time for innovative activities such as model-based reasoning, and instead focuses on repeating discrete facts on tests. Additionally, educators have turned to cheating - erasing and refilling tests for students in order to secure funding for their schools and districts. This framework of tests to increase the legibility of child learning to the state in order to implement incentives as motivators has possibly reached its limits, creating more challenges for learning than solutions (cf. Kohn 1999, 2011; Scott, 1998). Furthermore, evidence is mounting that the problems that these policies are aiming to solve are more economic than pedagogical in nature (cf. Labaree, 2010). These problems are not necessarily solvable in a single masters thesis, but I believe that any work aimed at progressive education must be done with these ideas in mind.

GAMES
To discuss a game for learning, it is important to first delineate a definition of a game. Zimmerman and Salen (2003), in order to kick off their exceptionally thorough game design tome, did a tremendous synthesis of foregoing definitions from fields as diverse as philosophy, anthropology, and digital game design practice to produce a relatively robust definition. Taking consideration of definitions by Parlett (1992), Abt (1970), Huizinga (1955), Caillois (2003), Suits & Hurka (2005), Crawford (1984), Costikyan (1994), and Avedon & Sutton-Smith (1971), they searched out commonalities, “cobbling together elements from the previous definitions and whittling away the unnecessary bits leaves us with the following definition: A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.”(P. 80). This is a remarkable useful definition for game designer, providing a few select features to highlight, creating a heuristic starting place for novice designers, but it is not necessarily
so prescriptive that is does not allow for innovation or creativity within the bounds of the definition.

In their more recent book, also in the field of game design, Elias et al. (2012) are willing to, for their purposes of discussion, define an orthogame, or "correct game," as, "a game for two or more players, with rules that result in a ranking or weighting of the players, and done for entertainment. Explicit winners or losers, scores, or time to completion all count as rankings or weightings—the point is something explicit to tell you how well you've performed" (pg. 8). Nevertheless, they are generally interested in avoiding a proscriptive definition of games. They appeal to Wittgenstein and his notion of "family resemblances":

There is the tendency to look for something in common to all the entities we commonly subsume under a general term, We are inclined to think that there must be something in common to all games, say, and that this common property is the justification for applying the general term “game” to the various games; whereas games form a family the members of which have family likenesses. Some of them have the same nose, others the same eyebrows and others again the same way of walking; and these likenesses overlap (pg. 5).

By way of example, they state that, for instance, Hearts and Chess might be, "especially good examples of games," Settlers of Catan (1995) and the word game ghost might be less so. They establish that some might consider footraces and crossword puzzles even more marginal, and yet the respectively (possibly) similar Mario Kart (1992) and Bejeweled (2001) are quite commonly accepted as games (pg. 5). In other words, It can be remarkably difficult to delineate an inclusive and impenetrable definition of games, but one can both create a definition to suit any single discussion (as with "orthogame") or discuss something's "gameness" by discussing its "family" relationships through the games' characteristics.

It has become increasingly obvious to the field that games cannot even be constrained simply to the shipped product, or a set of rules and goals, or an event in time. Education scholar Constance Steinkuehler (2006), while attempting to describe the evolving practices in the Massively Multiplayer Online Roleplaying Game (MMORPG) Lineage (1998), relates games to Pickering's Mangle, a, "view of science as ‘an evolving field of human and material agencies reciprocally engaged in a play of resistance and accommodation where the former seeks to capture the latter' (p. 23) (1995)".
Games are designed experiences and, as such, their study requires understanding not just the formal rule systems designed into them but also the full range of human practices through which players actively inhabit their worlds and render them meaningful. Games are a “mangle” (Pickering, 1995) of production and consumption—of human intentions (with designers and players in conversation with one another; Robison, 2005), material constraints and affordances, evolving sociocultural practices, and brute chance.

As such, a study of a game should take documenting the human intention of designers and players of the game, the material constraints and affordances of the game, the evolving sociocultural practices of the game, and the effects of brute chance seriously. For Steinkuehler’s part, she describes as much of each of these parts as she can in order to convey her point that game she describes in her article will not exist down the road because games are not subject to nor constrained by, “game design, rules, EULAs, or whatnot” (pg. 211).

Along similar lines, sociologist T.L. Taylor (2009) suggests that games be treated as assemblages, quoting Rabinow (2003): “one way to help us understand the range of actors (system, technologies, player, body, community, company, legal structures, etc.), concepts, practices, and relations that make up the play moment.” While games studies, to this point, has largely focused on the players on pursuing narrow definitions around the technological product or rule set and material objects of the game, these scholars wished to see the unexpected, subversive, and/or co-creative practices of players incorporated into any analysis of game play. In other words, similar to DBR, understanding the complexity of play cannot be developed in a vacuum devoid of human players. Taylor uses a description of the World of Warcraft (2004) raiding add-on, a player-created piece of software enlisted in the practice of a huge number of players, including its affordances and practices as a means to begin understanding the features and meanings of the assemblage itself.

Finally, Thomas Malaby (2007) adds another important variation on the same theme, underlining that games need not necessarily be playful, particularly because play is, “a shallowly examined term, historically and culturally specific to Western modernity.” In particular, he calls out three specific features of play for disputation: “It is separable from everyday life (especially as against ‘work’; it exists within a ‘magic circle’), safe (‘consequence free’ or nonproductive), and pleasurable or ‘fun’ (normatively positive).” Malaby makes the point that not all games have these features when examined empirically, a point bourn out by Steinkuehler and Taylor’s definitions. In discussing
Greek gamblers and Chinese goldfarmers, Malaby makes a key point that he is not claiming, “that games are not engaging, whether intellectually, emotionally, or bodily. The key point is that any account of the player’s experience when gaming must avoid a priori normative assumptions about ‘fun’ and the like.”

Malaby’s counter-proposed definition of a game is that it, “is a semibounded and socially legitimate domain of contrived contingency that generates interpretable outcomes.” He stresses that games are processual and negotiational or contingent. Citing the house rules that players can invoke in board games or schoolyard games as well as changes in play style created by play within the rules like Oscar Robertson and Julius Erving taking professional basketball “above the rim,” he stresses that games are, “grounded in (and constituted by) human practice and are therefore always in a process of becoming” (pg. 103). He argues that, in this way, games are, “like many social processes, dynamic and recursive, largely reproducing their form through time, but always containing the possibility of emergent change” (pg. 104). In order to re-characterize the features of games then, He focuses on three key features of his definition. First, games must have outcomes that are interpretable, but they need not be the outcomes that are predetermined or final. Second, games produce meanings which are interpretable, but these meanings cannot be purely determined - they are subject to interpretation because of the contingent nature of practice and representation a la Aarseth (1997).

Third and last, contingency is a key feature of games—unpredictability, simply put, or “that which could have been otherwise” (pg 107). This contingency has many distinct types for Malaby. The first is stochastic contingency, the randomness produced by game systems or tools beyond the control of the players, like dice, network lag, or the implicit emergence of procedurality (Murray, 1997; Bogost, 2006). The second is social contingency, or the need to act while uncertain of what another person might do. Third, performative contingency refers to the uncertainty that an act may be produced as intended, whether it will fail or succeed, whether in the form of a javelin toss for distance or moving your Monopoly token the appropriate number of spaces, on order. Finally, there is semiotic contingency, which is the unpredictability of the meaning of a game’s outcomes.

I have discussed these many definitions of a game so that I can not only make a claim that Sanctuary is a game, but also so that I can refer clearly to various features of Sanctuary in a way that is robustly located in practice, in theory, and in empirical work.
None of these definitions are necessarily superior to one another - in fact, most of them make it clear that there can be no single way in which to recognize a game or draw boundaries around one. These definitions produce useful terminology for describing and locating a designed intervention.

**GAMES AND LEARNING**

At last, we come to games and learning. There are a large number of educational products produced under the name ‘game,’ often with little to no justifiable claim to the titles of game (or “learning”/“education” intervention, for that matter). Gains are regularly being made in math and science education, but adoption is slow and fraught with complex issues. There is also some early promise in using learning games and simulations on computers for teaching in these fields. The National Research Council dedicated resources and pulled together a compelling report in 2011, detailing the state of research on these topics. Many respected scholars pulled together a compelling case, citing games and simulations’ ability to provide situated, probable problem spaces with clear goals and visualizations of complex problems. Several fantastic games for science learning for this high/middle school audience have emerged in recent years as well, such as Filament Games’ *Resilient Planet* (2008) or ERIA Interactive’s *Citizen Science* (2011). They do not frequently allow for multiple perspectives on a play space due to insufficient budgeting or scope. Augmented Reality games and participatory simulations such as those developed by Klopfer et al. (2008) have experimented with role-based decision-making, but particularly in large workshops that are hours long and require specialized technology.

This work and community comes on the back of a great tide of scholars with a serious interest in learning from play and games. The most often cited origin for this work is James Paul Gee’s *What Video Games Have to Teach Us About Learning and Literacy* (2003). Gee, a linguist by training, had been steeped in the complexities of Media Literacy and inequality for many years, at least back to his involvement in The New London Group and their ground-breaking report on media literacy (1996). Where the New London Group stopped, Gee was able to pick up many years later while watching his young son play a Nintendo game called *Pikmin* (2005). Gee quickly came to understand that the best video games are remarkable semiotic domains with their own internal symbols and meanings that manage to compel their players to work hard, to try on new identities, to systematically probe and re-probe phenomena and environments as scientists might, and to trade information and support in affinity groups. Gee saw that
if such work were being done by children in schools, and if schools were as well-designed and compelling as the best games, our school systems could make real gains. Gee's careful and methodical argument was well-timed, as many other researchers were fomenting new interventions for science and mathematics learning based on games or with game-like features, including Chris Dede's EcoMUVE River City (2004), Sasha Barab's environmental thinking and literacy intervention Quest Atlantis, (2004), Yasmin Kafai's work investigating the girls science learning website Whyville (1999), and Klopfer and Squire's work in MIT's Education Arcade with Augmented Reality games. As documented in the NRC report, games were a likely match for science learning in particular because they allow players to investigate spaces with underlying rules and principles that are not immediately obvious. Although many of these projects sought to increase learning games, it s only now that we are beginning to see progress in this dimension. The Doorways to Dreams Fund has developed remarkable financial literacy programs with games designed by the Education Arcade and recently tested their programs. They found that although the games made less of an impact on players’ self-confidence and knowledge than reading about topics like saving retirement, they produced greater gains than nothing, which was the point of their work. Similarly, Klopfer et al. (2013) have recently produced a somewhat nuanced picture of learning gains in their Ubiq Games project. While not all of these projects demonstrated that they slowed down life in the classroom or that they were destructive to learning, however, it has been the case that games are slow to be adopted in classrooms. Nevertheless, Clark et al. (2013) recently complete a metastudy of existing learning and found an overall positive effect from learning with games.

One possible reason for this may be that learning from games can be remarkably different from traditional “broadcast” models of education. Games demand learning by doing instead of learning by listening. Many of the games described above demand that the students time be turned over to the students so that they can learn by exploring and following their own interests, as opposed to sitting quietly and listening to a teacher. With or without the explicit goals and rules of games, this has been a running tradition throughout progressive education. In the field of experiential learning, frequently associated with outdoor education (ropes courses, etc.) to which game-based learning owes much, teachers/instructors/guides have an explicit role to play, focusing the students’ attention on the experience they are about to have, supporting them and providing feedback throughout the experience, and then helping them to make sense of the experience by debriefing it with them afterwards (Kolb, 1984; Joplin, 1981).
Problem-Based Learning frameworks, which also have a great deal of overlap with game based learning and developed from medical education, have students learn by solving problems and reflecting on their experiences (Barrows and Tamblyn, 1980). Hmelo-Silver (2004) performed a meta-analysis and found that there is ample evidence that PBL can help learners 1) construct an extensive and flexible knowledge base 2) develop effective problem-solving skills and 3) develop self-directed, lifelong learning skills, but it may not be as successful at its goals of 4) becoming effective collaborators or 5) becoming intrinsically motivated to learn (Barrows and Kelson, 1993). Sanctuary aims to be a scion of the tradition, posing a problem to be solved in a learning community context, and then communally reflected upon.

The ideas of learning by doing are associated with Dewey, Lewin, and Piaget, but learning by doing with computers means Papert. Seymour Papert created *Logo* as a “Math World” (1980) where exploring by doing was nothing like a game or even a problem, but following your intrinsic interest. Papert long ago said that, “the computer will blow up the school,” changing curricula forever, but we haven’t really managed that. Gains are being made here and there, but most school computers sit inert or are poorly used (Cuban, 2005). As the dawn of iPad programs for school turns into a morning, perhaps there is an opportunity to move thoughtful, well-designed learning games into the classroom.

Game based learning, may not always solve the problem of intrinsic interest, but games may instead function or be thought of like books. Just as with reading, you cannot make someone play a game. Scholar Ian Bogost has made much of reading a game’s “procedural rhetoric” (2006), taking meaning from how the game positions players in a set of rules and processes. Subsequently, he has appealed to McLuhan to say that, “Games—like photography, like music, like any medium—shouldn’t be shoehorned into one of two kinds of uses, serious or superficial, highbrow or lowbrow, useful or useless. Neither entertainment nor seriousness nor the two together should be a satisfactory account of what games are capable of. After all, we don’t distinguish between only two types of books, or music, or photography, or film” (2011). As iPad programs in schools grow, it seems useful to explore how we might have well-designed experiential learning content for students. Perhaps if they get treated like books, they might be better incorporated into the classroom.
Sanctuary, the game at the center of this thesis, could then be a new paradigm for performing Problem Based Learning in schools. While this thesis only covers the early stages of creating and revising the design, the work with incorporating the jigsaw format (see the Constructions chapter) onto tablets for the purposes of formalizing tacit thinking as well as allowing coaches and guides to work with students with greater ease. By extending the logic of the classroom classic, the jigsaw, with nascent-but-growing trends in multiplayer video gaming, Sanctuary requires players to collaborate in order to succeed. If the design is successful, meaning that players collaborate in interesting ways, this could prove to be a compelling design to extend and further develop. Bringing this work to the learning sciences community may allow developers, educators, and students to access new ideas about how not only to play together with a new platform, while integrating into existing school culture. If this this is maximally effective, the integration of this game and its more robust future cousins will slowly pull school cultures of science learning toward more playful, deep, and collaborative paradigm. I do not contend that game-based and collaborative learning could or should be the whole of school STEM learning. Despite inconclusive results regarding whether or not different learning styles exist, it is a useful paradigm to remind us that not every approach will work for every student at any given moment. Instead, true success for this project would mean simply extending the range of possibilities in schools.

Next, how can we think of a game designed for STEM learning? To begin, we must acknowledge that “science” is “disunified” - there is no monolithic way of doing science (Gallison and Stump, 1996). Similarly, there are challenges in understanding what it might mean to teach mathematics, engineering, or “technology.” For this project, I am taking “STEM learning” to mean relating and/or requiring skills relevant to STEM practice and understanding, including broad skills such as inquiry, problem-solving, and collaboration in addition to narrow discipline-specific skills such as budgeting and quadrant sampling. More broadly, I mean the computational or procedural thinking of Papert (1980), Bogost (2007), and Mateas (2008). There are many ways to approach STEM learning, and this project will focus on skills that are described by in the nature of science literature. In particular, Sanctuary, in its procedural rhetoric, attempts to convey four of these ideas:

- Science is based on observation and inference, which are guided by scientists' prior knowledge and perspectives of current science. Multiple perspectives can lead to multiple valid inferences.
• Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher themselves, based on observations and inferences of the natural world.

• Scientific knowledge is created from human imaginations and logical reasoning, based on observations and inferences of the natural world.

• There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, a variety of ways including observation, analysis, speculation, library investigation and experimentation.

I make no claim that players of Sanctuary might at any point become skilled managers of a wildlife sanctuary, or even that they will understand the scope and principles behind the skills implemented in the game. Instead, the focus of this game is to provide the “preparation for future learning” (Bransford & Schwartz, 1999) for more formal discourse on these topics. As Donald Schöen reported, even professional practitioners are not necessarily aware of the actions they take, the skills they use, or the mental models they hold regarding their practices and domains. “When [the professional practitioner] tries, on rare occasions, to say what he knows - when he tries to put his knowing into the form of knowledge - his formulations of principles, theories, maxims, and rules of thumb are often incongruent with the understanding and know-how implicit in his pattern of practice” (1987). Instead, the full learning experiences in Sanctuary are meant to be drawn out by a trained educator after players have had time to experiment, reason, make conjectures, analyze results and share perspectives. The manner in which the game’s design allows for this will be discussed below.

To achieve these ends, I draw upon the model of the epistemic game (Shaffer, 2006). According to Shaffer (2012), “[I]n epistemic games, players inhabit a game world in which they are novices training to be a particular kind” (p. 35). The learning in an epistemic game stems from epistemic frame hypothesis, which posits that, “any community of practice has a culture, and that culture has a grammar, a structure composed of:

• **Skills**: the things that people with in the community do
• **Knowledge**: the understandings that people in the community share
• **Identity**: the way that members of the community see themselves
- **Values**: the beliefs that members of the community hold
- **Epistemology**: the warrants that justify actions or claims as legitimate within the community (p. 36)

He (2006) likens epistemic frames to, "the proverbial ‘hats’ or ‘glasses’ we don as we take on a variety of identities or perspectives in dealing with different situations," saying that they, "may represent a ... tight linkage between practices and ways of knowing, but at the level of the local cultures developed by individual communities of practice." The frame a) binds together the above grammatical units, b) is internalized through one’s initiation into the community of practice (training etc.), and c) becomes one’s leaping off point when dealing with situations via that community or their role in it (2012).

Of course, he also indicates that, “[a] key component in turning activity in a virtual world into understanding in the real world is reflection: a player’s ability to step back from what he or she is doing and talk with peers and mentors about what worked, what didn’t work, and why” (2012). Without reflection, it is virtually guaranteed that the practitioners will resemble those described by Schön above - unable to speak critically about their practice and their values. Many of Shaffer’s experimental games have a strong in-person component with a larger group, but it is unclear from the literature how closely his experiments resemble a jigsaw, for instance, with interdependence fostered through group goals interwoven with individual accountability. What is clear is that students in his work are part of an active community of practice, working on similar (if not the same) problems.

In *Sanctuary* then, students are given the opportunity to acquire the skills, knowledge, identity, values, and epistemologies of wildlife sanctuary managers, but more specifically, they are able to begin that process by acquiring STEM skills in a pretend context. This is, essentially, a constructivist mode of learning. "Constructivism is a theory about learning, one where the learner has ‘a self-regulated process of resolving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse and reflection’ (Brooks and Brooks 1993: vii)." While students are afforded the opportunity to learn skills etc. in a typical, familiar context (school), they are projecting into another, fake context (the game). The degree to which players can then make sense of or use these skills is an important question to this thesis. I do not expect players to be fully prepared to operate as wildlife sanctuary managers, but as a means to spark interest in STEM careers and provide a situated context for exploring
and encountering complex generative ideas that align with the pedagogical ideas of the nature of science.

Furthermore, the game is designed to promote science identity in users. To define science identity, we may use Shaffer's definition: "the way the members of a community see themselves." Seymour Papert and Sherry Turkle, arguing that identity and epistemologies may not be separated, posit that at least some children learn not through "hard," rationalist, logical, top-down ways of thinking, but through a "soft" approach that has an important "negotiational and contextual element." They invoke Levi-Strauss' idea of the bricoleur, or the "scientist of the concrete," who, "does not move abstractly and hierarchically from axiom to theory to corollary," but, "construct[s] theories by arranging and rearranging, by negotiating and renegotiating with a set of well-known materials." Bricoleurs, "use a mastery of associations and interactions," and, "a navigation of midcourse corrections," and see programming in Logo as, "a collaborative venture with machine" and a, "conversation." (1990?)

Copier's work on the magic circle though, is specifically useful in this situation as a means to tie the psychological theories of learning to more anthropological literature. In her studies of Live Action Role Players (LARPers), she says, "One of the most important ritual acts of role-players is bricolage. In role-playing games, but also during their daily life, players are constantly constructing intertextual relationships between imaginary fantasy worlds, history, religion, experiences from daily life, etc. Within this often very transparent act, they are not only constructing and connecting worlds or spaces, but also identities and meaning." She quotes theatre scholar Richard Schechner, who has connected performance and ritual previously: "More and more people experience their life as connected series of performances [...]". In other words, the work of a role playing game player, a bricoleur, is not just negotiating with and rearranging materials, but with their identities and the space around them. Turkle herself, in Life on the Screen (1995), writes, "Role-playing games can serve in this evocative capacity because they stand betwixt the unreal and the real; they are a game and something more" (p. 188). Stevens et al. (2007) indicate that in their "outdoor psychology" ethnographic study of students playing games found little evidence beyond occasional gestural copying of actually sharing an identity with an onscreen character, "more like echoes than borrowed durable elements for a real-world persona," (p. 63), but they allow that psychologists may say, "that all the really important stuff was going on in their heads" (p. 63).
But are bricoleurs conscious of their learning or formalizing their learning? In the examples under discussion, Turkle's Live Action Role Player deliberately chose to play a game role in order to specifically work through issues with her mother, but Stevens et al.'s (2007) student game players were not necessarily deliberately engaging with Zoo Tycoon as a means to think about the world or their values. As such, learning from games is best considered to be a form of experiential learning, a form of constructivism in which learners are helped to make sense of their experience by an instructor or other support that focuses the learner on their experience beforehand, support and give feedback throughout the experience, and debrief the experience afterwards. (Kolb; Joplin) Unsurprisingly, these steps mimic/are similar to our current understanding of what allows for increased expertise and possibly transfer.

As discussed earlier, transfer is a somewhat fraught topic. As Shaffer (2012) says, "No term, no word, no concept is as problematic, as debated, or as contentious. Schema theorists say that it is essential, socio-cultural theorists say that it doesn’t exist, and never the twain shall meet, it seems." This thesis is not an experimental psychology thesis, so it will lean on the socio-cultural interpretations and ideas of learning. This viewpoint arises from Vygotsky and is enhanced by the theories of Piaget and Papert. In Stevens et al. (2007)'s project, they reviewed an exceptional amount of video and conducting interviews in order to demonstrate the learning that occurs with gaming in homes. What they found was that, "video game play is tangled up in other parts of kids’ lives, including their relationships with siblings, parents, schools, and their own futures" (pg. 44). The researchers found that game play could be highly contextual—players may cheat or configure games differently depending on who was playing with them; players may involve their siblings as just-in-time resources or peripherally participating mentees; players may create their own goals within games or derive deep satisfaction from completing or excelling in the game’s goals. When searching for an interesting comparison for their study, they actually decided to focus on players’ homework behaviors for comparison, saying:

(a) like video game play, homework is something kids do at home in shared family spaces and their rooms (i.e., the same spaces games were played in), (b) homework, like games, is—in varying degrees—strategic, repetitive, scored, and designed to challenge, and (c) there are different moral stances about how homework, like games, ought to be played (i.e., should they be pursued collaboratively, should you cheat, etc.). (Pg. 44).

Their conclusions are:
...[H]ow media consuming and repurposing has affected these young people is complicated and contingent; it depends on differing dispositions and purposes that people bring to play, who they play with, and perhaps more importantly what people make of these experiences in other times and places in their lives. By emphasizing this active role of making something of game playing experiences, we are stepping quite far away from any simple generalizations about effects of video game play (Pg. 63).

Similarly, Berland (2012) has made a study of group cognition in contemporary strategic board games, particularly a growing procedural literacy, writing:

In fact, board games, rather than being self-learning environments, can be excellent collaborative learning environments (Berland & Lee, 2010; Zagal, Rick, & Hsi, 2006). They share myriad characteristics with environments that “foster communities of learners” (Brown, 1992); such environments have been shown to be an effective way to support learning complex content. That is, they:
- Engage a group of learners in solving a joint task
- Encourage learners to share information to move towards a unified goal
- Engage in a consequential independent task serving the unified goal
- Engage learners in reflection about the viability of their contribution

As a result of this mounting evidence and theory, the development of Sanctuary focuses on being an object for a shared learning process. Its affordances are similar to and yet different from existing practices.

**PURSUING GAME-BASED LEARNING IN SCHOOLS**

Given the dialogue around school policies and best practices for learning, there is possibly a place in the conversation for learning games as evocative objects to stimulate and, in extreme cases, create learning communities. While not every game is necessarily right for these tasks, it is plausible that there could be, like Froebel’s gifts, evocative objects that invite questions and inquiry. These gifts are social though, making them an interesting type of gift, one that can drive and unify the discussion in an active and collaborative learning environment.

As discussed above, any given educational innovation may fail to be successfully implemented in classrooms, and of course no single educational institution, let alone intervention, can solve the massive problems created by inequality. While innovators may strive for the de-schooled society and learning webs of Illich (1970), generations of Americans seem prone to returning to the ideas and forms of “real” school. Tyack and
Cuban (1995) assert that what is needed is a national discussion on schooling, but their call for intervention is almost 20 years old and the necessary discussions are still yet to come. In the meantime, games offer one strong way to allow people to learn in a way that best suits us as a species, a social and negotiational meaning making process (as in Malaby's definition of a game), that requires empathy and communication skills in addition to thinking skills. In particular, collaborative games can achieve these aims, but competitive games may have their place as well. In fact, there is likely more benefit and communal social creation that takes place in a social game whose outcome doesn't matter, like tag, than there might be in the existing competitive grammar of school which resembles Elias et al.'s orthogame, locking learning identities into winners and losers at an institutional level over a period of about fifteen years.

It is important to understand that *Sanctuary* is in no way a process of "gamification" in the behaviorist sense, perhaps best represented in the advertising copy for *Gamification by Design: Implementing Game Mechanics in Web and Mobile Apps* (Zichermann and Cunningham, 2011):

> Whether you're an executive, developer, producer, or product specialist, Gamification by Design will show you how game mechanics can help you build customer loyalty.

- Discover the motivational framework game designers use to segment and engage consumers
- Understand core game mechanics such as points, badges, levels, challenges, and leaderboards
- Engage your consumers with reward structures, positive reinforcement, and feedback loops
- Combine game mechanics with social interaction for activities such as collecting, gifting, heroism, and status
- Dive into case studies on Nike and Yahoo!, and analyze interactions at Google, Facebook, and Zynga
- Get the architecture and code to gamify a basic consumer site, and learn how to use mainstream gamification APIs from Badgeville (Zichermann & Cunningham, 2013)

One potential method of attack on the orthogame culture of traditional school is to help people understand the value of more negotiational and less state-legible outcomes for learning communities. By creating more opportunities for discussion and meaning making in our classrooms, perhaps we can begin the cultural change discussed by Tyack and Cuban.
CONSTRUCTIONS

This section refers to the specifics and questions of craft and reflection on that craft involved in developing Sanctuary. While discussed in more detail in the “Explorations” section of this thesis, it is important to frame this section not only as a craft narrative, but in a tradition of educational intervention design. In order to evaluate Sanctuary, I will be locating it in the tradition of Design Based Research (DBR), which focuses on the iterative evaluation and development of the project in the service of developing new theories about learning. Good DBR establishes the goals and features of the intended design, and then documents the subsequent phases (Collins et al, 2004), so this chapter will describe the goals and initial design for Sanctuary, before research with students. Thoughts and changes that occur during the work with students will be found in the “Explorations” section, and Subsequent thoughts and plans for the future will be found in the “Reflections” section.

In order to describe Sanctuary’s design, I will begin by concretely describing the game’s features with images. Then, in order to connect it to the foundations discussed in the previous chapter, Elias et al.’s Characteristics of Games (2012) provides a useful framework for breaking down the game’s features/characteristics. The study and design of games has, perhaps for very good reason, not yielded codified descriptions of features of games. As discussed in Foundations, games are probably best defined as such by their family resemblances, so a common language may be harmfully reductive. The downside to accepting this loose taxonomy is a very thorough explanation in order to say exactly what we mean regarding features and design intentions. Bear with me in this section.

FEATURES OF SANCTUARY
The game is a turn-based strategy game for two players. Each player adopts a role in the game, to be played throughout the course of the play session. The roles, by virtue of having a constrained set of tools, necessarily have an epistemology and thus provide an epistemological frame (Shaffer, 2006) on the shared problem spaces of the game. The game’s scenario is a variation on agent-based simulations that replicate unique ecological scenarios and ask players to reach shared, targeted goals (“Eliminate species X,” for instance). In the best case scenario, the intended interaction is that players take turns influencing the space and its actors with their tools in a coordinated
way. In this way, the players will become familiar with the powerful ideas (Papert, 1980) in ecology, such as small changes having large effects (and vice versa), interrelatedness, proportionality, and feedback. In this shared microworld, the players will be able to develop a sense of the capacities and capabilities needed in order to operate in the fields of science and mathematics represented.

Sanctuary runs on two tablets, allowing two players to tackle the ecological management of a single game space, but each player has completely different tools. For instance the level in the game may have the goal of preserving several flowering plant species in the ecosystem. The biologist has tools that allow them to examine the ecosystem and its inter-relations, while the mathematician player has the ability to consider strategic swaps of creatures (e.g. “will losing two wolves but gaining 17 deer be a good decision?”) and to extrapolate future trends using statistical tools. The players must then engage in a shared epistemic frame, that of the collaborative scientist, in order to successfully complete the level together. By donning these “hats” and “glasses” in order to probe these simulated systems, players then come to understand what it is to know things as a biologist or a mathematician might, including being collaborative. This allows Sanctuary to impact a neglected aspect of science and math education, teaching students collaborative problem solving across disciplines. The interactive nature of this game also makes it an exciting tool to share in a poster session, allowing the researcher to share this work in a hands-on fashion with fellow attendees.

The game has 2 players sit near each other, potentially looking at, commenting on, and even touching one another’s iPads. They are told that they are the managers of a wildlife sanctuary, and that they must sustain adequate levels of three plants, red, white and blue, which are the central attraction for this sanctuary. Players are shown their tools and features of their interfaces, and then asked to make decisions based on how to spend their budget each turn.

The game was constructed in the Unity game engine, coded in C#. It employs the Toolkit 2D library to organize interface elements and simplify Unity’s 3D options down in order to create a look more consistent with the game’s “board game-style” feel. A great deal of assistance was provided by three undergraduate researchers: Nick Benson, Jordan Haines, and Nethanel Roitman. Nethanel provided early code. Nick made all of the art and sounds and mastered the interface. Jordan provided the bulk of the code. This includes providing quick fixes described by email or over the phone during testing.
The conceptualization, design, and production tasks were all mine, but the game could not have been the success it was without their work. I mention this in the text of the thesis in part because their efforts deserve canonization and in part because it is crucial to recognize how much work can be poured into a software project like this. While something with less beautiful art or less functional code might have been viable for testing purposes, my prior experiences in testing with young people led me to believe that aesthetic values matter to them. Projects with “programmer art” or no sound may not be embraced as enthusiastically because of what I’ll call a “prototype effect.”

The game is networked over wifi protocols. In order to get started, the players must be on the same wireless network with two Retina iPads. The biologist’s iPad is the host, storing and processing the game, and the mathematician’s iPad is the client, updated via a transmitted string of the state’s delta each turn. Upon starting the app on the iPads, the screen looks something like this:
Players connect the tablets together via the interfaces on both iPads, allow the game to load, and then begin play. Once inside, the game portrays the titular sanctuary as a 300 by 300 checked field, covered by three species of flowering plant (the aforementioned red, blue, and white breeds), two species of grass, and five species of animal: wolves, deer, birds, bees, and locusts. The art is in a "classic" 16-bit graphic style largely because that was the art style available to me. In general, I was pleased with it because it was so friendly and bright-looking.

The food web of this faux ecosystem was designed as such:

![Food Web Diagram]

This web was chosen in order to be ultimately decipherable in a short time frame, but not without effort. Students in high school should generally be familiar with simple food webs like wolves eat deer, which eat grass. Ideas of competition however, might not be as clear. So while the locusts are the principal problem for the flowering plants in this ecosystem, they also face a serious threat from the second grass, where they cannot grow. This web also attempts to use the charismatic megafauna like wolves and deer as distractors. While they are prominent in the ecosystem, and easily understood, they ultimately play little role in the health of the flowering plants.
For the simulated model underlying the game, all species reproduce and die with certain probabilities. Animals develop hunger, and going hungry for too long will kill them. Animals must encounter their prey to eat them, but they do not really have prey-seeking behavior. Bees do not eat the flowering plants, but the flowering plants must be visited by bees in order to reproduce.

The game only had this single level at the time of testing, and this seemed to be enough to produce an experience of about thirty to forty-five minutes. Players play for 12 turns, trying to keep the red, white, and blue plants above 33% of their starting value. Players must investigate their park to discover what makes it tick and take actions in order to meet their goal. During the player turns, time effectively stands still in the simulation. Once both players have committed their actions, the simulation passes through thirty “ticks,” the game’s internal clock that manages movement, reproduction, and other elements.
Features of the Biologist’s Interface:

1) **Budget**: Players have a shared budget with which to make decisions and take actions. The budget is replenished each turn depending on how the plants are doing, an analog for how popular the sanctuary.

2) **Flower Levels**: Players can see how well their plants are doing. The plants’ names are printed in green when things are going well, yellow when things are getting dangerously low, and red when plants are below the specified threshold.

3) **Turn Number**: Players are required to keep things going for 12 turns. The turn number appears here.

4) **Mark and Recapture**: This is the first biologist ability. Players can stretch out any number of square patches on the field. Within these squares, the number of animals in these squares is counted (not every animal is represented visually, described in detail below). The computer then extrapolates the population numbers for the sanctuary. This number is stored to be accessed via a mathematician’s tool.

5) **Quadrant Sampling**: This functions the same as M&R, but provides detail on plants and insects.

6) **Observer**: This ability, more expensive than the others, places an ranger in the field that observes and logs the relationships between any of the species that occur in the observer’s square and every contiguous square.

7) **Show Web**: This ability is free, and reveals all logged species relationship data, collected via the Observer ability.

8) **Next Turn**: Once players have completed all their activities for the turn, they commit them via this button. If the biologist is the first to finish their activities, it displays a “Waiting on Mathematician” message. If the mathematician finishes first, it says, “Waiting on you.”
Features of the Mathematician's Interface:

1) **Budget:** Identical to the biologist's budget view.
2) **Store:** In the store, players can, each turn, purchase pesticide, pay to have an amount of a random species added or pay to have an amount of a random species removed.
3) **Advertising:** Players have the option to spend some money on advertising to drive tourists to their sanctuary.
4) **Charting:** All of the extrapolated data from both Mark and Recapture and Quadrant Sampling is stored in a chart at each time period. The fidelity of this data to the actual numbers of the simulation is dependent on how well-developed players’ sampling strategies are. The numbers are only registered at the time steps at which they were sampled (i.e., during which turn they were sampled).
5) **Next Turn:** Has the same functionality as the biologist’s.
These features, providing players with a relatively small number of possible actions, creates a rich opportunity for players to have a discussion as they strategically manage their budgets and the wildlife in their sanctuary. There's no guarantee of the type of experience players can have, but there are what the design community calls “affordances.” Noted designer Donald Norman (2002) says of affordances, “A good designer makes sure that the appropriate actions are perceptible and inappropriate.
ones invisible” (pg. xii). In order to understand what sorts of things affordances are, it may be helpful to discuss Sanctuary’s characteristics via Elias et al. Before this analytical discussion however, it may be useful to have a hypothetical, idealized version of play to create a useful mental model for the reader.

**A SAMPLE WALK THROUGH of SANCTUARY**

Coming into Sanctuary, players would be made aware of the goals, the tools and their functionality, and the framing fiction of the game. Then the two players (let us call them Mary the mathematician and Barry the biologist) would enter the game and begin their work. Players may be trusted to network the tablets together if their teacher or mentor believes they can handle the task, but this is not an essential part of the experience.

In round one, players may be interested in discovering how their tools work. While analytic description of the function game tools can be useful, it often common for players to understand how tools work by using them in context. In the first round, players do not have access to their most expensive tools yet (Observers for Barry and Charting for Mary). Mary opens the store and the advertising options in order to consider her options. Barry’s options are more limited. The players politely consult with each other, asking the other’s opinion about how to proceed. Neither has a clear idea about how their tools work, so they decide to make a quick commitment in order to evaluate the tools. Mary purchases a magazine advertisement, while Barry opts to conduct quadrant sampling in a few small areas of the sanctuary. Once they have both committed their actions, the system updates the state on all of the game’s plants and animals, adds extra money to the team’s budget due to the advertisement purchased, and collects and extrapolates data from the quadrant sample. This information is then imported by Mary’s charting ability at time point (round) one.

In round two, players have more options, with the budget able to support charting and supporters now. Barry and Mary are curious, and so both opt to try out their new abilities. Barry quickly leaps in and places an Observer in the sanctuary. Mary is not far behind in using the Charting ability, bringing up a dialog box that reveals a chart where the flowers and insects sampled by Barry in round one have been extrapolated to estimate the number of flowers and insects in the entire park. Barry’s sampling strategy was not exactly robust, so the quality of the data provided is good, but not great. Mary mentions these results to Barry, which he notes. Seeing that there is some budget left over, Barry asks if he should place another Observer in the sanctuary, feeling that there
is probably more to be learned. Mary agrees, so Barry seeks out a different section of the Sanctuary with different creatures visible on the screen from those around where he placed his first observer (i.e., “well, I observed an area with birds and red flowers visible first, so I’ll try this area with white flowers, deer, and wolves visible now”). Having exhausted their budget, Barry and Mary commit their moves and they game updates the state, collecting and saving the observed creature and plant interactions in the squares around the Observers, to be accessed by the “Show Web” button on Barry’s interface. For the third round, Barry and Mary decide to use their remaining tools in order to round out their understanding of the game. Barry first looks at his “Show Web” box in order to see what relationships exist in the park. He sees the deer eat grasses, wolves eat deer, and locusts eat the red and blue flowering plants. Barry decides it is important to sample the animals in the sanctuary via the Mag and Recapture ability and tries his best to sample animals from around the sanctuary. Mary, meanwhile, investigates the store. Barry did not yet relate that the locusts are eating the red and blue plants, so she is not immediately drawn to the Pesticide option. The Add Species/Remove Species option this round is bees, so she asks Barry if he thinks she should add or remove bees. Barry has not data yet, so they decide that, using their existing knowledge, bees probably help flowering plants, they take a gamble and Mary adds bees to the sanctuary. The system updates and collects the relevant information from the Mark and Recapture ability.

Over levels four through eight, Mary and Barry develop an investigative rhythm. Barry places Observers to flesh out the ecosystem’s food web, refining a sampling strategy for Quadrant Sampling and Mark and Recapture in consultation with Mary. Mary’s job is somewhat more complicated, watching the budget carefully, trying out Pesticides in order to determine their effects, looking at charts of Barry’s collected data, adding species that they think might be helpful based on Barry’s observations, and advertising when there is money left in the budget. Over this time period, they also see a dip in the levels of the flowering plants, putting a little pressure on their decision-making.

In levels nine through twelve, it becomes plain to Barry and Mary that locusts the biggest problem in the sanctuary, so they agree to focus their efforts on them. Barry uses Quadrant Sampling each round in order to get as careful a reading as he can both on how many locusts there are in the sanctuary, but also to get a sense of where there might be more than other places in the park. Mary focuses extensively on using pesticides in order to kill locusts, making judgments based on the visual display of where locusts are as well as Barry’s reports. She even uses the high concentration of
pesticide once, which she believes kills more than just insects. She feels somewhat guilty about this, but Barry waves her on. The team has a close call, but they have played well, and they emerge victorious.

In the classroom discussion afterwards, Barry and Mary have done better than about half their classmates because of their expert play, and their teacher teases out various complex decisions the teams that succeeded made, including the sampling strategies these teams used. The teacher also asks the teams that did not succeed about the sampling strategies they used, and why they made those decisions. During the discussion, Mary also mentions her guilt at deciding to use the high concentration of pesticide despite having strong suspicions of its negative effects. A couple of other brave players mention having similar thoughts about the ethics of the pesticide. This causes more students to wonder why the goal of sustaining the flowering plants was important in the first place, and invites a lengthy discussion about human goals in working with the natural world that closes out the class.

**CHARACTERISTICS OF SANCTUARY**

**Heuristics**

So how might we describe this experience analytically? It may be useful to begin by thinking about the game heuristically. Elias et al., when describing how you might address the basic features of a game conversationally, use the term “heuristics” - “rules of thumb that help them play the game” (pp. 29). In other words, you wouldn’t tell a friend about Monopoly by rattling off all the rules, but instead you might talk about how the game is about circling a community, purchasing property, and becoming wealthy by charging all of your opponents for rent during their travels. As you play the game, theoretically your heuristics for the game get more and more sophisticated. The authors describe heuristics as falling into principal categories: positional heuristics, which, “evaluate the state of the game,” and directional heuristics, which, “tell you what strategy you should follow” (pg. 30). Heuristics, of course, is also a familiar term from research and theory in expertise and thinking skills. In the learning and cognition communities, the use of heuristics to solve problems is common among experts, but they will only use it to start the problem solving. For instance, Glaser (1992) writes:

Somewhat like novices, experts bring general problem-solving processes to bear...In general, where problems do not yield to straightforward approaches, experts can usefully resort to analogies with systems they understand well and search for matches and mismatches...In a
sense, the use of general heuristics reflects the attempt to move ill-structured problems of
discovery into the familiar domain where extant knowledge can be brought into play. Rather than
using general heuristics in a decontextualized way—as free-floating interrogators of a situation—
the expert uses them to make contact with available knowledge and the solution processes it
might afford. The abstract use of general heuristics in courses on thinking skills or reasoning may
not be successful for this reason (pg. 68).

Elias et al.'s ideas "climbing the Heuristics Tree" (pg. 32) has a clear but not explicit
connection to this research - they posit that a good game can be investigated to
increasing levels of expertise in the game's processes, "learning successively better and
more sophisticated heuristics for a given game" (pg. 32). Sanctuary is designed to be
understood in increasingly more sophisticated ways and to have the possibilities for
increasingly more sophisticated heuristics. Beginning players, for instance, may develop
early heuristics around how the tools work, and more sophisticated players may have
more expert sampling strategies. This theoretically would create a compelling learning
experience.

**Length of Play**
Elias et al. characterize game length as the relationship between Atoms ("the smallest
complete unit of play...e.g. One level in Donkey Kong (1981)"), Games ("a 'standard' full
round of play"), Sessions ("e.g., an evening of play"), Campaigns ("a series of
games...linked in some way (the weekly poker game...or an ongoing paper role-playing
game)") and Matches ("best two out of three' or similar grouping"). For the purposes of
this thesis, Sanctuary is a single level comprised of 12 atoms - turns in which both
players must commit an action. Importantly, player turns are simultaneous in order to
encourage players working together and to minimize players waiting for one another
(what Elias et al. Call "downtime."), as they might in a game with serial turns. Players
may still have to wait for one another, but the design of the game and the game
instructions invite players to be involved in one another's turn. A great deal of downtime
is undesirable Sanctuary limits the length of play not through a timer, but through a goal
structure that involves sustaining through a certain number of rounds. This is very
similar to the board game Pandemic (2008)'s limiting mechanic, in which players must
resist outbreaks of four fictional diseases until a cure can be found or a set number of
levels have passed. It is also similar to the inning structure of baseball, which is distinct
among major American sports in not having a "clock" to work against. This decision was
crucial because time pressure can frequently add unnecessary stress to a learning
experience and completely turn off some players. I believe it is more likely that a
learning game will be adopted if the play is appealing to the largest number of players.

**Number of Players**
*Sanctuary* currently requires exactly 2 players. In the first, there are material conditions
that limited the scope of the project. I made this decision because engineering two
unique interfaces in the intervening time would prove to be challenging enough. I also
made this decision because acquiring a third Retina Display iPad in order to play the
game would have been prohibitive.

In thinking of gameplay, Elias et al. would likely categorize *Sanctuary* as a one-sided
team game, “a single side playing against an AI (or against the rules of the game); this
is simply the team analog of a single player game…” (pg. 23). *Sanctuary* should be
considered a specific type of single player game, more like “pure” one-player games
than “one human, simulated opponent” games, according to their taxonomy. In pure
one-player games, players, “play…more against ‘the system’ than an imaginary
opponent” (pg. 22). Games that exist in this realm, according to them, include,
“[c]rossword puzzles, Tetris (1984), card solitaire, Zork (1980) or Myst, (1993), and
Asteroids (1979)” (pg. 22). The distinction is that the games, “have no playerlike
elements…(e.g., when you play Tetris, there is no computer player arranging blocks in
the same way you are)” (pg. 22).

There are many reasons to like this definition, but a key one is that players are engaged
in an “artificial conflict,” but the definition does not specify that they must be in conflict
with one another. They may be in conflict with the system itself, as is the case in my
game. In collaborative games, players are given the same goals and must work toward
them.

Salen and Zimmerman (2003) have something useful to offer as well on the nature of
collaboration in games (although they use the term cooperation). To begin this
discussion, they cite games guru Bernard DeKoven, from his *The Well-Played Game*
(2013):

> It is clear to me now that such a union [playing to win] is separation, always separation. It divides
> us into winners and losers, those who have achieved and those who have failed. The division
> then leads us into further division. It becomes difficult, now that some of us have won and some
> of us have lost, to find a game that we are all willing to play together. It was never our focus at all.
Though what we have always cherished most is the game in which we are playing well together, winning takes precedence. (Salen & Zimmerman: pg. 255)

They assert though that all games require cooperation on some level though, because players must willingly enter into playing the game in the first place. Their term for this, “The Magic Circle,” borrowed from Huizinga (1955) and extended means that, “to play a game is to submit your behavior to the rules of the game, to enter into the time and space that the game demarcates, to traffic in the special meanings that the game offers up.” (pg. 256) All players of a game have necessarily decided to cooperate in some fashion. The magic circle has been problematized by scholars since the arrival of this book (Consalvo, 2009; Copier, 2005; Taylor, 2007), and Zimmerman has since responded, clarifying that the Magic Circle invoked in their book is, because the book is a game design text book, a heuristic for game designers, not a formal, non-porous, binary border that is useful for every discipline (2012).

To complicate matters, Salen and Zimmerman also assert that all games have competition in them as well, including games with what they call player cooperation, in which the players do not compete against one another. In these games, the players are competing with the system of the game. To this end, they invoke the Latin roots of competition—“con petire,” or “to seek together” (pp. 255-256). It is this sense of cooperation—player cooperation against the system of the game—that best describes the positioning of players relative to one another in Sanctuary.

The gameplay (and, I would assert, learning and research) problems involved with a third player may be best explained by Lewis Pulsipher. In his essay, “The Three Player Problem,” (2011) Pulsipher says that the three-player problem is actually two problems. The first version of the problem is that in three player infinite games (games without ends), “the two players who are behind will usually beat on the one who is ahead, resulting in a perpetual stalemate.” (p.19). In three player games with a definite end point, something similar happens: “…[l]t is frequently possible for one player (call him ‘A’), if he believes he will lose and cannot catch up in the remaining duration of the game, to determine which other player wins. That is, late in the game the losing player exerts all his efforts against another player ‘B,’ which tends to let the third player ‘C’ win.” (p.19). Elias et al. call this problem “Kingmaking” (pp. 51-56). Even though Sanctuary is a cooperative game, I believe that a spirit of competition, or at least exclusion, becomes more likely with a third player. Players may be more willing to
strategize with someone they know and neglect the third player, etc. A two-player game leaves players on more even footing, creating a theoretically more stable learning unit.

As a researcher, having two players was also key because it made tracking conversation and collecting data easier, but it had a more important pedagogical/research feature, which was that players could not "hide" without standing out. In other words, with only two voices in the conversation, a group that is exceptionally quiet because one or both players aren't communicating will stand out more readily in a classroom situation.

**Infrastructure**

If a goal, however distant, of this project is to in part reconfigure the learning culture of classrooms, then the structure of the experience is crucial. Elias et al define a game’s infrastructure as, “the basic systemic elements of games: ingredients of the game system that help make the game what it is” (pg. 71). The first element of a game’s infrastructure is its rules. Elias et al. characterize a game’s rules in three principal ways: the instructions given to players, the rules enforced by the players, and the rules that are essentially a function of the environment. In Sanctuary, players are told that their goal is to use the tools and keep the three central flowering plants alive at acceptable levels. As in most digital games, the better part of the game’s rules are embedded in the game’s computer code, the product of the game’s environment in the way that many of the dynamics of football are derived from the physics of the Earth. Sanctuary’s internal, programmed rules govern the movement of the creatures in the sanctuary’s ecosystem, as well as the functions of the tools described above. That includes the turn-taking in the game, which is also enforced by the code.

The authors also mention an infrastructural offshoot of rules, groups of rules called, “standards” (pp. 76-77). Standards allow players to quickly understand what is happening in a game, by sharing features in common with other games such as when PC video games share a navigation scheme in the W, A, S, and D keys or the consistency offered by a deck of 52 cards across multiple different games. Sanctuary does not use many standards, although it invokes several standard iPad touch screen conventions. The game also invokes some user interface standards, displaying information and abilities on a frame around the edge of the camera over the sanctuary.
Another crucial infrastructural element is the game’s outcome/ending condition. By Elias et al.’s definitions, Sanctuary meets the definition of a nonorthogame without winners or losers. The players can either succeed or not succeed, but it’s difficult to say that players win. Players can never come to a “draw” with the system, but if the players fail to meet the ending condition goals, they are immediately given the opportunity to start over. This was a deliberate decision, implemented to minimize any frustration or shame associated with learning, but also to encourage the idea that inquiry doesn’t always go well, and that failure should be taken in stride.

Elias et al. also address what they call positional asymmetry. While Sanctuary mitigates a form of asymmetry by allowing players to take their turns simultaneously, it creates asymmetric information through the creation of roles. The separation of the in-game tools onto separate iPad interfaces in Sanctuary is done principally in order to demand collaboration from players. While players are able to see the same camera view of the wildlife sanctuary, but the tools available to each player allow them to see differing information. This is not proscriptive - players can look at each other’s interfaces, swap iPads, and touch each other’s screens. It is basically impossible to succeed in the game with out using tools on each iPad, however.

While this game aims to be located in the tradition of games with asymmetric interfaces, from lightly asymmetric (as in Dungeons & Dragons (1974), World of Warcraft (2004) or Team Fortress 2 (2007)) to highly asymmetric (as in the Artemis Bridge Simulator (2012) or Carnegie Mellon’s Fusion (2010)), none of these games are designed for science and mathematics learning, and it might be a considerable stretch to teach with them. The success of many of these games is built on interdependence, networked computing, and shared goals, as will be discussed below. In some sense, this draws on an academic gaming tradition of roleplaying in science learning and pluralism. MIT Professor Lawrence Susskind has done work on negotiation in environmental decision making for decades (see www.lawrencesusskind.com). The ERIA Interactive group at the University of Wisconsin-Madison’s Institute for Discovery has begun work on a very thorough simulation for environmental planning, Trails Forward (see Shapiro et al., 2011). The work of these groups though, is principally to help professionals and pre-professionals make careful decisions at the highest level. Sanctuary aims to reduce the complexity to a manageable level for high school students, as well as to provide them with strictly collaborative goals (in both Susskind’s games and in Trails Forward, collaboration is the goal, but players enter into the situation with competing objectives).
Another purpose for the asymmetric interfaces is to make visible to the players, in an unobtrusive way, the existence of multiple epistemologies being brought to bear on a shared problem. As mentioned in the Foundations section, constructing knowledge is often best done in a community setting, and splitting the central, goal-driven task into pieces is a manner in which to provide the community with some structure and promoting community. There is a tremendous body of work in this area, perhaps most famously and succinctly covered by Eliot Aronson’s Jigsaw method.

To lay a foundation, Aronson starts his book on the Jigsaw with two sections - “Competition in Society” and “Competition in the Classroom.” In the former section, he says that while, “competition can be fun...we have found that unbridled competition—the relentless concern being number one, with beating the other person—can be, at best, limiting and, at worst, destructive and debilitating” (p. 3). In the latter section, he says that, “...virtually all classrooms share two common aspects: (1) the major ‘process’ that occurs is highly competitive, and (2) the ultimate goal of the competition among students is to win the approval and respect of teachers—perhaps even their love” (p. 3). Continuing this discussion, he says that through a typical classroom process like a teacher asking a question and calling on a single student, “…students learn several things. The first is that there is one and only one expert in the classroom: the teacher. They also learn that there is one and only one answer to any question: the one in the teacher’s head. The task is to figure out what is in the teacher’s head” (pp. 3-4). This process of competing to tell the teacher the answer in his or her head, “is virtually guaranteed to not promote friendliness, understanding, and cooperation among students” (p. 4). The jigsaw method, then is designed to counteract this excessive competition and the guessing game for respect and love.

Aronson relates that the method developed in response to the intractable problem of newly desegregated Austin, Texas schools in 1971. Aronson, a professor of social psychology, was called in to help by a desperate former student now teaching in the school. As such, the method is driven by a pragmatic, value driven need to act. Aronson says, “...it wasn’t our intention...to invent a new teaching method” (pg. xv). The Jigsaw classroom breaks students into groups of five or six and asks each group to complete a task together. Each student is given a portion of the task to complete. In Aronson’s example, a short reading comprehension task for elementary school students is broken up by paragraph, and one student is responsible for the material in each paragraph.
First, the students read their paragraph, then discuss the paragraph in “expert groups” consisting of the children who have the same paragraph from the other groups. The students then return to their “home” groups and each student then teaches the other students about their paragraph, bolstered by their experience in the “expert” groups. Every student will be responsible for knowing the entire passage, so the students must pay attention to one another and have an incentive to both make their best effort and to help other students put forward their best effort as well, including helping shy students feel comfortable, etc. Aronson says, “[the teacher] was no longer the major learning resource for each of the learning groups. This process made it imperative that the students treat each other as resources” (p. 8). According to him, this happens in three ways:

1. The learning process was structured so that individual competitiveness was incompatible with success.
2. Success could only occur after there was cooperative behavior among the students in a group.
3. All students (no matter what their prior status in the classroom) were in a position to bring to their groupmates a unique gift of knowledge—a piece of vital information that was not readily available except from that individual student” (p. 8).

“Interdependence is required,” he says (pg. 10). The interdependence not only helps students to know one another and to build their skills in cooperation and their relationships, but also their sense of being active in their own learning and taking it seriously. In order to help their peers do well, they must try to work hard and do well themselves. The major findings of jigsaw research indicates that students become attached to their groupmates, like school better (and consequently show up), have more self esteem, outperform their colleagues in competitive classrooms, and are more empathic (p. 13).

There’s an important caveat to the creation of expert groups in the asymmetry of the jigsaw. Aronson writes:

“As psychologist Roger Brown has pointed out, if it weren’t for the expert groups, the jigsaw method might backfire. Brown likens the jigsaw to playing Little League baseball: if the boy playing right field keeps dropping fly balls, it hurts the team and you might begin to get annoyed at him. By analogy; suppose you are dependent on the performance of a Hispanic youngster who is less than perfectly adept in English, and is having some difficulty articulating his segment of the lesson. You might resent him. The expert groups provide all students with the opportunity to get a clear idea of the material—regardless of prior inequities in skill or preparation” (pg. 9).
It is crucial to recognize that simply providing an activity with roles to a classroom will not be enough. By adding expert groups, the activity becomes legitimately equitable, or at least takes equity seriously.

As time has progressed since the first jigsaw experiments, many people have tried further innovations in cooperative learning (Slavin, 1983; Johnson & Johnson, 1989), but meta analyses seem to indicate that for social-emotional learning benefits in cooperative learning, there are two essential design features: “individual effort and group goals”, with three important but less essential features: “positive face-to-face interaction,” “direct instruction in the component interpersonal skills,” and “instruction in group process skills” (pp. 20 – 21).

Consequently, Sanctuary is a two-player collaborative game in which face to face players must put forth individual efforts work to accomplish group goals. While I might have, during the observation, provided some reminders about playing civilly or help to support the students’ interpersonal skills during the session, it is outside the scope of this project to provide a full course of instruction in either group process skills or interpersonal skills.

It is worth taking a moment to talk about the roles for cooperation and competition in classrooms however. Games are media with certain meanings and ideas in society, so it is worth talking about how this tension can be thought about in schools. Although I did not realize it when I began this design, it was pointed out to me this winter that my design extends the Jigsaw method (Aronson, 1978; 2011), an important and groundbreaking way to modify the educational practices that emerged at the turn of the 20th century to take cooperation and competition into better consideration.

It is worth addressing Elias et al.’s teamwork characteristic here as well. Relating directly to Brown’s comments about teamwork in the expert groups. Elias et al. state that:

[1]n deliberately designed games where different roles are built in, two common strategies can help each player feel she’s making a contribution. One is to balance the roles, and so that no one player contributes more to the team’s victory than another. The other is to give each role unique abilities, as in an RPG where one player can heal and the others cannot. If everyone can heal a little, but some are better than others, then the roles may still be different, but the feeling a player has that her contribution is unique will be less.
Sanctuary descends from such RPGs, separating players into unique roles. Brad McQuaid, a designer and producer of the MMORPG Everquest was quoted as saying:

The key to creating community is interdependence. In Everquest, we forced interdependence in several ways and although we've been criticized for it, I think it's one of a couple of reasons behind our success and current lead. By creating a class-based system, players NEED each other. By creating an environment often too challenging for a solo player, people are compelled to group and even to form large guilds and alliances. All of this builds community, and it keeps players coming back for more and more (Aihoshi, 2002).

Team-based games get a careful write up in Characteristics of Games, and then specify how those issues apply, a game that, “were relatively rare until recently” (pg. 68). They postulate that, “an opponent provides so much in terms of uncertainty of outcome and repeat play value...Now the computer can be your opponent...The existence of both AI opponents and computer networking allows games to offer the social benefits and heuristics of team play” (pg. 68). One associated issue of team games is the challenge of communication. Expert players may often “play for” beginning players in team games. Elias et al. specify that in games with opposing teams, this might produce a reaction of, “Hey, that's cheating,” where it may produce a more mild, “I'd rather play myself, thanks,” from the beginner player without an opposing team (pg. 68). The authors also point out the limited re-playability of single-sided games, pointing out that, “MMOs suffer from this problem, and the pressure on the content creators of MMO is large...How many people would go on the same MMO raid as often as they do if not for the need to help their guildmates?” (pg. 69). These issues are exactly relevant to Sanctuary. The research of this thesis was principally designed to see what learning effects may be like in situations where one student either is an expert or perceives themselves as more expert. Further, as I will discuss in the Reflections section, learning games made in the Sanctuary model will always have a content bottleneck issue, where new systems and tools will continually need to be engineered in order to expand them.

Asymmetry also adds value by making student thinking visible in context. Visible to the student themselves, to their partner, and to teachers or other learning mentors in the community where it is being played. There are no communication tools in the game, meaning that players must speak out loud with one another in order to coordinate with one another. This will be discussed further in the “superstructure” characteristic below.
A final aspect of a game’s infrastructure, according to Elias et al., is sensory feedback. “The game provides...information to the player, and player inputs her choices to the game somehow...This flow to and from the user is extremely important for any game, regardless of genre” (pp. 96-97). They also point out that there are two sensory dimensions to a game’s sensory feedback: Its aesthetic dimension and its usability.

Visual: As reported above, the game’s 16-bit, retro graphic style chosen for Sanctuary was chosen principally because it was available to me. Nick is an accomplished 16-bit artist and was willing to work with me. It is also an art style that has a certain nostalgic JOYfulness, with bright colors and an iconic, abstracted form factor (at least, this was the intention). A similar aesthetic has been quite popular in the recent game Minecraft (2009), or the iPad game Tiny Tower (2011). The art is all two-dimensional in part because three-dimensional art is frequently more time consuming, and in part because the game works better with a “board game” form factor. The game uses drop shadows to keep the various denizens of the sanctuary separate from one another, visually. There is a certain amount of visual “busy-ness” to Sanctuary’s visual style, but I was comfortable with it because the visual legibility of the sanctuary is not the point. I prefer that the visual representation be difficult to scan for clear information in this game (see the description of its systems). Also, as reported above, it was important to me to have the game be an aesthetically pleasing object to ease its acceptance by the students in their roles as research subjects, but also because the creation of aesthetically pleasing objects is a good. Further, noted games and learning scholar Kurt Squire has been advancing the opinion that in an attention economy, perhaps we have a moral obligation to create aesthetically appealing interventions for learning.

Audio: Sanctuary’s audio is almost entirely for usability - a series of 8-bit blips and bleeps for confirmation at all of the game’s dialog boxes. This decision was made in order to help players given that touchscreen interfaces do not offer some of the comforting tactile feedback of buttons and switches, that touchscreen interfaces can sometimes be uncertain, and that Sanctuary is somewhat demanding on the iPad’s computing resources, meaning that at crucial moments, there is some lag as the game’s state updates.

Tactile/Control Feel: Aesthetically, Sanctuary is implemented on tablets because of the flexibility of the platform. Tablets can be picked up and put down like books, possibly
facilitating more eye contact between the co-located players. I also chose tablets because some research I have done with games in museums revealed that many find gaming experiences on tablets more “intimate” and “personal,” even in a busy science center (Chu et al, 2013). Further, there is evidence that certain types of concepts may be learned better on tablets through touch and learning with the hand. Sanctuary doesn’t necessarily produce the same interactions or learning opportunities, but I am interested in following up on these ideas. Finally (this will be discussed more completely in the Superstructure section), iPads seem to be a gaming device embraced equally by both genders, which may or may not have an aesthetic dimension.

Simulation/Systems
Sanctuary is in part inspired by tremendous research studying the value of agent-based simulations for science learning. Clark et al. (2009) describe four primary dimensions of simulations for science learning: “(1) the degree of user control, (2) the extent and nature of the surrounding guiding framework in which the simulations are embedded, (3) how information is represented, and (4) the nature of what is being modeled” (NRC, 2011). Agent-based simulations like PhET (2004) or EcoBeaker (2008) display emergent effects of biological and chemical systems by displaying individual molecules or creatures as a singular acting agent within a system. The theory of change in these simulations is that you can see the change (in proportion or orientation etc.) over time. Some of these simulations, like StarLogo, NetLogo, and ToolBlocks, allow users to understand these complex simulations by allowing them to modify them or to build their own, exemplifying the model-based reasoning ideas described in How People Learn and the constructionist ideas of Seymour Papert (Papert, 1980; Resnick, 1991). In Sanctuary, however, in particular because I wanted to employ modes of inquiry from biology, it was important that players not be able to simply count the plants and animals in the world. Just as a ranger going into their own park may be able to establish some baseline for the things in their park simply by walking around and casually observing, players of Sanctuary may be able to understand some aspects of their populations by looking around the map/board, but they cannot get very clear ideas on population numbers etc. without analyzing the park via quadrant sampling etc. Additionally, as the creatures and plants of Sanctuary are laid out on a grid and multiple plants and animals can occupy any square on the grid, it was necessary to hide some agents in order to produce something legible.
It is worth noting that this information-obscuring, dynamic system is exactly the sort of system described by Zimmerman and Salen. Players must work against the structures of the game together, competing with this “third player,” a piece of software operating on two tablet computers.

The simulated system also engages the characteristic of indeterminacy because of Sanctuary’s chief distinction from a traditional board game. This is, to a degree, the contingency mentioned by Malaby. For Elias et al., indeterminacy consists principally of the interactions between Randomness, Luck and Skill, and Hidden Information. While the authors are reluctant to define games, they do concede that, “it is safe to say that most if not all games have some uncertainty as to their outcome” (pg. 37). The authors say, “in some sense, if there is no uncertainty in outcome, there is arguably no game at all...Most games tend to exist in the space where there is some opportunity to make meaningful decisions, which means it is possible to play better or worse, but possible always to play 100 percent correctly” (pg. 139). In order to explain the affordances of luck and skill, they say, “[I]f there’s a lot of luck in a game, then the best player may not always win. The more a skilled player can win at a game, the higher returns to skill we say that a game has” (pg. 152). They define hidden information as, “things about the game state that are not known to all players...[it] falls into at least three rough (nonexclusive) categories: Private information, “Puzzlelike” hidden information, and Randomness” (pg. 161). Private information is, “a card I hold that you can’t see, or a portion of a [Real Time Strategy game] map that is fogged out to you but not to me” (pg. 161) and “Puzzlelike information” is when, “the game has information that the player does not know and part (or all) of the game is figuring out this hidden information, based on some mixture of experimentation and clues provided by the game” (pg. 163).

Sanctuary’s uncertainty is generally puzzlelike hidden information, as the game is demanding to be figured out, much as nature begs to be investigated and figured out by human curiosity. All of the biologist’s tools are about directly investigating the game’s system, and the mathematician’s tools are about cracking the game’s economy. Elias et al. write, “[I]n general, puzzlelike hidden information does not tend to make for very repeatable gameplay...once you know the secret, it’s time to move on. There are a few exceptions where the hidden information is regenerated each time you play and thus you can rediscover it” (pg. 163). This is not necessarily problematic for an intervention like Sanctuary, as it is designed to illustrate certain aspects of ecology in discrete units
in biology classes, as opposed to a consumer product that might be under more pressure to remain evergreen.

**Player Effort**
The next characteristic they describe is what they deem player effort. Many of the aspects of this characteristic are covered in other places, but for the sake of clarity, I will expound here. Player effort, for Elias et al., is determined by costs, rewards, downtime, busywork, and the ratio of reward to effort. The costs for *Sanctuary*, in its finished form, would likely be minimal to student players. As a game designed to be sold into learning communities for a deliberate purpose, it would have minimal appeal in an open software market like the iTunes or Google app stores. It would be sold into schools likely at a district level, as my prior research has indicated that teachers and even department heads tend to have very little purchasing power for supplementary interventions. The cost in time might actually be negative. As I will discuss in the Explorations section, players often indicated that they would rather participate in activities like this instead of their usual classroom activities. Harvard education professor David Dockterman has been quoted as saying of playful interventions in schools, “you’re not competing with *World of Warcraft* - you’re competing with jail.” While wryly stated, this statement highlights a similar philosophy to that which animates *Sanctuary*. This may also impact how players see rewards in the game. The impact of *Sanctuary*, properly implemented, may be a richer learning community, but students may see the reward foremost as a relief from traditional schoolwork. This sort of reaction may, in some cases, produce an undesirable scenario derived from concepts in Foundations, where teachers co-opt an intervention as a mere reward for participating in traditional schooling activities.

The downtime and busywork in the game are designed to be minimal. As stated earlier, players taking their turns simultaneously was a design decision made for encouraging equity among the players, but it was also implemented with use in classes in mind. A frequent complaint levied against rich learning interventions is that they can be “inefficient.” In order to facilitate adoption then, *Sanctuary* was designed with the time constraints of classroom teachers in mind.

Finally, the way to think about the ratio of effort to reward in *Sanctuary* is to point out that it requires no physical exertion, but definitely relies on the players’ desire and ability to make what the authors refer to as, “calculations.” Calculations are not necessarily pure arithmetic operations performed in one’s head, but could also be counting cards,
reading out a series of moves into the future, etc. The goal of the game is to have a learning curve that focuses only on the skills that are absolutely required (the mathematical and biological reasoning skills desired), and to eliminate other complicated elements that would distract from the core mechanics.

**Superstructure**
The last top-level characteristic defined by the authors is the superstructure of a game. As they say, “a great deal of what matters in a game takes place outside of or alongside the gameplay proper. Some of the relevant aspects include the metagame, the conceit or motif, the story or narrative, spectation, and misbehavior. The metagame, according to Elias et al., is the “game outside the game. It includes all the activities connected with the game that aren’t part of playing the game itself” (pg. 203). For *Sanctuary*, the metagame could be said to be the Foundations section of this thesis. All of the topics swirling around learning and games, as well as schools and ecology and technology all tie into *Sanctuary*, constituting its metagame. This is not to say that a player of these games will be conscious of all of these factors—in fact, it’s very unlikely that students are familiar with their school’s technology purchasing policies, but their teachers almost certainly are. As a deliberately designed game that, although a mere iPad application, aims to foster a richer learning community, it is important to be as aware as possible of the barriers to implementation. Many issues are ambiguous however. For instance, it is unclear whether or not being an iPad application is a good choice for *Sanctuary*. On one hand, for better or worse, schools seem to be buying iPads at an incredible clip. For instance, the Los Angeles Unified School District has recently announced a $500 million purchase of iPads, despite having a $543 million shortfall (Guzdial, 2013). A recent report surveyed more than 550 district-level technology leaders and found that:

“59.6 percent of respondents said their districts have already implemented mobile technologies in 25 percent or more of their district's schools; and another 15.5 percent said their districts were likely to do so within the next two years. However, according to the report's authors, ‘Very few districts reported that classrooms have 1-to-1 ratio of mobile devices to students. However, a large majority of respondents expressed interest in implementing or expanding a 1-to-1 solution using mobile devices if budget allowed’ (Nagel, 2013).

So even if schools and districts do not have an iPad program, there is a substantial chance that they are either in the process of implementing one or they are very interested in doing so, possibly at a loss. It becomes a question then of whether it is responsible or not to find ways to leverage these devices in order to create rich
compelling learning experiences. On the one hand, if projects like Sanctuary are successfully driving interest, does that artificially drive demand for these devices? If the devices are being purchased for classrooms (whether or not the districts even have the money), should we work to develop for them as a means to attempt reform? And what of the many questions surrounding the policies of Apple and the iTunes store, or the evolution of NewsCorp's Amplify tablets and the broad range of Android tablets? These are complicated questions beyond the scope of this thesis, but they are an important part of the metagame for Sanctuary.

The conceit/motif/story/narrative for Sanctuary is important for the project and is an important part of its metagame. The environmental theme was chosen in part because these topics are part of the curriculum in high school, and partly because involving students in relevant concepts and helping activities seems to be an increasingly successful trajectory for science education (Barab et al.; NextGen Standards). I think it's an important possibility though, that a classroom could have a discussion around the values of playing this environmental game on an iPad, which was created with some potentially hazardous environmental conditions, mining a limited amount of rare earth metals, for instance.

The metagame characteristic of spectation is also extremely important for the learning community aspect of Sanctuary. One inspiration for this decision is the work of Douglas Wilson. The game J. S. Joust (2011) is game designed with spectation in mind - groups of people ringing an arena where players are engaged in a digitally enhanced version of the classic folk/playground game (cf. Wilson, 2012). Of course, this game and its contemporary peers did not invent spectated games, but they are an interesting model for how to use digital technology to enhance the human, processual experience of games between people as opposed to employing a computer's artificial intelligence as the major opponent of the game. While Sanctuary still employs computational artificial intelligence as the major opponent in the game, the process of engaging with the game in a community of inquiry is a spectatable process.

This idea of Sanctuary creating a spectacle to be participated in and consumed by a community is also derived in part from the Visible Thinking project at Harvard University's Project Zero. A description of their program from their website:
Visible Thinking is a broad and flexible framework for enriching classroom learning in the content areas and fostering students' intellectual development at the same time. Here are some of its key goals:

- Deeper understanding of content
- Greater motivation for learning
- Development of learners' thinking and learning abilities.
- Development of learners' attitudes toward thinking and learning and their alertness to opportunities for thinking and learning (the "dispositional" side of thinking).
- A shift in classroom culture toward a community of enthusiastically engaged thinkers and learners.

Toward achieving these goals, Visible Thinking involves several practices and resources. Teachers are invited to use with their students a number of "thinking routines" -- simple protocols for exploring ideas -- around whatever topics are important, say fractions arithmetic, the Industrial Revolution, World War II, the meaning of a poem, the nature of democracy. Visible Thinking includes attention to four "thinking ideals" -- understanding, truth, fairness, and creativity. Visible Thinking emphasizes several ways of making students' thinking visible to themselves and one another, so that they can improve it.

The idea of visible thinking helps to make concrete what a thoughtful classroom might look like. At any moment, we can ask, "Is thinking visible here? Are students explaining things to one another? Are students offering creative ideas? Are they, and I as their teacher, using the language of thinking? Is there a brainstorm about alternative interpretations on the wall? Are students debating a plan?"

When the answers to questions like these are consistently yes, students are more likely to show interest and commitment as learning unfolds in the classroom. They find more meaning in the subject matters and more meaningful connections between school and everyday life. They begin to display the sorts of attitudes toward thinking and learning we would most like to see in young learners -- not closed-minded but open-minded, not bored but curious, neither gullible nor sweepingly negative but appropriately skeptical, not satisfied with "just the facts" but wanting to understand. (Visible Thinking, 2008)

Classrooms participating in this sort of framework would be the perfect place to deploy Sanctuary. The use of jigsaw framework could enhance a community already practicing these sorts of collaborative thinking skills. Of course, as described above, moving away from a community hyper-focused on individual learning outcomes to a community more focused on community outcomes may be challenging in the current policy environment.
Finally, misbehavior is an important characteristic of this game’s superstructure. In games, misbehavior is the realm of Huizinga’s spoilsport (1955) - those who refuse to play according to the rules. Elias et al. characterize misbehavior as cheating, sharp play, and griefing. They define cheaters as those, “that disobey the rules” (pg. 231). Sharp play is play that is within the rules, “but is still somehow ‘disreputable’—as taking advantage somehow” (pg. 234). Griefing is, “gameplay behavior that does not benefit their own position in the game, but instead merely makes another player miserable” (pg. 236). Schools also traditionally have a great deal of concern with the behavior of their students and the rules. While misbehavior in traditional schooling might take the form of speaking out of turn in class, or academic dishonesty (such as plagiarism), it might also take on the form of bullying and other anti-social behavior. With respect to cheating and class disruption, these types of misbehavior can mar an experience for a community of players or learners, but they do not necessarily cause long-term harm to the community. More likely, the cheater will be looked down on by the other members of the community and suffer because of this new alienation. By contrast, griefing and bullying can cause real, long-term damage to a community and shared bad feelings. The difference between in-game griefing and bullying can be challenging to tease apart, if they even are separate. Often, this is contextual, depending on how much it “matters” to participants. Grieving a friend in a game can be fun for all involved, but sometimes this can go “too far” and cause bad feelings outside of the game. These sorts of behaviors they, must be carefully watched during the play of Sanctuary if some part of the game’s designed work is the development and structuring of a successful learning community. As a result, as we will discuss in the Explorations section, particular detail will be paid to the opportunities and situations for power imbalances and misbehavior to spoil the larger work intended by the game. To be clear, these behaviors are very human and I do not submit that a designer or a game can control or eliminate these behaviors. Perhaps it is not even desirable to do so. Mia Consalvo writes that cheating, “can also lead to further educational moments, as players negotiate how to deal with transgressors appropriately. It also allows players another level of agency or activity in the game, rather than forcing them into the role of ‘passive victim of the cheat’” (Consalvo, 2005). This reinforces that although Sanctuary is a designed artifact, the processes around the game are crucially important.

**PROCESS**

Game design is an iterative process, and no successful game can be designed and implemented in one fell swoop. Such experiential processes must be exposed to
multiple points of view in an iterative fashion, making the desired experience as legible as possible to the largest number of people. Games that are designed to advance an idea or values require an even more involved iterative cycle, checking that with each iteration that the desired ideas or values are still present and active in the game. Mary Flanagan (2009) advances an agenda of values-based game design that reinforces this point. Similarly, Barab et al. (2007) have published on Critical Design Work, a design process that can be used to develop successful interventions with designed ideas and values. The steps in this process are:

1) Build a Rich Understanding
2) Developing Critical Commitments
3) Reifying Commitments into Design
4) Expanding the Impact and
5) Making Theoretical Contributions

This can be a long process, and this project will really only portray the first two and a half to three steps of Barab’s steps. Developing an understanding of the complex moving parts of Sanctuary took a long time, as did making the appropriate critical commitments described in Foundations. The development of most of the functionality of the game also took a very long time, making an iterative process impossible on the timeline for this project. A longer version of this project would deploy the game many more times with an eye to fully developing the game, the classroom processes around it, and further refining the vision for the project.
FRAMEWORK

A "Prudent" Approach to Design-Based Research

My approach for this thesis, Design-Based Research (DBR), a research paradigm that arose in the early nineties (Brown, 1992; Collins, 1992). Before describing the intervention, it is useful to explain the nature of this framework so that the features of the intervention and the design decisions that produced them can be appropriately contextualized. DBR contends that the study of educational interventions must be done in real, situated contexts with hundreds of unknown variables instead of the clean, small number of variables of laboratory study. In a 2004 article with co-authors Diane Joseph and Katerine Bielaczyc, Collins recalls his perspective on Design Based Research originating in Herbert Simon's ideas of Design Science (1969), particularly the "distinction between analytic (or natural) sciences and design sciences." Where the natural sciences are trying to, "understand how phenomena in the world can be explained," design sciences try to, "determine how designed artifacts...behave under different conditions." Collins' extension to education then is a need to, "investigate how different learning-environment designs affect dependent variables in teaching and learning." (2004:17)

Reeves (2006) produced a graphical representation between Predictive Research and...
Design Research, reproduced above.

Writing at the same time as Collins et al., Hoadley (2004), a co-PI of the Design Research Collective (2003), describes the outcomes of DBR as a, “culmination of the interaction between designed interventions, human psychology, personal histories or experiences, and local contexts.” He relates, from the Design-Based Research Collective’s founding document (2003, p. 5) that, “…the intervention is the outcome…in an important sense.”

As to rigor, Hoadley (2004) goes on to say that, “although some of the tenets of experimental research are violated (such as changing treatment protocols mid-implementation)...I propose that design-based research is more rigorous in certain ways. In particular, design-based research is strong at helping connect interventions to outcomes through mechanisms and can lead to better alignment between theory, treatments, and measurement than experimental research in complex realistic settings like the classroom.” Collins et al. (2004: p. 21) make the perhaps less controversial claim that, “Design experiments are contextualized in educational settings, but with a focus on generalizing from those settings to guide the design process. They fill a niche in the array of experimental methods that is needed to improve educational practices.” Collins et al. (2004: p. 35) go on to specify that there are at least five different ways to look at an intervention:

- **Cognitive level:** What do learners understand before they enter a particular learning environment, and how does that understanding change over time? Some of the tools for analysis at this level include observations of thinking through learners’ representations and explanations. Through the visual and verbal descriptions of ideas, researchers ask learners to expose their thinking. Are the explanations clear? Do representations capture important relationships?
- **Interpersonal level:** This viewpoint addresses how well teachers and students interact personally. Is there sharing knowledge? Have the students bonded with each other so that they respect and help each other? Researchers use ethnographic techniques to observe these kinds of interactions.
- **Group or classroom level:** This viewpoint addresses issues of participant structure, group identity, and authority relationships. Is everyone participating? Is there a sense of the goals and identity of the group? Again, ethnography is an effective approach to analysis.
- **Resource level:** This level deals with what resources are available to learners and if they are easy to understand and use. How accessible are the resources? How well are they integrated into the activity?

- **Institutional or school level:** At this level issues arise as to communication with outside parties and support from the entire institution. Are parents happy with the design? Do administrators support it strongly? What are the micropolitical issues that impact the design?

Before talking about the particulars of the design of this study, with my perspective on what is important to this study and the limitations on this particular investigation of this tool, I would like to introduce a companion idea that has come to shape my thinking about some latent ideas in DBR. Collins et al. (2004) more or less explicitly state that DBR steals from the social science of ethnography because, “ethnographic research produces rich descriptions that make it possible to understand what is happening and why” (p. 21). They make the distinction that ethnographers, “make no attempt to change educational practice, as in design experiments” (p. 21). Bent Flyvbjerg, a Danish political scientist who was interested in Democracy in his city of Aalborg, diligently produced an active criticism (2001) of all social science that directly addresses whether or not an ethnographer should intervene in their sites or perhaps more specifically, should the positioning of social scientists as objective scientists prevent them from intervening in their sites.

To frame this criticism of supposedly objective social science, Flyvbjerg (2001) begins by addressing the fact that social science cannot be as stable or predictive as the natural sciences because via four increasingly compelling arguments (p.47). First, what he calls the *pre-paradigmatic argument:* “At present, there exist no normal-science theories in the social sciences, and there is no reason to believe a priori in the existence of the abstract context-independent concepts which such theories would pre-suppose.” Second, the *hermeneutic-phenomenological argument,* which draws on Anthony Giddens and Harold Garfinkel: “[T]he study of human activity must be based on people’s situational self-interpretation, and...such studies can only be as stable as these interpretations.” Third, and somewhat similarly, the *historical contingency argument,* which draws on Foucault: “[S]table and cumulative sciences which study human behavior are not possible because humans both constitute these sciences and are at the same time their object. No science can objectivize the skills which make it possible.” And finally, (and neatly for this thesis) the *tacit skills* *argument,* drawing on the learning
theories of Dreyfus as well as on Bourdieu: “[S]table and cumulative social sciences presume a necessary but apparently impossible theory of human background skills...because human skills are context-dependent and cannot be reduced to rules, whereas a theory must be free of context and have rules.”

In forging a new direction for social science, Flyvbjerg (2001) reaches back to Aristotle’s three intellectual virtues: episteme, techne, and phronesis: Episteme, from which we draw the word “epistemology” is the irreducible, predictive knowledge of science. Techne, from which we draw the word “technology,” is the knowledge of craft or art - how to do things. Phronesis, whose root has more or less been forgotten, translates more or less to “prudence.” Flyvbjerg lists out its characterization as, “Ethics. Deliberation about values with reference to praxis. Pragmatic, variable, context-dependent. Oriented toward action. Based on practical value-rationality. The original concept has no analogous contemporary term” (p. 57). Flyvbjerg extracts the following “value-rational” questions from Aristotle as the core departure from traditional research: “1) Where are we going? 2) Is this desirable? And 3) What should be done?” (p. 60).

After a thorough analysis on the importance of a Foucauldian understanding of power in social science which I cannot and should not repeat here, Flyvbjerg adds a fourth value-rational question to the list, “Who gains, and who loses, and by which mechanisms of power?” (p.145). While much is still left to be discussed and debated about what a phronetic research approach may entail, a more recent volume presents some guide. In response to a number of case studies, Flyvbjerg et al. (2011) indicate that,”[p]roblematisation of tension points is emerging as a particularly important theme for phronetic research, because a focus on tension points appears to be especially effective for generating the type of change in policy and practice that is the hallmark of phronetic social science.” Tension points are described as, “power relations that are particularly susceptible to problematization, and thus to change, because they are fraught with dubious practices, contestable knowledge and potential conflict.”

Reading this compelling book, I felt it was not only important to incorporate values and questions of phronesis into Design-Based Research—it was necessary. Reeves locates DBR in an “action” orientation:

The overall goal of research within the empirical tradition is to develop long-lasting theories and unambiguous principles that can be handed off to practitioners for implementation. Development research, on the other hand, requires a pragmatic epistemology that regards learning theory as being collaboratively shaped by researchers and practitioners. The overall goal of development
research is to solve real problems while at the same time constructing Design-principles that can inform future decisions.” (2000: p. 12).

While much of the DBR discussion in this chapter so far and in the above paragraph entail addressing the “how to” questions of techne, Reeves hints at a values orientation by stating that the overall goal of development research, “is to solve real problems.” Sasha Barab et al. (2007) have already addressed the inclusion of values in DBR to a degree as well, stating: “design-based researchers can instantiate a critical stance in different aspects of their design work and at different levels of its implementation, including transforming the curriculum, the student, the teacher, and the sociocultural contexts in which their designs are being realized.” These authors suggest that designs can incorporate a “critical agenda” that criticizes “the status quo” (pg. 256). As such, this thesis will be attempting to take stock of “tension points” encountered during this work, not to “problematize” them necessarily, given the time and scope of the work, but as a place to inform further work.

**RESEARCH DESIGN**

Collins et al (2004) indicate that the reporting of Design Based Research should typically have the following features:

- **Goals and elements of design** - identify the critical elements of the design and how they fit together to accomplish the goals of the design. (pg. 38)
- **Settings where implemented** - The description of settings need to include all of the information relevant to the success of the design outlined [as independent variables] (see below). (pg. 38)
- **Description of each phase** - The design is likely to go through a different evolution in each setting, so it is necessary to describe each phase in each setting. (pg. 39)
- **Outcomes** - The outcomes should be reported in terms of a profile of values on the dependent variables in the different settings. (pg. 39)
- **Lessons learned** - Considering what happened in the different implementations, the report should attempt to pull together all the findings into a coherent picture of how the design evolved in different settings. (pg.39)

The first point on this list, *the goals and elements of the design*, were described in the foregoing Constructions section. In this section, I describe the *setting*, the *phase of exploration*, and the *outcomes* and *lessons learned*. The Reflections & Projections
section will extrapolate on these outcomes and lessons learned. Where the Foundations and Construction section focus on an idealized design of the project, this section and the following one will discuss what happened when the ideal design met the realities of research.

**STUDY DESIGN**

This study provided high school students taking math and science classes with roughly an hour play experience in pairs, during which the players are observed and then interviewed about their experience. This data was then synthesized and analyzed in a narrative structure of case studied. The study will speak to the Learning Sciences community through the Design-Based Research (Brown, 1992; Collins, 1992; Barab & Squire, 2004) framework. This study will comprise the first four stages of a “Compleat Design Experiment”: 1) Initial design 2) the design of the artifact/intervention 3) a feasibility study and 4) prototyping and trials (Middleton et al., 2008). Phases 5 and 6 (a full field trial and then a definitive trial) are outside the scope of this project, as a year is a very short time to develop a learning intervention and say anything meaningful in a summative way.

While DBR takes place in settings with a large number of variables, Collins et al (2004) classify the dependent variable into (at least) three categories:

- **Climate variables** such as engagement, cooperation, risk taking, student control
- **Learning variables**, such as content knowledge, skills, dispositions, metacognitive strategies, learning strategies.
- **Systemic variables**, such as sustainability, spread, scalability, ease of adoption, and costs. (pg. 36)

Accordingly, Collins et al. list the independent variables in a DBR experiment will be the setting, the nature of the learners, the required resources and support for implementation, professional development, financial requirements, and the implementation path (pp. 37 – 38). Given the scope of this thesis, not all of the variables that were possible to measure were measured. The dependent variables I chose to pay attention to going into the experience are primarily climate variables, with a secondary focus on learning variables, of the small number of encounters under study, the single locale, and the short duration of the experiment.
Population & Sampling
I drew a small sample of students taking the relevant topics (integrated mathematics and/or biology) in high school. In order to be completed within a year, the project targeted twelve students in six pairs via nonrandom stratified sampling (Trost, 1986) on what I believe is the most relevant cognitive skill—how these students appear to be doing in traditional measures of math and science learning. This was be determined by grade and teacher report (in order to correct for unusual circumstances). The unit of analysis is “pairs,” and whether or not those pairs fit my condition is determined by the skill status of the students that compose that pair. Students were paired in groups as “both doing well in math in science,” “one doing well in math and science,” or “neither doing well in math and science” (see table below). The realities of the execution on this design are described later.

<table>
<thead>
<tr>
<th>Both strong</th>
<th>1 strong; 1 weak</th>
<th>Both weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any combo (M/F)</td>
<td>Both male</td>
<td>Any combo (M/F)</td>
</tr>
<tr>
<td>Any combo (M/F)</td>
<td>Both female</td>
<td>Any combo (M/F)</td>
</tr>
</tbody>
</table>

*Above: A table demonstrating the non-random stratified sampling of this study.*

The strata were designed as doubled in order to be able to allow redundancies in case something goes wrong (as they did), but to also address issues of gender and speech when it comes to science and math learning. Because of this, in the situation where one student is strong and one is weak, those pairs were designed to be unisex, allowing any mentorship or other power dynamics that may occur to be uncomplicated by gender. I was more comfortable mixing gender in the pairs where the players may be on more equal footing.

While there was no explicit effort to sample for saturation in other more traditional social science variables, such as race and socio-economic status, they will be important to note. Variety in these dimensions may produce richer data. It is also ideal to have variety in the players’ comfort with games, how well the players know one another and how much or how well they have collaborated in the past.
Data Collection
The methodology behind this study and the initial stages of Design Based Research generally can be likened to the extended case model (see Small, 2009). Play sessions were held at Bedford High School, described below. Players were observed during their play session by me, as well as videotaped during their play session for further analysis. Field notes and queries were recorded in a notebook. After the play session, players were interviewed as a pair about their experiences in long, semi-structured, audio-recorded interviews. During this data collection, I looked for play patterns and both verbal and non-verbal expressions shared between players as well as individual verbal and non-verbal expressions of affect.

Operationalized Concepts (Observation)
The concepts below are chosen to identify moments of interaction between players while they play Sanctuary. The theory of Sanctuary is that their communication during the game is a crucial reflection of their thinking and learning. The concepts below represent a kind of scale of imprecise the depth of their knowledge and engagement in the activity. Communication can be seen as a confirmation of involvement, but a potentially shallow engagement. Players strategizing together about the future might be said to be seriously engaged and competent participants.

Communication: This is whether players interact with one another intentionally during the experience, whether through direct address or non-verbal means such as pointing. Communication has verbal and non-verbal dimensions, as previously specified. As the study was conducted in pairs, communication was be unilateral or bilateral. Another dimension is whether communications are being received. Its indicator is the presence or absence of directed speech or gesturing by one player to another, and the response or lack thereof to the same. The quality of this discourse may also be measured by characterizing the vocabulary as "everyday," "scientific," or "Type 2" - something in between. The importance of Type 2 vocabulary has been documented in struggling readers (see Beck, McKeown, & Kucan, 2002) and in science students by Kafai et al. (2010) and Squire & Jan (2007).

Argumentation: This is whether players attempt to convince one another of something via an argument. Argumentation was indicated by one player stating a thesis and attempting to back that thesis with evidence. Arguments have dimensionality in both
their quality and their nature. They were ranked as strong or weak by the research team based principally on the depth and relevance of the evidence.

Coordination: This is whether players deliberately coordinate their activities in the game. Coordination was indicated by both players making any given action in the game as a result of planning together. This is a presence/absence indicator, although the dimensionality includes attempted coordination by one player, not received by the other. Another dimension of coordination is whether the coordination was experimental in nature ("Let’s see what happens if...") or deliberate ("OK, we need to do A then B to get C"). The final dimension of coordination is whether it is negotiated or merely advanced and accepted.

Co-strategization: This is whether players adopted a long-term strategy for the puzzle together. Co-strategization is similar to Coordination, but differentiated by its timescale and intentionality. It is a presence/absence indicator, marked by players planning two or more turns ahead together. It has the same dimensions of attempted or not, experimental or deliberate, and negotiated or accepted.

Operationalized Concepts (Interview)
The concepts below represent players’ reflections on the process of playing Sanctuary, and the expression of their experience. In order understand their experiences and to make quality improvements to the game, it is important to know whether players had fun, knew what to do, and were generally able to make sense of the experience.

Engagement/Fun: Players were asked how much they enjoyed the experience and/or whether they had fun. They were also asked to elaborate on this experience, in effect operationalizing the concept with the researcher. Going into the interviews, the players were presumed engaged if they played the game throughout the allotted playtime, as well as if they laughed, smiled, or otherwise demonstrated enjoyment during the process.

Usability: Players were asked about their experience using the game as a tool and piece of software. They will be asked to elaborate on the clarity of the interface, whether anything confused them, and how attractive they found the game. Players were also asked about how they felt the game could or should be used in schools.
Role/Expertise Differentiation: Players were asked in directly about their epistemic frames on the game world through the tools and knowledge they had to use in the game. Players will be asked to summarize their use of each tool and to explain their use of that tool. They were asked if they felt they had a clear job to perform. They will be asked if they had used or seen a similar tool previously, and if they feel they could use that tool or a similar one in the “real world.” Finally, they were asked about their role in relation to the other player—did they work together well? Was it easy to talk to one another about the tools? Were they able to share ideas easily? Could they describe the other players tools and role?

Conceptual Understanding/Learning: Finally, as this is an exploratory, formative study for this project, it is not necessary to demonstrate clear learning gains through something as theoretically unambiguous as a random control trial (see above regarding phronesis and design based research). Nevertheless, learning is of great interest to the end goal of the project, so players were asked if they felt they learned anything in the process of playing the game.

Analysis
Once collected, the data was synthesized and analyzed to produce a narrative account of play sessions that targets the players’ experiences of the game and the qualities of player communication during the experience. Each dyad was treated as a case study, extracting meaning therefrom. The goal of the final stage of the research however, is to develop a better sense of how students, teachers, and schools interact with the game/intervention and to isolate best practices for improving the game, for implementing it in schools.

SITE DESCRIPTION

About Bedford
Bedford, Massachusetts is a small and prosperous community outside of Boston. It has a population of 13,814 (2009), and an estimated median household income of $112,918, compared to a statewide average of $64,081. The racial composition is: 89.9% White; 5.4% Asian; 1.8% Hispanic; 1.6% Black; 1% Multiracial; .2% American Indian; and .1% Other.
In terms of educational outcomes, 94.9% of the population has a high school education or higher. 57.4% have a bachelor’s degree or higher. 27.3% have a graduate or professional degree, and only 2.3% are unemployed. The top 3 industries that Bedford men indicate work in are: professional, scientific, and technical services (24%); computer and electronic products (12%); and construction (7%). For women, the top three industries are: professional, scientific, and technical services (17%) health care (15%); and educational services (15%). The top 3 male occupations are: computer specialists (12%); engineers (9%); and other management occupations except farmers and farm managers (8%). The top three female occupations are: computer specialists (8%); secretaries and administrative assistants (7%); and other management occupations except farmers and farm managers (7%).

**Bedford High School By The Numbers**

Bedford High is a strong performing high school in Massachusetts, ranked 10th in Massachusetts in 2012 by Boston Magazine (2012). Enrollment for 2012-2013 was reported to be 912 students (451 male, 461 female). The school’s racial composition is white 73.7%; Asian: 10.4%; African American 7.9%; Hispanic 4.6%; Multirace non hispanic: 2.6%; Native American: 0.7%; and Native Hawaiian, Pacific Islander: 0.1%. Other demographic information includes students with a first language not English of 4.4%; students with limited English proficiency of 0.4%. The school is 13.2% special education students, 4.4% students on free lunch, and 1.3% students on reduced lunch. The school has a 96.8% Graduation rate, and 77% go on to a 4 year college. The student teacher ratio is 12.9:1, compared to a state score of 13.5:1. The school’s performance on the Massachusetts Comprehensive Assessment System’s 10th grade exam, regarded as one of the finest in the country, is quite exceptional. 60% of students are rated advanced on the English Language Arts exam, 40% proficient, 1% Needs Improvement, and 0% Warning/Failing. On the Mathematics exam, 73% are rated Advanced, 20% Proficient, 7% Needs Improvement, and 0% Warning/Failing. On the Science and Technology/Engineering exam, 51% were Advanced, 37% Proficient, 12% Needs Improvement, and 0% Warning/Failing. The College Profile document on their website also reports that the students’ SAT scores are above both state and national averages (1734 out of 2400 for the class of 2012) (2012). The same document also boasts about the new iPad program in which all freshmen and sophomores in the 2012-2013 school year were provided with iPads, one to one.
Experiencing Bedford High
It was not shocking to, after the fact, discover that Bedford High is in someone’s top 10. The school building itself is quite contemporary, and while institutional, feels very warm and vibrant. Ceramics projects fill glass cases that line a major hallway. The school’s commitment to public health is made plain by student posters on the walls describing the ill effects of drugs, alcohol, and sexually transmitted diseases. In the science wing, careful drawings of reptile anatomies greet you. The school’s spirit is also evident in the ever-present royal blue and white Bedford Buccaneer logos and theming. There were always adults in the hall engaged with students and the students seemed generally happy and well-behaved, but not suspiciously so. There was a great deal of laughter and affectionate horseplay on display.

Some of this may be due to the fact that the end of the school year was nigh. Elections were happening, and while I waited at various points in the science office for my research subjects, I could overhear teachers very engaged with the politics and achievements of student government. It was also a very festive week, being the end of school. Prom was the night after my first day of research, and over the course of the week, there was a graduation in Lowell, a strange event in the school that involved some parents covering a hallway in mylar and Twilight posters (passing students could be heard expressing that a) they had no idea what was going on and b) Twilight is so over), and an annual ritual in which the night before graduation, the juniors meet below the bleachers of the school’s major playing field and have a massive "fight" with blue and white paint, allowing it to dry on their skin and in their hair and clothes (which they sleep in), coming to school the next day proudly displaying the results of their battle.

Bedford High was not my first choice research site. I was encouraged to pursue a high school near me, Arlington High School (number 40 in the same Boston Magazine ratings). In many ways, it would have been more appealing to conduct this research in a school and community that was struggling a bit more. While I was able to easily make initial contact with Arlington though, it was a great challenge to actually get into the school to do the research, due principally to availability. The district science coordinator ultimately wrote in an email:

I am sorry to say that I haven't heard from any students. I posted flyers as well as placed a notice on the spyponders email system. I think disruptions like our power outage last week for which students and staff were sent home, and the fact that the term just ended this week and tests and grades being due may have everyone distracted.
Prior to this, when committing attempting to find subjects through teachers, he wrote:

I have tried several times to get volunteers through the teachers, but with no luck. I think the range of initiatives on the table right now, coupled with meetings on various issues, snow days and MCAS exams, teachers are overwhelmed.

I include this because it is important to note that when committing to doing research in schools, the schools that may need interventions the most may be a real challenge to gain access to, and the schools with a great deal of success may grant an ease of access allowed by not struggling.

**RESEARCH**

When I was able to finally arrange to conduct research at Bedford High, I was able to only recruit 5 pairs of students (10 students in all) through the Science Department head and one of his other teachers. Because of the difficulties in accessing students' grades under the law, I had the teachers arrange the pairs based on my directions, described above. The research sessions then were conducted by me, blind to the academic achievement levels of the students in each pair. Once the research sessions were conducted, I met with the students in the Bedford High School science office at a long table. Students were first observed and video taped with a mobile phone camera, and then interviewed as a dyad. Afterwards, the Science Department Chair reported the student grades to me via the following ranges: High (85-100), Medium (84-75), or Low (below 75). Pairs 1, 2, 4, and 5 are freshmen; pair 3 are juniors and honor students. The results of my observations and interviews are reported below first as case studies, with thematic “lessons learned” following. These lessons learned would, in a larger project, be folded into iterative, further work on Sanctuary.

**Some general notes:** The program was mostly finished by the time testing began, but there were particularly frustrating snags during the first two sessions that limited some of the collaborative activity. As the Science Department Chair said on the last day, “It’s gotten better reviews as the week has gone on.” Additionally, although I didn’t change the protocol much from day to day, there was one major change. On the first session I thought it would be a good idea to allow students to try to figure it out. This failed disastrously, as I will discuss below, so for every subsequent session, the players got a lengthy in person, over the shoulder tutorial from me about the tools and the space of the game. Before every session, I verbally provided students with the following instructions to make their function there as clear as possible and to set them at ease with the processes and equipment of research:
You're here to help me make it better.
The best thing you can do is really try to play.
I will be observing.
If you need me, feel free to help for help, clarification etc., as if I was your teacher.
I may, if I think it's appropriate, intervene, ask questions, etc.
Because I'm doing that stuff, I need to film you with this camera.
OK? Any questions?
The idea is that you are park rangers. You each have different tools to help manage the park.
Go!

The research dyads are presented below in chronological order. I have provided the subjects with pseudonyms in order to protect them, but to also make it easy for the reader to find which student I'm talking about at any given moment. If you compare the demographic data of my sample to the school's demographics above, you will see that I have (roughly) oversampled for males and Asians. It is also fair to say that with two low performing students, it is possible that I am oversampling for poor performance, although I do not know the MCAS scores for these students, or the relationship between their grades and their MCAS scores. As stated above, when conducting research in a school, one must, especially on short timelines, accept the subjects available to you. It is also worth pointing out that the teacher doing some of the pairing pointed out that in a situation like this, the lower (and even the higher) achieving students that volunteered tend to be of a more helpful nature, which is a type of bias. Each student is presented in pairs, first by pseudonym, then by race, then by gender, and then age. As Collins et al. reflected, this is another DBR project with too much data to analyze it all, so the bulk of the analysis here will focus on the interview data taken after the play sessions. This decision was in part made because players were, for the most part, not very communicative with each other during game play, mostly communicating about clerical functions, like whose turn it is.

Pair 1: Rachel (medium, caucasian, female, 15) & Erica (high, caucasian, female, 15)
Rachel and Erica were my first pair of subjects. I was warned before I met Rachel that a french fry from a fast food vendor allowed to set up on campus for the day had given her sister an allergic reaction and so she might not show up at all. When, to my great relief, she did show up, she was teeming with energy. Due to her sister's hospitalization, her mother could not pick her up, so it became clear that we would have to cut our session shorter than expected so that she could take the bus home.
It was clear right away that Erica and Rachel are friends. They had an easy, funny rapport. Rachel is the louder and more direct of the two, while Erica is simultaneously arch and reserved in a relaxed way. Because, as related above, I was determined to let players figure out the game from the beginning on my first trip out, I told the girls the minimum they needed to know to get started, and then sat across from them to observe. Over the course of about 45 minutes, the game failed, the girls were confused, and I became thoroughly enmeshed in their experience. They were talking to me at least as much as they talked to each other, and this was pair that over all talked to each other the most. We had become a triad. By the time we were engaged in the interview, their rapport with me was mostly informal - I was not their friend, but I was a denizen from MIT that was willing to banter with them. Still, there are some revealing excerpts from their play. These three excerpts are indicative of our (but principally their) discourse.

In this first episode, Erica is attempting to make progress, reasoning through her options, and Rachel is struggling aloud and engaging the researcher. She demonstrates concern about her identity:

**Erica:** So like what are my options that I do...for this? Obviously, my option is Pesticide, level 2.

**Rachel:** Now, in complicatedness, this is pretty equal to the Matrix, but maybe I’m just not getting it.

**Researcher:** No, that’s entirely possible, but, uh...[unintelligible]

**Rachel:** But Erica knows I’m not too good with directions. [laughter]

**Erica:** [laughter] Are you kidding me?

**Rachel:** Okay, so now it’s waiting on...

**Erica:** ...You...

**Rachel:** No, it’s...

**Erica:** No...me... Now what am I supposed to do?

**Rachel:** Did you do that?

**Erica:** I did something...

**Erica:** I want to buy more pesticide.

**Rachel:** Is anybody going to watch this tape other than you?

**Researcher:** No.

**Rachel:** Oh, Okay.

**Erica:** [laughter]

**Erica:** [committing an action] There.

**Researcher:** Absolutely not.

**Rachel:** Not that I really care, I just don’t people to see me being silly.

**Erica:** I know, we’re not the brightest people.

**Rachel:** And like, the whole...

**Researcher:** That’s the same reason I can’t tell everyone who my research subjects are.
Rachel: Oooooh. I wouldn't want the whole of MIT to see me and my weird sneezes. Why does it keep doing that?
Erica: [laughter] It's like, you apply there and they say 'no' because they saw this.
Rachel: [sarcastic] Yes, Erica, I will be applying to MIT.

Rachel is concerned about seeming silly and being embarrassed while struggling with something that is Matrix-level complicated. Erica, who is a high achiever by traditional measures, says, “we’re not the brightest people,” and it is unclear whether she is trying to make her friend feel better or whether she legitimately feels this way. When Erica laughs about the idea of a research video getting in the way of college admission, Rachel sarcastically reveals how she feels about her ability to get into MIT. Clearly, there are impediments to these girls fully taking on identities as scientists. An advantage here of Sanctuary is that these girls’ thinking is now exposed. It may not happen with a traditional teacher or other mentor who is not from MIT, but their thinking is exposed. In this second vignette, the players are once again working through the processes of the game, and Rachel, when challenged, performs a pretty clever reasoning through her problem. This time, her thinking is visible to herself.

Erica: Okay, now we’ve got $1316. What should we...should we do some advertising? Should we experiment?
Rachel: Do we want to do more advertising? Do a brochure?
Erica: Sure...
Rachel: Brochures are good...
Erica: We don’t have that much money...No, hold on...waiting on you.
Rachel: Oh. I...Do you want me to an Observer? What does the information from the Observer give you though? How does it help you?
Researcher: Um...
Erica: Does it benefit our budget in any way?
Researcher: Well, how do you think it might help?
Rachel: [laughter] ...Well, I think if I...
Researcher: So, what kind of information was...
Rachel:...understood the game a little better, I’d probably get it that...well, the information just...it just gets...the thing is, it’s that the wolf eats the deer, so that might tell us that the deer population is going down, but we also don’t know how high the fertility rate is for the deer, so we don’t know how many more deer there are, so I’m not sure if there’s an equilibrium of the wolf and the deer, or if there’s a decreasing population of the deer and that’s a problem, but is it a problem...
Erica: [laughter]
Rachel: because the deer...Oh! vegetation! Oh!
Erica: [laughter]
Rachel: I see, if the deer...the more I talk...if there’s a decreased population of deer then there might be more vegetation, which is what we want, right? The bushes? So is it good that the wolf
ate the deer? Should we be introducing more wolves into the environment? Like, how do you produce more wolves?

Erica: Well, that happened last time...
Rachel: Because all you can do is introduce bees...
Erica: No, it happened last time.

Unfortunately, a malfunction with the software in its first time in school meant that Rachel couldn’t follow up on her hunch. Still, a combination of the problem space of Sanctuary and the right question from me (although I argue it could be any mentor) seemed to give her the opportunity to reason and demonstrate quality scientific thinking. Not only that, but she was able to bring content knowledge from somewhere else into the game, regarding the idea of equilibria in complex systems.

Finally, in this last episode, Rachel offers a vivid and creative idea, that while not necessarily perfect for Sanctuary, demonstrates an engagement with scientific concepts and ideas.

Rachel: Um, do you want to do...so did you want to do more pesticide, then? Or no, because they’re just visiting the flowers though. That’s good, right?
Erica: Yeah, I’m not really...
Rachel:...or is it not good?
Researcher: Uh, yeah. The bees aren’t destroying your flowers.
Erica: Non-purple flowers.
Rachel: Are there poachers? Oh, you should totally add poachers!
Erica: Oh my god! You’re so weird!
Rachel: You know those rhinos...There are rhinos on a preserve in Thailand where the rangers are protecting these like...the rare rhinos, but then the poachers are paying off the rangers, to tell them...
Erica: Hey, look what happened!
Rachel:...to tell the poachers where the rhinos are, so it’s like this awful cycle, where the rhinos are dying at the hands of the people who are supposed to protect them.

I am not entirely certain what to make of Erica’s comment, "you’re so weird," here. Erica has been supportive and encouraging of Rachel’s efforts throughout the rest of the session, so it probably does not mean much. Perhaps she was embarrassed that Rachel was wandering off track? Once again, I believe that the virtue here is that the players’ thoughts and ideas are made visible in the small learning community of our pilot.
During my interview with Rebecca and Erica, a major message was that they wanted more guidance in the game, sometimes calling for a, “user’s guide...that tells you what everything is.” The girls were definitely lost a lot, saying that by the end, the goal I had given them was “distant,” and, “we got lost because we were focusing so much on the animals that we forgot that the animals were going to give us data that would help us with that, but that and that didn’t really come together.” The software and I had let them down, and neither seemed particularly inclined towards games in the first place. The girls seemed to be not have much of a gaming background, and Rachel in particular was very focused on some of the stability of the traditional classroom. She said:

Like, I can just picture it being like a classroom of twenty-five kids and they're all asking the questions we're asking, and the teacher’s getting frustrated and stuff, and at the end is just like, ‘Oh, screw this’...At the level it is now, I can see it not being as efficient in the classroom...I can see how, um, it depends...I guess the creator of the app...would have to work closely with the teachers who create the curriculum, and like the...worksheets afterwards, so they would need, like more of a bridging...like, bridging paperwork...?

This is definitely an accurate assessment of the long-term plan for Sanctuary (or projects like it), so Rachel is definitely “getting it,” even when she claims not to be.

These girls are not unserious about STEM, however. Erica stated outright that despite the fact that she wants to work at either the FBI or as a social worker, she, “love[s] math.” Her grades, if grades are a reflection of such things, certainly indicate that. When Rachel was asked if she wanted to be have a career similar to that of a sanctuary director, she stated that, “I want to be an industrial or organizational psychologist, but I could also see myself running a place like this and have it be animal focused.”

Throughout the interview, she unostentatiously demonstrated a scientific mind, at one point inquiring is Arlington had iPads and then suggesting a comparative experiment. At another point she related that she had an experiment with small children she wished to try, but we ran out of time before she could tell me what it was.

Finally, the girls provided some of the best insight into how students might thing about collaboration. When asked about working together, Erica stated, “I think we worked perfectly.” Rachel replied, “I mean, being friends with the person helps, having easy communication with the person.” Erica then expressed a fairly gender stereotypical response, “I’m curious to see how it goes with like a guy and girl, or like two guys.”

When given the opportunity to advocate for a version Sanctuary with a single player option, Rachel said, “That’s a...no. I don’t think so,” and Erica followed up saying, “We
would be lost.” Rachel summed things up moments later, saying, “I think it will be better, and kids will be more excited to do it if it’s in pairs.”

After Rachel and Erica’s ordeal, I gave every pair a very thorough walkthrough of the game and its features before the play session started.

**Pair 2: Jonathan** (low, caucasian, male, 16) & **Alex** (high, caucasian, male, 15)

Jonathan and Alex were perhaps the least comfortable pair of subjects. Jonathan is handsome and projected as a surfer, tan with a coral necklace and a surf shop t-shirt on. Alex, although only a year younger, is much smaller, pale, and somewhat frail-seeming. In moments, it seems almost as if Jonathan is being lightly dismissive of Alex for reasons unknown (it might be easy to imagine narrative, given Jonathan’s low achievement and Alex’ high achievement, but one can only speculate). They indicated that they had been in shared classes before, but that they do not hang out together. And yet, during the gameplay, the two were quite friendly. They laughed and worked together well. Although they were working together well, both were extremely quiet, hardly talking during the game play experience, and when they did, never above a whisper. They did a great deal of looking at one another’s screens though, occasionally making comments and discussing strategy. This excerpt from their play session at least illustrates that they were speaking so quietly that my recording of them was largely unintelligible.

**Alex:** [smiles and pushes his tablet to Jonathan]
[both shake their head and laugh.]
[Alex looks to the researcher]
**Jonathan:** I’ll put it all over... are you ready?
**Alex:** Yep.
**Jonathan:** [forlorn] $42...
[waits for the game to update]
**Jonathan:** Oh god, there’s a lot of bugs.
**Alex:** [startled and looks over]
**Jonathan:** More bugs...
**Alex:** Um, we could find some...
**Jonathan:** Yeah, there are a lot of insects.
[more shared smiles and laughter]
**Alex:** It doesn’t look like it costs that much money...
[shared smiles and laughter]
**Alex:** [unintelligible]
**Alex:** I don’t think we have enough money...
**Jonathan:** Oh, yeah, we don’t.
The benefits of Sanctuary were not readily available here the way there were with Erica and Rachel. They remained quiet during the interview. The most animated they became during the interview was when we discussed potential features they would add and changes they would make to Sanctuary. A slow interview took off when we discussed gaming briefly. Jonathan said that he was into, “shooting,” with a laugh, and Alex expressed a fondness for Minecraft. Alex expressed an interest in seeing Sanctuary-style play in Minecraft. He said, “Yeah, so you can like, it’s kind of like the multiplayer of that you can have your own world and lots of people can join into that. And you’re like first person kind of... and you can walk around. So you can like, actually see how many animals there are, not like having to...[rely on abstractions, as in Sanctuary]. Yeah but like with goals, kind of...like, you have to find like three species of animals, kind of like...that you did not know were in that park or something...” Jonathan said he would definitely do that, but also pushed for a single player version of the game: “Well, like it would be a good game for like a single player AND a multiplayer...like if you want to play by yourself...Like if people like to work alone, they could do that, but if people want to work in a group, they could do that also.” Alex agreed.

**Pair 3: Kermit (high, east asian, male, 17) & Olivia (higher!, african american, female, 17)**

Kermit and Olivia were a very compelling interview, in part because they were older students, taking Advanced Placement Environmental Science. Kermit was self-assured but not obnoxious student dressed in preppy clothed, and Olivia was a tall, slender, but perhaps sullen woman with braids. Their exchanges exhibited the desired behaviors. Consider this this exchange:

**Kermit:** I think I just placed an Observer somewhere. It says, “bee eats flower 1,” “locust eats flower 2”

**Olivia:** Um.

**Researcher:** So, the flowers...

**Kermit:** Flower 1 would be the rosebush.

**Researcher:** Yeah, exactly. You got it.

**Kermit:** The yucca bushes would be flower 2.

**Olivia:** OK. So the bee’s eating them?

**Kermit:** So I guess we should kill them.

**Olivia:** OK.
Kermit: I guess. I'm not sure. Isn't that the point? To study the interactions and then buy pesticides to like...I don't know.
Olivia: [unintelligible] So, I'm just...apply in the area near these bushes...
Researcher: I mean, what I'll say is, that's a very plausible way...it seems like a reasonable way to attack. There's not necessarily one way to do things, but...
Kermit: Mmhmm.

These players are engaged, although Kermit is doing most of the talking. They're also engaging me as a mentor, looking for confirmation. Later, they were operating on their own, and more vocally collaborative than the previous two pairs, as you might hope an expert pair would be.

Kermit: We have $2562...
Olivia: Mmhmm.
Kermit: So should we just spend all of it?
Olivia: Yeah, ok.
[laughter]
Kermit: OK, let's spend all of it...
Olivia: Do you like advertising? Or we could do more spraying.
[looking at Olivia's tablet]
Olivia: Pesticides...or remove the bee.
Kermit: Oh, yeah.
Olivia: The bee's not that much of a problem. [reconsidering] Well...
Kermit: We should deposit species. We should put more bees in. We don't want the bees to get sick.
Olivia: I just ...I guess more pesticide?
Kermit: You want to buy more pesticide?
Olivia: Because, like, look...the bees are just...declining.
[looks at her tablet]
Kermit: OK

While they were enthusiastic about Sanctuary, they wanted more from the experience. Their desires were typified by an exchange like this during the interview, calling into question a major option in Sanctuary:

Olivia: ...I was expecting a point where something could happen to the plants, like they could all die because of the pesticide use.
Kermit: But like, you could add more variety, to add like control, like more like biological controls and stuff like that...
Olivia: Yeah.
Kermit: To like maybe, I don't know, you can choose between the pesticide and, I don't know, like, integrated pest management—stuff, options that like give a more wider spectrum of environmental, I guess, lessons that we're trying to learn.
Olivia: ...I feel like that's a big part of environmental control nowadays, because like we lean more and more towards like not pesticide use, I feel like, so...I mean it's good to like integrate more biological controls than chemical controls.

It is interesting though that there is a form of biological control in the game, adding species. Perhaps this did not feel like a real option to them though because the species you can add each turn is chosen at random “by the market.” They were bringing their content knowledge into the experience though, and demonstrating a concern for the environment and frustration with their perceived limited pest control options.

Their expert demands for Sanctuary continued when they were asked what features they might add to the game. Kermit was ready right out of the gate: “Definitely add like meters, maybe like meters by the side to show like if I were to click pesticide, you could see like the levels, and you can click each level, and maybe you can see like the price of each pesticide. If you selected one, you could see a meter that shows the effectiveness of it...?" Olivia was ready too, saying, “I would also make the economics of running the refuge harder, because like, I could just spend money however I wanted to and Kermit could do whatever he wanted to do, and it wasn't like we were running like a risk, and I [never felt constrained by the money]. I felt like it was too easy to win.”

Olivia used an untested strategy of purchasing advertising every turn, which seemed to provide more than enough capital for the pair to do as they wished. This was not a desired winning strategy. In fact, playing the mathematician, she wanted a goal she felt she could call her own: “I feel like there should be a money goal, or an economic goal, since I am like...I feel like that would just make it more well-rounded. That there’s some sort of monetary goal.” It makes sense that players with more expertise would like more and increasingly difficult choices, and it is an interesting proposition to attempt to scale the difficulty of this type of project. Kermit said, “I would definitely use this in our APES class. That'd be fun...[especially with more data and choices)...It could exemplify all the things that we've been going through this year.”

As interested and filled with ideas during the interview though, they ultimately interacted very little during game play. The exchanges above were some of their only interactions. This was another team with fairly quiet and subdued interactions that wanted to have a single player version of the game. This may have been more one-sided though, as Olivia said, "What I was thinking initially was it would be fun to have it like...you could have different sorts of games where one is sort of like just an economic...that’s like your
goal, and then the other one is just a biological, and one is a mix, maybe, so you could...” Kermit then related, “Actually, I like this working together thing. It made it more interactive. I feel like that was a lot of fun.”

It may also be worth noting that this study’s most accomplished pair have a great deal of STEM occupations in their immediate family. Kermit’s father is a statistician, and Olivia’s mother is a nurse. She also said her father was an engineer.

Pair 4: Ervin (medium, south asian, male, 14) & Archer (medium, caucasian, male, 16)
Ervin and Archer were a similar study to Rachel and Erica, in that things ended up being rushed. Archer was not scheduled to be in the study as of that morning, but the young man selected to be Ervin’s partner had forgotten to bring back his consent forms. This is somewhat remarkable, as I watched his teacher remind him the afternoon before. Archer was selected because he was able to get out of his class that period, had appropriate grades, and could ostensibly get his parents to consent on short notice. All of that proved true, but while the teachers looked around for a replacement for me, I got to know Ervin. Ervin is a rabid video game fan who only plays Nintendo titles because his mother is very strict about what he is allowed to play. I was excited to hear that he is a fan of unconventional control schemes as he raved about Luigi’s Mansion, a series in which Nintendo’s famous Luigi character navigates a haunted house filled with ghosts by pointing an in-game flashlight and turning it on and off at the appropriate times to solve puzzles. When Archer showed up, he was exceptionally gracious and polite, and in his first interview answer, he revealed that while playing the mathematician, he was utilizing strategies from a game he played called Megalopolis. Ervin then responded that his strategies for thinking about extracting information from the environment were in part inspired by his play in “Clash of Clans.”

Archer and Ervin were more involved and into coordination than any of the other pairs of strangers in the study, but they did not approach the coordination and rapport had by Rachel and Erica. They seemed to have fun nonetheless though, and their experiences with games of strategy seem to have helped them think procedurally.

Ervin: Alright, so I put down an observer.
Archer: OK
Ervin: The Yucca Bush went up to green again.
Archer: Money.
Ervin: The other two are still down.
Archer: Oh wow - good change. Increased money as well.
[committing turn]
Archer: OK, hopefully that...I'm going to give you some [unintelligible] species. Hopefully that, um, will increase the...
Ervin: It increased the Yucca bush a little bit.
Archer: A little bit? Alright...
Archer: [to himself]...[unintelligible, but while looking at the budget] six...pesticide level three...
Archer: [to Ervin] I'm going to throw out a TV commercial.
Ervin: OK, I'm just going to put down some small ones to see what the fox does. But that's not too much.
Archer: All set? That should increase revenues...
Archer: How'd it go?
Ervin: Good. I found out that locusts eat all the flowers.
Archer: Locusts?
Ervin: Yeah.

Later in the game, their exchanges got shorter as they developed a rapport and some seeming expertise.
Archer: So I tried to throw down some pesticide on a large area of locusts. How's it going?
Ervin: Blue is still red, and I'm putting an observer down.
Archer: Alright, I decreased the species of locusts. Aaaand...I'll do an outdoor magazine ad. The budget's down to $238.

Sanctuary was also useful for helping to generate questions. You can see here that, similar to the way that Sanctuary helped Rachel generate questions, it does the same here for Ervin.
Ervin: Alright, the rose is down to...red is low, but the yucca's doing really good.
Archer: OK. How can we increase the roses?
Ervin: I'm not sure. I should find that out.
Archer: Alright.

Archer's father works at the nearby military base, and he could be very formal, but he was also very excited about working with the money in the game as the mathematician. In the interview section, he said, "I actually liked being in control of the income. That was pretty nifty to hold all that money and be like, 'alright, this is how we're going to do it.'" Ervin was extremely agreeable, if a little unfocused. In the biologist's role, Ervin said, "I liked how you had to find out what's right or wrong to do. It's like you have to work together, because I'm finding out information to tell the mathematician and the mathematician does the pesticide to get rid of something." Oddly though, moments later,
Ervin revealed that he didn’t understand that all quadrant sampling and mark and recapture data that he had been collecting were showing up in Archer’s chart log on the mathematician’s interface. This is one of the key tools for collaboration in Sanctuary.

Perhaps the experience of this odd couple playing the game could be summarized by Archer’s pronouncement that, “[having a partner] felt good, and I think it’s based upon the people, not the game, because communication is vital,” was followed pretty closely by Ervin’s expression of weakness: “I like having a partner. It makes it easier to manage everything, instead of thinking like, ‘Oh I have to do this as well as do this.’ Because, I feel like if I had both, I’d put all my money into one thing. Like, for example, I’d put all my money into advertisements and completely forget about being the biologist. And all the plants would die because I’d have nothing.” These strange characters working together and having fun with Sanctuary was definitely inspiring for me as a designer.

Pair 5: Jeremiah (high, caucasian, male, 14) & Nicholas (low, caucasian, male, 15) Jeremiah seems like a mellow but focused kid, and reminds me of many of the kids on my high school baseball team. Smart and thoughtful, but not really aggressive. While Nicholas was not cracking jokes during the session, he radiated a benevolent sense of fun that gave me the sense he gets laughs in social situations. Like many of the other pairs, Jeremiah and Nicholas did not know each other, but my time with them was hallmarked by the two of them generating a bushelful of great ideas for the game that would trump every other session in terms of idea generation, including Kermit and Olivia. I am discussing co-designed features below though, so allow me to briefly report on the case of Jeremiah and Nicholas.

The two of them worked well together and decided to play through the game again, switching roles. During the second session though, Jeremiah took the lead pretty strongly, possibly because he felt he had mastered the biologist’s tools, or because he was the higher achiever in the pair. This could be because he was simply more confident, or maybe he was aware of their relationship in the academic pecking order.

Jeremiah: Mkay. I’m going to put some pesticide down, and...advertising...? [scratches chin] I’m going to do some advertising too.
Nicholas: Mmhm.
Jeremiah: I’m going to do a TV Commercial...
Jeremiah: [to himself now]...pesticide level two...
Jeremiah: I just pressed “Remove Species: Bee,” so...
Jeremiah: I just like [unintelligible] a whole bunch of [unintelligible]...do you want to look at my
Nicholas: [pointing to his tablet]. . . This is track birds, right?
Jeremiah: Yeah, that one does that and the other one does the plants and insects.
Jeremiah: So, I need everything so far...
Nicholas: Yeah
Jeremiah: . . . so just send it...
Nicholas: Alright...
Nicholas: You good?
Jeremiah: Oh yeah. . . Do an outdoor magazine ad?... Pesticide... You know if there’s one that needs pesticide? Which one is the lowest? The white?
Nicholas: Yeah.

One exchange during the interview demonstrated my concerns about Sanctuary fairly well. Note that this is an asymmetric group and read the following:
Jeremiah: I like it better than school work. School work here, you’re just doing like worksheets and stuff. And this is like actually putting it to use and kind of just like throwing you out there, so...
Nicholas: Yeah, I think if at the start they gave you a little more help... just for younger kids who may not understand the whole process of how different animals work, but...
Researcher: Yeah, this is, there’s... it’s definitely a complex subject.
Nicholas: But yeah, I definitely think this would be much better than sitting and watching a piece of paper or seeing two different animals stare at each other.
Jeremiah: Yeah, rather than just like writing worksheets on how like eco... ’cause that’s supposed to be like how ecosystems and stuff...
Researcher: Right, yeah.
Jeremiah: Yeah, so just like instead of just like learning it by reading about it, that’s like actually doing it, so you actually get like first hand experience on how it works and everything.

Jeremiah is capable of perfectly articulating my approach to using technology in the classroom, and my belief that it can be used in ways superior to contemporary practice. Nicholas, however, is possibly exactly articulating my fear (by directing his own anxieties to younger children) that interventions like this could do more harm than good without the in-classroom structural support of something like the jigsaw method.

A THEMATIC EXAMINATION

Fun/Engagement
In general, I think it is safe to say that Bedford High is a relatively healthy learning environment. In the science office where I conducted my research (as well as on the school’s website, is posted the school’s extremely progressive general educational philosophy:
Bedford High School students will be:

1. **Active Learners** – engaged in the quest for knowledge and understanding
   Students will:
   - understand and use what they learn
   - read actively and purposefully
   - engage in inquiry and self-directed learning
   - use feedback and self-reflection to extend learning

2. **Resourceful Thinkers** – engaged in solving problems, making meaning and developing understanding
   Students will:
   - employ creative thinking skills
   - employ critical thinking skills
   - evaluate frames of reference
   - make meaningful connections
   - conduct analytical research

3. **Effective Communicators** – engaged in sharing information, insights, and ideas
   Students will:
   - present in oral and written form with clarity, purpose, and understanding
   - express knowledge and skills creatively using a variety of media, technology and the arts
   - engage effectively in discussion

**Social and Civic Expectations**
Bedford High School students will:
- act with integrity, respect, and responsibility towards themselves, others, and the environment
- value cultural diversity and recognize global interdependence
- practice the democratic principles of tolerance, activism, responsibility for and service to one’s community
- think independently and work cooperatively to achieve goals and resolve issues

Despite all of this messaging though, every pair, when describing the advantages they saw for *Sanctuary* and interventions like it, mentioned that doing this type of "hands on" work would be far superior learning to the traditional worksheets. Worksheets! If I am problematizing any tension points in this thesis, let it be this one. To me this is a signal that even in the most well-considered and advantaged learning environments, there are
significant gains to be made in the pedagogical tools available and in use. In fact, while idly passing the time waiting for subjects, one teacher I conversed with made the desire for two types of educational technology known. One, many of the simulations they use in chemistry and physics are developed in Flash, and this teacher really wanted HTML 5 versions of the same so that the students could use them on their new iPads. Similarly, this teacher expressed a belief that the entrepreneur that invents a grading application that allows a teacher to accept, comment upon, and grade student work without downloading a file would become exceptionally wealthy.

The players in every pair but Pair 1 reported that the game was fun, and then further committed to this idea by advocating for ways to make it even more fun. It is hard to blame Pair 1 for their opinion—the version of the game that they played had pretty frustrating technical difficulties after only a brief period of play.

**Usability**

Discussing usability in *Sanctuary* is tricky. Much of the game’s play experiences were designed to be deliberately uncertain. Hidden information is *Sanctuary*’s bread and butter, and there are a wide variety of experiences as a result. For instance, consider this telling quotation from Kermit:

I don’t know. Just the last part, when we decided to put in the wolf, it said that the deers were eating flower 1 and flower 2, so I would assume that was the rose bushes and the yucca plants. So then, if we were to put in the wolf, I thought, in my mind, that the wolf would eat the deers...and that would maybe raise the rose bushes and the yucca plants, but instead it didn’t do that, so I didn’t really understand that interaction. But, I mean, maybe there’s more to it than meets the eye. I’m not sure.

Of course, this is a very difficult scenario to address from a usability perspective. There were a number of legitimate complaints from players - more things should have been labeled, some features were not as polished as they could be, and some features are unsolved issues with the touch screen. But an issue like Kermit’s is an important pedagogical issue. This is a notorious issue with learning complexity - some levers on complex systems do not generate the results one might expect because of the stochasticity of the system. Kermit bringing this issue up means that a) he is revealing the current model for this system that he has in his head, and b) he has been primed by this system to ask an interesting question. In a learning community with a trained mentor, Kermit’s question could be used as a leaping off point for an inquiry discussion.
Inside a proper learning community, this designed affordance is a useful contribution to the intellectual lives of these students, but encountered in the wild or in a testing session, it might be a usability issue.

**Role/Expertise Differentiation**

There was minimal evidence that players found themselves enmeshed in the identities and skills of professionals via the game play here. The evidence there is is similar to Erica’s declaration that she “love[s] math,” and therefore took on the role of the mathematician. Multiple teams reported that the mathematician had more work to do, but I believe this is in part because the biological tools are less comprehensible without proper training. Again, I believe this means that it is challenging to talk about Sanctuary divorced from a longer-term project that engages in fostering a learning community where the complexities of developing a sampling strategy in a plot of land could be appreciated.

Even still, Kermit above is one of the strongest students in the Advanced Placement Environmental Sciences class at what may be the tenth strongest high school in Massachusetts. It may be that developing skills that professional are not appropriate for high school students. Still, Shaffer’s epistemic games fostered success in architecture and xenotransplantation in long-term interventions, and I believe that biological sampling strategies may be more approachable than those topics.

As for my sampling strategy, I think it had mixed results. In the case of Pair 1, Rachel and Erica, I believe that they are aware of the relative difference in their grades, but it does not seem to necessarily diminish their friendship. While Erica offers a steady hand in moments during our session, or reassures Rachel, it also becomes clear that Erica benefits enormously from Rachel’s effervescence. There is certainly evidence that grades factor into Rachel’s identity, such as when she talks about her, “limited brain cells” holding her back, but it is not the whole of her identity, and she is an enthusiastic generator of questions.

On the other hand, Pair 3’s interview gave me pause while transcribing it. In reading the full transcript, it becomes very obvious that Kermit talked almost non-stop during our interview, and Olivia mostly contributes a steady stream of “mmhmm’s” and “yeah’s.” When she expresses her ideas, they are clear and quite clever, but this particular
aspect of the research really highlighted for me how pernicious gender might be when creating paired activities.

**Conceptual Understanding/Learning**

Sanctuary was designed to generate questions that would then be addressed in a formal learning community, activated and alert to its affordances and to the nature of learning. I did not measure and certainly would not presume that students learned anything specific from playing Sanctuary. Many subjects, though, were quite excited to have the questions. Consider again the conversation between Jeremiah, Nicholas, and myself. Jeremiah was excited to be in the deep end in order to learn to swim. Similarly, Kermit, Archer, and Olivia are enthusiastic about harder questions with more data and decisions to mire in.

**Co-Design**

This theme was not one that was part of the plan coming into my research, but it became an obvious and rewarding one. Where gameplay and structure perhaps did not break down the barriers between strangers, I was heartened by the warming up that occurred when Alex and Jonathan got on the same page for a moment, becoming excited about a first-person, Minecraft-style version of Sanctuary. The brainstorming that went on, and the features that were dreamt up in the process of discussing this game with them were some of the great pleasures of working with these students. In fact, building a thesis project with great undergraduates was also one of the pleasures of this project.

*Increased Difficulty/Complexity | Single Player/Multiplayer | First Person (Multiple Teams)*

All of these are standard features of commercial, off the shelf video games. The fact that they were among the early features suggested for adding to this game does not take away from the cleverness that they were suggested.

*Bird’s Eye View/Compass (Multiple Teams/Rachel)*

One of the principle concerns of the players seemed to be that they had a hard time knowing what their partner was doing, and where they were. Because the game’s camera does not zoom all the way out, players must use “landmarks” in order to find one another. The camera was limited in this way to pose a challenge that requires communication, but confusion can be a poor substitute for challenge. This was perhaps
most evident with Rachel and Erica, who seemed genuinely a little bereft at times when they could not find one another. Tools that allow players to find one another can only be a good thing.

*Cross screen messaging (Olivia & Nicholas)*

Similarly, I have come to believe that players are going to look over one another’s shoulders in this game no matter what. Olivia suggested that players might be notified over half their screen about state updates from their partner, but this seems challenging on the screen of an iPad. It rarely works on big screen TVs, after all. Nicholas suggested a simple text message get pushed across the network though, which I believe would be a fairly easy feature to implement, and provide great value to the players.

*Separation/History (Nicholas & Jeremiah)*

Jeremiah advocated for running a version of this game where players cannot look over each other’s shoulders and instead must talk because they have been physically separated. They would be in the same space, close enough to be heard with a normal speaking voice, but looking over your partner’s shoulder is impossible.

Moments later, Nicholas suggested a historical version of *Sanctuary* in which players tend multiple crops on multiple fields. This suggested to me a version of *Sanctuary* in which the players are tending multiple locations at once, meaning that casually looking over your partner’s shoulder would not necessarily yield the bumper crop of useful information that it currently does, because they may be looking at a different field or sanctuary. This achieves the ends of Jeremiah’s innovation without sacrificing a useful physical intimacy between players.

*Specialized Tiles (Nicholas)*

This was a feature that got cut from the release version of *Sanctuary*, but Nicholas got the idea that having different types of map tiles that attract different types of creatures (specifically water tiles) could produce interesting dynamics.

*Specimen Lab (Jeremiah)*

This is definitely one of the more brilliant contributions. Much of the design of *Sanctuary* relies on players extracting hidden information from the system however they can.
Several players, described above, rightly took umbrage with the fact that for some types of hidden information in the game, there is no way for players to extract it. Jeremiah suggested a side lab where players could conduct experiments to determine what the effects of the different levels of pesticide are on various plants and creatures, for instance. This would be a challenging feature to create, but I imagine it add great pedagogical value and great transgressive fun to the game.
REFLECTIONS & PROJECTIONS

Sanctuary has been a complicated project to imagine and execute. During its development, I have strengthened my resolve to serve schools while being let down by them. I have been inspired by non-traditional digital gaming platforms, the long history of human beings playing together, inventing and remaking their rules, and a complex argument against les grands hommes and the science envy that has caused so much harm in the social sciences for decades.

I have also been deeply inspired by young talent, dedicated teachers, and young people striving to make sense of the world. A cynic may say that they do so from a golden perch, but that doesn’t diminish their efforts in my eyes. I have also been inspired by numerous ideas that are not Sanctuary, and have had to sit on my hands while finishing this work.

If Sanctuary were to have the future that my research wants for it, to remain the tinkering prototype for a new(-ish) type of intervention, what might that look like? A final destination would be some sort of unit replacement in a local school, attempting to work with high quality educators to make a difference in a community that needs it, wants it, and wants to work on it with me. That is a tremendous amount of human capital to move, but given the complex works subsumed into its core, Sanctuary seems to demand this kind of commitment.

Of course, when I talk about Sanctuary this way, I’m talking about much more than a single piece of software, or a mode of interaction with a type of hardware. The technology at the core of Sanctuary will come and go, and the things that get swapped in will likely create even more opportunities. Along the way though, there will be many important design challenges to conquer. Even as the intervention is the outcome in an important sense, it must be adaptable to communities or it isn’t an outcome at all.

As mentioned at the end of Explorations, co-design appears to me to be one of the most appealing outcomes of this process. The time needed to develop the basic infrastructure of Sanctuary created too many barriers to a truly iterative design process. These students were the first people outside the development process to be welcomed into the process, and their contributions were immediate and brilliant. Moreover, they
established a new center of gravity for the project that could make the intervention into the project they need it to be. I believe that with any intervention, the more people that are invited in, the stronger it can be.

How might more voices enter the discussion? One extreme answer might be to open up the hood and allow people to create both the tools and simulations they want to study. The creation of a platform for such complexity might extend existing projects like ToolBlocks, or might be built from the ground up. Given the my experiences with Pair 1 though, I must admit that some of the cultural stigma against digital gaming, particularly by young women, makes even a gaming device with extremely gender equitable distribution a potentially uncomfortable option.

The animating idea behind Sanctuary was to use the power of fast computing to develop board game style interventions for learning about complexity. One possibility for opening up a platform like Sanctuary might be to move even further away from the screens. There are some really wonderful ideas at work at les éditions volumiques, for instance (http://volumique.com/v2/). Moving away from tablets entirely to an even more subtle use of technology is also an appealing option to consider. The attention to gender and power that this project came to late in its development has become an important animating idea to the spirit of Sanctuary. In some ways, history seems like one long negotiation of power, and it is important to not let the design of our interventions shut out or even mildly reduce the interest of half of the population.

Along the lines of adding voices, I also believe that adding players is an important part of expanding the scope and effectiveness of these structured activities. While pairing was an important aspect of the first version of this intervention, and a decision made with care, I believe there is a head to head aspect, even in collaborative play, that makes for uncomfortable moments when a given player doesn’t necessarily feel like perfect exertion.

The decisions above, of course, may lead to an even greater bottleneck than before. More subtle uses of technology may come to involve less democratic technologies. These counterbalancing factors must be considered. In some ways, the jigsaw model that is essential to Sanctuary could be a real boon in mitigating this problem. For instance, imagine some sort of large-scale project that involves the development of
modules. The development of a work force could do worse than the creation of expert
groups and jigsaw groups and the careful integration of the two.

Whatever form *Sanctuary* takes next, it will be crucial to take the steps begun here as a
beginning, not a final form.
REFERENCES

WORKS CITED


109


P. Gallison & D. Stump (Eds.), The disunity of science: boundaries, contexts, and power (writing science) Palo Alto: Stanford University Press.


Guzdial, M. (2013, August 01). Lausd has a $543m shortfall, but is spending $500m on ipads?. Retrieved from http://computinged.wordpress.com/2013/08/01/lausd-has-a-543m-shortfall-but-is-spending-500m-on-ipads/


Kohn, A. (1999). *Punished by rewards, the trouble with gold stars, incentive plans, a's, praise, and other bribes*. Mariner Books.


**SOFTWARE**


ERIA Interactive. (in development). Trails forward [computer software]. Madison, WI.


Nintendo Corporation, Ltd. (1981). Donkey Kong [computer software]. Redmond, WA.

Nintendo Corporation, Ltd. (1992). Mario Kart. [computer software]. Redmond, WA.


Valve Software. (2007). Team fortress 2 [computer software]. Kirkland, WA.

BOARD GAMES