Into the weeds: A critical analysis of game mechanics and learning goals in games for learning

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Abstract

Into the weeds: A critical analysis of game mechanics and learning goals in games for learning

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In the broadest scope, the purpose of this research is to expose the range and complexity of how educational games support learning. In a more narrowed scope, the purpose is to develop a method to help identify the qualities of educational video games that support learning. This is accomplished by analyzing the design of the game and the relationship between the in-game representations of learning goals and objectives with game mechanics and game play. In this research I analyze the fraction math game Refraction. Through a critical analysis of the game in a design walkthrough and player video data I reveal the complexity of the relationship between the type of game mechanics used support the intended learning objectives; demonstrating the tensions that arise between the two. This work focuses on three primary areas in relation to each other. It includes; 1) an account of the learning goals and objectives and how they are represented and incorporated into the game; 2) an analysis of the game itself; game mechanic(s) and how game play and game mechanics are represented and incorporated in relation to the learning goals and objectives (or not); 3) the player experience; player response to game play and

learning goals. Analyzing the design of the game maps the implications for learning and can explain why some educational games are better than others. This research provides a foundation for evaluating the quality of games for learning, and demonstrates the design of educational games requires a hybrid design approach of both instructional and game design strategies.

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Chapter 1

Introduction

Introduction

The first game I designed was in 1998-99. I was working for a start up that, at the time, had a single distribution center. Our project managers were making some decisions in each department that would adversely effect other departments in the workflow. Without understanding the full implications of their choices, and of how each of the departments were interrelated, these decisions continued to create problems with efficiency and re-work. My training and development team tried explaining to each department what the other departments did and how they fit in with the whole distribution center but 1) training was brutally fast and we didn't have the time and, 2) they weren't interested in the level of detail we needed to provide for any department other than their own. There was just too much to learn in a short period of time and if we didn't address the issue it would be replicated in future distribution centers.

At the time, it made sense that a game would be a viable solution. It could be something of sped-up simulation of the distribution center that showed a system level view of the workflow. Players could adjust the parameters to change the production workflow and act as lead in another department to experience the types of decisions they had to make that were different from their own. This all sounded like a great opportunity but when we partnered with an out-of-state development team it ended as an epic failure. As a junior designer, not only did I discover traditional curriculum development strategies didn't work, the team I was working with had never built a game designed to teach. Without a blueprint of how to design a game specifically for learning we were making it up as we went along. Though mock-ups and prototypes were built, there was never a finished product we could use.

This opportunity was fun, challenging, and I learned valuable lessons that would become central to future, more successful designs. Over the years as I continued to design and develop technology-focused curriculum and courses (including games) in a variety of industry and educational settings, I've found the factors that contributed to the failure of the initial attempt are still at play. These include developing a shared language and understanding of what learning is and how it is to be represented in game play, developing or adapting tools to effectively communicate across all members of the design and development team, and addressing concerns that playing video games and learning were not mutually exclusive.

However hard I worked to address these factors in application, through project management and communication, there are two perspectives I've noticed persist over the years. These two perspectives weighed heavily on my decision to pursue the issues of games for learning as research. First, the consistent under-utilization of what the available technology can afford to support learning, which is particularly true for digital games. Under-utilization can range from a misunderstanding of the function of technology (e.g. using a wiki for single-person publishing) or projecting instructional design practices of an older technology onto a new one (e.g. replicating a brick-and-mortar classroom in a 3D virtual environment). Second, learning didn't appear to be the primary objective of the courses I was designing. Too often the goals or objectives placed emphasis on instigating or creating changes in learner behavior or achieving desired summative assessment and test scores. Though both of these things are ever-present challenges I wanted to know more about why this happened so frequently and, in particular, with the introduction of new technologies because it interfered with learning. Studying games for learning appeared to capture both the challenges consistently.

While the use of games for learning easily pre-date my experience the popularity and acceptance of using digital games for learning has increased. The rapid uptake of using games for learning lacks the critical analysis to address the issue of under-utilizing technology and meeting learning goals and objectives. Over the years it has been suggested that a variety of learning can take place in video games and even sometimes it's viewed as just a matter of getting people to play and they will learn. The assumption that all digital games hold the same potential for learning is plagued with complications. For educational games this includes, but is not limited to;

1) The quality of game play; how much fun it is for the player and how engaging it is (which can vary by player), how well designed the game is, and how well it performs (Salen & Zimmerman, 2003; Schell, 2008; Fullerton, 2008).
2) What exactly are players learning; learning how to play the game, learning to become an expert at the game, and learning educational content or discipline specific content from the game. (Gee, 2003; Salen, 2008).
3) Contexts of game use; the type of community to support learning, external materials to support learning; how is the learning situated to enable transfer from in-game to out-of-game contexts (Bransford & National Research Council, 2000; Bransford & Schwartz, 2001; Salen, 2008; Barab, Gresalfi, & Ingram-Goble, 2010).

I believe there is a disconnect between what is anticipated games can do as demonstrated in well-designed entertainment games and what games actually deliver in terms of an learning experience. Looking at the design and structure of games, in consideration of the contexts in which they are played and the players who are playing them, we can better understand what makes a game a good educational game and determine if there design strategies that are better than others.

My suspicion is that its not enough to make a side-scrolling adventure game[1] with math questions inserted at key intervals for the player to answer before progressing to the next stage. In this hypothetical example, the learning content (math) is completely separate from any necessary game mechanics. In other words, the math question is not integral to game play in a way where the learner discovers, reconstructs or puts together or plays with the math solution in a meaningful way. Just as in some free-to-play games where the player has to purchase access to additional content or perform tasks such as adding friends from social networks to continue to play, the experience is no longer is a game (i.e. there are no interesting choices [Koster, 2005] but a task or a chore to complete before being allowed to play. Looking more closely at this, the relationship between learning content and game mechanic (and game play) it is difficult to articulate which works best and why.

The current popularity of video games for learning and the expansiveness of the domain have also become increasingly complex and challenging areas to navigate. Game-based learning and games for learning can include anything from curriculum designed as a game (e.g. *Quest Atlantis*), a particular game (e.g. *BioShock*) or set of games (e.g. *DreamBox*) as the focal point of the curriculum, or integrating a game into curriculum or professional training and development (e.g. flight simulators) to target a particular set of learning objectives. Using games for learning occur in a wide range of formal and informal learning environments and for a variety of audiences from school curriculum to health care professional development. Even the decision to use a video game for learning can depend on a number of factors. This includes assumptions bound with educational games about concepts of play, types of engagement, levels of immersion,

[1] For a complete definition of terms see *Appendix A*.

scaffolding of information, just-in-time learning, cognitive load, video games as cultural commentary, as just a few that may influence the decision to use games for learning.

Using the educational math game *Refraction* (2011), I explore these issues through an analysis of the design of the game and player video data. This research is targeted for designers, developers and users of educational games in both formal and informal settings. The work described in the following chapters contributes a method of research designed to identify qualities and attributes to improve games for learning. Educational games research is a collaborative endeavor. As a disclaimer, though the game used in this research is a game about fractions, I am not an expert in math or math education and rely heavily on those who possess this knowledge when working on *Refraction*.

Chapter One presents an overview of issues related to games for learning research, explains the purpose of the research, presents the research questions guiding this study, and details the conceptual framework. Chapter Two is a review of the literature covering instructional and game design, educational games research and methods and learning as it relates to video games. Chapter Three outlines the research methodology and procedures used for this research and Chapter Four lays out the approach to analysis of the game *Refraction* alongside player video data. Lastly, Chapter Five discusses the findings and implications. Finally, Chapter Six summarizes and concludes the work described.

Overview of the problem

The challenges of creating video games that support learning are not new, as is evident with previous technologies introduced into education, such as television and video. Though attractive and promising new technologies may be at risk of being underutilized because of lack of attention or unable to access full potential and the capabilities the technology may afford (Kerr, 2005). Designers, developers, and practitioners looking to use new technology may also have to challenge deeply rooted practices and positions, including traditional pedagogical approaches of schooling and assessments of success, that don't fit with the parameters of the new technology. Changing the "approved" pedagogical approaches of teaching and assessments used in schools may take time and slow the adoption of new ways to help students learn (Collins & Halverson, 2009). The increased interest in educational games, games for learning, and game-based learning across communities of researchers, academics, practitioners and industry represents innovations focused on digital games for learning. As broad and as deep as the interest is in thinking of digital games as educational tools has taken root, in general, the quality of digital games for learning remains elusive. Games for learning continue to fall short of expectations built up through the examples of commercial video games. This may be attributed in part to the broadly cited of reasons for using games for learning (e.g. motivating, engaging, adaptive) and the characteristics of play states thought to improve learning (e.g. persistence, interactive, learning through failure). However complex the network of qualities of games for learning may be, the crux of the issue is that not all games achieve learning success that good game design may address (Gee, 2008). At the same time, while entertainment games are engaging and fun, they may fall short of educational expectations. This includes demonstrating the educational value of digital games that struggle with assessment or the limited ways in which students engage in video game play in formal environments (Spires, 2008).

It is necessary to understand the effectiveness of games for learning requires that we challenge any assumption that all games are of a baseline quality. For example, Gee (2003) outlines learning principles that *can* be found in video games but that doesn't guarantee that all games promote all (or some) of these learning principles. In addition, not all players are aware of the types of learning that might be taking place. It is the variation in the types of games, quality of games, game play, and meaningful assessments that might be complicating our ability to better assess the effectiveness of games for learning. In addition, studies in educational research do not often provide a detailed, critical analysis of the games themselves. Instead, the focus is on the learning outcomes removed from the context of how and why the educational game in question was created.

There are a number of factors that may influence the constraints and affordances of learning in educational games. Understanding the relationship of how the learning goals and objectives are integrated with game play and then supported in broader context is one of those key factors. One way to do so is in understanding the game design choices as related to the representations of learning goals and objectives through game play (in other words, how the learning goals and objectives are being represented through the combination of graphics, text, and game interactions). More specifically, identifying how the player makes sense of the game space as evident from their decision making process through the game mechanics and representations[2] of game content and educational content. Analyzing educational games for the representation of learning goals and objectives through game play should also expose particular game design choices that might be altered to better support learning. These findings will lead to questions such as "what is it that makes this part of this game optimal?", "how can I fix this part to improve both player motivation and learning?" and "how can we show learning has occurred?"

A potential problem with games for learning, in particular math games, is the game space may consist of interactions that can be reduced to drill and practice. Some math games are no

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[2] See Appendix A definition of terms.

more than digital interactions that may have some game-like qualities (e.g. *Math Vs. Monsters*, *Penguin Jump*) or embed math problems within a game-like environment (e.g. *Math Man*, *Math Racing*). Similar to gamification which uses game-like qualities in non-game contexts (Deterding, 2011), integrating math content into digital games can range from assigning badges or a competitive point system to adding workbook math problems in a First-Person Shooter (FPS). Though these types of digital interactions can be useful in appropriate contexts with instructional support they structurally may not differ that much from non-digital instructional strategies, nor as mentioned earlier, do they take advantage of the potential of what digital games can offer.

In summary, there are a few issues and challenges unique to games for learning; 1) recognizing and taking advantage of the potential of game space while fitting in with existing pedagogical practices, specifically when it comes to assessment, 2) identifying which aspects of educational games support the learning goals and objectives desired, and 3) how to create meaningful game play that is conducive to targeted learning. With ever changing advances in gaming and educational technology though patterns and principles may be identifiable in relation to game design it may not be possible to define prescriptive methods for designing games for learning. However, it is possible to map the implications for learning and reveal theoretical and conceptual underpinnings by analyzing the design of the game and explain why some educational games may be better than others.

Purpose statement

In the broadest scope, the purpose of this research is to expose the range and complexity of how educational games support learning. In a more narrowed scope, the purpose of this research is to develop a method to help identify the qualities of educational video games that support learning by analyzing the design of the game and the relationship between the in-game representations of learning goals and objectives with game mechanics and game play. In this research I analyze the fraction math game *Refraction*. Through the analysis of the game and player data I reveal the complexity of the relationship between the type of game mechanics used support the intended learning objectives; demonstrating the tensions that arise between the two. My aim is to contribute a method of analysis to better understand why games for learning may or may not work, provide a foundation for evaluating the quality of games for learning, and to demonstrate the design of educational games requires a hybrid design approach of both instructional and game design strategies.

Study Focus

The research focuses on three primary areas in relation to each other. It includes: 1) an account of the learning goals and objectives and how they are taken-up, interpreted, represented and incorporated into the game; 2) an analysis of the game itself; game mechanic(s) and how game play and game mechanics are interpreted, taken-up, and incorporated in relation to the learning goals and objectives (or not); 3) the player experience and player behavior in relation to game play and learning goals.

From within the three primary areas, the gaps in research are four pivotal topics; 1) how learning goals objectives are interpreted and incorporated into game content, game mechanics and game play, 2) how learning goals and objectives are represented visually (i.e. splitting lasers as representations of fractions), how learning goals and objectives are integrated into interactions, and how the games supports players to make sense of these visualizations and interactions, 3) unpacking how the game space creates a player experience which enhances a complex relationship between play and learning, 4) the contexts in which the games are played and the educational supports outside of the game to "bridge" learning and support transfer to out-of-game contexts (J. Bransford, personal communication, Feb. 14, 2013; Stevens, Satwicz, & McCarthy, 2008).

The focus of this research is to explore how students are learning in general—across game and educational content—as constrained and afforded by the design of the game. Specifically, for the game *Refraction*, the focus is not limited to learning math content (fractions) but also includes learning game content (i.e. how to play the game and developing play strategies) as it relates to math content. This approach may get at the broader issue of the design of educational games that prevents having to look prescriptive design methods or specific measures of adapting individual instances of curriculum, such as using the ADDIE model (Gordon & Zemke, 2000; Tripp & Bichelmeyer, 1990).

Study Importance

Analyzing the structure and design of games for learning provides an opportunity to unpack assumptions about the qualities and attributes of video games that support learning. This analysis may also help to inform strategies for designing educational video games by revealing embedded conflicts and contradictions in the design and demonstrate how to better integrate learning goals and objectives with game play. The methodology includes an analysis of the game alongside player data also has important implications for future research in games for learning.

Research questions

Educational research has identified the potential of games for learning but industry, academics, and research communities continue to struggle with developing games for learning that produce consistent results. To better understand this problem the questions guiding this research are:

1. What can the structure and design of games for learning reveal about the constraints and affordances of player learning in game play? Specifically:
   - What do players' in-game decisions reveal about their learning?
   - How do the game design and the in-game representations of learning goals and objects constrain and afford player learning in educational games?

Conceptual Framework

The framing of this research is rooted in sociocultural learning theory by identifying the constraints and affordances of games for learning and the contexts of their use and communities of practice (Wenger, White, & Smith, 2009; Lave & Wenger, 1991). Similar to the learning ecologies of gaming, game design, and play (Salen, 2008) this research considers and analyzes the relationship between learning content, game, player and context in an effort to help us understand which games for learning are more successful than others and why. Hutchins' account of distributed cognition supports the notion that video games are a way of mediating understanding through managing tasks in a game space. In addition, the game space as a tool for supporting and capturing player thinking. In considering player interactions within the game as a system, creating the opportunity to better understand how players use the game to think through their problem solving but also how to improve the game design to support player problem solving (Hutchins, 1995; Hutchins, 1996).

Lastly, video games used in the appropriate contexts have the potential to provide players an opportunity to learn from failures and direct their own learning. Considering the role of deliberate practice in developing expertise, designing and situating educational games in contexts that specifically "maximize the influence of environmental activities" as well support appropriate "levels of motivation and concentration" (Ericsson et al., 1993) will better support player learning. Though an educational video game about fractions may not sustain the time and level of commitment necessary to develop math expertise, designing a game space that fosters and rewards persistence has the potential to guide players into developing deliberate practice.

The framework for this dissertation contains three primary areas mentioned earlier; learning goals and objectives, the game itself and player experience (Image 1).

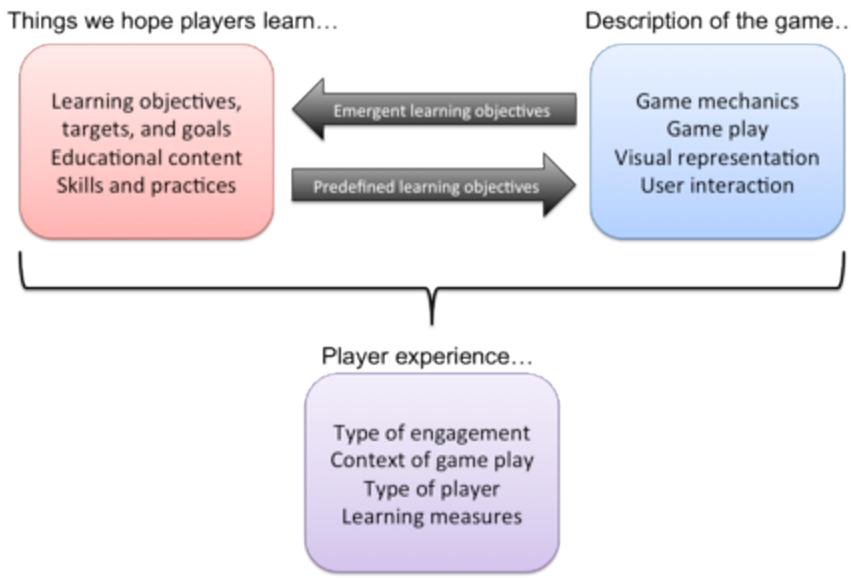

Image 1. Three areas of analysis.

The first area contains an analysis of the learning objectives, targets, or goals and how they are taken-up, interpreted, represented and incorporated into the game and game play. This means not only identifying the instructional strategies that are chosen for a particular set of learning objectives but capturing the range of the types of learning content. For example, discerning between educational content which may align with some common core standards from practices such as general, disciplinary skills (e.g. scientific practices or how a math expert approaches problems). Understanding the types of learning content in a game for learning helps establish one boundary that allows us to measure the constraints and affordances of how well they are represented in game mechanics and game play.

The second area is an analysis and design walkthrough of the game itself. This includes a description of the game mechanic(s), how the game plays, visual representations, and user interactions. This approach is similar to critical analysis of games as texts which allow us to better understand the player experience and player interpretation of game play. Unlike iterative game design protocols of testing and revision, it provides an opportunity to analyze what the game means to the player in relation to how it functions. This analysis on its own can be a critique of the game as a cultural artifact or as a text but when conducted in relation to the learning objectives we can expose potential incongruities of the play experience and the intended learning outcome.

The middle arrows in Image 1 indicate that learning objectives can either be pre-defined (e.g. this game teaches math) or unplanned (e.g. opportunities for students to mentor each other through game play advice). The latter allows us to formally recognize emergent learning that can occur through play as being provided by the game.

Both of these areas inform an analysis of the player experience. Play analytics (e.g. amount of time played or levels completed) can tell us about player behavior but it may not necessarily tell us about how the player is thinking about or making meaning as part of their play process. Including qualitative data regarding the player experience and response to both game play (e.g. provide explanations of their decision making process) and learning can help us better understand the ways in which the games are or are not working, including understanding the contexts and conditions that may or may not support transfer (Phillips & Horstman, 2013).

The analysis of these areas includes examining the relationship between them (Image 2). This begins with a play-by-play analysis of the game where the purpose is to (1) gain a better understanding of the options made available to players, (2) understand how the learning objectives of a game for learning are represented and (3) to be able to describe the player's experience. From this we can better understand specific moments in the player video and interview data.

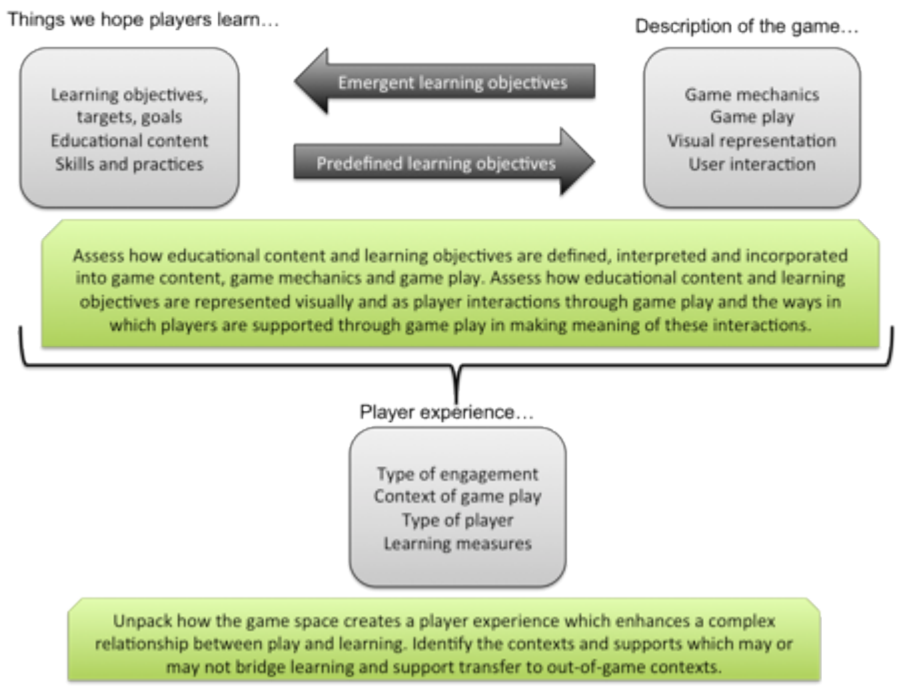

Image 2. Description of the goals of analysis

Identifying the quality and effectiveness of games for learning through examining the relationship of the game mechanics and learning objectives and player experience will eventually lend insight to design decisions.

Summary

This chapter presented an overview of issues related to games for learning research, an explanation of the purpose of the research, the guiding research questions and an overview of the conceptual framework. In the next chapter, Chapter Two, is a review of the literature covering instructional and game design, educational games research and methods and learning as it relates to video games.

Chapter 2

Review of Literature

Review of Literature

Games for learning and educational games research stems from a number of different disciplinary perspectives and can cover a broad spectrum of topics. As with any other developing area of research, understandings are built from existing and established domains. A broad range of educational researchers focus on a number of different areas including, the effectiveness of using educational games, using educational games in different contexts, and using games for learning in domain specific research such as math and science education, to name a few. In addition, important contributions come from critical game theory which analyzes the relevance and importance of games and their meaning, computer science with research in technology and development, and the game industry for innovation in design and development.

To narrow the scope, the research presented in this work focuses specifically on digital games and considers the design of the game in relation to player learning. This vein of research is based on these assumptions: (1) that there is a discrepancy between the design of educational games and typically identified representatives of entertainment games. (2) that the practices in designing games for learning utilize design strategies rooted in instructional strategies that may conflict with game design strategies typical of entertainment video games. I will draw from literature to outline and better understand this tension. (3) that methods for analyzing educational games are lacking within educational research.

Chapter Outline

This chapter begins with a description of the literature selection process. Then followed by four sections on design, contexts of game use, games research, methods and ending with a summary.

Selection Process

The literature was selected based on industry standards and games research. Works were also selected to demonstrate the broad spectrum of games research that touches upon learning but expands to other disciplinary interests.

For educational game design, I chose literature that reflects the most recent practices in industry for both instructional and game design. Books and articles were selected because of their key contribution to the development of these fields and/or their potential to lend insight into design strategies. I chose to include literature that attempts to bridge the gap between theory and practice in both disciplines (and across disciplines). I believe the quality of the literature is, in part, measured by how readily it is taken up in each of the communities. For instructional design, I chose writings that reflect research and theoretical foundations which inform the application and practice of instructional and curriculum design as it relates to digital technology. For game design literature, I selected work that approaches or intersects specifically with the challenges of designing games for learning but at the same time recognizes and acknowledges industry standards.

For the purposes of this research, I've selected literature that emphasizes learning and games as well as design. Though math is the disciplinary topic of the game selected in this research my intent is to look, not just at the domain specific strategies, but also at the potential structures and design of educational games that may not be domain or discipline specific.

Lastly, I've included a review of literature on methods of analysis for educational games. I've selected literature based on industry practices as well as educational research methodologies to illustrate the gap in research methods specific to educational games.

Contexts of Game Use

Understanding how the game mechanics support the learning objectives is just one part of the research missing in educational research for understanding how learning is supported in video game play. The another part includes considering the contexts of where the games are played. For games for learning, context includes single-player versus multi-player settings and how the game is situated within the curriculum in both more formal and more informal settings.

The social interactions and supports that occur during game play help players figure out the game in very different ways (Steinkuehler, 2004). Players playing together online or alone-together online (i.e. MMO) support each other differently than those playing a multi-player console game in the same physical space, and different still from those playing single-player games together in the same physical space (Turkle,1995; Salen & Zimmerman, 2003; Stevens, Satwicz, & Mccarthy 2008;). In many cases, especially with mobile games, the social aspect is a built in part of the game mechanic (e.g. *Draw Something*, *Bakery Story*) and requires players to interact with other players. Even in single-player games there may be communities of players who share play strategies online (e.g. walkthroughs). It could be argued that there aren't any games that don't already have a social component to them but how the game is structured to support each player varies greatly.

How games are framed as a learning activity (as the focus of the curriculum, as a portion of the curriculum, or as a recreational activity) is also part of the context. In structured learning experiences, the prominence of the game within the curriculum, or how much emphasis is place on the game, has something to do with how well of a learning tool it is. In instances where the game is the primary focal point of the curriculum, supplemental materials help tease out the nuances and complexities of the learning material. For example the game itself can be used as the focus of study as Edmond Chang (University of Washington) and Timothy Welsh (Loyola

University, New Orleans) (https://depts.washington.edu/critgame/wordpress/courses/) use *close play* as a method to engage students to reflect upon not only the content of the game (e.g. *Bioshock*) as cultural artifact but encourage players to reflect upon their role as player and participant within the game context. In this example student learning is similar to that in a literature class, constructing and supporting interpretations of the game through critical play, class discussions and critical writing.

In a slightly different example, using a commercial game *SimCity* in an urban planning course, Gaber (2007) explains the game itself contains some part of the learning content which is tied to additional classroom (or other context of) work to provide the appropriate and additional scaffolds and supports to reach the learning objectives. Using *SimCity* as an urban planning tool without the reinforcement of other course content is insufficient as the game itself misrepresents some aspects of urban planning. However, the misrepresentations in the game are a powerful for springboard for deeper discussions of complex issues of urban planning if integrated with the proper supplemental teaching materials (Gaber, 2007).

Quest Atlantis is a custom-built educational game built on a gaming engine that "leverages a 3-D multiuser environment, educational quests, unit plans, comic books, a novel, a board game, trading cards, a series of social commitments, various characters, ways of behaving, and other participant resources" (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Barab and colleagues consider Quest Atlantis to be an "example of a distributed, transmedia narrative, referring to the fact that the story line does not reside in one location or in one form of medium but is spread across various media that come together and are given meaning as the user participates in the fictional game context and investigates relevant personal issues." In addition, Quest Atlantis was implemented in a variety of settings including after-school programs (Boys and Girls club) and classrooms. This example shows that though the game itself is the focal point of the curriculum it is supported extensively with additional game-like materials which allow play not just in the 3D game but distributed and linked into different real-world contexts.

Using games, such as a browser-based game to supplement or as part of the curriculum may provide easier access and are easier to produce. However, smaller, browser-based or mobile games may make learning discrete facts fun for a short period but the game design and mechanic may not support deep context as a role-playing game (RPG) can without supplemental materials. As seen in the case of *The Blood Typing Game* (2011), the tutorials provided deeper explanations of the concepts introduced through game play but the allowing the tutorials to be optional did not ensure all players have the same educational experience. Games like *Foldit* (2008) are categorized as educational but, similar to Steinkuehler, & Duncan observations (2008), they don't formally teach protein folding in the same sense as a classroom but *can* teach scientific practice and thinking in the right conditions (Horstman, Chen, Cooper, & Bell, 2012).

If we consider an analysis and review of the games in these examples with the larger context of the curriculum objectives, we can visually represent an approximation of the relative amount of supplemental educational materials needed. In Image 1, the curriculum is represented as the rectangle outlines and the relative prominence of the game is situated within the curriculum. The remaining space indicates the relative amount of supplemental educational material required to properly support learning.

Image 1. Representations of games relative prominence as situated in curriculum.

With the example of close play, *BioShock* is the focal point of the curriculum as the vehicle for learning critical analysis (much like a literature class). The primary student activity is playing *BioShock*, supplemented with classroom and forum discussions, reflective play journals and a final project. In the examples of *SimCity* and *Quest Atlantis* the video game itself is central to the curriculum but the games lack the comprehensive material to meet the learning objectives. In the case of *SimCity* it is used as a platform for discussing and digging deeper into issues of urban planning missing from the game. In the case of *Quest Atlantis*, the video game portion is one part of a network of components. Lastly, as seen in the formal analysis and review of *The Blood Typing Game*, only with supplemental materials can we ensure players have an understanding of the learning content.

Lastly, understanding how learning is supported in video game play specifically in formal learning environments may be easier because we can control how the game is being used within that context. In informal environments, though we can describe how learning might take place in video games (Gee's Learning Principles, Salen and Zimmerman Rules of Play) but it is more difficult to isolate precisely when and why learning takes place. As mentioned with *The Blood Typing Game*, some players may never look at the tutorial materials and may not get the same level of understanding of blood types as the players who do. Similar to Kafai's observation that "There is a definite need for game studies to develop a more comprehensive research agenda that will provide instructional designers with better understanding of what works when, for what, and for whom." (Kafai, 2006) future research includes clarifying how to identify the process and conditions to replicate successful educational game design. This includes the ability to recognize the appropriate opportunities to use games for learning and whether or not the content is appropriate (or would benefit) from using a game. The process by which educators make the decision to use a video game for learning assumes a great deal about what type of game to use, whether explicitly stated or not and additional analysis is required to better understand how to determine what type of game is most appropriate for the type of instruction, content, or learning goals.

In the examples provided, the games themselves can range from very simple (i.e. crossword puzzle) to complex (i.e. MMOG). In addition the range of contexts, particularly how the game is supported by supplemental material plays a role in understanding how video game play supports learning. All of these categories are meant to demonstrate the complexity of choices available and to suggest that there isn't a simple answer for selecting which type of game to use for any given content. The context (i.e. after school program), the content (i.e. fractions), the resources (i.e. time, technology) all play a key role in successfully designing and creating a game for learning.

Design

Introduction

Over time, domain specific design practices establish norms and expectations unique to their fields. For example, the ADDIE model is a widely used instructional design method in curriculum development (Gordon & Zemke, 2000; Tripp & Bichelmeyer, 1990). The practices aligned with each of the stages, (analyze, design, develop, implement, and evaluate) can vary depending on the type of course development and the configuration of the design team, but share primary values.

Design practices across domains is a research endeavor in and of itself. Schön's account of design practice is a back-and-forth discourse between designer and the design problem or situation. His proposed "reflection-in-action" as a key characteristic of successful design strategy. He also proposes the designer's ability to do so is central to expertly solving design problems in application (Schön, 1993). He explains that practitioners do a type of research in order to solve a design problem:

"The practice context is different from the research context in several important ways, all of which have to do with the relationship between changing things and understanding them. The practitioner has an interest in transforming the situation from what it is to something he likes better. He also has an interest in understanding the situation, but it is in the service of his interest in change. When the practitioner reflects-in-action in a case he perceives as unique, paying attention to phenomena and surfacing his intuitive understanding of them, his experimenting is at once exploratory, move testing, and hypothesis testing. The three functions are fulfilled by the very same actions. And from this fact follows the distinctive character of experimenting in practice." (P. 147)

Universal design practices, such as what Schön has outlined, ground expectations when comparing design practices across domains. Though the design literature as a whole is beyond the scope of this paper this section does include a literature review across two primary areas; game design and instructional design practices as they relate to games for learning. This section considers the process, understandings, approaches, and practices of designing games and attempts to bridge the meaning of the design decisions made on those issues with the learning outcomes and analysis of game play.

Instructional/curriculum design specific to technology and games

In this section the juxtapositioning of instructional design practices with game design practices is informed by three different approaches. One approach is to look at the research for multi-media development and learning (Clark & Mayer, 2008; Aldrich 2005; Horton, 2012; Allen 2003) and seek to incorporate those design principles into game design. Another approach is to find evidence of learning theories by examining entertainment games (Gee, 2003; Kafai, 2006, Becker, 2007). Lastly, people who have designed and built games reveal the theoretical frameworks and system qualities they've uncovered in their research and focus in on particular aspects that have marked unique successes in specific contexts (Barab, 2005; Salen, 2008; Zimmerman, 2008; Steinkeuhler & Duncan, 2008).

Major works on instructional design practices closest to game design include e-learning and distance learning design strategies of Clark & Mayer (2008), Horton (2012), and Allen (2003). Their work outlines learning design strategies specific to multimedia and online courses and whose guidelines on e-learning design are taken up by both industry and educational communities as a practical guideline for instructional design. Clark & Mayer (2008) lay the foundation for instructional design for e-learning and provides explicit instructions for how to incorporate media into learning in their book *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*. Though Clark & Mayer's work is not geared towards designing video games for learning their work is important in revealing how e-learning designers are guided in thinking about how to use computer-based technology and incorporating media and interaction into coursework. The differences in approach can make more tangible design strategies best suited for games. For example, the author's recommendation to minimizing interface complexity (Clark & Mayer, 2008, p. 368) to ensure learners aren't overwhelmed is very different than the design approach in gaming which is to distribute player information within a gaming interface—not to confuse ease of use with complexity. This does not mean a reduction in complexity but can mean more scaffolds to get the player to proficiency and ensures the player has what she needs when she needs it to support the type of interactions required for game play. These sorts of slight distinctions in approaches (either learning content focused or game experience focused) may be in direct conflict with each other.

The design recommendations outlined in Clark & Mayer are informed by Cognitive Theory and managing cognitive load (Clark & Mayer, 2008, p. 39) but this conceptual stance contributes to what makes e-learning less game-like (interactive, emerging) as it focuses on segmenting, chunking, and *presenting* information to the learner rather than creating opportunities for learners to experience content as a game does. Clark & Mayer's guidelines for creating e-learning curriculum is intended to ease creation and development of e-learning and is not meant as design guidelines for educational games. Though authors briefly summarize the desired qualities and appropriate times to use games and simulations for learning, they do not discuss designing a game strictly for educational purposes.

Clark & Mayer's work represent an intersection where pedagogical practice meets technology design that reveal assumptions about what makes good instructional design. These practices may get adopted into designing games for learning but don't support good game design. In Clark Aldrich's book *Learning by Doing: A Comprehensive Guide to Simulations, Computer Games, and Pedagogy in e-learning and Other Educational Experiences* the author bridges the gap between the potential for e-learning and games and simulations for learning by examining a ranges of simulations and potential uses. Through explaining the features and functions of games, game structures (i.e. Role play) and simulations Aldrich is able to compile a list of characteristics essential for successful learning. Though it isn't as prescriptive as Clark and Mayer's account for e-learning design the result is we are given a collection of game structures, commercial games, and simulations that are helpful in identifying successful games for learning for specific conditions.

Becker provides a thorough analysis of learning theory evident in games including "Gagné's Nine Events (Gagné et al., 1992), Reigeluth's Elaboration Theory (Reigeluth et al., 1980), and two more recent works: Bruner's Socio-Cultural Approach to Education (Bruner, 1996), and Merrill's First Principles of Instruction (Merrill, 2002)" (Becker, 2007). The author addresses educational content in entertainment and games and ties this with the intent of instructional design: “Even though many offerings in film, on radio, and in television are designed primarily to entertain, there are also many that are intended to deliver a message – *to teach us something* – and that intent lies at the very heart of instructional design.” (Becker, 2007). Becker concludes that when educational theory “is viewed in the context of video games, once again, the organization and design of good games already meet many criteria for well-organized instruction.” (Becker, 2007) recognizing that the correlation between instruction and *good* game design.

Similarly, Kafai looks at games for learning from an instructionist and constructionist perspective and argues that we need to be looking at games for learning both as an activity of playing the games and as an opportunity to learn through making games (Kafai, 2006). She recognizes that from an instructionist’s perspective there is a deeper philosophical issue “hidden within the premise of instructional games: that we need games to “sweeten” the learning of difficult ideas” (Kafai, 2006) revealing an underlying motivation for using games for learning. Kafai also explains that “In the case of instructional games, a great deal of thought is spent by educational designers on content matters, graphical representations, and instructional venues. The greatest learning benefit remains reserved for those engaged in the design process, the game designers, and not those at the receiving end, the game players.” (Kafai, 2006) revealing stance that the design process itself is a learning opportunity.

A more broadly based account of the correlation between video games and learning theory, instructional strategies can be derived from Gee’s work. Games for learning as a topic/field was bolstered by Gee’s work (2003) where he identifies “learning principles” which can be potentially found as inherent qualities of digital games. To understand how to design games for learning from another angle, Gee (2003) evaluates the learning potential in entertainment video games. Gee's book *What Video Games Have To Teach Us About Literacy and Learning* is an account of the attributes and conditions of video games that enable and promote learning. His description of the qualities of game play is an important bridge to education, particularly for those who may not play video games but are interested in understanding how they can be useful. From his experience and observation of game play he describes 36 learning principles found in video games. Principles such as the distributed principle where "Meaning/knowledge is distributed across the learner, objects, tools, symbols, technologies, and the environment." and the "bottom-up skills principle" where "basic skills are not learned in isolation or out of context; rather, what counts as a basic skill is discovered bottom up by engaging in more and more of the game/domain..." (Gee, 2003). What is pivotal about Gee's book is that he concretizes the learning that can take place in well designed video games into generalizable principles some of which can be found in any learning context. Though he doesn't specifically explain how we should be using these principles to design games for learning his observations useful for seeing the qualities games can potentially possess.

Gee describes gaming experiences using specific types of games (i.e. *Deux Ex*, *Tomb Raider*, *The Sims*), yet there isn't evidence that all 36 learning principles exist in each of the games he played. In other words, his list is an aggregate of play experience. This can be problematic if we are to take his 36 learning principles into design consideration for making a new game. For example the narrative in *The Sims* is user generated through game play and the narrative in *Arcanum* is part of the player experience as the story unfolds, however both can be viewed as successful games but for different qualities and reasons. So remains unanswered how to best replicate different learning principles into different games.

Breuer and Bente take a slightly different approach by examining the use of commercial off-the-shelf (COTS) games for learning in educational contexts. In their article *Why so serious ? On the Relation of Serious Games and Learning* the author describes the landscape of serious games with the focus on "relation between serious games and learning" (Breuer & Bente, 2010). The authors suggest "design and implementation strategies that allow the integration of commercial off-the-shelf entertainment games and of specially designed serious/educational games in embedded learning settings" (Breuer & Bente, 2010) similar to Gaber's use of *SimCity* as part of an urban planning course (Gaber, 2007). In this design strategy the authors propose is "the initial step should be to identify the playful elements of learning and to design games for educational purposes accordingly" (Breuer & Bente, 2010) and propose categories to help identify how to use commercial off-the-shelf (COTS) games for learning. The significance of using commercial games in a formal educational setting is the faults of the game content present an opportunity to discuss some of the more complex issues. For example, studying issues of gender in MMO's (Taylor, 2006) or the overlooked details, such as socio-economic status and urban planning (Gaber, 2007).

In other research, complex theoretical frameworks for designing games for learning, are becoming increasingly more visible (Barab, Gresalfi, and Ingram-Goble 2010; Salen (2008); Salen and Zimmerman, 2003) as researchers reflect on more narrowed and specific qualities of games for learning. Barab, Gresalfi, and Ingram-Goble (2010) explain the potential of well-designed games through a custom-built game, *Quest Atlantis*, which is focused on playable narratives. The authors argue that "videogames— with narratives that are playable—have the additional potential to position players to experience a sense of agency and consequentiality (Gee, 2003)." They explain transformative play is a type of narrative driven play where players possess "dramatic agency: They make decisions that affect the direction of an unfolding story line central to the fictional game context (Murray, 1997)." (Barab, Gresalfi, and Ingram-Goble, 2010).

In designing *Quest Atlantis* the authors identify the core elements of consequentiality, intentionality, and legitimacy bounded by person, context, and content (respectively). This is important as "Merely playing a game does not ensure that one is engaged in transformational play. Playing transformationally involves (a) taking on the role of a protagonist (b) who must employ conceptual understandings (c) to make choices (d) that have the potential to transform (e) a problem-based fictional context and ultimately (f) the player's understanding of the content as well as of (g) herself as someone who has used academic content to address a socially significant problem." (Barab, Gresalfi, and Ingram-Goble, 2010). Because of this the authors propose their design "build(s) on a theory of learning that assumes that learners, content, and context are inextricably bound together; our designs therefore position learners as active decision makers who use their understandings to inquire into particular circumstances and change them" (Barab, Gresalfi, and Ingram-Goble, 2010). This design approach suggests creating a game environment that supports the player actively engaging in transformational play and that the learning objectives and educational content are folded into this structure.

In *Toward an Ecology of Gaming* Salen describes an "overall "ecology" of gaming, game design, and play, in the sense of how all of the various elements—from code to rhetoric to social practices and aesthetics—cohabit and populate the game world" (Salen, 2008). By looking at the learning ecologies, hidden agendas, and gaming literacies as conceptual categories that allow us to think of gaming beyond just the play state and game but to consider the game and the context as a complex system. Similarly, the work of Steinkuehler & Duncan (2008) on video games and science learning and practice runs parallel with the games in this research. They draw upon Jenkin's participatory consumption and understanding informal contexts from Lave and Wenger they examine forum discussions from *World of Warcraft* to show collaborative construction of knowledge. They argue examining these informal game spaces shows "scientific reasoning that emerge as a natural part of gameplay in informal MMOs" (Steinkeuhler and Duncan, 2008). Their research points to the notion that playing certain games promote "scientific habits of mind".

In *Gaming Literacy: Game Design as a Model for Literacy in the Twenty-First Century*, Zimmerman looks at gaming literacy as "an approach to literacy based on game design" (Zimmerman, 2008). In his definition of gaming literacy, he states; "Gaming literacy is literacy—it is the ability to understand and create specific kinds of meanings" and this literacy involves "having a systems point of view (being systems literate)" and "understanding the world as dynamic sets of parts with complex, constantly changing interrelationships—seeing the structures that underlie our world, and comprehending how these structures function" that become known through play and game design. Zimmerman's intent is to show how game design as a practice is an "investigation of the possibility of meaning, truly gets at the heart of gaming literacy, and ties together systems, play, and design into a unified and integrated process" (Zimmerman, 2008).

For Zimmerman, gaming literacy does not include "serious games"—games designed to teach you subject matter", "persuasive games" that are designed to impart some kind of message or social agenda to the player", or "training professional game designers, or even about the idea that anyone can be a game designer." His objective is to show that game design requires a literacy based in play (Zimmerman, 2008). Though his focus is using game design as a pedagogical tool his insights into the design process are also very helpful in understanding how games for learning might be most successful. For instance, central to what make games powerful learning tools is the "game design's affinity for the process of making meaning, it is also radically interdisciplinary" and "game design, as the investigation of the possibility of meaning" (Zimmerman, 2008). This raises important design strategies such as seeing the content manifest itself in a number of different, but potentially, playable ways; requiring the designer to understand, not only the game content but how the game content will play itself out with players and "creating a set of possibilities" (Zimmerman, 2008). Lastly, Zimmerman explains a position essential to successful game design and insight for games for learning;

"A game creates its own meanings (blue means enemy; yellow means power-up), but also traffics with meanings from the outside (horror film music in a shooter means danger is coming; poker means a fun evening with friends). For a game designer, the creation of meaning is a second-order problem. The game designer creates structures of rules directly, but only indirectly creates the experience of play when the rules are enacted by players." (Zimmerman, 2008)

Player's interpretation of the game space isn't a result of a controlled environment. At best game designers can suggest, sometimes strongly, how a player is to best proceed. It is in the player's engagement, the interaction, that the meaning is created. For learning this means the designer can present an experience for the player but not secure a specific outcome.

Squire (2007, 2008) proposes games as dynamic systems and performative spaces that promote player interactions and requires a type of gaming literacy. In Squire's article, *Video-Game Literacy: A Literacy of Expertise,* he describes games as dynamic systems and interactive texts where "cycles of action comprise of feedback loops whereby the player iteratively develops goals, takes an action, experiences feedback on that action, and shifts goals and actions accordingly" (Squire, 2008). Squire elaborates on game-based literacies that "include a constellation of literacy practices that are quite different: texts are spaces to inhabit, learning as a productive, performative act, knowledge is legitimized through its ability to function in the world, participation requires producing as well as consuming media, expertise means leveraging digital spaces to further one's goals, and social systems have permeable boundaries with overlapping trajectories of participation" (Squire, 2008). Though he is talking about literacy specifically his observations support a shift in design perspective. To design a game for learning is to design a space, an experience and requires an alternative method of interpreting curricular content normally associated with instructional design practices.

Though the works presented here represent a range of research interests and indicate the breadth and variety of how games for learning can be researched, they only begin to touch upon revealing a strategy for designing games for learning. Instructional strategies for designing educational games is broad and vague though we have successes to work from.

Gee offers great insight but it is not clear whether all learning principles are evident in all games and how do we determine which learning principles are best used in which games for which learning objectives or is this just a tool to help us analyze and think about game design and learning. Though the authors outline an insightful theoretical design, it still remains unclear how to best apply their framework, duplicate the effort or what the implications are on applying their framework to a new set of learning objectives. For the broader observations such as Salen and others, descriptions of the potential of the system design are helpful in allowing us to assess the quality of existing games but they don't do much in helping us strategize how to build certain types of games for certain learning goals. The latter ones focus on system attributes that if a designer were to focus their attentions solely on fulfilling that requirement might forfeit others such as learning.

Instructional design assumes there are sets of strategies best suited for designing curriculum. These strategies can be determined by the contexts (e.g. Classroom) and/or the pedagogical approaches (e.g. Project-based learning). Though it may be argued that no instructional design strategy guarantees a specific outcome for all students in all contexts certain guidelines are accepted as standard practices.

In considering the instructional design strategies best suited for designing games for learning and/or using games for learning we must draw upon existing pedagogical practices that may not be best suited for game design. This includes considering the instructional design practitioners' interpretation of educational content into games versus multi-media. To clarify how are the learning goals and objectives represented in the game space? Is it a text description, simulation, story-based, puzzle?

Though the works presented here represent a range of research interests and indicate the breadth and variety of how games for learning can be researched, they only begin to touch upon revealing a strategy for designing games for learning. The issues raised lead to a broader question central to games, designing play. Looking to the game design literature I'll consider their design strategies and how game designers best incorporate learning experiences into game design practice.

Game Design

Game design research spans across a number of domains, HCI, Computer Science, Education, and Information Sciences, to name a few. In addition much of game design research comes from standards and best practices in industry. This is because the games themselves are the artifacts that serve to prove whether certain things work or not. If a game does well, or an aspect of the game is taken up and used in other games, then the practice, taken up by they community proves as evidence. Academically, this may not be the best logical choice for designing games - in that there are probably much stronger and better ideas about game design that exist but don't get taken up by industry because of cost, conflict of interest, etc. For example, game companies in the late 90's early 2000's were reluctant to align themselves with educational materials because they didn't want to marginalize their very important target market. However, since then some game companies have broached the gap by creating different types of gaming consoles targeted at a different audience and therefore allowing a more forgiving definition of what it means to be a gamer without risking losing money. All of this aside, pulling from the gaming literature though they are not targeted specifically for designing instruction we can gather general notions on best practices.

Part of understanding how to design and build video games is to understand the different components of what makes a good game and why. Though there is a range of emphasized attributes, these qualities aren't necessarily viewed as being mutually exclusive across game design. In early video game history Malone recognized that in games "For an activity to be challenging, it needs to have a goal whose outcome is uncertain" and during play "Users need some kind of *Performance feedback*" (Malone, 1981). Malone recommends that to support uncertainty in computer games they have to have "*multiple level goals* all present in the environment at the same time" (Malone, 1981). Malone also provides a set of heuristics for educational game designers organized by three categories; challenge, fantasy, and curiosity (which includes sensory and cognitive) to help ensure the same level of engagement demonstrated in video games. He recognizes that "Computer games can evoke a learner's curiosity by providing environments that have an optimal level of informational complexity" (Malone, 1981). In other words, the environments should be neither too complicated nor too simple with respect to the learner's existing knowledge" (Malone, 1980). Creating an optimal level of complexity that is both accessible and challenging is a common them found in all of the authors presented.

In *Chris Crawford on Game Design* Crawford explains the components foundational to understanding how to design games including the history and definition of play, the dimensions of challenge, different types of conflict, the definition and types of interactivity, and creativity. He describes common mistakes game designers make including the tendency to concentrate on how a game looks and recommends that cosmetic decisions should be made based on how they support game play; "In order to support the gameplay, the cosmetic feature must in some way provide the player with information that is relevant to the choices that the player must make" (Crawford, 2003). Another mistake Crawford points out is the use of storyboards to capture game play. "Storyboards do to game design what GOTO statements did to programming: They encourage a way of thinking that's just wrong for the task….a storyboard is an anti-interactive construct" (Crawford, 2003). This carries important consequences for production in that how we commit design ideas into specific forms using specific types of tools inevitably narrows how we are able to envision the final product.

Crawford reviews the design and development process of multiple games and captures indications of what game designers should pay attention to; the history and meaning of key terms associated with games, knowledge of known errors in game design (knowledge of the history of games) and an appreciation for learning how to design games by reflecting on past game design and development projects. Using numerous case studies to illustrate many of the key concepts covered, *Game Developer* magazine has a similar section for *postmortems* where game designers and developers talk about their successes and failures during the course of production. This window into the industry helps expose how non-play factors have a highly influential impact on the final game design and what designers and developers can do avoid them. Crawford's worked examples and *Game Developer's* postmortems both demonstrate good game design practices illustrated through past projects and is a practice representative of a fundamental component in developing game design skills.

In Rollings & Morris' *Game Architecture and Design* (2004) they capture a start-to-finish description addressing the practical day-to-day challenges of design and development, including team building and team development. From analyzing the feasibility of a game for development to identifying the core design and types of interactivity. The authors consider the ever-changing landscape of technological capabilities and how this influences game design. For example, they discuss the processing power available at one point supported a design that used a symbolic approach (where a player is rewarded for following a specific path, such as walking into a room through a door to trigger a monster attack) (Rollings & Morris, 2004). However, as processing capabilities improved nonsymbolic design could be supported (if the player discovers another way into the room, the monster still attacks). This nonsymbolic design rewards the goal, "not the method the player uses to achieve the goal" (quote of Harvey Smith, designer of Deus Ex at GDCE conference in London 2002) (as cited by Rollings & Morris, 2004). This is an important consideration for educational game designers as the representation of content is conflated with what it is we want the player to learn. It also emphasizes a type of problem solving we may or may not want to encourage (or may not be prepared to address). Allowing players to roam and test the boundaries of the game world (see the *The Elder Scrolls III: Morrowind* speed run as an example http://www.youtube.com/watch?v=m1IRxTN-_kU) is part of the design and sometimes players even find themselves in virtual parts of the game world unintended by the designers. Furthermore, this form of exploration is an accepted form of play preference.

In Salen & Zimmerman's book, *Rules of Play* (2003) the authors organize content by game design schemas (core concepts, rules, play, and culture) to help game designers think about game design practice through different frameworks. Each of these schemas contain sub-schemas to help the designer consider more deeply the different facets of design decisions. For example the authors explore play as experience, pleasure, and meaning drawing from a thorough collection of definitions, discussions, and examples supplies a rich collection of different perspectives. For example, dive deeply into defining the success of a game. The authors state that "The goal of successful game design is the creation of meaningful play" and that meaningful play can take two forms:

"Meaningful play in a gem emerges from the relationship between player action and system outcome; it is the process by which a player takes action within the designed system of a game and the system responds to the action. The meaning of an action in a game resides in the relationship between action and outcome."
"Meaningful play occurs when the relationships between actions and outcomes in a game are both discernible and integrated into the larger context of the game. Creating meaningful play is the goal of successful game design." (Salen & Zimmerman, 2003, P. 34)

This book doesn't provide the same kind of practical day-to-day guidelines as Rollings and Morris but instead draws upon game studies to provide a semi-structured list of guidelines for designing games. For example, the authors discuss complexity and emergence as qualities of game play and where a complex game cannot be too ordered nor too chaotic and emergence is when "one can describe all the rules, but not necessarily all the products of the rules" (Salen & Zimmerman, 2003, p. 158). Though the game design qualities outlined in this book may be applicable to educational game design, a few of the qualities such as complexity and emergence, may challenge assumptions or notions of appropriate pedagogical structures. That said, Salen & Zimmerman note that more rules does not equal complexity and more complexity does not equal meaningful play (Salen & Zimmerman, 2003, p. 165).

Salen & Zimmerman provide an exhaustive list of guidelines for reviewing and studying games but it is difficult to manage all of the parameters at one time to applied to game design. For instance, in the interactivity section there are six sub-topics on outcomes, four modes of interactivity, anatomy of choice, internal and external events, and space of possibility. Though this is an incredibly insightful and helpful breakdown of the complexities of interactivity alone, the bridging of these rich observations with application is a complicated task. This book looks at concepts integral to game design from a theoretical and conceptual level and provides a thorough use of examples to demonstrate each one. This work deserves to be more thoroughly researched alongside educational game review to help isolate why some educational games are successful and others not. In addition there are numerous key points, such as the chapter on Play as Meaning, relevant to educational game design but the question remains, how does designer cover it all?

In *The Art of Game Design: A book of lenses* Schell describes game design as "the act of deciding what a game should be" (Schell, 2008, p. xxiv) and that the design principles will come from everywhere because design is everywhere (Schell, 2008, p. xxvii). However he is careful to explain the "game enables the experience, but it *is not the experience*" (Schell, 2008, p. 10) and the meaning of the experience rises from the game play. Schell organizes design concepts by lenses; each lens captures and highlights a specific attribute of games such as the "lens of surprise" or the "lens of feedback". There are a total of 100 lenses and he uses these to explain the role of the game designer. For example, the "lens of unification" he recommends the designer ask: "What is my theme?" and "am I using every means possible to reinforce that them?" (Schell, 2008). These prompts are supported by a section examining what it means in a game, situates the designer in a space to reflect upon their design decisions as though they are playing the game themselves.

The organization is something of a hybrid between the Rollings & Morris approach (practical hands-on development) and Salen & Zimmerman (deeper discussions of game concepts with design advice) in that there is guidance in practical strategies (such as brainstorming tips) but also in positioning the designer as an artist. He discusses different rules that are in games but highlights the most important rule is "the object of the game" (Schell, 2008, p. 148). He breaks down physical and virtual interface when he asks questions to help the reader consider the underlying goals or purpose to the design. For example, "if you can't create a custom physical interface, what metaphor are you using when you map the inputs to the game world?" (Schell, 2008). The author points out to the designer that game structures (in this case, interface) shape how the player is able to interact (and make meaning) of the game. This is particularly evident in the questions for the lens of feedback for example, "what do players need to know at this moment?", "what do players want to know at this moment", positioning the designer as player in order to better understand play experience (Schell, 2008).

Schell also addresses how a designer wants a player to act within game and explains how different elements of game design contribute to influencing how the player responds in game play. This includes designing constraints, goals, interface, visual design, characters, and music. All of these components influence how players perceive the game experience (and make sense of it). They influence player's choice of actions and can support (or repress) the player's overall sense of freedom in game (Schell, 2008). Schell comments on games for learning specifically and notes that "good educational games are hard to make" some of the constraints being time and resources but also that games are just another tool as an educational resources and should not be considered a complete educational system in and of itself but can be helpful in some instances can be helpful for teaching facts, problem solving, and systems of relationships (Schell, 2008).

Understanding components of digital games is only part of being a good game designer. Costikyan focuses on a component of game design and unpacks what gameplay is with the assumption that in order to be a good designer we have to understand what gameplay is. He states "The game interacts with the players (and the players with each other), changing state as they play…If it isn't interactive, it's a puzzle, not a game" (Costikyan, 2002, P. 11). For Costikyan interactivity is essential for gameplay and similar to Schell and Salen & Zimmerman, he states "even for skill-and-action games, interaction is purposeful" (Costikyan, 2002, P. 11). From a designer perspective understanding the game structure as it relates to gameplay is essential for good game design as "a small change in structure breeds a big change in player behavior" (Costikyan, 2002, P. 20).

Costikyan recognizes that the game designer doesn't have absolute control over player behavior but rather it "shapes player behavior; it does not determine it" (Costikyan, 2002, P. 20). For designers it is also essential to understand how the design creates a player experience that isn't determined but constructed through the relationship between the different game components. He explains that it is important "to understand how and why game structures do shape player behavior; indeed, understanding this is fundamental to mastering the craft of game design. You cannot simply throw together a bunch of different game elements, and expect them to cohere; you must consciously set out to decide what kind of experiences you want to impart to your players, and create systems that enable those experiences" (Costikyan, 2002, P. 20). Ultimately a game designer's goal is to imagine the types of experiences players will have and try to create a system that is responsive to their play. He elaborates that game design is the "creative attempt to imagine, a priori, the kinds of experiences players will have with your game, and through that act of imagination, to create a structure to point them toward the kinds of experiences you'd like them to feel" (Costikyan, 2002, P. 32-33)

Also, Costikyan notes that games are structures that "requires players to struggle toward goals" (Costikyan, 2002, P. 21) and the games' goals are couched within the context of the game structure. He elaborates, saying "A game's structure creates its own meanings. The meaning grows out of the structure; it is caused by the structure; it is endogenous to the structure" (Costikyan, 2002, P.22). Though Costikyan's account of design is less thorough than Rollings & Morris or Salen & Zimmerman, the notion of games possessing endogenous meaning is an important distinction. This is particularly important for games for learning because in order to create a meaningful game it is essential to incorporate the learning content into the game structure.

Fabricatore focuses on gameplay, playability and the games' context as the cornerstone of game design and that "functional elements of a game cannot be balanced by any non-functional aspect of the design, since a very good game context cannot sustain motivation if gameplay activities are ill-designed (Fabricatore, 1999)." In addition, Fabricatore addresses the type of learning that takes place in games and the consequences to designers. Learning a new game mechanic can be engaging and rewarding if "enough feedback is provided to the player", indicating his progress in the learning process (as cited in Fabricatore, 2007) but he continues to explain that after the player masters the new mechanic the player loses interest. He cites Cook (2006) to explain this is considered player "burnout", which is a "state of completed learning, where the player finally figures out that a particular action no longer yields meaningful results" (as cited by Fabricatore, 2007).

Avoiding "burnout" means introducing new game content in an appropriately scaffolded way to maintain player interest and engagement. Game mechanics are the core of player interaction but there are many game mechanics working together to support the game play experience. Fabricatore also explains the different types of mechanics in video games and the benefits of introducing "satellite game mechanics". Enhancements, alternate, and opposition mechanics make game play more challenging for the player. Alternate mechanics "require new learning, a price that many players are willing to pay if that allows tackling activities in new ways." (Fabricatore, 2007). In the end he offers these guidelines for designing game mechanics: "1) Minimize the learning time required to master core mechanics' features. 2) Minimize the number of core mechanics, and the amount of features for each one of them. 3) Make sure that all core mechanics are relevant throughout most of the game, and that there are no functional redundancies amongst them. 4) Exploit polyvalence in game mechanics design. 5) Exploit satellite mechanics in order to sustain and enhance players' motivation in using core mechanics. 6) Suspend temporarily the use of specific mechanics in order to renew players' interest in them. 7) Build the gameplay mostly based on core gameplay and core meta-gameplay activities, providing through them the doses of challenge, mastership and reward that players seek. 8) Minimize the use of peripheral gameplay." (Fabricatore, 2007).

Though the particular focus on game design varies amongst the authors covered here there is a remarkable uniformity regarding some of the aspects accepted as good game design practices and what produces good games. In addition to game design research, critical game theory can provide additional conceptual frameworks to evaluate the type and quality of game play and design.

Summary

Salen & Zimmerman (2003) provide an exhaustive summary of what they've outlined as the components of game design. In their descriptions they dive deeply into the conceptual understandings and frameworks of these qualities, such as the meaning of play and types of interactivity. This is in contrast to Rollings & Adams (2003) and Rolling & Morris (2004) whose work focuses on understanding the components of game design in relation to the practical implications of the design and development process. Schell (2008) is a hybrid of the first two others, providing deeper descriptions of the elements of games but with the awareness of the restrictions of practical application. Designer Chris Crawford demonstrates preferences for exploring the narrative in games as a key feature for game design (2003). Salen & Zimmerman and Crawford's design concepts get close to learning theory but not to the same degree as the research specific to learning and games. Understanding and knowing what the game parts are and how they work together, knowledge of playing games is essential for designing them, Game design strategies don't provide enough guidance for designing instruction into the games specifically but they do call out best practices as evident in the games that are produced. The inherent quality of games as a learning tool is not predictable enough (or dependent on the quality of games) to ensure learning takes place in games in the same standards of measurement we use in curriculum - so how do we determine or find evidence of learning in games based on their design and analysis of the game itself. Rather, this review points to the idea that reviews of games are also needed to better understand how to design them better.

Games Research

In entertainment games there are categories of game genres and sub-genres such as First Person Shooter (FPS) or Massive Multiplayer Online Role-Playing Game (MMORPG). In addition to these traditional game genres there are terms that differentiate types of games for learning. *Serious games* incorporate serious topics (i.e. Healthcare, politics, science, etc.) into games and are related to games with purpose or *persuasive* games how games may influence players (Bogost, 2007). In a related cluster are games considered *edutainment*, *advergames*, and the more recently declared *gamification*. *Edutainment* seeks to bridge education and entertainment in the form of games (and other media) (Dondlinger, 2007). *Advergames* uses games to "inform" players of goods and products, such as a re-skinned puzzle game in the theme of the advertiser. *Gamification* is the application of game mechanics to an otherwise non-game context (Deterding, 2011). While proponents have identified the potential of video games for learning (Gee, 2003; McGonigal, 2011), critics propose these types of games skirt the real issues of learning as another form of "chocolate covered broccoli" (as cited by Galarneau, 2005). More broad categories used such as *games for learning* and *game-based learning* encompass a wide range of different types of games, play strategies, are games with predefined learning goals and objectives and methods for using game-like or game qualities in teaching and learning situations. In addition, using games for learning can be classified into three categories: 1) using an existing commercial, off-the-shelf game as it is, 2) modifying an existing commercial, off-the-shelf game, or 3) creating a custom-built game (Horstman, 2010). This variety of ways of categorizing types of games and games for learning will become important in recognizing the qualities best suitable for specific types of games in specific types of contexts. However, all are variants of the same theme, using games or an attribute of games to present specific ideas to players through playing experience and to successfully merge learning with game play.

Critical Game Theory

To supplement game review and analysis, critical game theory may provide examples of the types of grounding theoretical frameworks from which games are analyzed. These frameworks can provide structure for thinking about player experience, game meaning, and game play. Though the theories in critical game studies may not be directed towards game design or games for learning specifically, the analysis strategies may help in understanding the player experience of games for learning as well as prompt shifts in design thinking and allow us to re-examine game design practices. This section introduces one example of critical game theory that may be helpful in educational research for reviewing and analyzing game structure, mechanics, and play as it relates to learning.

In one such framework, Galloway (2006) identifies a quadrant of game tendencies in video games: diegetic and nondiegetic, machine and operator acts (Galloway, 2006). These four moments of game action is one way of describing and making sense of the player experience. To elaborate, "Diegetic operator acts are diegetic because they take place within the world of gameplay; they are operator acts because they are perpetrated by the game player rather than the game software or any outside force. Diegetic operator acts appear as either *move acts* or *expressive acts" (*italics original, 2006). This method of categorizing particular game experiences, for example differentiating between actions that players initiate within the game space versus actions players initiate that occur outside the game space influence how the player interprets the play experience. He goes on to describe an important consequence of this category, "…move acts change the physical position or orientation of the game environment." The player's ability to change the character's position and gaze within the game world is a type of mechanism of making new content visible and enables player/character agency in a particular way. These game mechanic parameters shape how the player/character experiences new game content. This is in contrast to nondiegetic machine acts which are "…actions performed by the machine and integral to the entire experience of play" but not limited to the world of gameplay. In other words, game mechanics such as *save game* and *game over* states are essential to the parameters of game play but are outside of container of game world. Players accept and appreciate these game parameters even if it leads to a *game over* state. Galloway's quadrant of gamic action is a conceptual lens that compartmentalizes different aspects of game play into categories of types of player experiences. In order to interpret the game space Galloway analyzes and interprets game play and mechanics to help make sense of what the construct of the game may mean to the player experience. However, this is just one example of a theoretical framework within the larger body of critical game theory.

Critical game theorists look at games as cultural artifacts (Squire, 2002; Bogost, 2006), narratives (Jenkins, 2004), and economic systems (Castronova, 2005). Game designers, academics, and educators have recognized the potential for learning in games (Salen & Zimmerman, 2003; Gee, 2003). In addition, game reviewers have long since recognized the value in breaking down the game components in order to show how a game plays and what the game design decisions mean to the player. Game walkthroughs created and produced by players, provide detailed accounts of game play. Walkthroughs outline features and content that players may or may not pay attention to during game play, detailing, and sharing the play options available to players that may not be readily apparent.

Learning and Games

There are researchers who have outlined methods for identifying the qualities of games for learning. Successful games for learning are the perfect storm of a well-made game, appropriate learning content, context which supports learning, and players inclined to the type and genre of game provided. By considering educational games as part of a complex ecology of learning (Salen, 2008) we are able to identify which instances where learning is more likely to be facilitated by the game.

Games for learning as a topic/field was bolstered in part by Gee's work (2003) where he identifies "learning principles" which can be potentially found as inherent qualities of digital games. The work of Steinkuehler & Duncan (2008) on video games and science learning and practice runs parallel with the games in this research. Their research points to the notion that playing certain games promotes "scientific habits of mind". Squire (2007, 2008) proposes games as dynamic systems and performative spaces that promote player interactions and require a type of gaming literacy which can be linked to developing skills and practices. Similarly, Barab, Gresalfi, and Ingram-Goble (2010) explain the potential of well-designed games through a custom game, *Quest Atlantis*, which is focused on playable narratives. The authors argue with the example of the above that "videogames— with narratives that are playable—have the additional potential to position players to experience a sense of agency and consequentiality (Gee, 2003)." Transformative play is a type of narrative driven play where players possess "dramatic agency: They make decisions that affect the direction of an unfolding story line central to the fictional game context (Murray, 1997)."

In designing *Quest Atlantis* the Barab, Gresalfi, and Ingram-Goble explain "Merely playing a game does not ensure that one is engaged in transformational play. Playing transformationally involves (a) taking on the role of a protagonist (b) who must employ conceptual understandings (c) to make choices (d) that have the potential to transform (e) a problem-based fictional context and ultimately (f) the player's understanding of the content as well as of (g) herself as someone who has used academic content to address a socially significant problem" (Barab, Gresalfi, & Ingram-Goble, 2010). Because of this the authors propose their design "build(s) on a theory of learning that assumes that learners, content, and context are inextricably bound together; our designs therefore position learners as active decision makers who use their understandings to inquire into particular circumstances and change them." This design approach suggests creating a game environment that supports these objectives and the learning objectives and educational content are folded into the structure. Though the authors outline an insightful theoretical design framework, it still remains unclear how to best apply their framework and duplicate the effort or what the implications are for applying their framework to a new set of learning objectives. This may be due not to the lack of thoughtful design and implementation of *Quest Atlantis* but because incorporating descriptive detailed analysis of the design of the game is not part of standard educational research practice.

Barab, Gresalfi, and Ingram-Goble's notion of "transformational play" leads to a broader question regarding video game play and learning. Game designers recognize a range of definitions of play from meaningful play to designed experiences (Schell, 2008; Crawford, 2003; Salen & Zimmerman, 2003) but the types of play afforded by games for learning may not be explicitly explored in research. In examining the game mechanics as they relate to learning objectives, understanding and describing the play experience becomes an important aspect of analysis.

Summary

Games research helps to identify and categorize different genres of games and particular areas of research. In addition, critical game theory considers games as artifacts that warrant structural and cultural analysis. Lastly, educational games research has examined how instructional strategies are supported games for learning. However, missing from the educational research is the player perspective and sufficient detail about the game play experience sufficiently. I argue that in order to evaluate the quality of educational games we first need to establish a method for analyzing them; recognizing game components as they relate to learning content and contexts and quality of game play. This type of analysis of games will help in understanding the player experience that eventually leads us to identify how the learning goals and objectives are integrated into the game play experience.

Methods

Part of the challenge of evaluating and assessing educational games is combining the research methods of multiple disciplines in order to arrive at an accurate account of what players may be learning from digital games. In this section I summarize the potential methods for researching digital games and outline how each of these may help in forming a research method unique to researching games for learning.

My initial interest in finding a method suitable for researching educational games stemmed from an array of educational research articles focused on using games for learning in a variety of settings. Though the focus and outcomes of each article was different most of them had one thing in common, they often did not include detailed analysis or descriptions of the games. Much like content analysis of curriculum that extends beyond a checklist of topics covered but considers the quality and presentation (National Research Council, 2004), I wanted to know about the structure and sequencing of game play, how the learning goals and objectives were blended into game play and what the player experience was like in relation to the aims of the research. However, unlike curriculum content analysis for educational research, the analysis of the structure of educational games seemed to be largely unaccounted for.

For analyzing the games themselves it's beneficial to consider processes from commercial game development and critical game theory. Video games are readily reviewed by players and industry. Game reviews not only assess the qualities of a game but they also do so by detailing the game mechanic, game play, aesthetic, storyline, replayability, quality of graphics, bugs, comparison to other games, etc. Not all games receive high ratings and some less-than-great games are really fun in certain conditions to some players. Reviews evaluate and provide a descriptive analysis for potential players to determine if game is worth playing. In addition game designers reference these reviews and existing games as part of their practice in designing and developing games (Crawford, 2003; Rollings & Morris, 2004; Salen & Zimmerman, 2003).

Part of the design and development process also involves usability testing and/or play testing (Rolling & Morris, 2004; Rollings & Adams, 2003; Schell, 2008; Fullerton, 2008). The general purpose of this type of testing is to flush out bugs in the software, identify issues that need to be fixed, identify design flaws that might impact or hinder desired game play, and to gather feedback on specific game components that may be in question. Though these processes could be adapted to include some form of summative assessments, typically usability and play testing does not involve extensive data collection on what the user has learned during the testing process. Furthermore, though it may capture aspects of usability that may be confusing or not useful to the user, this type of testing does not typically attempt to illustrate how users are making sense of the software or game.

For play testing in particular, measures of how much the player likes or dislikes the game space may be tracked but do not account for how the players are making sense of the game space. It can be argued that play testing tutorial levels do account for how much and how well the player is learning about the game as a means for gathering recommendations for adjusting the tutorial levels to make them more effective but measuring learning of concepts that extend outside of game play is not the end goal of play testing. In addition play testing may only document player choices but not attempt to explain why players made choices, particularly if those explanations do not provide direct feedback on how to improve game play.

Interaction analysis is another strategy for examining the details of player activity. Kaptelinin and Nardi (2006) use activity theory to examine the contexts and results of interaction design. Their theory of accounting for how users needs are being met through the design of the software in consideration of their motives and context can be applied to games. However, this approach my over-emphasize context in exchange for overlooking detailed design attributes. In addition, Barron (2003) describes a microanalysis of interactions of collaborators with the exception that the analysis is between the player and the game. She explains "*The research in this article is concerned with advancing the understanding of how microinteractional processes between collaborators influence collective achievements and what individuals learn from their interactions.*" (p. 309). This type of microanalysis between player and game reveals players' learning.

Another approach to consider in analyzing video games is from a big data perspective. These research efforts provide large data sets to account for a variety of play behaviors and sustained data gathering to predict future player behaviors. Mobile and social games, produced from companies like Zynga use these large data sets to inform design changes for updated releases of games. This has been further explored in developing tools that visualize player data patterns over time to better understand fraction learning in *Refraction* (Martin et al., 2013). Though these methods are useful for understanding trends across large populations over time, it doesn't reveal how the player is making sense of the game space or make visible their play strategies and problem solving.

Ethnographic research in virtual worlds and MMOs lends itself to better understanding how players make sense of the games space. Qualitative research methods examine the many facets of the video games (Boellstorff, 2012; Nardi, 2010) and gaming experience such as gender and identity (Taylor, 2006; Pearce, & Artemesia, 2009). Though ethnographic researchers uncover components of game play and player behavior that can inform design practices to improve games for learning. Ethnographic research isn't necessarily geared towards understanding or improving comprehensively game design specifically for learning.

There are a number of research methods and analysis across disciplines that can potentially be used in analyzing games for learning. I've selected these methods because some aspect of each method seemed partially applicable to the approaches I want to investigate. None of these methods capture the detail of the game space and at the same time captures the depth of player learning. Though game and software development testing methods capture user affect and use of the digital space it does not tend to measure how users make sense of the game or what users are learning as they use the applications.

Discussion

Looking at the educational research on games for learning to better understand how to design games for learning we find there are three categories of research. One approach is to look at the research for multi-media development and learning (Clark & Meyer, 2008; Aldrich, 2005; Horton, 2012) and incorporate those design principles into game design. Another approach is to find evidence of learning theories by examining entertainment games (Gee, 2003; Kafai, 2006; Becker, 2007). Lastly, people who have designed and built games reveal the theoretical frameworks and system qualities they've uncovered in their research and focus in on particular aspects that have marked unique successes in specific contexts (Barab et al., 2005; Salen, 2008; Zimmerman, 2008; Steinkeuhler & Duncan, 2008; Squire, 2008).

The review of literature reveals that though there are a number of sources of research of games for learning there is very little that analyzes the design of these games in relation to the learning objectives. Looking to e-learning or instructional design strategies, reveals these recommendations are too stringent to allow for creative game design as some recommendations are in direct conflict with game design principles. For example, in game environments multiple tasks might be assigned simultaneously where the player decides how to proceed next. Whereas, the instructional design recommendation is to "chunk" and sequence material so its more easily accessible to the learner (Clark & Mayer, 2008). In rich game environments, this method of content organization can kill the play quality because it takes away the agency of the player of having to choose what to pay attention to. The action of choosing is what makes the game such a powerful learning potential (Gee, 2003).

On the other side, game design strategies don't provide enough guidance for incorporating formal instruction. Though there are a lot of documented best practices which are flexible for innovation but there isn't a successful merging of learning objectives with game play. Overall the body of research on video game design shows some degree of uniformity in practices with the differences being in the details. Reflective design practice is an overarching theme in the form of participating in game play (using other games), imagining the game play and game space, feedback from players, responsive and iterative design practice, knowing and being able to define key concepts, and (or in the case of Schell) the designer understanding the implications of his or her assumptions. These measures aren't necessarily prescriptive but stress the need for the designer to continue to learn and improve through the design process and this in turn promotes good game design.

One theme that emerged across the video game design literature is the idea of the designer creating a play experience. Engineering a game space assumes the designer knows the optimal path and wants the player to experience a set of defined experiences. Designing a game space is a process, however, which also leaves open the possibility that the designer may not know the play result and it can only be discovered through play itself. Designing a game requires a special kind of knowledge and understanding of both the constraints and affordances of the process in relation to the parameters of the content in which it is meant to represent and a flexibility to adapt the design according to player feedback.

Play testing and player feedback is also a consistent key point in the game design literature. This is a particularly important difference from instructional design practices as learner feedback and iterative design is not often used to improve the learner experience. Designing a game for learning requires the same kind of kind of play testing and feedback loop but may involve additional questions not found in the game design literature which may include additional feedback in the form of assessment questions embedded in game play. Understanding what the players are learning serves not just as a measure of what the student/player knows but it captures how well the game is designed to teach a specific experience.

There are differences within the game design literature that impact what may be considered as good game design. For instance, Crawford does not consider *The Sims* a game but instead an interactive experience whereas Salen & Zimmerman would consider it a game because of the player structures created to make it play. Schell's related comments on passive entertainment and interactivity relate that "the difference only comes in the participant's ability to take action" (Schell, 2008, p. 263) indicating that the level of player agency measures whether it is a game. This demonstrates that there are differences across designers in definitions like "game" but these differences function much like a theoretical framework for the designer to frame game play.

The potential of digital games for learning has been widely explored and the process by which entertainment digital games are designed is well documented and supported. In addition, there exists a healthy variety of settings and context where games for learning are being researched. However, there is a lack of research that combines game design strategies with learning strategies as a way of understanding the quality of play and effectiveness of games for learning. In the cases where game design strategies conflict with instructional strategies an examination of the game design practices may reveal how these conflicts are reconciled in the game. I suspect that successful designers of games for learning identify the moments of intersection where a game would be most beneficial to learning and in the same moment hold a notion of what that game is and how it plays. Instructional strategies may also need reframing as its not the organizing of learning content that helps learners but the experience of play and interaction with content that helps the player organize the learning content themselves.

What is important to consider in this particular parsing and description of game play experience is that it doesn't lead to suggesting prescriptive attributes for game design but reminds us that the player experience is a process of interpretation and these moments aid in a specific way to help the player make sense of the game. To clarify, *game over* states are effective when the player can return to the beginning of the game and try again. Yet if the difficultly is too great (or the stakes too high), *game over* takes away from the quality of game play (some high risk games require frequent player "saving" to ensure player/character progress isn't loss).

Reviewing and evaluating the quality of educational games is an essential component in the design and development process. Just as with commercial games, iterative design cycles allow the design and development team to make adjustments and shifts in direction throughout the project cycle. Play testing, prototyping, reviewing, and analyzing the game as it is being developed is as important as the design itself. After the game has been built understanding the learning objectives of the games, or being able to anticipate the possible uses of the games.

What Makes a Good Game?

Defining what makes a video game good introduces an important distinction between entertainment and educational video games. Game design tries to achieve certain goals while educational game design has some additional requirements alluded to in the introduction. The success of an entertainment video game is measured by the number of sales, replayability, the size of the fan and player base, respect within the gamer/gaming community, innovation, quality of game play (fun, engaging, challenging), and the quality of game overall (art, lore, music) are measures of the success of a video game (or a combination of these). Game designers also speak to knowing your target audience (Crawford, 2003; Schell, 2008; Rollings & Morris, 2004) and strive to innovate game design and game play.

Defining success for educational video games entails a slightly different but related measure of success. In addition to wanting to achieve at least some of the measures of success above, educational video games must also ensure the players achieve the intended learning objectives. Instructional designers also must know their target audience but the purpose of educational game design is not necessarily to innovate game play and game design, it is to innovate education. The purpose of the entertainment video game designer is make the game fun and playable. The purpose of the educational game designer is to make the game fun and playable and present content the designer(s) believe to be important for the player to take away. Acknowledging the different measures of success between entertainment and educational video games uncovers some of the qualities (and assumptions about those qualities) associated with educational video games. Examining these assumptions more closely is essential in understanding what makes an educational video game successful.

Pedagogical Strategies

A key understanding missing in games for learning is the distinction between teaching and practicing in the form of the game mechanic and within game play. The game design literature reviewed recognizes the strategies for introducing new game content to players (i.e. new character interaction) and balancing the distribution of new and existing content within game play. As Costikyan (2202) referenced as "burnout", the designer makes sure the player stays engaged with play but balancing learning new skill with mastering it (like teaching and practicing). However in games for learning, learning and mastering new skills may also include content knowledge (i.e. fractions) in addition to game content and mechanics. The emphasis on teaching and learning is placed on the educational content knowledge without critically examining the balance between the game mechanic teaching (introducing new content) and mastering (through practice) as in commercial games. The result are games for learning that require the teaching (didactic) educational content *outside* of the game mechanic and then provide a mechanic that supports practice of educational content (without teaching). Following the entertainment game design standards is not a well designed game because the continuity of play (and learning) is not supported within the game.

Another challenge is interpreting the theoretical frameworks and applying them into design practice. Specifically, there is a big difference in reflecting on how learning theories are evident in existing video games but it is another thing entirely to take up and design specifically to one or more theories. These thorough investigations are important and essential for understanding the capacity of video games and for making visible the underlying components of how people learn. However it is challenging to choose a theoretical framework to design a game for learning from because games can reflect many different theoretical frameworks. In game design the evolution of games is built upon the play and design experience of the design team.

The historical understanding of games is essential to a game designers success both from the designers experience with playing video games but in their experience of failed and successful designs. In games for learning these practices may get lost in the effort to adhere to a particular learning theory such as chunking information (Clark & Mayer, 2008) or how to best organize content in order to provide evidence of learning instead of supporting play. In this case the developmental sequencing of content may not correlate with play progression. Perhaps the solution is in the design process itself which allows for a learning theory to emerge through the design of the game structure, game content, and game play.

Gee describes 36 learning principles evident in entertainment video games which haven proven essential for understanding the capacity for teaching and learning in video games (Gee, 2003). However, not all of these principles are evident in all games which leaves open the question for designers; how do we decide which strategies are the better learning tool and for learning what? Related to the conclusion reached in the previous paragraph it may well be that reflecting on the existing theories (i.e. learning principles) helps designers recognize opportunities in designing new games just as postmortems help game designers recognize and reflect on completed projects. The purpose isn't to draw up prescriptive accounts of steps for designing games but to build expertise in recognizing similar conditions in which past experience may be relevant. In this case, the appropriate learning theory may become visible through the design process, not as a prescriptive measure to start with. Allowing the game structure, game content, and game play form the appropriate learning theory unique to its condition.

During the design process the tools and resources used to capture and communicate ideas influence how those ideas develop and take shape. Crawford explains that there are important consequences about how we commit our design ideas into specific forms using specific types of tools. In the case of using storyboards he reports that it inevitably narrows how we see the final product (Crawford, 2003). The process by which educational games are designed and developed are largely left out of the literature leaving little insight as to how design ideas take shape or how the conditions of the game design and development process inevitably influenced the final game product. As Costikyan recalled the smallest change in game design has a profound impact on player experience and good designers are required to anticipate how these small changes impact game play experience. In game design these conditions are tracked and accounted for through the project but in educational research for games for learning this kind of documentation is lean and not typically part of the research practice.

Another notable difference in designing games for learning and entertainment games is measures of competency and assessment. Salen & Zimmerman explain that in video games competency isn't measured by a single choice or decision but by the cumulative actions in the context of the game space (Salen & Zimmerman, 2003, p. 445) which reflects current thinking on expertise (National Research Council, 2000). This is not to say that key player decisions don't impact or influence play outcomes but rather the player choice is the demonstration of understanding and choice is considered evidence of their thinking, independent of what is a "right" or "wrong" choice. This differs considerably from educational assessment models such as standardized tests but may have some correlation with other models such as project-based learning.

Lastly, critical game theory can play an informative role in helping educational research re-examining learning theory in relation to video games. There is an interesting correlation between Galloway's gamic actions (Galloway,, 2006) and Gee's three perspectives (player,

player/character, character) (Gee, 2003). Considering Galloway's diegetic and nondiegetic machine and operator if Gee were to add "machine" to his list of perspectives there would be a complete correlation between the two. Both emphasizing the flexibility in perspective players demonstrate during play. As game designers this flexibility is important to understanding the players experience in game and with the machine - an attribute primarily discussed in game design but left out of the educational research on games for learning covered here. Theoretical frameworks from critical game theory such as Galloway's may help us reposition assumptions about games for learning . The educational game designer must follow the tenets of good game design as well as successfully integrate play and learning. Galarneau purports "Games and simulations are only as effective as the pedagogical approach that is employed in their design and development" (Galarneau, 2005) but it can be argued that games and simulations are only as effective as the pedagogical approach *discovered* during design and development. This distinction between employing and discovering during the design process may help make games for learning more playable and more valuable for learning.

Summary

The review of literature reveals that though there are a number of sources of research of games for learning there is very little that analyzes the games themselves and the design of these games in relation to the learning objectives. Many of the guidelines developed and shared in the game design community may not be taken up as hard, fast rules but as guidelines to be adjusted for innovation. Looking to e-learning or instructional design strategies, reveals these recommendations are too stringent to allow for creative game design as some recommendations are in direct conflict with game design principles. For example, in game environments multiple tasks might be assigned simultaneously where the player decides how to proceed next. Whereas, the instructional design recommendation is to "chunk" and sequence material so its more easily accessible to the learner (Clark & Mayer, 2008). In rich game environments, this method of content organization can kill the play quality because it takes away the agency of the player of having to choose what to pay attention to. The action of choosing is what makes the game such a powerful learning potential (Gee, 2003). The practices in designing games for learning utilize design strategies rooted in instructional strategies that may conflict with game design strategies typical of well-designed video games.

The review of the literature reveals the potential of digital games for learning has been widely explored and the process by which entertainment digital games are designed is well documented and supported. In addition, there exists a healthy variety of settings and context where games for learning are being researched. However, there is a lack of research that combines game design strategies with learning strategies as a way of understanding the quality of play and effectiveness of games for learning. This can be further expanded to include dimensions of learning not just concerned with targeted learning goals and objectives but for understanding learning processes, adapting learning environments to player interests and experience, and out-of-game supports for learning. In the cases where game design conflict with instructional strategies an examination of the game design practices may reveal how these conflicts are reconciled in the game. I suspect that successful designers of games for learning identify the moments of intersection where a game would be most beneficial to learning and in the same moment hold a notion of what that game is and how it plays. Instructional strategies may also need reframing as its not the organizing of learning content that helps learners but the experience of play and interaction with content that helps the player organize the learning content themselves. It also could be that games for learning is another technology meme to catch the attention of the educational community much in the same way previous technologies have been taken up. Perhaps it is the idea of using games has overtaken us but our ability to design and implement is greatly inhibited (Kerr, 2005).

Unpacking the assumptions bound with digital games may expose a group of questions emphasizing the influence of interpretation; both from an educational stance of integrated game mechanics with learning content but also from the entertainment video game stance and the practice of interpreting learning materials *as* game mechanics (or game play). Both game designer's and instructional designer's interpretation (and their context) can constrain the player/learner experience in significant ways producing unintended consequences of design decisions. My suspicion is that there are pivotal moments in educational game design not normally faced during the (entertainment) game design process. As Costikyan recognizes that the game designer doesn't have absolute control over player behavior but rather it "shapes player behavior; it does not determine it." (2002). This conflicts with the additional requirements for integrating a particular type of content and guaranteeing a particular learning experience. Meeting educational requirements or learning objectives is above and beyond normal game play design strategies and could get lost in the design process. These moments of interpreting learning game content, game mechanics and game play in the design process should be examined more closely.

Combining different types of data to arrive at an understanding about the research can't follow prescriptive methods but rather requires examining other research examples where combining different types of data was successful (Becker, 1996). There is a gap in the literature regarding methods for researching the viability of educational video games lacks the detailed hybrid learning content/interaction analysis of the game space, evaluation of how the design of the game affords and constrains learning that includes details of the game and the contexts it is being played. Without this level of detail it is difficult to pinpoint which games are effective learning spaces and which are not. A method of analysis that includes a breakdown of the game structure and mechanics, the representation of the learning goals and objectives and a play-by-play of the player experience may expose the necessary details to evaluate the quality of the game as a learning system. My intent is not to discourage the use of video games or the pursuit of creating video games for learning but to underscore and emphasize the difficulty and complexity of using them as educational tools.

Chapter 3

Methods

Methods

For this research I have developed a game analysis method that combines an analysis of the design details of an educational game with video game play screen-captures and video recordings of player think-alouds. In short, the game analysis is a detailed design walkthrough of the game and outlines the full scope of game play options as they are made available to the player. In the game analysis procedures I focus particularly on capturing how the learning goals are represented both as in-game content and potential player interactions. The player videos afford insight into how the players are making sense of the representations and potential play options by examining how the players describe their play strategies through think-alouds and examining their in-game choices from the screen captures. In the player video analysis I focus particularly on what players report they are focused on attending to with what their on-screen activity might indicate (a detailed diagram of this method is covered later in this chapter). The combination of capturing detailed game structures in relation to player choices and statements reveals what options are available to how players *can* make sense of the game space in relation to how players *do* make sense of the game space. From this analysis it is possible to identify which aspects of game design afford and constrain learning across different players with different play strategies. Insight into how players make sense of the play space in relation to the learning objectives can inform design decisions to improve the quality of games for learning.

This chapter outlines the methods used in this study. The first section describes the settings and participants. The second section describes the procedures used to analyze the game *Refraction* and the player video data. The final section summarizes the procedures and explains how they shaped the analysis.

Setting & Participants

The data gathered in this study took place in an urban, mid-sized elementary school in the Southern/Central part of the United States. The school serves as a lab school for a large university. In the 2011-2012 school year, the school served 260 students and the demographic makeup was 72% Hispanic, 16% African American, 11% White, and 1% Asian. 68% of the students qualified for free and reduced lunch. Participants in this study were 28 fourth and 30 fifth graders (ages 8-10) from the elementary school.

All of the 4th grade participants were playing *Refraction* for the first time. All but one of the 5th grade participants, had played a version of *Refraction* the previous year. All players were aware that *Refraction* is a video game intended to teach math. Each participant played alone and was accompanied by a single researcher. None of the players played together or in the same play session.

Analysis Procedures

Introduction: Analysis Procedures

Since the focus of the study is on the design of educational digital games it is important to consider in detail the components that make up an educational game. This includes both from the perspective of the intended design and the perspective of the player experience. However, detailing a dynamic space such as a digital game requires a step-by-step analysis of the game space (presented in the *Analysis* chapter). This section begins with a description of the educational game used in this study, *Refraction*. It is followed by a detailed description of the procedure for analyzing *Refraction*. Then, a detailed description of the procedure followed for analyzing player video is presented. Lastly, a summary of the key components as a roadmap to following the next chapter, *Analysis,* is shared.

Overview of Refraction

Refraction is a single-player, web-based, puzzle game about creating fractions modeled from the concept of partitioning and splitting (Confrey, Maloney, & Carolina, 2010). The object of the game is to direct lasers of the correct size to power and rescue animals stranded in ships dispersed in space. Each spaceship is labeled with a fraction and the player must create the correct sized lasers (using *splitters*) and direct the laser to the ship (using *benders*) to power the spaceship and rescue the animals.

The learning goals and objectives of the game are to teach players division and multiplication equivalent fractions. The initial fractions presented in the game include 1/2, 1/4, 1/3 and their equivalents in later levels. The game also requires players to use visual and spatial reasoning to figure out sequencing and placement of the benders and splitters. *Refraction* can be used in conjunction with fraction and math course work but for this study, *Refraction* was used as a stand alone activity and was not integrated into classroom activity.

The version of *Refraction* used in this study contains nine level packs with one to four levels per pack (with a total of 26 levels). There are four types of levels:

1. Initial tutorial levels designed to help the player learn the basic functionality of the game (1-1 through 1-4)
2. Assessments levels (3-1 through 3-4) and Embedded Assessments (levels 2-1 and 8-1) are designed to measure player understanding
3. Standard play levels which introduce new concepts and more difficult challenges (levels 4-1 through 7-2)
4. Variation on fraction representation levels (9-1 through 9-4) for the purposes of gathering player feedback

The version of *Refraction* used in this study was released in February 2012 at http://games.cs.washington.edu/UTQualitative/login.html. The version of the game used has not altered since the release date at the time when these screen shots were captured (Jan. 31, 2013). Other versions of the game Refraction auto-generate levels for game play, however, the levels designed for this study were fixed and were specifically designed progressions which will be detailed in the *Analysis* chapter.

Procedures for Game Analysis

As discussed in the literature review, the procedure used for analyzing the game *Refraction* is different than cataloging results from procedures such as play testing, user-testing and other game and software development methods for measuring player interactions and response (Schell, 2008; Fullerton, 2008; Rollings & Morris, 2004; Bartle, 2004). The primary difference being the focus on understanding how the learning goals are represented and how player behavior and think-aloud talk reveal how the player is making sense of the game space. The game analysis used in this research may be similar to a *play walkthrough* where players outline a detailed account of game options as a map for other players to follow in order to achieve certain goals or successfully complete games (Schell, 2008; Rollings & Morris, 2004). However, instead of describing the game play walkthrough for other players, this game analysis is more like a walkthrough for designers. The game analysis as a design walkthrough accounts for design details, including the learning goals, that outline all potential play possibilities. The purpose of a design walkthrough is to understand the full scope of what players can potentially do in the game space.

Analysis of educational digital games looks for player learning as afforded and constrained by the build of the game. The following section outlines components of this procedure. This section includes a description of the game analysis and design walkthrough which 1) accounts for the cumulative structure of game play, 2) clarifies the parameters of what to include in game analysis, 3) explains how the emergent categories identified in the game analysis inform the codes used in this study, and 4) addresses domains specific content with game content. Lastly, there is a summary of game analysis and a road map of the procedure.

Description of Game Analysis: Design Walkthrough

The game analysis or design walkthrough is a written description of the game play experience accounting for all the components made available to the player. This includes describing moments of possible player decisions, game rules, mechanics, and learning content. The purpose of a play-by-play analysis is to (1) gain a better understanding of the options made available to players, (2) understand how the learning goals of a game are represented visually and through interactions and (3) to be able to describe the player's experience in an effort to better understand what the player may be learning. From this detailed account we can generated questions that begin to frame the way to examine at the player video.

The sequence, as presented in the *Analysis* chapter, of the game progression includes a description of:

- what takes place on screen automatically without player interventions
- game objects and user interface
- what options and interactions are available to the players
- what players are intended to do
- what players can do (including subverting what they are supposed to do)
- Screenshots to illustrate descriptions

The detailed, play-by-play description of the constraints and affordances existing within the game space is necessary to categorize qualities of player actions that help identify game qualities and characteristics that may (or may not) contribute to learning. Partial reconstruction of the game play experience does not account for enough of the contributing factors that may impact player learning. Not detailing the game space is to potentially overlook, not only moments of opportunity to adjust the player experience to be more conducive to learning, but to underestimate the impact of the cumulative effects of the game experience from beginning to end, as it supports learning. The following section describes how the full description of an educational game allows us to account for the cumulative effects of game play and how this benefits our understanding of the player experience.

Accounting for the Cumulative Effects of Game Play

From a player perspective, one component of game play is the discovery and development of play strategies over time. In complex games, player strategies adjust according to shifting variables such as other players and changing game mechanics and content (Salen & Zimmerman, 2003; Fullerton, 2008; Bartle, 2004). In addition, player strategies that develop over time can be connected through varied but deliberate practice and experience (Bransford & Schwartz, 2001; Ericsson et al., 2003). However, all of these require allowing enough time to play with strategies that may fail and test the parameters of success within the game space.

From the perspective of design, the combination and complexity of game mechanics, rules, and conditions build upon each other as the game progresses (Salen & Zimmerman, 2003; Schell, 2008; Crawford, 2003). This means designers should be mindful of consistent and predictable game progressions and at the same time strategically integrate and introduce new and challenging material. The type, or genre, of game may be an indicator of the number of and degree of complexity the mechanics, rules and conditions are combined. Also, the design of the extent of the built-in tutorials serve as an indicator of how much unique information to the game the player must know as opposed to generic information that may be afforded from previous game play experience (Salen & Zimmerman, 2003; Rollings & Adams, 2003; Schell, 2008). For example, puzzle games typically have a few introductory levels for demonstrating the basic game mechanics. These game mechanics stay the same through the duration of the rest of the game. Learning these mechanics are unique to this game. Whereas in an MMORPG, some mechanics are standard for the genre of game (e.g. AWSD as movement keys), so tutorial levels may focus primarily on mechanics unique to that game (e.g. layout of the user interface). In addition, in more complex games there may be optional tutorial material built into the game or additional information provided outside of the game (e.g. game website, fan sites) to support players learning about the game.

Plotting the progression of game play and detailing the design of the game space provides a complete picture of how many ways a player may be able to navigate from the beginning to the end of a game (if there is an end to the game). In games with a discrete ending this allows us to account for all possible outcomes. Being able to plot the player's experience from beginning to end is an opportunity to capture the intended and potential learning opportunities as afforded by the design of the game as well as expose player's methods for developing play strategies. More on how play strategies reveal learning will be detailed in the following section; *Procedures for Analyzing Player Video*.

In part, it is the intent of the methods developed in this research to demonstrate that, without the detailed description of game progression and the analysis of players' strategies, we can not create a complete picture of how the player understands and makes sense of the game space through their play strategy. In other words, play strategy is one way of evaluating what players are learning about a game. Without an understanding of how the player's are developing their play strategies over time we cannot make recommendations on how to improve the game design to support learning.

To be able to account for the cumulative effects of game play in games with discrete endings we have to account for game play from start to finish. In games that are continuous we have to be able to partition off a substantive portion of game play in order to observe an adequate representation of player progression of the learning gains we are most concerned with.

Documenting the introduction of new variables and game content in game analysis allows us to map game experience and strategy development as cumulative over time. Not only does it reveal patterns of play and sense making but it also exposes the fluctuations in successes and failures which are not necessarily mapped on an even trajectory. A player may struggle on one level and excel on another but not always in the order anticipated, it depends on which game mechanic or game/learning content is being introduced.

The version of *Refraction* in this study was not open ended and it introduced new game components, content or a variation of both in each of the 26 levels (as outlined in the following chapter, *Analysis*). Because there is a discrete ending to this version of *Refraction* I chose to document the game analysis from beginning to end.

Defining the Parameters of Game Analysis: Design Walkthrough

Creating a detailed game analysis or design walkthrough can be a daunting task given the variety of game types. Not all games are organized by "levels" or even have a uniform end goal. To better understand how to keep game analysis focused within the scope of learning this section describes the parameters for completing a thorough but concise game analysis design walkthrough.

The primary parameter for keeping the game analysis within the scope of player learning is to determine at which level does the game stop introducing new content or variables. New content or variables can include game mechanics, storyline, objects, or other components that may alter a player's actions or play strategy (Schell, 2008; Fullerton, 2008; Rollings & Morris, 2004; Rollings & Adams, 2003; Crawford, 2003). Game analysis of an entire game is not useful or necessary when there are no new or limited variables being introduced. We can see the advantages of limiting or focusing the length of game analysis with the following examples of games.

In puzzle games that have limited or less complex game mechanics, once the initial mechanic is learned there are often predictable variables introduced to increase the difficulty but without introducing new content or mechanics. In a game such as *Tetris* (1999), the initial mechanic for a player to master is rotating and moving each of the different types of shapes descending from the top of the screen. After understanding that basic mechanic (rotating the falling piece) the player develops strategies for organizing the shapes in the most efficient pattern and to avoid "losing" the game (i.e. when there is no more room for new pieces to descend). The player's strategies are further challenged as two new variables introduced; 1) increase in speed in which the pieces descend, and 2) increase of difficulty in the sequence of the types of pieces that descend. The game itself is endless, it only ends because the player cannot keep up with the ever increasing descent rate of the pieces.

In a game like *Tetris*, we can examine learning in relation to game design with a relatively short game analysis. This is due to the fact the player makes the same types of decisions with the same game information repeatedly, only faster, as the player progresses. If the research questions are regarding how players develop strategies over the quickening pace of the game then perhaps extended accounts of game play are needed but the basic description of the game analysis can be kept to a minimum.

On the opposite end of the digital game spectrum there are highly complex play spaces such as MMO's that may continuously introduce new content and game variables. In games with new content being added (e.g. *Guild Wars 2*) or games without distinguishable levels/questions, instances of new content may be isolated and evaluated within the context of the larger game. However, appropriate game analysis will call out the mechanics that are used repeatedly and focus on new content or variables that build up over time. For example, for a specific character type a player may develop a strategy for fighting certain mobs (or enemies). Though character fighting skills may be introduced a few at a time eventually all of the skills will be available and remain the same for a sustained period of time, during which the player develops different strategies for fighting different mobs. When faced with a new mob, the player tests combinations based on previous experience. In a detailed game analysis, the parameters of this process would be shaped by determining which learning goals and objectives are in question. Then identifying all of the components related to those learning goals. In the example provided, understanding how players learn develop character strategies in different contexts is a defining parameter.

These types of games also have multiple ways players can focus, engage and end play so not all play experiences are the same for all players (e.g. player focus on Player vs. Player (PvP), Player vs. Environment (PvE), or achievements). In addition, player focus and player play preferences may shift over time depending on variables outside of the game (e.g. high group participation for a short period of time). This means a single player may focus on completing a difficult quest with a group then move on to completing a crafting achievement as an individual. Given the volume and complexity of these large scale games, a complete analysis of all potential outcomes is not practical or may not be useful. Here, partitioning a portion of the game which is concerned with particular aspects of learning may be necessary.

In respect to examining learning in relation to the design of the game, identifying which excerpts of play to focus on may be challenging. The parameters of what to capture in the game analysis should be restricted to the mechanics, rules, and content that create opportunities for learning. Though game analysis should account for the whole of game play experience it should identify which content is repeated and which content is really new enough to require player learning. At the same time, game analysis must document the progression of play to reflect how learning new content may develop over time.

Emergent Categories for Coding

Through documenting the design of the game *Refraction* initial questions specific to level progressions began to emerge. These questions were sparked by unique characteristics or shifts in game content that might render interesting player responses. For example, the detailed description of Level 1-2 (detailed descriptions of each level are included in the *Analysis* chapter) generated the following questions and comments. This is because the game analysis revealed this is the first level where players are introduced to "bending" the laser towards its destination, a ship. As part of the beginning tutorial levels, it is also the first time the player is given a choice (rather than simply following instructions) as to which *bender* to use first. From the description of this level the actions and statements to look for in the player video included:

1. Description of what the trends were for game play for this level.
2. Do players refer to the directionality of the laser?
3. Do players talk about the size of the laser (1)?
4. What were the missteps and how can we categorize those missteps?

To elaborate, question 2 is in reference to the spatial/visual understanding required for the game and question 3 is in reference to whether or not players are yet attentive to the values (math) presented in the game up to this point. The purpose of questions 1 and 4 is to capture player actions or utterances that may indicate other ways of making sense of this level outside of math or spatial/visual. Over the course of several levels trends of the types of decisions made available to players allowed for initial and emergent codes used in the player video analysis (as described in the next sub-section), such as math and spatial understanding.

These initial questions generated in the game analysis not only identified trends in game play as the game progresses but also captured the unique qualities of each level as it relates to player learning. In this example, understanding how players responded to the directionality of the laser upon its first introduction shapes how we can interpret changes (or no changes) in their understanding in later levels. The questions and comments generated during the game analysis vary from level to level because of each level's unique features. A list of all the questions and comments generated during the game analysis are available in *Appendix B: Initial Questions from Game Analysis*.

Disciplinary/Domain Content versus Game Content

The analysis described here works well with educational games that have a clear beginning and end. Though the game *Refraction* in this research focuses on fraction learning, game analysis and design walkthroughs are not meant to be domain or discipline specific. The emphasis of this research is how players learn, both the disciplinary content and how to play and master the game. Furthermore, it is meant to explore the complex relationship between disciplinary and game content learning emphasizing how the play progression and game context integrates desired learning goals. Potentially explaining how a player learns how to play the game effects how they learn the disciplinary content (and vice versa). I believe this method of analysis, or some modification of it, is applicable to all educational games. More on game analysis for other educational games will be covered in the *Discussion and Implications chapter*.

Summary

The game analysis: design walkthrough procedure begins with documenting a description of the progression of game play (Image 1). During which special attention is given to moments where new content and variables are introduced to the player as well as writing enough of a description that captures the full scope of play progression. During the game analysis for

Refraction, this meant a level-by-level description that also flagged moments that generated questions or comments that might be of interest in the player videos. These questions and comments later informed the initial and emergent coding structure of the player video analysis. The following is a process map of the game analysis procedure:

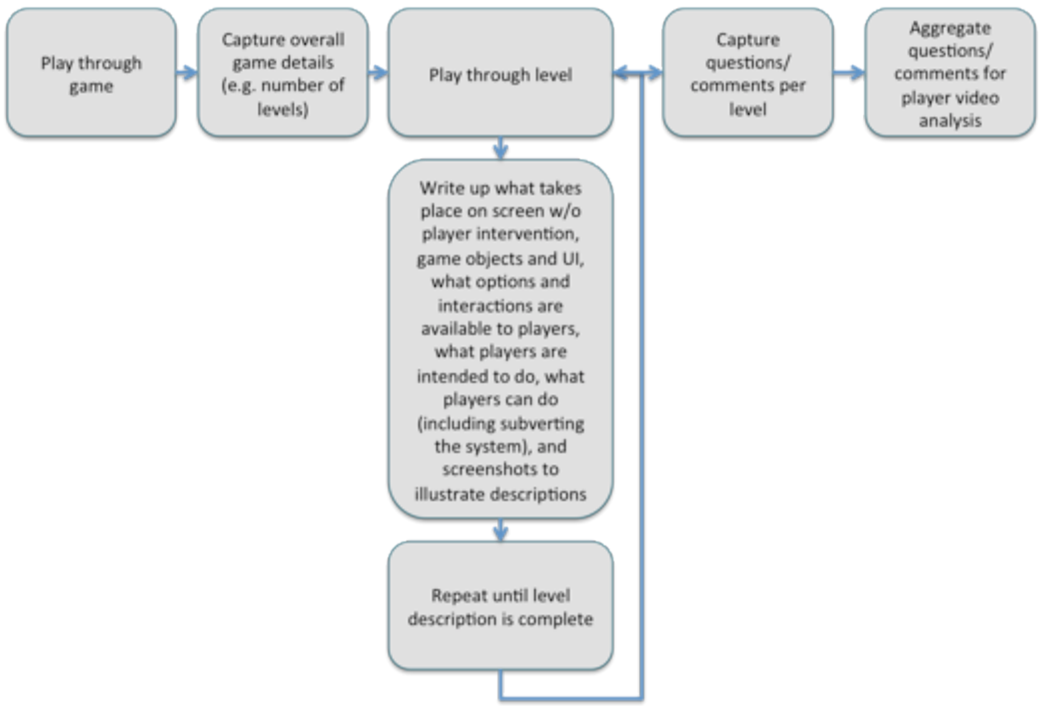

Image 1: Game analysis: design walkthrough process map

Procedure for Analyzing Player Video

The player video is the second component in helping determine the design qualities of a game that may or may not support learning. Player video provides an opportunity to identify moments in game play where players may struggle (or not) and observe play patterns to build an understanding of how the player is making sense of the game space.

Students were removed from their classrooms and worked one-on-one with a researcher for approximately 20-minutes of game play. Each student played the game *Refraction* and answered fractions assessment items embedded in the game. During game play, students were video recorded and were asked what they were thinking and feeling, as well as, asked to explain their game play choices while playing.

This section describes the procedures used for analyzing the player video. Each of the following sections contained here detail the think-aloud protocol, interviewer positioning, video data available and procedure for selection, category and coding structure, an explanation of play strategies as evidence of learning, and a summary with a process map.

Player Video

During the recorded play sessions, participants were asked to talk about their decision making and game playing using a think-aloud protocol (See *Appendix D* for complete protocol). Each session was recorded using a software application called *IShowU*. *IShowU* records a screen capture of on-screen activity and at the same time uses a webcam to video and audio record the player. These recordings are automatically synced in *IShowU*, allowing researchers to view on-screen play activity and at the same time listen and watch the player. At the beginning of this study, there were a total of 23 4th grade videos and 28 5th grade videos conducted by two different interviewers.

For this study, I selected the videos conducted by one of the interviewers to reduce variation between the two interviewers and to retain consistency in the think-aloud prompts and protocol. This left nine 4th grade and 18 5th grade videos available for analysis. From these videos I selected eight 4th grade and 15 5th grade videos based on the length and quality of the recording. The videos dropped did not capture the entire play session and others had audio/visual quality issues. Total video time used for 4th grade players was approximately three hours and total video time for 5th graders was approximately six hours. It was important in this study to include enough videos to be able to identify different play strategies amongst players but not too many videos that each couldn't be closely analyzed. The player videos were watched several times with each iteration focused on clarifying emergent themes and defining codes.

The videos were transcribed and transcriptions imported into *InqScribe*. In *InqScribe*, timestamps were added to indicate where each player started and when they completed each level. During the level time stamping, initial categories were logged based on the questions documented in the game analysis (see Appendix B). The first viewing of the player videos involved working from the game analysis document as an outline and a starting point for framing the player video. I watched the videos level-by-level across students rather than watching an entire play session of a single student. For example, I watched Level 1-1 for each 4th grade, then 5th grade student. After watching all of the level 1-1 sessions, I watched Level 1-2 for each 4th grade, then 5th grader, etc. Isolating and watching by level, rather than by player, helped to identify patterns, play behavior, and player explanations of their choices unique to each level (and subsequently to new content introduced in each level). This initial viewing of the player video established initial similarities and differences amongst players from their patterns and utterances. This viewing also captured initial categories of potential codes as informed by the questions raised in the game analysis document and by the observations made for each level.

The second viewing of the player videos involved a second round of test codes. These were also tracked in *InqScribe*. The third and final viewing finalized the coding structure and the modified *InqScribe* transcripts were then migrated to *Dedoose* for final test coding and inter-rater reliability testing. Details on the coding categories and structures are detailed in a later sub-section.

The final phase involved aggregated the coded data in *Dedoose* and writing up a summary of the findings for each of the levels as it related to the game analysis of the same level.

The aggregated player video data along with level-by-level game analysis captured results of how players played each level, and subsequently, made sense of each level. Combining the game analysis write-up in relation to the player video data allowed for a comparison of what was meant to be accomplished (both in game play and for learning) and what happened. Through this process key points were tracked for further consideration in the *Discussion & Implications* chapter.

Think-aloud protocol

An essential component to the player video are the “think-alouds”. Think-alouds prompt players to articulate why they are making particular in-game decisions and to express their thinking during problem solving activities. More importantly, think-alouds reveal, to some degree, how the player is making sense of the game space and makes visible their play strategy. In this study the interviewer asked questions and made statements to prompt players to reflect upon their actions and choices and describe their thinking to the interviewer.

The interviewer also asked players to explain their actions as they were performing them or explain what they planned to do as they were beginning to make decisions. Players were not encouraged to stop playing in order to answer questions unless to clarify an incomplete thought, but primarily players continued to play while conversing with the interviewer.

In the videos selected, generic questions and prompts were not instructional or meant to suggest a particular course of action. For example, the interviewer may ask questions such as, “what do you think of this?”, “how are you going to solve this level?”, or “tell me what you are thinking”. Also, the interviewer allowed players to struggle during game player and only after allowing players to struggle would the interviewer ask players if they wanted a hint. This preserved the purpose not to get players through as much of the game as possible but to see how long players took on their own to figure out each level. The think-aloud protocol was to encourage players to talk through their thinking and decision making and to provide help only to avoid adverse frustration.

A potential drawback of using think-alouds during game play is that sometimes the activity of describing one's actions alters the choice of action as player become aware of what they are doing through describing it to another person. Though it makes visible the player's thinking, it may alter their play pattern than if they were playing uninterrupted and alone. However, it can also be said that the play patterns would be altered if there were other students playing the same game at the same time in the same room; sharing strategies and discoveries as the game progresses. In short, think-aloud protocol may not capture an unaltered play pattern but it can still capture player thinking and reasoning.

Interviewer Position and Prompts

As mentioned earlier, for this study, I selected the videos conducted by one of the interviewers to reduce variation in the protocol and retain consistency in the prompts and questions. The interviewer's position and prompts influence how the player responds in a think-aloud. The role of the interviewer is to ask players to describe her or his thinking as they play the game. This means asking open-ended questions such as "why did you make that choice?", "why did you put that back and try the other one?", "what do you think about this level?" and "can you describe what you are thinking about this?".

During game play there were moments where the interviewer intervened to help guide players who were stuck but these interventions followed a pattern. If a player appeared stuck the interviewer would wait to make sure not to intervene too early. The interviewer determined when it would be appropriate to step in by how long the player remained inactive. If a player was struggling but making a lot of selections and activities then she would not intervene. If the playing around was not productive or led to repeated play patterns she would ask if the player wanted a hint. If the player was inactive and not making any actions or making very infrequent actions the interviewer would intervene sooner.

The interventions also followed a pattern. The interviewer limited direct instruction for how to complete a level or how to work through a particular problem. First, the interviewer would ask pointed questions about how the player was thinking about the problem. For example, when a player makes a selection the interviewer would ask "what do you think that guy is going to do?" or "what do you think will happen if you place that guy there?". These questions would appropriately focus player attention and provide an opportunity for the player to reflect on his or her choice and describe what he or she believed would happen, then be able to test it. The results of the choice provided further opportunity to ask another direct question. The scaffolded questions would help lead players to success through player reflection and without having to provide direct instruction. It should be noted there were a few instances at the end of the play session where after struggling and scaffolded questions, the player could not figure out the level, and the interviewer would show the player the solution. The end-of-session levels solved by the interviewer are accounted for and noted in the *Analysis* chapter.

The interviewer did ask questions about players' feelings about the game and math at different points in the game play. These questions were meant to gauge affect towards math and games. For the purposes of this study, questions regarding affect have not been included unless they directly relate to evidence of learning.

Throughout the play session, players were not discouraged from interacting with the interviewer and were encouraged to talk as much as possible. Some participants did ask questions about the game or how to solve certain problems during game play. However, as mentioned, the interviewer's responses did not provide direct instruction. If a player's questions were in regard to needing help, the interviewer intervened with patterns described above.

Categories and Codes

The *Refraction* game analysis described in the previous section, *Procedures for Game Analysis*, provided a detailed landscape of the play progression of the game. From this process I was able to identify key points in game play that might be of interest to look at in the video. I created a matrix of the moments in question based on game attributes (see Appendix B) (Miles & Huberman, 1994). This provided a foundation from which I could look for key moments in the video data. In keeping with open and axial coding in grounded theory (Miles & Huberman, 1994) I analyzed the video data patterns relating to these initial questions. While tracking emergent patterns flagged and prioritized the data patterns worth further investigation (Lofland & Lofland, 1995).

To track initial categories drafted during the game analysis and capture the emerging categories witnessed in the videos I created a matrix. Since the focus is on the design and organization of the game as it relates to the learning goals (rather than case studies of individual players) I organized the matrix by game levels. As explained earlier, I watched Level 1-1 across each of the 4th grade videos and then each of the 5th grade videos. Then I aggregated player data by each level.

Given the research questions and the type of analysis used there were three goals for the codes that became clear as they emerged. The codes needed to 1) reflect the learning and game play goals, 2) capture change in play strategy over time, and 3) capture the sequence of play actions as well as player utterances. For example, learning and game play goals were coded in relation to math and spatial understanding and struggle. Changes in play strategy over time were tracked by the sequences of actions, such as tracking the first choice of a player (e.g. correct funnel two splitter). The sequence of actions in relation to the context of the level revealed how the player was making sense of the unique challenges to that level. It's important to note that for some codes its not the frequency of the occurrence that matter so much as the sequence and context of the sequence as a way of explaining players' understanding and sense making.

The following is a summary of the final codes used in the analysis of the player videos (for complete description and examples of each code see *Appendix C: Complete Code List*). Only codes open for interpretation were used to establish inter-rater reliability (i.e. assessment level codes were not included).

Type	**Code**	**Description**
First Choice	Correct Funnel	Funnel of the bender or splitter is facing the correct direction to receive the laser.
	Incorrect Funnel	Funnel of the bender or splitter is NOT facing the correct direction and the laser goes into the side of the bender or splitter.
	Two-Splitter	Player chooses two-splitter
	Three-Splitter	Player chooses three-splitter
	Bender	Player chooses bender
Instructions & Pop-up Messages	Reads instructions	Reads on screen instructions or pop-up messages to self or out loud
	Doesn't read instructions	Glances, skims or ignores instructions or pop-up messages.
Play Strategy	Trial-and-Error	Player appears to be randomly selecting benders or splitters to see what their outcome is. Incorrect placement and incorrect sequence of benders and splitters. An initial action may be random but subsequent actions may be informed by that first action. Actions may develop into a pattern of discovery over time. Player appears to be making selections based on previously observed information but may not know the outcome. Series of

		moves where the player learns and modifies actions based on previous move. Not mutually exclusive to spatial struggle or math struggle. Repeats patterns and incorrect actions. Player keeps trying the same action even when it doesn't produce different results.
	Accident/Discovery	Player accidentally discovers a solution or solves a level.
Understanding (Player choices reflect what they are trying to solve for. The final, completing step of a level is not coded. Length of text and actions selected for these codes should include enough context to positively identify the code and not limited to one line or partial excerpts that do not provide enough context.)	Math	Player demonstrates math understanding through their description in the think-aloud and in-game actions. Self-corrects math problem-solving. A series of selections and decisions based on the size of the laser, the size of the ship, and/or the size of the splitter. Player uses math terms to talk about game or in think-aloud.
	Spatial	Player demonstrates spatial understanding based on the correct selection and decisions of funnel facing and laser output direction. Self-corrects errors regarding direction of funnel and lasers. A series of selections and decisions based on trying to get the laser to go to a certain direction regardless of the size of the laser or the size of the ship.
	Math & Spatial	Articulates and makes a series of choices and decisions that demonstrate an understanding of math (size of the laser, size of the ship, and/or size of the splitter) and, at the same time, makes correct decisions on the direction of the laser and maneuvering around obstacles.
	Not Clear	It can't be determined by the decisions and selections being made or the player utterances whether or not their choices and selections are driven by direction (spatial) or solving for the ship (math).
	Spatial struggle	Player pauses or appears indecisive when making a decision. Confused or doesn't know what to do. Pauses for longer intervals to make decisions. More than one attempt to get one laser to output in the desired direction in a level. Placed the wrong-facing funnel direction more than once in a level.
	Math struggle	Player pauses or appears indecisive when making a decision. Appears to get the directionality of the funnel and the laser but does not use the correct sequence to get

		the appropriately sized laser.
	Color	Player uses the color of the laser as a way of making sense of the space. Player uses the color of the splitters to make sense of the game.
	Power	Player notices lightening bolts animation is a cue to the player to make a change or player notices the size of the laser states the ship is getting too much/too little power.
Interviewer Intervention	Intervention	Interviewer asks a sequence of guided questions to help player think through a particular parts of a level or the entire level itself. Student asks for help or hint. Must be more than one statement or question from the interviewer. Note when the interviewer makes an intervention for each issue or each scaffold.
	One Intervention	Interviewer asks a limited number of guided questions to help player through a small portion or one aspect of a level. Student asks for help or hint that can be addressed with a limited number of guided questions or player only needs help ONCE in the level.
Level 3-1 through 3-4 Assessment	Correct answer	Answers level correctly
	Incorrect answer	Answers level incorrectly
	Partial Correct	Answers some of the assessment level questions correctly

Inter-rater reliability was established through double coding with one additional researcher. Levels selected did not include assessments and represented only regular game play levels. The additional researcher was instructed to group in-game actions and utterances, rather than code each individual instance, to capture the evolution of a series of actions.

The first code test session involved two videos (one 4th grade and one 5th grade) with two levels each (levels 4-3 and 4-4; and levels 4-2 and 4-3 respectively). The second code test involved one 5th grade video from start to finish excluding the assessment levels. After each test code session we reviewed, discussed and revised code definitions.

After clarifying and discussing the code definitions the additional researcher was given 45-minutes of player video data for double coding (ten percent of total video was 40-minutes)[3]. Initial coding accuracy was 81% and after discussion we came to 100% agreement. The remainder of the player video was coded accordingly.

Summary

In this section I've outlined the procedures used for analyzing player videos. Accounting for in-game actions and at the same time player utterance in think-aloud protocol are two key components of the player video data. The game play actions reveal play strategies and player thinking while the think-alouds prompt players to articulate why they are making particular in-game decisions and to express their thinking during problem solving activities. Revealing player thinking around play strategies sets up the opportunity to examine how players make sense of the game space in relation to how it is designed. This allows further consideration of how players may or may not be learning game and discipline-specific content. The following is a process map of the procedure for analyzing player videos (Image 2):

[3] Since no interpretative codes were used for Level Pack 3 (only correct, incorrect and partial correct answers were logged) the total video time calculated for inter-rater reliability does not include Level Pack 3.

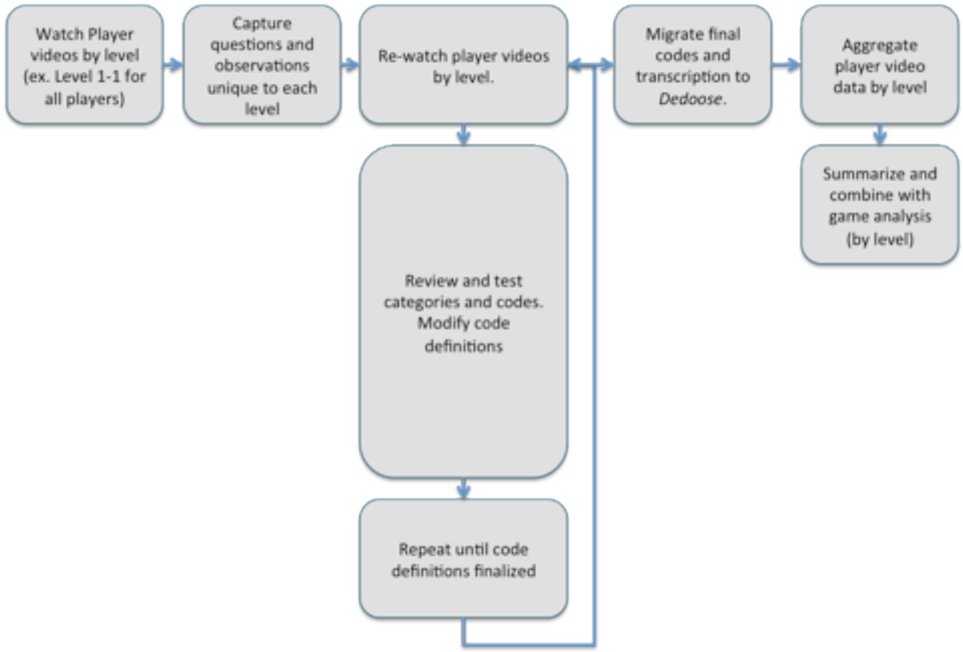

Image 2: Player video process map

Methods Summary

This chapter described the setting and participants and detailed the analysis procedures for game analysis and player video data. Game analysis is a step-by-step description of game play, or design walkthrough, which accounts for all game content and potential player actions. Player videos captured both on-screen play activity as well as recording player think-aloud dialogue during game play. From the game analysis key moments are identified for potential player learning. This, combined with aggregated player video data by level, allows visibility to what the game play sequence may mean to the player and what they are or are not learning. The procedures outlined in this chapter are concerned not necessarily with discipline or domain specific learning only but more able to point at what players are learning and why. The game analysis and player data combined help us identify what they might be learning and how they are learning it. This leads to the implications of the design of the game as explored in the discussion.

Game analysis is a necessary component for evaluating games for learning. As this type of analysis reveals that players are interpreting game content and interactions from a variety of perspectives and making sense of those meanings in ways that may or may not afford the desired learning. This insight to how players make sense of games for learning can be a benefit to both educators, designers and developers alike. The next chapter, *Analysis*, includes the final analysis of the game *Refraction* as outlined in this chapter.

Chapter 4

Analysis

Analysis

This chapter is consists of an overview of *Refraction*, a summary of levels completed by players, a summary of players who required interviewer intervention by level, and the analysis. The full analysis of *Refraction* is organized sequentially by level. However, in this chapter the level description and player data may be summarized. Each level contains three parts:

1. Game analysis: Design Walkthrough
   - What takes place on-screen automatically without player intervention
   - Game objects and user interface functionality
   - What options and interactions are available to players
   - What players are intended to do
   - What players can do (including subverting what they are supposed to do)
   - Screenshots to illustrate descriptions
2. Results of player data for the corresponding level
3. Discussion of the level results

Refraction Overview

As described in the *Methods* chapter the version of *Refraction* used in this research contains nine level packs with one to four levels per pack (for a total of 26 levels). There are four types of levels:

1. Initial tutorial levels designed to help the player learn the basic functionality of the game (Levels 1-1 through 1-4)
2. Assessments (Level 3-1 through 3-4) and Embedded Assessments (Levels 2-1 and 8-1) designed to measure player understanding

3. Standard play levels which introduce new concepts and more difficult challenges (Levels 4-1 through 7-2)
4. Variation on fraction representation (Levels 9-1 through 9-4) for the purposes of gathering player feedback on alternate representations.

These four types of levels (tutorial, assessments, regular game play, alternate fraction representation) group certain types of content but each type brings its own set of play parameters that may not be included in the other level packs. For example, tutorial levels are very easy introducing one or two new concepts and typically have far fewer choices available to the player. This changes in regular game play levels where more choices are made available and step-by-step instructions are no longer included. As a result, the analysis of some levels may contain data not present in other levels.

Level Completion by Grade

Each student played *Refraction* for approximately 20 minutes. Players were allowed to progress at their own pace and were not actively encouraged to finish as many levels as possible (see *Methods* chapter for details on I*nterviewer Position and Prompts* for details). In the assessment levels (3-1-through 3-4) some students accidentally skipped a level or more because of the placement of the "submit" button on screen. Also, some students were encouraged to skip a later assessment level if they were taking too long to answer the questions to allow them equal time in regular game play. Table 1 illustrates the number of players, separated by grade, who completed each level within the 20-minute time frame.

Level	Number of players who played each level	
	4^{th} grade (8 total)	5^{th} grade (16 total)
1-1	8	16

1-2	8	16
1-3	8	16
1-4	8	16
2-1	8	16
3-1	8	11 (5 players skipped)
3-2	8	14 (2 players skipped)
3-3	8	15 (1 player skipped)
3-4	6 (2 players skipped)	16
4-1	8	16
4-2	8	16
4-3	7	16
4-4	6	14
5-1	4	13
5-2	4	13
6-1	3	13
6-2	3	12
6-3	1	12
6-4	1	12
7-1	1	9
7-2	-	6
8-1	-	6
9-1	-	5
9-2	-	4
9-3	-	-
9-4	-	-

Table 1. Number of players who completed each level.

Analysis & Results

Level Select Menu

The game begins with the start screen. The player selects **Start Game** (Image1) to begin.

Image 1. Start screen.

The player selects the level by clicking one of the bubbles next to the level number. In this study, players were instructed to start at the beginning level 1-1 in the upper left-side of the screen (Image 2). In some instances the interviewer clicked through the start and level-select screen in order to get the player to Level 1-1 more quickly.

Players do not see the level-select screen at all during the course of game play. The player can choose to view the level select screen if they select it from the menu but there are no in-game prompts or requirement for players to do so.

In this analysis I will refer to Level 1-1, the first number is the level pack and the second number is the level within the level pack. For example, the first row shown in image 2a includes (reading from left to right) levels 1-1, 1-2, 1-3 and 1-4.

Image 2a. Level select menu.

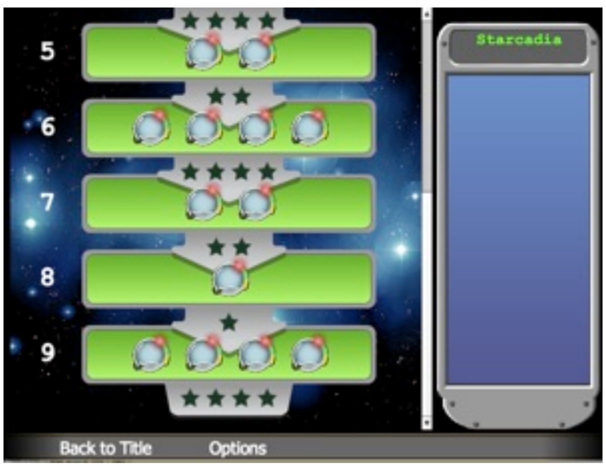

Image 2b. Level select menu cont'd.

Having the level select menu visible at the start of game play and not visible during the normal course of play means that a player's orientation and awareness of their progression is largely not visible unless they intentional return to the level select screen. Players automatically progress from one level to the next as each level is completed.

Level Select Menu Player Video

All 4th and 5th grade players progressed through the ordered levels and none of the players accessed the level-select menu outside the original start. Two 5th grade players accidentally clicked the wrong bubble and started on Level 1-4 instead. In two instances, the interviewer accessed the menu mid-game to help the player reset a level but did not view the level-select screen.

Level Select Menu Discussion

None of the players accessed the level select menu during game play. However, in this version of *Refraction* the level select menu has the potential to serve three functions. Players can choose which level to play in any order and potentially skipping introductory content. Players can replay levels or complete unfinished levels. Lastly, the level select menu makes visible the player's progression, how many levels completed and how many levels remain.

Level Pack 1: Tutorial

Level 1-1

In this study, players were instructed to start at Level 1-1 (Image 3). This part of the tutorial level pack (Level 1-1 through 1-4) designed to introduce the basic mechanic with the instructions, "*The goal of the game is to fix the space ships*". It also provides the first player interaction with the primary game mechanic of dragging and dropping, in this case a *bender*, or *splitter*. This level introduces *benders*, shown in the staging area on the right, whose purpose is to redirect the laser. Benders can not be rotated which means the players must work with the directionality of the bender as shown. All lasers are labeled with the size of the laser, in this case, "1". The laser is also animated so the number moves down the laser like a conveyor belt and repeats. The number on the spaceship in Level 1-1 is also "1". The player must click Next to continue.

Image 3. Level 1-1 first screen.

The layout of the second screen remains the same but replaced with new instructions: "*To fix a space ship, power it with the laser.*" (Image 4). The player must click Next to continue.

Image 4. Level 1-1 second screen

The third screen instructs the player to "*Click on the laser bender to pick it up.*" and a yellow arrow points to the highlighted bender (Image 5). This is the only action a player can make to progress in the game. When the player mouses over a bender (or "splitter" in later levels) there is an animated green line starting from the funnel side towards the direction of the pointer (not shown). This visually indicates the laser can only enter the bender (or splitter) through the funnel side and indicates the direction the laser will exit.

Image 5. Level 1-1 third screen.

After the player clicks the bender, a highlighted spot along the laser indicates where the player should place the bender (Image 6). The laser enters through the funnel side of the bender and exits out the direction of pointer. In this level the player only has one bender to choose from.

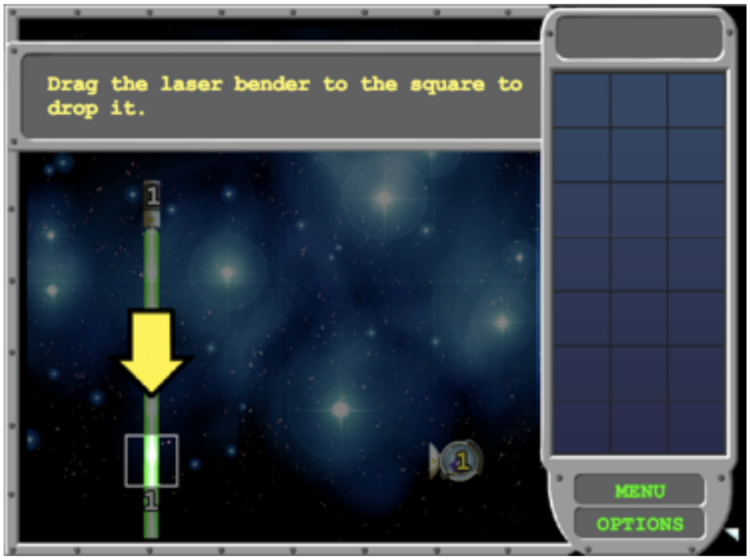

Image 6. Level 1-1 fourth screen

After the player places the bender in the highlighted square, the laser redirects into the spaceship (Image 7 & 8).

Image 7. Completing Level 1-1.

Image 8. Completing Level 1-1 cont'd.

After successfully directing the laser to the space ship there is an end-animation with the ship flying off, flying stars, and the animal in the ship dancing (Image 9). This animation sequence is the same for completing each of the subsequent levels.

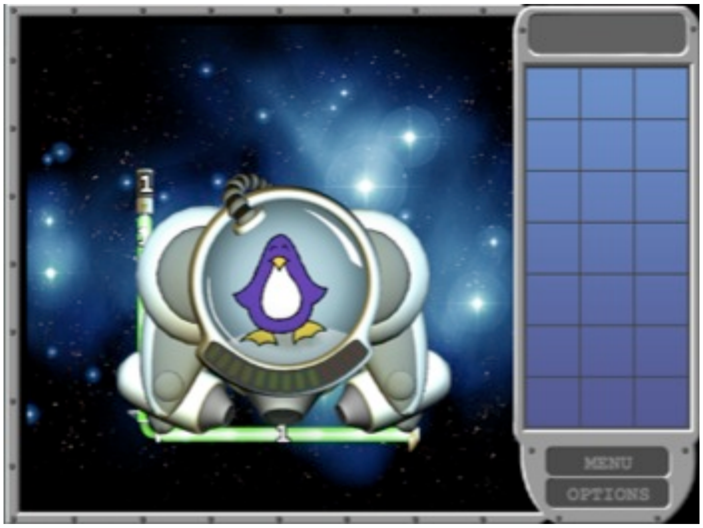

Image 9. End animation for each level.

Level 1-1 Player Data

All eight of the 4th grade players completed Level 1-1. One student hesitated when dropping the bender into the highlighted square which prompted interviewer guidance. Seven of the eight players outwardly expressed understanding the purpose of the game during the end-level animation began with expressions such as "*Oh, I get it*" and "*Oh, that's pretty cool*".

Of the 16 5th grade players, two players accidentally skipped level 1-1 because they selected the wrong level in the level select menu. One student commented on how easy the level was, another student recalls that the game requires you to "*split it up in fractions*" (referencing the laser). Another player recalls a previous version by explaining "*this where we try to do like the build thing*".

Level 1-1 Discussion

In the tutorial Level 1-1, the player completes the level in four moves and cannot divert from the four moves. After playing level 1-1 the player has learned that dragging and dropping objects is a primary game mechanic for completing the level.

Though the laser and the ship are labeled “1”, nothing in the instructions or the game mechanic requires the player to take notice of this detail. In addition, there aren’t any consequences or rewards to noticing and the player’s successful completion of the level does not require the player take notice of the equivalence labels “1” on the ship and laser.

In this level players are exposed to the idea that the orientation of the bender has significance. The direction of the funnel and output arrow of the bender is implied by the placement and success of correctly directing the laser. The direction of the input and output of the bender is also reinforced with a mouse-over animation showing where the laser will enter and exit. Because players are following step-by-step instructions and can’t deviate from each step to play with different options, it cannot be determined if all players picked up on the directionality of the funnel and arrow for each bender.

Though every student completed this level easily, for 4^{th} grade players the end-animation appeared to be a key marker in helping some of the players see and understand the purpose of the game. For the 5^{th} grade players, who had played before, this level was a refresher. Regardless, all of the players completed the Level 1-1 quickly.

Level 1-2

Level 1-2 begins immediately after the end animation of Level 1-1. It begins with the instructions “*You might need to bend the laser more than once.*” (Image 10). There are two benders available in the staging area to the right. The player must click “OK” to continue. The number on the laser and the space ship, “1”, remains the same from Level 1-1.

Image 10. First screen of Level 1-2.

Players can click “OK” and remove the instruction box or the player can drag and drop the benders onto the play area without removing the instructions. Players can place benders (and in future levels, *splitters*) anywhere on the outer space the background except on top of the ship or directly on top of the laser source (Image 11).

Image 11. Example of benders placed on the play area.

As on all levels, the underlying map is a grid which snaps the bender in place. This snap-to-grid is a subtle but important feedback mechanism which gives the player a sense of the bender and splitter placement limitations. The snap-to-grid informs the player of how to align the laser in relation to the ship.

In Level 1-2, the player can move the benders anywhere on the board as many times as he or she wants. There are no hints or interventions that appear after a certain number of attempts or time lapse.

If a player places a bender with the funnel facing the wrong direction in the path of the laser a pop-up message appears, "*The laser cannot enter from that side. It needs to go in the funnel.*" (Image 12).

Image 12. Funnel direction pop-up message.

As is appropriate for a tutorial level the configuration and complexity of the spatial problem solving of this level is limited. The player needs to bend the laser twice and with only two benders available there are a limited number of sequencing and placement choices available. Given the orientation of the funnel direction of both benders, there is only one bender as a viable first choice (Image 13).

Image 13. One viable first choice bender.

Even if the player places the second bender incorrectly, any placement along the trajectory of the laser will make the potential correct answer visible (Image 14).

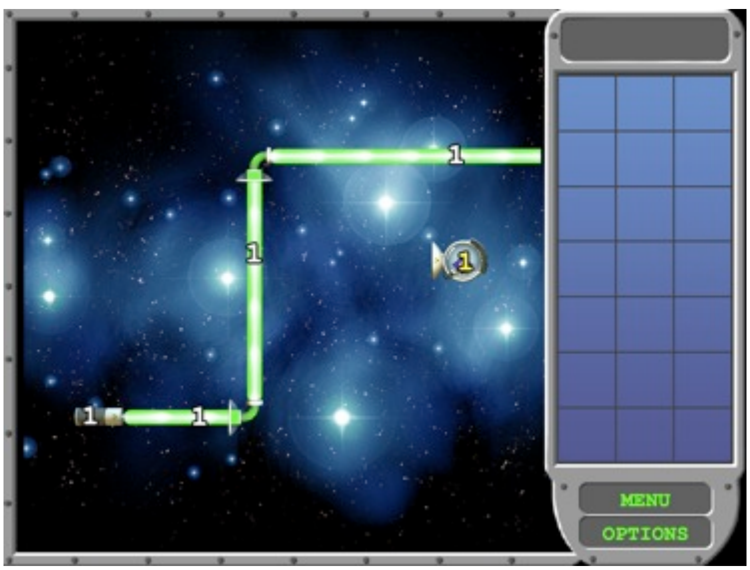

Image 14. Misaligned second bender.

After player successfully directs the laser into the ship, the end level animation begins and immediately progresses the player to the next level.

Level 1-2 Player Data

Six of the eight 4th grade players (41, 42, 44, 45, 46, & 48) completed the level without assistance or prompting from the interviewer. These students also finished the level quickly without hesitation or exploring. Two (44 & 46) of the 4th graders demonstrated slight hesitation but solved the level without interviewer intervention. For example, one player asked "*where do I put this one?*" but answering her own question before allowing the interviewer to respond. The other player accidentally misplaced the bender because of the snap-to-grid feature but self-corrected.

One 4th grade player (49) did not require interviewer intervention but took much longer to figure out the sequence and placement of the benders. This player initially chose the correct sequence of benders but placed both to the far right of the space ship, causing the laser to go behind the space ship. The player self-corrects without intervention but in doing so tries to shortcut by using the benders out of sequence, then notices choosing the other bender first is the wrong sequence because the funnel is facing the wrong direction. The player reverts back to the correct sequence of benders and places them to the left of the ship, allowing the laser to be directed into the ship and solves the level.

One 4th grade player (47) required interviewer intervention. This player got the sequencing of the benders correct but placed the second bender in the wrong location (so the laser went two rows above the ship just as in Image 14). It took prompting from the interviewer for this player to notice that to move the second bender down would direct the laser into the ship.

None of the 4th grade players referenced the size of the laser (“1”) or the number on the ship (“1”).

Of the 16 5th grade players, 13 completed Level 1-2 without interviewer intervention. Two players (55 & 516) accidentally skipped this level when they selected the wrong level from the level-select menu in the beginning. One player hesitated trying to figure out how to drag-and-drop the bender, but after three quick mouse-click attempts she did so without interviewer intervention.

Two 5th grade players (511 & 518) required interviewer intervention to complete the level. One player (511) required scaffolded guidance from the interviewer to think through the level. This player did not read the instructions and selected the incorrect bender first. She didn't place the incorrect bender immediately but held it along the length of the laser, then eventually placed it back in the staging area. She then picked up the correct bender but struggled with getting the correct placement and then the sequence of the benders. The interviewer guides her by asking her to recall the instructions but even after doing so the player decides the (correct) bender is not going to work because "*because it's going up instead of going to here*" (implying that laser would be going in the wrong direction), missing the idea that the player may have to use more than one bender and bend the laser more than once. After receiving scaffolded questions from the interviewer such as "*How many benders do you need to bend it more than once?*" and completing the level the player explains "*Sometimes just, if I don't get it, that doesn't mean it's bad, because I don't get things on the first try*".

The second 5th grade player (518) who needed one interviewer intervention selected the correct bender first but placed it directly under the space ship (missing the funnel of the ship). Though she knew the correct sequencing of the benders, she could not quit figure out the placement without the interviewer restating the pop-up message the player missed ("*it said the* *laser has to go into the funnel side of the ship*”). Once the player was reminded of this information she was able to complete the level without further assistance.

None of the 5th grade players made mention of the size of the laser (“1”) or the space ship (“1”). However, when asked what he though about the game, one player mentioned fractions and learning. “*I think it’s cool ‘cause you get a — you--you guys to teach us while we’re thinking…and--and more about fractions, and so…it’s--it’s a good game…to play, because you learn about more fractions*”. Another student commented on the structure of the game when she said “*I guess the first it’ll — times it’ll be easier then, because it’s like, like it’s just teaching you how to kind of do it, and it’s easy*”.

Level 1-2 Discussion

Level 1-2 is the first level for players to explore the game space without being held to following step-by-step instructions. With the ability to choose from more than one piece and to place either piece on the games space it becomes apparent there are three aspects of the spatial puzzle component of game play that players must learn to be successful. First, the orientation of the funnel for where the laser enters the bender (or splitter, in later levels). Second, the orientation of the output of the bender (or splitter) and the output direction of the laser. Third, the sequence in which the benders (or splitters) must be used in order to direct the lasers to the correct location. At this beginning level, four players (44, 47, 511, & 518) required one interviewer intervention to work through a combination of these spatial components.

There is no formal introduction to number equivalencies and the relationship between the size of the laser and the size of the ship. This is also evident in the interviewer interventions. The scaffolded questions helped players through the spatial problem solving components of game play and did not include math concepts, emphasizing this level is for learning how to play the spatial aspect of the puzzle – not the math.

The detailing of the problem solving process of the spatial reasoning component of this level reveals that the player must figure out the correct sequence and placement of benders. However, figuring out the correct sequence and placement of benders is not related to math understanding. None of the players made mention of the size of the laser, the size of the ship, or their number relationship to each other. In this level, just as the one before, understanding the relationship between the "1" of the laser and the "1" of the spaceship as equivalent has no bearing on the player's ability figure out how to redirect the laser to the correct location. As will be shown in higher levels, the complexity of the sequence and placement of benders (and splitters) creates tension for some players between figuring out the directionality of the laser and understanding the value of the ship and the size of the laser.

In addition, the introduction to the spatial reasoning component of the game (sequencing and placement of benders and splitters) before introducing equivalencies (which comes next in level 1-3) is a way of prioritizing spatial game content over math content. This isn't to say that introducing the basic game mechanics before the math content isn't the correct order but it opens an opportunity to evaluate how players are making sense of this space, both for math understanding, spatial reasoning, and learning the necessary game mechanic.

With player choice there is also evidence of player strategies beginning to develop, such as trial and error. One player (518) is aware of her struggle but persists demonstrating she may have been exploring the parameters of the game by not paying attention to the "rules" or instructions. This isn't to say this approach is a good or bad but to make note that it is another way in which players learn about the game space, such as exploring and repeating failures. As the player progresses through higher, more complex levels, the question remains is if trial and error as a play strategy helps in learning fractions as much as it helps in learning the spatial component of the game.

Level 1-3

The first screen of Level 1-3 begins the same as the previous two levels displaying instructions; "*Numbers on space ships show how much power they need.*" (Image 15). In Level 1-3 the player is introduced to the numbers on the lasers and ships. In image 15 the "1" is highlighted. This level also introduces *splitters*. These objects split the lasers into ½ (two splitter) or 1/3 (three splitter). In Level 1-3 there are four pieces available; two benders, one two splitter, and one three splitter (Image 15). There is also new game content, boulders, added to the play space. In Level 1-3 the boulders are not a direct obstacle where the player has to maneuver the laser around the boulders but rather, the boulders are placed as guideposts that create paths the laser can follow.

Image 15. First screen in Level 1-3.

The player must click Next to continue. The second screen displays another set of instructions “*To give the ship the right amount of power, you might need to split the laser*.” (Image 16).

Image 16. Second screen of Level 1-3.

The player must click Next again. The third screen displays the instructions “*Pick up this divider, which splits the laser into two equal parts.*” (Image 17). The corresponding two splitter is highlighted with a yellow arrow pointing to it. The player must click and drag the highlighted two splitter to continue. The instructions do not use the terms one-half or one-third to describe two- and three splitters.

Image 17. Third screen of Level 1-3.

After selecting the two splitter the instructions "*Drag the laser divider to the square to drop it*." appear (Image 18). The player must place the two splitter in the highlighted square. The directions do not explicitly point to or state the value of the ships (1/2) and the value of the laser (1).

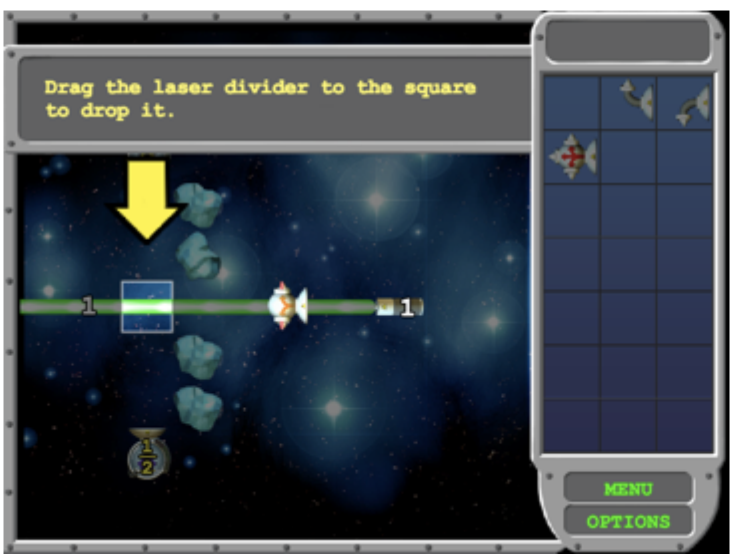

Image 18. Dragging and dropping the two splitter.

Dragging and dropping the two splitter into the highlighted square automatically completes the level (Image 19).

Image 19. Level 1-3 complete.

Level 1-3 Player Data

Seven of the eight 4th grade players completed the level 1-3 without interviewer intervention. One player picked the correct splitter and started to place it but then put it back in the staging area. When asked "*So, why did you start with that one and then go back?*". He picks the splitter up again and places it in the square. He starts to explain "*Because I've noticed that it was not really…*" but stops mid-point to watch the animation then says *"…well…oh, that's a good one*". This indicates the animation was an important part to his understanding of how to complete the level.

Two 4th grade players reference the purpose of splitting the laser. When the interviewer asked "*So, what do you think that is going to do?*" [referring to the splitter]. The player replied "*Divide it.*" The interviewer responded, "*Yeah. Into how many pieces?*" and she replies "*Two?"* and places the two splitter. For the other player the interviewer asks "*So, you see what happened there?*" and the player replies, "*It splits the lasers to two of the ships.*" It is not clear based on his response if he is referring to the size of the laser (math) or the number of lasers the splitter makes.

Of the 16 5th grade players, two accidentally skipped this level by selecting the incorrect level on the level select menu. The remaining 14 5th grade players completed the level without interviewer intervention.

Two 5th grade players described the game in math terms without prompts from the interviewer. The first said "*Oh, and it can divide into like halves and fourths and thirds and stuff*". The second player was describing his actions out loud when he explained "*Oh, yeah. This thing clicks. [selects two-splitter] You click that and then it goes on and separates it. And then, they both get the equal amount that they need.*"

Level 1-3 Discussion

Players are given instructions to follow with very limited or no options for exploration. The only choice the player has is to click and drag the highlighted two-way splitter. The visual presence of the other, unusable benders and splitters might serve as an indicator to the observant player that in future levels they will have more choice in which types of benders or splitters to use. However this level of observance may vary depending on the experience and play style of the player.

Another game component that some players may notice (but to which there isn't a direct reference), are the boulders. They don't block or effect player choice but it is a visual indicator of a component that will effect spatial game play in later levels.

The instructions do not use the terms one-half or one-third. In addition, the player does not have a choice which splitter to select or where to place the two splitter for the final action. The absences of fraction description and limited player choice diminishes the level of effort the player must make to solve the level. Instead of exploring or thinking through which splitter to select the player follows instructions. While these instructions are explicit for understanding the game mechanic of clicking-and-dragging and splitting lasers the instructions do not elaborate on the mathematical meaning (creating one-half fraction) of the game action.

This level may be an important opportunity to point out to the player the mathematical relationship between the two-splitter, laser (1), and the ship (½). Without explicitly stating the numerical relationship between the laser and ship, either through written instructions or through game play, there is no way to ensure the player notices the correlation. In addition, in the step-by-step instruction of the the tutorial level, there is no risk to the player because they can't fail. Removing risk and failure may also not be sufficient motivation for players to notice anything except for what successfully completes the level. The player's attention is focused on following instructions not making sense of and understanding their game play choices through failure.

Though two players described the purpose of splitting, the discussion was prompted by the interviewer asking about their understanding. The content or mechanics of the game itself do not require or press players to reflect upon their own understanding in this way. The animations in the tutorial levels provided insight to some players. As one player indicated while playing Level 1-3 "*Because I've noticed that it was not really…*" stops mid-point to watch the animation then says *"…well…oh, that's a good one*". Indicating the animation was an important part of his understanding of how to complete the level.

Given the limited math instruction embedded in game play up to Level 1-3, the players who spoke in math terms are demonstrating their knowledge of fractions prior to game play. For the two 5th grade players who described the game in math terms they did so using their best terms. Sometimes the descriptions are accurate "*Oh, and it can divide into like halves and* *fourths and thirds and stuff*" and other times it could be math thinking but using the inaccurate terms "*You click that and then it goes on and separates it. [uses it; completes level] And then, they both get the equal amount that they need"*.

Level 1-4

Level 1-4 introduces a new game mechanic, the magnifying glass. The magnifying glass allows players to view the size of the laser close up. For the first screen in Level 1-4, the player must click on the arrow to test the magnifying glass to proceed (Image 20). The player has one bender, one two splitter and one three splitter. There are more boulders in the play space but they are not direct obstacles to completing the level. This level is the first level to represent "1/3" ship.

Image 20. First step for Level 1-4.

The player must click on the highlighted box to view the magnifying glass (Image 21) to proceed.

Image 21. Using the magnifying glass to view the laser.

After viewing the magnifying glass there is a quick animation removing the magnifying glass, the instructions at the top of the screen, and the three splitter from the play space. This is an important transition as the resulting screen, which the player will attempt to solve, shows the same ship that was receiving the correct laser size (1/3) is now getting the incorrect amount (1) (Image 22). Removing the three splitter in the animation is an important detail that can serve as a clue to which piece to select, but not all players may not notice the subtle laser switch from 1/3 to 1.

This leads to another game component introduced in Level 1-4. There is an animation for the ship if a ship is receiving too much or too little power (lightening bolts and clouds of smoke respectively). In this level, when the tutorial ends and the size of the laser directed into the far left ship changes from 1/3 to 1 the “too much power” animation is present (Image 22).

Image 22. Too much power animation on far-left ship.

To complete this level the correct first choice is the three splitter. The three splitter being the only viable solution the too much or too little power animation is important feedback if a player starts with a bender or two splitter.

Given the layout of this level, if the player places the three-way splitter anywhere along the trajectory of the laser (without another other splitter or bender) it will automatically direct the laser into one of the ships (furthest left) by default. Then it is just a matter of adjusting to the appropriate location to direct all three lasers from the three splitter into the ships appropriately (Image 23). This completes the first level pack, Levels 1-1 through 1-4.

Image 23. Placement of the three splitter on laser.

Level 1-4 Player Data

In game levels with more player choice, such as Level 1-4, the player data is organized and presented in the categories in which the data was coded. The data presented here is an example of the complete player data for a single level. In future levels, the player data will be shortened or combined into the discussion.

Level Completion, Intervention & Play Strategy

All eight of the 4th grade players complete Level 1-4. Six of them completed the level without interviewer intervention. One 4th grader (45) required one intervention and another 4th grader (41) required interviewer intervention. Player 45 was also the only 4th grade player to use trial and error as a play strategy to determine which piece to use. All 16 of the 5th graders completed this level. One 5th grade player (519) used trial and error, selecting each of the bender and splitters, to test in the game space.

First Choice

The first choice a player makes can expose the player's focus and orientation to how they are approaching solving the problem. Six 4th graders selected the correct three splitter first but two (47 & 49) selected the incorrect two splitter first. 14 of the 16 5th grade players selected the correct three splitter first but two (515 & 519) of the 5th grade players picked the incorrect two splitter first.

Player Content Focus

Color

Two 4th grade players (41 & 45) made decisions based on the color of the laser, rather than the size. None of the 5th grade players referenced the color of the laser or the splitters as a factor in their decision making.

Power

Two 4th grade players (47 & 48) and two 5th grade players (52 & 515) articulated they noticed the "too much power" animation.

Spatial

Three 4th grade players (46, 47 & 49) made decisions based on the spatial components of play. This means making selections based on the directionality of the funnel and output of the bender or splitter instead of the size of the laser. Two 5th grade players (515, & 519) demonstrated their initial decisions were based on the spatial/visual components of play but after making their selection realized the size of the laser didn't work.

Math

One 4th grade player (41) articulated noticing the size of the laser matched the size of the space ship but this was also the same player that received interviewer intervention which means the player may not have been focused on math understanding in her decision making. Seven 5th grader players (51, 52, 54, 55, 59, 515, & 519) cited math as being the focal point of their decision making.

Math & Spatial

Two 4th grade players (42 & 44) and three 5th grade players (55, 510, & 517) articulated simultaneously both math and spatial understanding during this level.

Math Struggle

Math struggle refers to instances where the player says or demonstrates through game actions a misunderstanding of the math content. One 4th grade player (45) and one 5th grade player (519) demonstrated math struggle in Level 1-4.

Spatial Struggle

Three 4th grade players (45, 44, & 41) and one 5th grade player (52) demonstrated spatial struggle. However, it should be noted that none of the benders or splitters available in Level 1-4 had the funnel facing an incorrect direction.

Not Clear

Lastly, there was one 4th grade player (48) and three 5th grade players (53, 57, 58) whose reasons for selecting the three splitter were not clear. This means their actions and utterances could be interpreted as spatial or math understanding.

Level 1-4 Discussion

Introducing the magnifying glass is a major component of Level 1-4 yet the function of the magnifying glass doesn't help in explaining how differently sized lasers are achieved but rather serves as a zoom tool for viewing information that is already visible.

As seen in Level 1-2, when players are given more choices there is more opportunity to see individual player strategies and struggles. More player choices provide visibility into what players are attentive to and how they are making sense of the game space. The types of interviewer interventions needed also expose potential issues while the think-aloud protocol reveals the types of play strategies used. In addition the player's first choice is an initial indicator of the players' understanding of the game content (math, spatial, or both).

Interviewer Intervention

All 24 players completed this level but two required interviewer intervention to help complete the level. One 4^{th} grader (45) required one intervention where the interviewer reminded the player of the difference between a bender and splitter. Another 4^{th} grader (41) required interviewer intervention to pay attention to the size of the laser and to understand they did not have to use all the benders and splitters to complete the level. Both of these interventions could have been prevented with additional in-game materials such as roll-over text for the benders and splitters to explain which each does and instructions which explained the player does not have to use all the pieces available to solve the level. Though these two interventions do not focus on the spatial or math content of the game, it does illustrated the range in which players approach and interpret the game space.

Play Strategy

Only two players (45 & 519) used trial and error as a play strategy for figuring out which piece to use, meaning they cycled through the pieces available to figure out which one was correct. Players who use trial and error indicates the player is testing the parameters of the game space to better understand how to be successful and/or isn't reading the instructions or paying attention to tutorial feedback and is learning the rules of the game by doing.

One player (41) accidentally solved the level when she removed the bender and two splitter from the play space (leaving the three splitter that happened to be located in the correct position). Though these accidental discoveries are powerful learning moments it is difficult to be certain of what the player was attentive to when she made the discovery and what information she associates with her success. Was she paying attention to three lasers for three ships? Did she notice the size (1/3) that was created to complete the puzzle? Or did she believe she just found the right spot (spatial)? How these types of happy accidents inform a player's future decisions is also representative of what the player is learning in order to be successful.

First Choice

In Level 1-4 not all of the benders and splitters are required to complete the level. All the bender and splitter pieces available have the funnel direction facing the correct direction. In future levels, the benders and splitters may be rotated requiring the player to choose pieces whose funnel aligns correctly. As such, choosing an incorrect facing funnel was not an issue for Level 1-4. In Level 1-4, no one selected a bender as their first choice, however four players (47, 49, 515, & 519) picked the two splitter first. Picking a two splitter (which makes ½ laser) instead of the correct three splitter (to match the 1/3 ship) may indicate the player 1) doesn't yet understand the difference between two- and three-splitters, 2) isn't focused on or hasn't noticed the size of the laser, and/or 3) is focused on making the lasers go in a particular direction. Though an incorrect first choice gives the player an opportunity to explore the parameters of the game, such as discovering the results of different sequencing and placement combination of pieces, there is nothing in the design of this game that prevents players from trying all different combinations, such as player 519, without taking notice of the fractions on the size of the laser or the ships.

Player Content Focus

Level 1-4 is the first level with enough player choices that its possible to see the range in which players are making sense of the game space by what they are choosing to pay attention to.

Two 4th grade players (41 & 45) made decisions based on the color of the laser, rather than the size of the laser. The interviewer explained to both of these players the red laser did not mean they got it wrong and to pay attention to the number on the laser. In this and the previous levels there was no mention of the color of the lasers as an indicator or mechanism for determining if the laser is the correct size. Players who consider the color of the laser as part of their problem solving strategy is an example of the range of details players may take notice of in order to make sense of the game space.

Noticing "too much power" animation is an opportunity for understanding the difference in fractions as represented as the size of the laser and the space ship. These pop-up messages are an indicator to the player that they are not using the correct sized laser and need to make the laser bigger or smaller. Though the four players (47, 48, 52, & 515) who took notice of this animation eventually completed the level, the animation does not explain explicitly which fraction is smaller or larger. Rather, players can deduce from the difference in smoke cloud (too little power) or lightening bolts (too much power) which is smaller or larger compared to the size of the ship. For players who do not notice the distinction between the smoke cloud (too little power) and the lightening bolts (too much power) or players not familiar with fractions this animation feedback may only indicate they are doing something wrong but will not help them understand the size difference between ½ and 1/3. In Level 1-4, one player noticed the animation when the play portion of the level started but it wasn't clear how it influenced their game play, another player corrected their choice after noticing the animation, and two players continued to use the bender (which still provided too much power) not recognizing initially that splitters changed the size of the laser. However this cannot be guaranteed because they are allowed to progress without ensuring they understand this concept.

Five players (46, 47, 49, 515, & 519) made decisions based on spatial problem solving. This was evident in explanations as to why they chose a piece, such as "*Because that one just goes this way and, uh, goes forward and--and the left, and the other one goes all three sides, and it gets to the both of them, mm, yeah*" (49) and "*Because it was going all three ways*" (47). Players 515 and 519 demonstrated their initial decisions were based on the spatial reasoning but after making their selection realized the size of the laser didn't work. One player (515) explained his choice because "*I thought it would make an arrow. And now it's one-half…*" and the other player (519) explained *"…it'll only go to one and it will get overloaded*". Of these five players, three of them (46, 47, & 49) did not also cite math as part of their decision making process during any part of the level, which means they were able to solve the level without considering the size of the laser in relation to the size of the ship. Considering the size of the laser in relation to the ship is key for getting players to think about fractions.

Seven players (51, 52, 54, 55, 59, 515, & 519) cited math as being the focal point of part of their decision making. When asked why they made the choice they did, responses included "*Because it, um, this one's a whole, and if you divide it into three, it'll give you thirds*." (51), "*Because it split up into thirds.*" (54), "*you have to separate the energy into thirds.*" (52), "*Trying to figure out which one would make one-thirds*." (515). Two players (45 & 519) noted the size of the ship (1/3) but still tried to solve the level using the other splitter and/or bender. This indicating these two players hadn't associated "1/3" with the three splitter.

Five players (42, 44, 55, 510, & 517) were able to articulate their choices both in math and spatial terms. This was indicated when one player (42) made her selection because "*that guy is trying to get 1/3*" and "*I saw the three, you know, little points*" and player 44 explained "*Well, it said one and three halves, so probably want to get this one since it has three arrows that go out the tubes…And there's three spaceships.*" When the 5th graders asked about their choice the players responded, "*Because, see, uh, because it has — it's thirds and this was already thirds. And then it had--had three spots, and there was one going that way and one going down and one going up*" (55), "*Because it's splitting it into third, three pieces.*" (510), and "*Because the one-third…or like, every spaceship needs at least one-third*." (517). These utterances and actions indicate some players' strategies were rooted in considering both components of game play in their decision making process. Considering both spatial and math simultaneously is the ideal strategy for problem solving in Refraction because it combines both primary learning objectives of the game; spatial reasoning and fractions.

Two players indicated struggling with math understanding in Level 1-4. One 4th grade player (45) demonstrated math struggle when he states the size of the ship "*1/3*" but selects a two splitter to play explaining "*I thought it would help split it. Apparently not*" indicating he didn't understand the relationship between the type of splitter and the size of the laser it would produce. One 5th grade player (519) had taken notice of the size of the ship (1/3) at the beginning of the level but then could not identify which splitter to use to create it. In both instances there is an opportunity in future levels that cover the same problem, for the player to learn to associate the three splitter with 1/3. However, there aren't any direct feedback mechanisms in this level (or others) that explain directly in mathematical terms why the two splitter (1/2) doesn't work. Without directed feedback, the player's math learning is contingent on what the player notices as significant. It may be that after several instances of failing at the same problem the player will make the connection that three splitter is 1/3 but it depends on whether the player is paying attention to the math or the spatial problem.

Four players (41, 44, 45, & 52) demonstrated spatial struggle by repositioning benders and splitters or trying to get the laser to go in a particular direction but were not successful. Level 1-4 is a little more difficult than previous levels because players are given three pieces to choose from in the beginning but not too difficult because only one piece is needed to complete the level. It is the first level where players can experiment with different combinations of splitters and benders to see the results of their choices. However, given the limited number of bender and splitter choices it is the one move, the placement of the three-way splitter along the initial laser trajectory, which completes the level and makes the spatial challenge somewhat limited.

In this and future levels, repositioning benders and splitters serves as an indicator of what aspect of the spatial problem the player is struggling with. As will be evident in future levels, the spatial problem solving of *Refraction* includes solving for the orientation of the funnel, the direction the laser exits the bender or splitter, the sequence and placement of benders and splitters to navigate a laser around obstacles and/or to reach a ship.

There were four players (48, 53, 57, 58) whose choices weren't clearly associated with math or spatial reasoning making it difficult to determine how they were interpreting the game space. Player 48 explained she made the selection because "*Maybe it could go to all three of them*". Player 53 completed the level quickly and when asked "*do you automatically just know?*", he responded "*yeah*". Player 57 explained how he knew "*Because it goes three ways*" and player 58 said "*So, it could go in the--the three of them*." These responses make it difficult to determine if the players knew they needed thirds or if they counted the number of lasers needed to match the number of ships. The consequences of this is that players may be able to pass through this level without having to know that a three splitter divides 1 into 3 equal parts.

All of the player decisions made in Level 1-4 do not *require* the player have an understanding of fractions. Only the initial selection, the player's first choice has the potential for players to recognize the three splitter will create three, one-third lasers. However, as shown, players can successfully complete this level without having to reach that understanding. In game play, this misses an opportunity to help players understand the relationship between the size of the laser, the type of splitter and the size of the ship (and understanding fractions required to figure it out). The more levels a player encounters that do not require them to make this connection the greater the likelihood they will develop the skills to recognize the connection, hence the math.

Up until this point in the game, in order to successfully complete these levels players were required to demonstrate competency with the following. (1) understand *all* of the functionality of benders (e.g. orientation of funnel and direction of pointer, can't be placed on top of ships or lasers or other benders and splitters), (2) *some* of the functionality of the splitters (e.g. orientation of funnel and direction of pointer, can't be placed on top of ships, lasers, or other benders and splitters, two splitters create two lasers, and three splitters create three lasers) but not all (combinations of splitters used together not required), (3) objects are aligned in a fixed grid layout and pieces snap to place, (4) overpowered ships move around differently and means something is not right but does not produce any lasting consequences.

As players progress through game play and accumulate knowledge and understanding of the game environment there are opportunities to identify potential moments of evidence of learning math and spatial reasoning. The player who needed a reminder of what the benders and splitters did in game also needed help understanding the meaning of the color of the lasers. Once understood, she was able to focus her attention on the size of the laser which prompted her to explore different combinations to get the correct size. For the other player who missed the pop-up message, the interviewer explaining the ship was getting to much power, may have shifted her focus to select the correct three-way splitter or at the very least encouraged her to try a different configuration.

Level Pack 2: Embedded Assessment

Level 2-1

Level 2-1 is only one level in level pack 2. Level 2-1 is a timed embedded assessment (Image 24). The embedded assessment is designed to measure a player's understanding fractions which have not yet been presented in the game (one sixth and one-ninth). The embedded assessment is presented as standard game play (rather than a standard assessment you might find in school). There is a timer at the top of the screen that counts down from 2-minutes the moment the level begins. At the end of two minutes the player automatically progresses to the next level regardless if they've completed the level. Level 2-1 is the first timed level (only the embedded assessment levels, 2-1 and 8-1, are timed). The player has seven benders, four two splitters, and four three splitters of various directions to choose from. There are boulders present in this level, but they are not direct obstacles to the ships.

Image 24. Level 2-1 embedded assessment.

Level 2-1 is the first level that introduces the idea not all of lasers created from the three-splitter must be used to successfully finish the level. For example, using a three-splitter creates three lasers but there are only two ships that need to be solved for (Image 25). This leaves one remaining laser from the three-splitter unused. Extra, unused lasers may serve as a stumbling block for players who count lasers (three lasers for three ships) instead of looking at the size of the laser in relation to the size of the ship to solve the level. The extra laser also creates more viable combinations of sequencing and placement for a variety of benders and splitters not seen in previous levels.

Image 25. Only two of the three lasers created are needed.

Level 2-1 Player Data

Though 4th grade players made multiple attempts to complete the level, none of them this level before the timer ran out. Six of the 16 5th graders (51, 52, 54, 510, 516, & 517) completed the level before the timer ran out. Because this is an assessment level none of the players received interviewer intervention.

Level 2-1 Discussion

The embedded assessment level is designed to measure player's ability to create one-sixth (1/6) and one-ninth (1/9), fractions that have not yet been introduced in the game, using the primary game mechanic of bending and splitting lasers. The design rationale for the timer was to limit successful completion of the level to players who already understood the concepts of splitting and partitioning and prevent players who may not understand these concepts from eventually being successful through trial and error. Timing players also set parameters for comparing the results of Level 2-1 with the exact same embedded assessment in Level 8-1 to see if there was player improvement.

Since this level is designed to measure player competencies, for the purposes of this study I've presented player data regarding those who complete/do not complete Level 2-1 as a way of gauging how many players have mastered the game mechanic and demonstrated they know how to complete the level using math and spatial understanding. It is important to remember that the 5th graders had played a version of *Refraction* the year before as 4th graders.

Players who noticed the time restriction may have changed their play strategy depending on whether the timer was interpreted as a deterrent or motivator for the player. If Level 2-1 was not timed it might be possible to determine which players where successful due to strategic trial-and-error approach.

Level Pack 3: Assessment

After completing or the timer runs out in Level 2-1 the player automatically progresses to Level Pack 3. Level pack 3 is a pre-test with four levels. The pre-test was designed to reflect math problems similar in difficulty to the math problems integrated in the game but presented in a more traditional format. The questions were chosen based on assessments appropriate for 4th and 5th grade math skills. During Level Pack 3 assessment levels players did not receive interviewer intervention.

Level 3-1

In level 3-1 players are to select the greater fraction or decimal from each set by clicking on a fraction to indicate their answer (Image 26). Though it was not an intentional design choice, there are no restrictions that prevents a player from clicking submit without answering any of the questions. Once the player clicks submit they cannot return to the level. Players do not receive any feedback on the selections made. After clicking submit the player automatically progresses to level 3-2.

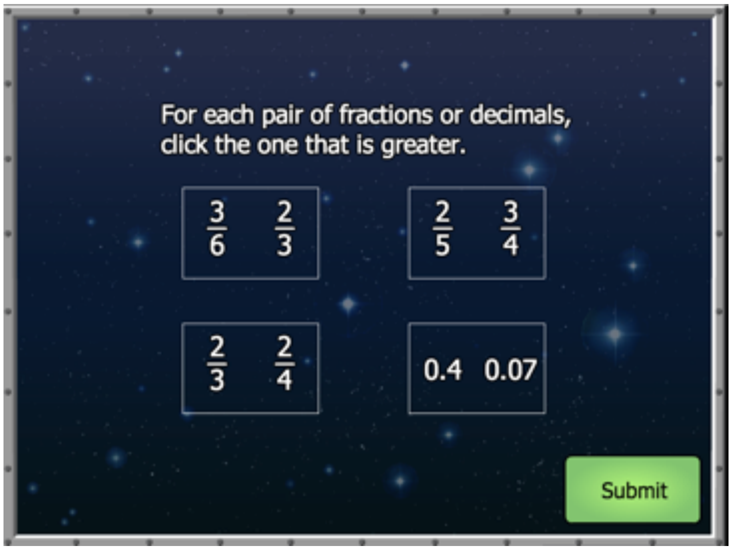

Image 26. First assessment question.

Level 3-1 Player Data

Player answers to Level 3-1 are present as selecting all the correct answers, selecting some of the correct answers (but not all), and selecting none of the correct answers.

4th Grade	41	42	44	45	46	47	48	49
All Correct								
Partially Correct								
All Incorrect								

5th Grade*	51	54	55	57	58	59	514	515	516	517	519
Correct											
Partially Correct											
All Incorrect											

*Five players (52, 53, 510, 511, & 518) accidentally skipped the level and are not included in the table.

Level 3-2

In Level 3-2 players select the icons: "*Split in 2*", "*Split in 3*", and "*Split in 5*" to divide the circle into eighths (Image 26). The directions state explicitly "*You can click on each button more than once.*" Though there is no restriction to the number of times the player can click these buttons (it will continue to make the “click” sound for each compression) the visual representation in the circle maxes out (Image 27). There are no indicators or hints to the player after clicking any of the buttons and there is no time limit to complete it.

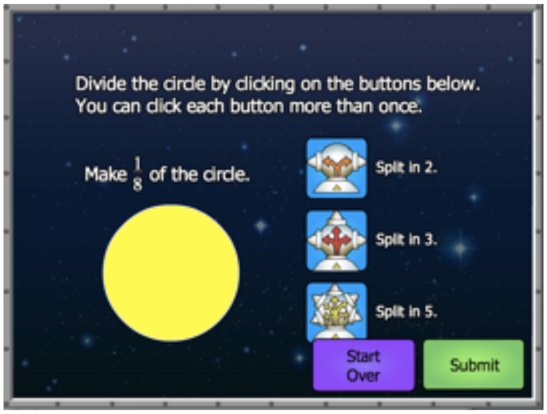

Image 26. Start screen Level 3-2.

Image 27. Smallest possible division.

Level 3-2 Player Data

4th Grade	41	42	44	45	46	47	48	49
Correct								
Incorrect								

5th Grade*	51	52	53	55	57	58	59	511	514	515	516	517	518	519
Correct														
Incorrect														

*Two players (54 & 510) accidentally skipped Level 3-2.

Level 3-3

In level 3-3 is a number line with the instructions “*Show where each number goes on the number line.*” displayed (Image 28). The player drags and drops each of the numbers contained in the box to a location on the number line between zero and one. Once the player moves the number to the number line the player cannot return the number to the box, the player cannot clear the number line and start over. However, once the number has been placed on the numberline the player can slide it along the number line freely. There is no locking or snap-to-grid mechanism to allow players to determine where to place the numbers in relation to others. Since this is an assessment, there are no hints or cues to the player if they are close or get the right placement. There is no time limit on this level.

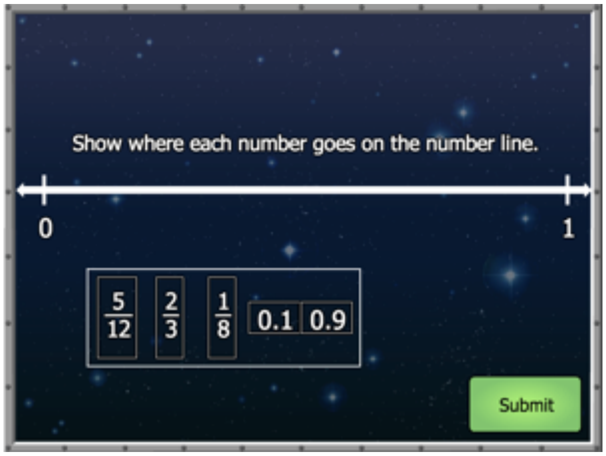

Image 28. Level 3-3 start screen.

Level 3-3 Player Data

4th Grade	41	42	44	45	46	47	48	49
Correct								
Incorrect	X	X	X	X	X	X	X	X

5th Grade*	51	52	53	54	55	57	58	59	511	514	515	516	517	518	519
Correct		X		X									X		X
Incorrect	X		X		X	X	X	X	X	X	X	X		X	

*One player (510) accidentally skipped Level 3-3.

Level 3-4

Level 3-4, displays the instructions "*Click any correct fraction addition problems.*" displayed (Image 29). From a list of four possible answers, the player is able to choose as many of the answers (or none) they think are correct. The player can select and deselect any answer as often as they like without hints or time restriction.

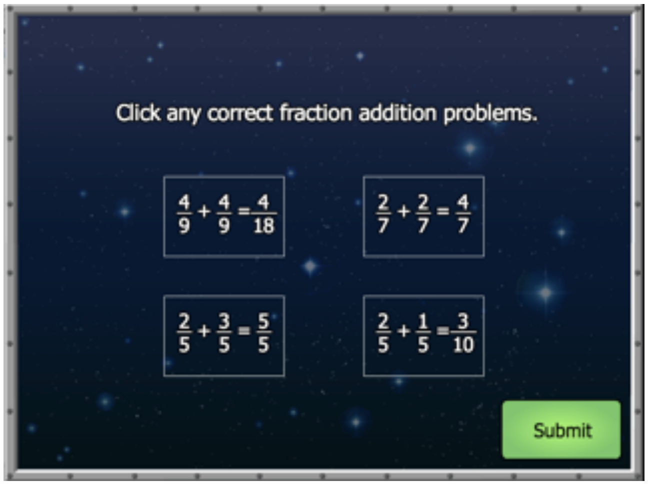

Image 29. Start screen Level 3-4.

Level 3-4 Player Data

4th Grade*	41	42	44	45	48	49
All Correct						
Partially Correct						
Incorrect						

*Two players (46 & 47) were asked to skip Level 3-4 because they had taken too much time and the interviewer wanted to give them sufficient game play time.

5th Grade	51	52	53	54	55	57	58	59	511	510	514	515	516	517	518	519
Correct																
Partially Correct																
Incorrect																

Level Pack 3 Discussion

As might be expected, overall the 5th grade players performed better in Level Pack 3 over 4th grade players. Comparing individual performances in Level Pack 3 with players' play strategies as they develop through higher levels will expose whether or not players are improving their understanding of fractions.

The user interface representing traditional classroom content may have also played a factor in the results of Level Pack 3. This is particularly true in Level 3-2 where players click a button to partition the circle rather than drawing a line. The result was a number of players using trial and error to figure out how the interface works as much as trying to figure out the number of divisions each click makes. In Level 3-3 the design may have interfered, particularly if players weren't accustomed to working with numberlines in this way. In Level 3-4, the assessment could be improved if additional instructions were added explaining the player can choose more than one box.

Level Pack 4

Level 4-1

After completing Level Pack 3 the player automatically progresses to level pack 4. Level 4-1 begins with the laser is labeled one (1) and two ships labeled one-half (1/2) each (Image 30). There are five boulders but none of them are positioned as direction obstacles to the ship. The position of the laser projects in the direction of the ships but does not go directly into either ship. There are more benders (3) and splitters (2) available than is required to complete the level.

Image 30. Level 4-1 start screen

Level 4-1 is the first level that is not either a tutorial (Level pack 1) or assessment (Level pack 2 & 3). Level 4-1 is representative of regular game play and subsequent non-assessment levels. Players are able to select any of the available benders or splitters in any order without a time constraint. The player may also return benders and splitters back to the staging area (right-side of the screen) or move them on any grid point on the screen not already occupied by another fixed object (i.e. ship, boulder).

Given the number of and directionality of the splitters and benders available it is not possible to solve Level 4-1 by placing any of the splitters or benders to the right of the boulders (Image 31) because there are not enough pieces.

Image 31. Level 4-1 cannot be solved if initial placement of a bender or splitter is to the right of the boulders.

Even with the above restriction, there is still more than one way to solve the level. A player can use one two-splitter and one bender (Image 32) or with one two-splitter and three benders (Image 33). There are no consequences or rewards for choosing one method over the other. There is no way to incorporate the three-splitter in as part of the solution. To successfully complete Level 4-1 the player must use the two-splitter first because funnel on both benders are facing the wrong direction and can't be used as first choice.

Image 32. One bender solution.

Image 33. Three bender solution.

Level 4-1 Player Data and Discussion

Level 4-1 is the first full level of game play where we can begin to see how players are making sense of the space given based one what they've experienced so far in the game (and for the 5th graders, what they remember from the previous version of the game). Given the increased number of choices the sequencing and placement of the benders and splitters indicates player thinking in their attempts to solve Level 4-1.

Interviewer Intervention

Two of the 24 players (44 & 511) required interviewer intervention. One needed help understanding that he didn't have to use all of the pieces available to him (44). This intervention is an example that came up in an earlier level and can be addressed by including instructions in the tutorial levels explaining to players they don't have to use all the pieces to solve each level. In the other intervention the player (511) needed prompting to help him think through why he selected the three splitter and what his next step should be. This intervention indicates the player has not yet understood or noticed the purpose of the three-splitter to create one-third (1/3) sized lasers and the size of the laser matters in relation to the fraction labeled on the ship.

Play Strategy

Four players used trial and error as a play strategy to solve for Level 4-1 (42, 45, 49, & 55). One player (49) cycles through the benders and splitters talking to himself to see which each one does. Another player (45) struggles with the funnel orientation and tries different benders and splitters to figure out which one will work and another player (42) uses trial and error and accidentally discovers the splitter makes both lasers “one halves”.

Trial and error strategy of play indicates player focus is on testing the boundaries of the game and at the same time developing a sense of the parameters of the game mechanics and objects. Testing the boundaries of game space is a common characteristic of play. For some players, this may mean less focused time on the learning goals of educational games and more on the mastery of the game space. However, focusing on mastering the game space doesn’t have to be mutually exclusive to mastering the learning goals depending on how the learning goals are represented and incorporated into game play. In Level 4-1, players can try each of the two- and three-splitters to discover how each work but the mechanic itself doesn’t guarantee the player notices the size (fraction) of the laser in relation to the fraction on the ship. It is is possible for a player to complete the level through trial and error without doing any math.

First Choice

In order to successfully complete Level 4-1 the player must use the two splitter first. Since neither bender will work as a first choice (because funnel is facing the wrong direction) players who choose benders first indicates the player is making decisions based on which direction they want the laser to go but without noticing the detail of funnel direction.

None of the 4th grade players selected the correct first choice, two-splitter. For first choice, four of the players (41, 45, 46, & 47) picked a bender with the funnel facing the wrong direction. This meant the laser could not go through the piece selected and indicates these players have not understood or were not attentive to the direction of the funnel in relation to the direction of the laser. The remaining four players (42, 44, 48, & 49) picked the three splitter (which has the funnel facing the correct direction). This meant the laser went through the three splitter but created the wrong sized laser and indicates these players were not attentive to the size of the laser in relation to the size of the ship.

In contrast, 13 out of 16 5th grade players selected the correct first choice, the two splitter. One 5th grade player (511) selected the three splitter as a first choice and one player (55) selected the bender with the funnel facing the correct direction, indicating the player was focused on directing the laser in a particular direction and not the size of the laser. The last 5th grade player (518) picked a bender with the funnel facing the wrong direction, indicating the same spatial struggle described for the four 4th grade players.

Player Content Focus

The color of the laser continued to be a focal point for some of the players (three total) in Level 4-1. Though the purpose of the different colored lasers is to indicate a different sized laser, only one of the three players in Level 4-1 made this connection, "*Um, I was just thinking since it was red and usually it wasn't supposed to be red, but then I realized the one-half on it*" (518). Player thinking around the color of the laser is similar across different levels. Given there is little variability across levels, the issue of players noticing laser color as a factor in their play strategy is discussed in full detail in the *Discussion* chapter.

Power

Five of the 4th grade players (41, 42, 46, 47, & 48) and two 5th grade players (511 & 518) noticed that the ship is receiving too much/too little power. However, players did not use math talk to describe their understanding. For example, players used phrases such as "*it's pumping too hard*" (48), "*it couldn't fill up both of it*" (47), and "*I think it said you're putting too much of* *something into there*" (511). The other three players did not make a comment but noted the animation and removed their pieces.

As mentioned in Level 1-4, how the players are interpreting "too much/too little power" animation varies. Though the intent of the "too much/too little power" animation is to draw attention to the size of the laser, lasers fueling ships as a metaphoric representation of fractions is flexible enough that players can interpret it a number of different ways ("fill up both…", "pumping too hard", etc.). The types of interpretations can be organized into two categories; those who understand the animation in math terms (the size of the fraction on the laser is too big or too small for the ship) and those who understand the animation to mean something other than math terms. Players in previous and subsequent levels follow the same pattern of interpreting the power animation in either math terms or not but with varied success in how their interpretation helps them complete the level.

Having established the two categories in which players are interpreting how "too much/too little power" animation influences their game play decisions, it is best to examine the "too much/too little power" animation across levels. In the effort of time the remaining analysis of the "too much/too little power" animation game component will be summarized and discussed in depth in the *Discussion* chapter.

Spatial and Math

Four of the eight 4th grade players (42, 44, 47, & 49) and five of the 16 5th grade players (53, 55, 57, 518, & 519) cited or demonstrated that spatial problem solving was the focus of their decisions. When asked why they made a particular selections players made statements such as "*Because it's gonna get — because it's gonna give, um, not energy down there*" (42), "*Two would be uneven, too*" (44, in reference to why she picked the three splitter),"*I need to get…this* *one*” (47), and “*trying to get to that one*” (53). The significance of these types of statements means nine of the 24 players are focused on solving for the directionality of the laser for a portion of game play decisions, rather than the math. These statements also explain developing player strategies that will help identify how players are making sense of the game space. Cumulatively, these instances help explain what players are attentive to and learning through each level.

Two of the 4th grade players (42 & 47) and five 5th grade players (52, 53, 59, 511, & 515) expressed math terms or cited math as a motive for their problem solving strategy. Players made statements such as “*its two*” (47) in reference to the split laser and the other player, “*its this one because it gives ½*” (42), and “because that one needs one-half” (52). These statements indicate that seven of the 24 player are focused on solving for the math for a portion of the game play decisions. Just as the spatial utterances indicate how players are making sense of the game space, math talk indicates to what degree players are considering fractions in their decision making process.

One of the 4th grade players (42) expressed solving for math and spatial simultaneously but did so at the end of the level after focusing on spatial then math (above). Seven 5th grade players (52, 53, 59, 511, 515, 517, & 518) expressed math terms or cited math as a motive for their problem solving strategy.

Math Struggle

None 4th or 5th grade players expressed math struggle, but only two of the eight 4th grade players cited math as a motive for problem solving in the level to begin with. Whereas, seven of the 5th grade players cite math as part of their problem solving but did not demonstrate any math struggle. Lack of math struggle indicates that either math wasn’t a focal point of the players problem solving process or solving for one-half (1/2) in Level 4-1 wasn't enough of a challenge to warrant paying attention to.

Spatial Struggle

Five 4th grade players (41, 44, 45, 46, & 47) and nine 5th grade players (52, 53, 58, 59, 510, 511, 514, 515, & 518) cited or demonstrated spatial struggle in Level 4-1. This includes trying to place a piece with the bender facing the wrong direction (41, 44, 45, 46, 47, 53, 58, 59, 511, & 514), indicating the player is not attentive to the directionality of the piece they've selected. Some players had to reposition a bender/splitter (41, 52, 58, 510, 511, 515, & 518), indicating the player needed to adjust a piece in order to get the laser to follow a different trajectory. One player did not realize that repositioning a bender/splitter would get the laser in the correct location and put it back instead (44). 14 of the 24 players indicated spatial struggle which indicates solving for the position and placement of the benders and splitters and direction of the laser where the focus of player's decision making process. The decisions made during spatial problem solving sequences were made independent of math thinking.

In Level 4-1 more players indicated struggling with the spatial problem solving aspect of game play than the math component for players who indicated struggle in Level 4-1. Over time and across levels we can see a trend in the proportion of spatial struggle to math struggle.

Not Clear

Of the 24 players, there were two 4th grade players (41 & 45) that were not clear if their motives for problem solving were spatial, math or both. This included explanations such as "Try *and make the laser — the--these lasers get to power up the, um —power up the space ships*." (41) and "*Because it's three arrows*" (45). In these statements its not clear if the choice is based of the number of lasers or the size of the lasers. Statements and in-game actions that don't clearly point to math and/or spatial thinking make it difficult to determine how to best support player thinking.

Level 4-1 Summary

As mentioned earlier, this level cannot be solved by placing a bender or splitter to the right of boulders. In levels that have more than one possible, one way of managing the difficulty of the level design is by making one viable first choice. In this level the only way to solve the level is to place the three-splitter first. In addition, the three-way splitter must be in a set of right location (one grid square to the left of the boulders). If this sequence and placement is not correct, the level can't solved. The restricted first move is not true for all later levels but can serve as a baseline by which we can begin to map the game's increased difficulty of the spatial problem solving.

Player strategy patterns and player preferences begin to emerge upon their first choice. One player may choose the bender first with the objective of turning the laser towards a specific direction indicating a focus on the spatial component of the puzzle by directing the laser. Another player may try to use a bender or splitter but the funnel is facing the wrong direction, indicating some struggle to understand the spatial component of game play. Some players note the size of the laser and the size of the ship, selecting their first choice based on what will produce the correct sized laser indicating the player understands the purpose of the game through math terms, whether they get it right or not. Lastly, some players make their first selection which combine both the spatial (correct funnel direction and laser direction) and math (knowing which size laser to create and which splitters to use to create it). None of the players used all three benders to find the solution to Level 4-1, all the players used the more efficient one bender and one splitter solution. These patterns over time demonstrate which players make predominately spatial comments/actions vs. those who make predominately math comments/actions vs. those who did both, and the success rate of each group.

Level 4-2

In Level 4-2, the laser is labeled “1” and there are three ships labeled “1/3” (Image 34). There are three benders, one two-splitter and one three-splitter. There is only one possible solution and this combination means there is an extra bender and two-splitter. Level 4-2 is the second level where the player needs to solve for 1/3. In the first instance where the player has to solve for 1/3 (Level 1-4) they used only the three-way splitter (no benders) to solve the level. This means the spatial and visual puzzle is a little more complex because the player has to use two benders to get the laser to go in the correct direction of the ship. As with Level 4-1, the player creates three lasers to be used for three ships (as opposed to having to create three lasers for only two ships, which appear in higher levels).

Image 34. Level 4-2 start screen.

In this level there is only one correct first choice, the three-splitter. If a player attempts to start with any of the other benders or splitters he or she cannot complete the level. The placement of the three-splitter is also important. Since the trajectory of the laser is through the middle of the three ships, the player must place the ship so that one of the lasers goes directly into one of the ships, otherwise there aren't enough benders to complete the level.

In image 35 the placement of the three-way splitter misses all three ships but moving the three-way splitter up or down the trajectory of the main laser to get the split laser into any of the three ships. The placement of three-way splitter into *which ship* becomes the important choice, further restricting possible correct placement, because with a limited number of benders only a specific combination will successfully direct the remaining two lasers into the remaining two ships.

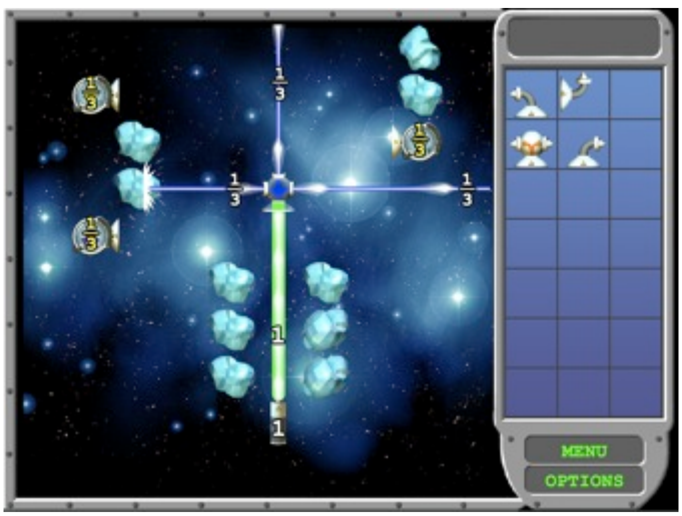

Image 35. Level 4-2 cannot be completed if the three-splitter placed is placed with the lasers missing all three ships.

If the player places the laser to go into the ship on the lower left, then there will be an appropriate number of benders to complete the level (Image 36).

Image 36. Correct placement of three-splitter to complete the level.

If the player places the three-way splitter so the laser goes to the ship on the right side or the upper left side there will not be enough benders to solve the level (Images 37 & 38).

Image 37. With the three-splitter placed in this location there are not enough benders to complete the level.

Image 38. With the three-splitter placed in this location there are not enough benders to complete the level.

Level 4-2 is the first level where the player must use more than one bender on a single laser to direct the laser to the ship (Image 39). Using more than one piece per laser increases the difficulty of the spatial component of the puzzle. It does not increase the math difficulty because the emphasis is on bending the laser, not splitting it.

Image 39. The laser to the right requires two benders to solve the level.

Level 4-2 Player Data and Discussion

Interviewer Intervention

Five of the eight 4th grade players (41, 44, 45, 47, & 49) required some form of interviewer intervention to complete Level 4-2. One player (41) couldn't complete the level on her own and required the interviewer to complete it for her. Another player (49) required one intervention to return the player back to a state where he was closest to completing the level, then he was able to finish it.

Six of the 16 5th grade players required some form of interviewer intervention. Two 5th grad players (511 & 518) stayed focused on only two of the lasers instead of all three and needed guidance noticing the third laser. These players also needed help remembering to stay focused on laser (instead of changing benders and splitters for the existing solved ships) and hints to use more than one bender per laser to solve the level. Four 5th grade players (53, 59, 514, & 519) required one interviewer intervention. Like the two players above, all four required the interviewer to guide the player to noticing the third, unused laser for the third ship.

Players not noticing the third, unused laser is a problem unique to Level 4-2. To elaborate, once the player places the three-splitter and creates three lasers, the players described above successfully directed two of the lasers into two of the ships. However, when they tried to get a laser into the third ship, they focused on one of the lasers already in use, instead of using the third unused laser. Some players attempted to place *repeatedly* a bender on top of another piece in order to direct the used laser into two directions without splitting it.

Not noticing the third, unused laser and player's struggling to use a single laser to get to two ships by using a bender indicates these players were focused on solving the spatial problem of the level. This is evident first, in not noticing all of the lasers available to them. Second, in their resistance to use another splitter, which would make the incorrect sized laser, and instead tried to figure out the mechanics of what a bender could do. Through this intervention, players learned to look for all lasers available to them and that benders cannot redirect a single laser into two directions. None of the interviewer interventions needed emphasized fraction learning.

Play Strategy

Just as in Level 4-1, some players (41, 46, 47, & 48) used trial and error as part of their play strategy to solve Leve 4-2. In Level 4-2 another play strategy emerged, accident/discovery. One player (42) accidentally discovered the three splitter creates 1/3 sized lasers and another player (518) made an accidental selection that led to a correct selection (she meant to grab the two splitter first).

As discussed in Level 4-1, the significance of trial and error can mean the player is exploring and testing the boundaries of the game but it can also indicate a player may not understand what their next best choice should be. Either instance is an important moment for learning, both to for how to play the game and educational content. Accidental discoveries is another strategy that emerges from players making attempts in which they don't know the outcome. In Level 4-2 is the first time accidental discoveries appear. These also are additional learning opportunities for players to better understand how to play the game and fraction learning.

Both of these generic play strategies continue to appear in future levels. Particularly as the difficulty of the levels increases so do the opportunities and need for players to utilize trial and error and to watch for accidental discoveries. However, what the players learn during these moments in play must be tracked and mapped across levels. Since the patterns for trial and error and accidental discoveries remain the same through the remaining levels, a summary of play strategies is discussed in further detail in the *Discussion* chapter.

First Choice

Three 4th grade players (42, 44, & 47) selected a bender with the funnel facing the correct direction for their first choice, indicating players were seeking to direct the laser before splitting. Three players (45, 48 & 49) selected the two-splitter, indicating they weren't aware or attentive to the size of the laser the two-splitter produced in relation to the size of the ship. Two players (41 & 46) selected the three-splitter. Of the 16 5th grade players, 15 selected the three-splitter and one player (53) selected the two splitter.

The first choice of the players can indicate how the player initially approached solving Level 4-2, whether in terms of spatial problem solving, math or both. Looking at what the player's focused on through the remainder of the level will help clarify their thinking and map how it changes through the course of their interactions within the level.

Player Content Focus

Spatial and Math

Seven of the eight 4th grade players (42, 44, 46, 47, 48, & 49) and eight out of 16 5th grade players (51, 52, 54, 55, 57, 58, 59, & 519) indicated spatial problem solving as a component of their game play. For example, player 42 tries to direct the laser using benders and the two splitter (which won't produce the correct sized laser for the ships). Player 44 moves the splitter to adjust where the laser is going because "*Well, because it was just — it's just going to the rocket, so— or this rock and I need to get it to somewhere else*". Having selected the correct three splitter, player 46 also focuses on directing the laser to a particular ships and trying to figure out how to get the three of the lasers from the three splitter into the three ships. Player 48 tries to make the lasers go into the ships but cannon figure out the correct combination to "*make* *it to all three of them*" indicating that he is counting the number of ships as a basis for his decision making rather than the size of the laser.

Three 4th grade players (42, 44, & 45) and eight out of 16 5th grade players (51, 53, 54, 59, 511, 514, 515, & 519) indicated math thinking in their decision making through indication such as "*thought it would divide it equally*" (45) and "*so, well, I think these are all like kind of fractions. Like, this one's ½…*" (42).

One 4th grade player (45) and five 5th grade players (52, 510, 514, 516, & 517) indicated simultaneous math and spatial thinking as their problem solving approach.

At some point during Level 4-2, 15 out of the 24 players focused only on their spatial understanding to solve the level and at some point during game play 11 out of 24 players focused on their math understanding to solve the level. Six out of 24 players indicated they used both spatial and math understanding simultaneously to solve for Level 4-2. The method for identifying what players are focusing on is not to illustrate players are thinking in either/or terms. Rather it is to illustrate the frequency and sequencing of what players are attentive to. This means that one player might at one point focus on math then at another point in the level focus on spatial but instead gives an account of the frequency in which players are focusing on different aspects of game play. In terms of learning, watching the *frequency* in which a player may concentrate solely on spatial OR math (as opposed to concentrating on both simultaneously) as part of their decision making process indicates the level of effort the player puts into that aspect of game play and whether that level of effort is targeting learning goals and objectives. Tracking the *sequence* in which players switch or maintain content focus (for example, focus on math, then spatial—then several more spatial decisions—then math) maps changes in the player's thinking and progression and whether or not those changes indicate learning (of either spatial, math or both).

Math and Spatial Struggle

Seven out of eight 4th grade players (41, 42, 44, 45, 46, 47, & 49) and four out of 16 5th grade players (55, 59, 511, & 518) indicated struggling with math at some point during this level. One player (49) didn't realize the two-splitter and three-splitter make fractions. Perhaps if the player could see 1 being divided by 3 to equal 1/3 (even in the tutorial levels), players would have a better understanding of the mathematical function of the splitters. Another player (45) wanted the splitters labeled "1/2" and "1/3" because she couldn't remember what size lasers they made. This indicates she wasn't making the connection that the laser ("1") split three-ways with a three-splitter equals one-third (1/3).

All eight 4th grade players and 14 of the 16 5th grade players indicated the same spatial struggles exhibited in Level 4-1 at some point during Level 4-1. One player (48) came close to solving the level but didn't follow the correct sequencing of benders and splitters and ran out of benders, requiring him to start over. Given the design of Level 4-2, if players had more benders available they could complete Level 4-2 without having to follow such strict sequencing (subsequently spend less time focused on spatial problem solving). At the same time, finishing the level faster doesn't necessarily mean the player will pay attention to what 1/3 means.

Though all players who attempted Level 4-2 completed it, 11 out of 24 players were struggling with math concepts and 22 out of 24 players 5TH Graders were struggling with spatial problem solving. Making it clear that for Level 4-2 the focus of problem solving was on the spatial aspect of game play rather than math. It is important to point out that players who demonstrate struggling with math or spatial content in game are in the process of problem solving and figuring out the game. These moments of struggle are the perfect learning opportunity for players to improve their game play and their understanding of the learning goals. The point in game design is not necessarily to reduce the amount of player struggle but to direct and support and create the right type of player struggle as part of game play. These are the challenges that can make games fun to overcome.

A majority of decisions made in this level are spatial focused and not math focused. This has two consequences to learning. First, the players are focused on spatial problem solving which has no consequence to their math understanding. Though this is a fun part of game play, it is helping players learn how to approach the challenge of the spatial complexities of each level. Second, players who may understand how to create one-third (1/3) from one (1) using a three-splitter are spending more time struggling with the spatial problem rather than being rewarded for their math understanding. From what the players are focused on, this prioritizes learning spatial reasoning over math.

Summary

The sequence of selecting the appropriate first splitter and the correct placement is an important mechanic of game play and especially important to the spatial problem solving aspect of the game. This is particularly challenging when it comes to levels like Level 4-2 where there is one solution. Though it appears the player has multiple choices available to her or him, the underlying imposed restrictions reinforce how the players must evaluate and approach the level. In this instance, knowing the three-splitter is the only viable choice may result in the players spatial understanding (directing three lasers into three ships) and/or math understanding (three splitter creates 1/3 laser from 1 laser which is needed for the 1/3 ships).

This has important implications for how players manage the problem solving process. For those who are initially focused on figuring out the correct sized laser (math), selecting the correct first piece (three-splitter) is in line with their problem solving strategy. For those who are initially focused on figuring out how to get a laser to the ship (spatial) and select a bender or two-splitter, they will have to shift their focus to solving for the math. However, a player may initially be focused on figuring out how to get all three lasers into three ships (counting the number of lasers) and not concerned with the size of the laser (creating 1/3 sized lasers). The in-game action is the same (using the three-splitter) but how the action is interpreted by the player is unmediated and unclear.

Limiting the number of potential correct solutions for any given level by requiring specific placement and sequencing of the player's first choice is not always a parameter in future levels. By including this parameter in an early level it sets precedence for the player and has implications on how players develop their problem solving strategy.

To elaborate, a player may successfully complete Level 4-2 based on their spatial understanding (directing three lasers into three ships) without having to acknowledge or demonstrate understanding that 1 split three ways is 1/3. This means a player may successfully select a three-splitter for math and/or spatial reasons. In future levels, the same player may make their first selection based on the understanding that 1) there is only one correct solution, therefore only one correct first choice, and 2) directing the laser (solving the spatial problem) comes before solving for creating a specific sized laser (math problem). As will be shown in the design of subsequent levels, neither of these assumptions are true.

Level 4-3

In this level the laser is labeled “1” and there are two ships labeled “1/2” (Image 40). There are three benders, one two-splitter, and one three-splitter. As in the last level, there is only one possible solution and not all benders and splitters are needed to solve the level (there is an extra bender and three-splitter). The placement of the boulders can potentially block the laser depending on the placement of the first bender or splitter.

Image 40. Level 4-3 start screen.

To complete Level 4-3 the player must use the two-splitter first. The arrangement of the boulders create a minimal obstacle as there is only one incorrect placement on the whole trajectory of the laser (Image 41); any other placement allows the player to continue to solve the puzzle.

Image 41. Only available incorrect placement of the two splitter along the laser trajectory.

If a player were to try to solve the puzzle using the three-way splitter first the result would show an animation of clouds around the ship and a pop-up message "*Too little! That's pumping in 1/3.*" indicating ship not getting enough power (Image 42).

Image 42. Too little power pop-up message.

Like level 4-2 the complexity of the spatial problem is reduced, but not eliminated, by minimizing the number of wrong first choices and limiting the number of extra choices (benders and splitters). After successfully placing the two-splitter along the laser (not in the spot closest to the boulders), the player needs only to use one bender per laser to solve the puzzle (Image 43).

Image 43. One more bender needed to complete Level 4-3.

Level 4-3 Player Data and Discussion

One 4th grade player (41) did not make it to this level, or subsequent levels, so there are only seven 4th grade players who played to Level 4-3 and beyond.

Interviewer Intervention & Play Strategy

None of the 4th or 5th grade players required interviewer intervention for Level 4-2. completed this level and none of them received interviewer intervention. Also, none of the 4th or 5th grade players used trial and error as a play strategy for solving Level 4-2. This indicates that Level 4-2 was less difficult than the previous level but we have to look player performance in Level 4-2 to determine if their experience in the previous level helped or if it was because Level 4-3 is less difficult.

First Choice

All of the seven 4th grade players selected a correct facing funnel piece (which means none of them selected a bender as those are the only choices with the funnel facing the wrong way). Four of the seven 4th grade players (45, 47, 48, & 49) selected the three splitter and three (42, 44, & 46) selected the two splitter.

All of the 16 5th grade players selected a correct facing funnel for their first choice. One player (53) selected a bender, two players (58 & 519) selected the three splitter, and the remaining 13 5th grade players selected the correct two splitter as their first choice. This appears to indicate that a majority of the 5th grade players knew to pick the two splitter first but we have to look closer to understand why they made that selection – was it the number of lasers? direction of lasers? or size of the lasers?

Though all the 4th and 5th grade players selected the correct facing funnel for their first choice, indicating they were paying attention to the directionality of the funnel (spatial), four out of seven of the 4th graders and three of the 16 5th graders selected three-splitters instead of two-splitters. As anticipated it appears the 5th graders have a better grasp of the size of the laser (see which players went on to do math thinking of these players).

Player Content Focus

Spatial and Math

Four of the seven 4th grade players (45, 47, 48, & 49) and four of 16 5th grade players (54, 55, 58, & 519) focused solely on spatial reasoning at some point during Level 4-3. Two of the seven 4th grade players (42 & 45) and six of the 16 5th grade players (51, 52, 53, 55, 58, & 514) indicated they considered math as part of their problem solving for Level 4-3. One 4th grade player (47) and four out of 16 5th grade players (59, 510, 511, & 515) demonstrated simultaneous math and spatial reasoning during Level 4-3. One 4th grade player (46) explained he made his first choice "*Because it — when I saw it right now, it matches these*" indicating "*how this is coming out*" pointing to the lasers. It was not clear if he is referring to the size, number or direction of the laser.

More 4th grade players were focused solely on spatial problem solving than the 5th grade players and more 5th grade players were focused solely on math problem solving that 4th grade players. In addition more 5th graders were able to solve the spatial and math simultaneously as part of their decision making process. This may be partly attributed to differences in math skills between grades and because 15 of the 16 5th graders played another version of *Refraction* the year prior.

Math and Spatial Struggle

One player (47) of the 23 demonstrated math struggle when he explained that the laser would be too little power when the fraction was actually too much. None of the 4th grade players indicated spatial struggle for Level 4-3 but Four of the 16 5th grade players (51, 58, 514, & 515) did.

As mentioned in Level 4-2, to begin to see how players are making sense of the level we have to look at player thinking as it emerges through game play across levels. There isn't any new content (game or math content) introduced or unique to 4-2 which means Level 4-2 is an early game play level that allows players to try a new configuration or puzzle layout. This is further supported by the lack of math and spatial struggle.

Summary

Player focus in Level 4-3 indicates a shift in difficulty in this level. Compared it to the performance in Level 4-2 and if the players' struggled less and focus more on the spatial component than the math. This may be in part due to two things. Level 4-2 doesn't introduce any new concepts for players to learn, either new game content or math content and those who received intervention in the previous level can practice what they've learned in this level.

Level 4-4

In Level 4-4 the laser is labeled "1" and there are three ships labeled "1/3" (Image 44). There are four benders, one two-splitter, and two three-splitters. There are several more boulders placed in such a way that they are direct obstacles to the ships.

Image 44. Level 4-3 start screen.

In level 4-4 the first bender or splitter selected is essential to successfully completing the level, limiting the number of correct combinations to complete the level. The placement of the boulders restrict the first move so the laser can only be up or down. The two available options to bend the laser down (one bender and a two-splitter) leads to failure (Image 45 & 46). In Image 45 there aren't enough benders to get the laser back up towards the ship to complete the level and the two-splitter in Image 45 creates the incorrect size laser.

Image 45. Using the downward bender.

Image 46. Using the two-splitter.

To bend the laser up the player only has one choice available (Image 47). The remaining pieces do not have the funnel facing the correct direction.

Image 47. The bender pointing upward is the only viable first choice for Level 4-4.

After the correct bender is placed, the only available next option is to use one of two available benders (Image 48 & 49). Again all the other remaining benders/splitters are facing the wrong direction to be able to use. Image 48 shows the laser bending towards the left of the screen. If this bender is selected there are not enough pieces to successfully completed the level.

Image 48. One of two second choices, bender pointing laser to the left.

Image 49 shows the correct bender to use that allows the player to continue and solve the level. The second bender can be placed anywhere along the trajectory of laser.

Image 49. Two of two second choices, bender pointing laser to the left.

If the bender in Image 49 is moved up on space then the laser goes directly into the ship. Since the laser has yet to be split, the size of the laser (1) is too big and the animation of the ship shows “too much power” animation with red lightening bolts (Image 50).

Image 50. Ship with red lightening bolts indicates the laser is too much for the ship.

To solve Level 4-4 the player must place the three-splitter after the second bender (Image 51). The three-splitter must be placed on the spot that directs two of the three lasers directly into the ship, otherwise there are not enough pieces to complete the level.

Image 51. Players must place three-splitter in the location that directs two of the lasers into two of the ships.

To complete Level 4-4 the player needs only to place only one more bender to bend the third laser towards the ship at the top of the screen.

Level 4-4 Player Data and Discussion

For reasons unknown, some of the players received a different version of Level 4-4. In the alternate version of Level 4-4 the lowest ship is below the boulders instead of in line with the boulders (Image 52).

Image 52. Alternate Level 4-4 start screen. Red circles indicate a change in location of one of the ships.

Though the difference is seemingly small, players who played the alternative level were not considered in the analysis of Level 4-4. The difference in screen layout changes how players approach making their first selection and their initial problem solving approach. In addition, the player progression that leads to the solution will produce different patterns of player content focus that can’t be compared to the group that played the original version.

Total number of players considered in Level 4-4 analysis was reduced because one 4^{th} grade player (47) and two 5^{th} grade players (55 & 511) did not make it to Level 4-4 or play any subsequent levels. In addition, seven players (42, 52, 52, 53, 54, 57, & 58) were excluded because they played the alternate version of Level 4-4 for reasons stated above. As a result there are a total of five 4th grade players (44, 45, 46, 48, & 49) and eight 5th grade players (59, 510, 514, 515, 516, 517, 518, & 519) included in Level 4-4's data set.

Interviewer Intervention & Play Strategy

Of the five remaining 4th grade players included in the Level 4-4 analysis, three players (44, 45 & 48) required interviewer intervention. Of the eight remaining 5th grade players, five (51, 514, 516, 517, & 519) required interviewer intervention. Two players (49 & 51) demonstrated trial and error as part of their play strategy in Level 4-4.

First Choice

All five 4th grade players (44, 45, 46, 48, & 49) selected the correct facing funnel on their first choice. Of these five, three (44, 45, & 46) selected a bender (the correct first choice for this level) and two players (48 & 49) selected the two splitter.

Of the eight 5th grade six players (59, 510, 515, 516, 517, & 519) selected the correct facing funnel as their first choice and two players (514 & 518) selected an incorrect facing funnel. One 5th grade player (514) selected the three splitter, four players (59, 515, 517, & 519) selected the two splitter, and the remaining three players (510, 516, & 518) selected the bender.

Player Content Focus

Spatial and Math

All five 4th grade players (44, 45, 46, 48 & 49) and four of the eight 5th grade players (515, 516, 518, & 519) indicate spatial reasoning alone as part of their decision making process.

Two of the 4th grade players (44 & 45) and cite math alone as part of their decision making process. Both of these players did not indicate math struggle (see below) but both required at least one intervention (see above). Indicating they needed spatial help. Three of the eight 5th grade players (59, 514, & 518) cite math alone as part of their decision making process.

One of the 4th grade players (49) and two of the eight 5th grade players (59 & 510) cite both math and spatial reasoning as simultaneously part of their decision making process.

Math and Spatial Struggle

None of the 4th or 5th grade players indicated math struggle. All five of the 4th grade players (44, 45, 46, 48 & 49) and Seven of the eight 5th grade players (59, 510, 514, 516, 517, 518, & 519) indicated spatial struggle at some point in Level 4-4. No math struggle but spatial struggle on the part of most of the players indicate that the emphasis of this level is mastering the spatial reasoning of the level.

Since none of the players struggled with math content the high number of interviewer interventions for Level 4-4 indicate the players struggled with the spatial aspect of the level. For example, two players (514 & 517) were shown all the pieces needed were already on the board, they just needed to be moved slightly to reach all the ships. One player (519) struggled with getting all three lasers to all three ships and needed help guiding the third laser to the ship. One player (516) knew to use the three-splitter but required an intervention that involved the interviewer suggesting the player trace the path where the laser should go and work backwards. Another player (44) wanted to use the three-splitter but struggled with getting the direction of laser to go into the funnel.

Level 4-4 Summary

There are three important design attributes of Level 4-4 that differ from the previous levels. First, the boulders are placed in such a way that it creates a direct obstacle for getting to the ships. Not only are there restricted first choices a player can make (as in previous levels) but the player must consider the consequences of their choices in relation to the boulders, making the boulder a prominent attribute of problem solving. Since the boulders do not possess any math related qualities, the focus of the player's problem solving is primarily spatial.

Second, the player must use benders before splitters to get to the ship. The sequence of selecting benders emphasizes the procedure for solving the spatial problem (directionality of the laser) before solving the math problem. Whereas, choosing splitters requires not only consideration of the directionality of the laser but the size of it in relation to the number on the ships. This limits the play style or approach a player may take in solving this level. For players whose strategy was to solve the math part of the puzzle first have to suspend placing the correct splitter and focus on solving the directionality of the laser first.

Third, this is the first time the player is presented with achieving a correct configuration (placement and sequence of benders) which produces an adverse result (red lightening bolts indicating "too much power"). To clarify, if the player places both benders in the only correct locations, as in Image 50, the result is the red lightening bolts animation. The "too much power" animation in previous levels was used as an indicator that something is wrong and it needs to be corrected. However, in Level 4-4 the player has to essentially ignore the animation and select the three-splitter to continue on the path to successfully completing the level. Played in this sequence the player has to *play through* the previous understanding of the animation or the discomfort of the "too much power" feedback. This poses two design problems. One the meaning of the animation feedback is inconsistent and may confuse players as to how to respond to this feedback in future levels (i.e. do they immediately change out the piece or do they ignore and play through the animation look for a potential solution. Second, depending on player style and disposition ignoring negative feedback may be more difficult for some than others and will try to avoid it even at the expense of being able to complete the level. For example, player (46) had selected the first two correct choices but removed them when he saw the laser going into the ship with too much power. The implications of the design of this animation in the overall game experience is explored further in the *Discussion and Implications* chapter.

Level Pack 5

Level 5-1

In Level 5-1 the laser is labeled “1” and the single ship labeled “1/2” (Image 53). There are two benders, one two splitter, and one three-splitter. Just as in level 4-4, the boulders are positioned as a direct obstacle to the ship.

Image 53. Level 5-1 start screen.

In Level 5-1 there is only one possible correct sequence to completing the level. To solve this level the player must start with the two-splitter first (Image 54).

Image 54. The two-splitter is the only correct first choice.

Because of the direction of the funnel, it is possible for players to start with a bender or three-splitter. However, the three-splitter creates the wrong size laser and using a bender first requires using the second bender but then the two-splitter laser doesn't meet the ship (Image 55).

Image 55. Level cannot be completed if the bender is selected first.

Level 5-1 Player Data & Discussion

Interviewer Intervention & Play Strategy

Four 4th grade players (42, 45, 48 & 49) made it to Level 5-1 and one player (42) required one interviewer intervention for Level 5-1. 13 5th grade players (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, 518, & 519) of the original 16 players made it to Level 5-1 and none of the 5th grade players required interviewer intervention.

None of the 4th grade or 5th grade players used trial and error or an accidental discovery as part of their play strategy for Level 5-1. This may indicate there were too few choices available, the level was too easy, or the level was just the right amount of difficulty for some players because players were able to make strategic choices rather than resorting to guessing.

First Choice

All four 4th grade players (42, 45, 48 & 49) selected a correct facing funnel piece as their first choice. Of these four, two players (45 & 49) selected the three splitter, one player (48) selected the two splitter, and one player (42) selected a bender.

All 13 of the 5th grade players selected a correct facing funnel piece as their first choice. Of these 13, 12 players (51, 52, 57, 58, 59, 510, 514, 515, 516, 517, 518, & 519) selected the three splitter and one player (54) selected a bender.

Player Content Focus

Spatial & Math

One 4th grade player (45) and three 5th grade players (51, 54, & 515) cited spatial reasoning as the sole driver for making decisions. One 4th grade player (42) and one 5th grade player (59) cited math as their reason for making in-game decisions. None of the 4th grade players cited both math and spatial simultaneously as their reasoning for making decisions. Two of the 5th grade players (58 & 519) cited both math and spatial simultaneously as their reasoning for making decisions.

Math & Spatial Struggle

One 4th grade player (42) and none of the 5th grade players demonstrated math struggle in Level 5-1. One 4th grade player (42) and one 5th grade player (51) demonstrated spatial struggle in Level 5-1.

Summary

This level was solved fairly quickly across the board making it difficult to capture player thinking around their decisions. There was very little in terms of utterances from most of the 5th grade players because they finished the level so quickly. Of the 17 players to make it to Level 5-1, most completed the level in a few choices. Only one player demonstrated math struggle and 2 players demonstrated spatial struggle

In the last level, the correct sequence was for the player to select a bender first, then use a splitter in order to complete the level. In this level, the correct sequence is the opposite, the player must split the laser first then bend to complete the level. This element of problem solving, deciding whether to focus on bending (spatial) or splitting (math) requires the player toggles between spatial or math focus depending on the level.

Level 5-2

In this level the laser is labeled “1” and there is one ship labeled “1/3” (Image 56). Just as in level 5-1, there are two benders, one two-splitter, and one three-splitter. However, the boulders are positioned not as direct obstacles to the ship.

Image 56. Level 5-2 start screen.

There are three possible first choices available, but only two correct sequences to this level. They player can place the two-way splitter first but this creates the wrong size laser. One of the correct solutions is if the player uses the three-splitter first on either side of the column of boulder (Image 57). Then direct the laser with a single bender into the ship.

Image 57. One of two potential correct first choice, the three-splitter.

The second correct sequence, the player uses two of the benders to direct the laser to the ship (Image 58). Then use the three-splitter to complete the level. If a player chooses this sequence they see the "too much power" animation (red lightening bolts). This is the second time (just as in level 4-4) where the player would have to play through the "too much power" animation in order to solve the level.

Image 58. Second potential first choice, bender.

Level 5-2 Player Data and Discussion

Interviewer Intervention & Play Strategy

Four (42, 45, 48 & 49) 4th grade and 13 (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, 518, & 519) 5th grade players made it to Level 5-2. None of the 17 players required interviewer intervention or used trial and error as a play strategy.

First Choice & Player Content Focus

Two of the four 4th grade players (42 & 48) selected a two-splitter and the two others (45 & 49) selected a bender all with the funnel facing the correct direction. This indicates that at least two of the 4th grade players were unaware of the laser size and the other two were initially focused on the direction of the laser (spatial).

One player (42) cited spatial and math independently of each other in their decision making. The same player also demonstrated math struggle. At another point in the level it wasn't clear if this player on whether he was focused on spatial, math or both. When asked why he made a particular selection he explained "*Just goes with the flow, because if I….Because if it shoots it up, it's just I'm not gonna shoot the same thing*".

One other 4th grade player (49) cite math reasoning as the sole reason for making in in-game decision and one other 4th grade player (45) demonstrated spatial struggle. Lastly, one 4th grade player (49) cites both spatial and math reasoning simultaneously as a motive for making in-game decisions.

Whereas all 13 5th grade players selected the three-splitter as their first choice and none of the 5th grade players referenced spatial reasoning as their sole reason for making an in-game decision. Five 5th grade players (51, 52, 54, 515 & 517) cite math reasoning as the sole reason for making in in-game decision. Three 5th grade players (57, 514, & 519) cite both spatial and math reasoning simultaneously as a motive for making in-game decisions. None of 5th grade players indicated math struggle during and two 5th grade players (51 & 510) demonstrated spatial struggle. One 5th grade player (52) wasn't clear whether they focused when asked why the level was easy "*Because--because it only needed two things. The less things it needs…. The less…. Well, less, uh, batteries or whatever, I think you call them, it needs….*". Overall, 5th grade players finished quickly with limited utterances, similar to Level 5-1.

Level 5-1 Summary

Level 5-1 was a little easier than 5-2 because the boulders weren't direct obstacles to the ship. In addition, both a splitter and bender are viable first choices. This unique design quality of this level allows players more than one correct solution to the level. This also increases the likelihood of a player being successful based on their first selection. Based on a players preference we can infer whether or not a player is solving for the math first (splitter) or the directionality of the spatial problem (bender).

Providing two potential correct first choices may add to the inconsistency in design mentioned earlier. Players who were solving for math first can make a math choice and players who were solving for spatial first can make a spatial choice they may not go with what their initial strategy depending on how they interpreted their experience of being forced to focus on spatial OR math with the previous two levels.

Level Pack 6

Level 6-1

In level 6-1 the laser is labeled "1" and there are four ships labeled "1/4" (Image 59). There are no benders but there are three two-splitters and three three-splitters. There are boulders but they are not placed as direct obstacles to the ships.

Image 59. Level 6-1 start screen.

In level 6-1 there is only one possible sequence to successfully complete the level. The player must place the correct directional two-way splitter, funnel facing towards the top of the screen, (Image 60) followed by the remaining two, two-way splitters. The player cannot complete this level if she or he attempts to use a three-way splitter at any point, as it won't produce the correct size laser.

Image 60. The two-splitter with the funnel facing upward is the only viable first choice for completing Level 6-1.

There is one key design attribute of this level that differentiates it from the other levels. This is the first level (outside of the embedded assessment) where the player is required to use two splitters, of the same type, to produce the correct size laser (in this case, two two-splitters). Given the boulders do not present a direct obstacle to the ships and there are no benders, by default of the number of choices available to the player, the attention of the player is directed toward solving for ¼ rather than concentrating only on the directionality of the lasers.

Level 6-1 Player Data & Discussion

Interviewer Intervention & Play Strategy

Of the original eight 4th grade players, three (45, 48 & 49) made it to Level 6-1 and none of them required any interviewer intervention. Of the original 16 5th grade players 13 (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, 518, & 519) made it to Level 6-1 and none of them required any interviewer intervention. One of the 4th grade players (49) and two 5th grade players (57 & 58) used trial and error as part of their play strategy.

First Choice

All three 4th grade players (45, 48, & 49) selected a three-splitter for their first choice. Two of them (48 & 49) selected a correct facing funnel and the other (45) did not. Six of the 5th grade players (57, 58, 514, 515, 517, & 519) selected the three-splitter and the other seven players (51, 52, 54, 59, 510, 516, & 518) selected the two-splitter. Only one player (51) selected a piece with the funnel facing the wrong direction.

For one of the 5th graders (517) that picked three splitters first and thought it would get them closer to ¼ until they realized they needed to use the two splitter. However based on their actions its not clear is if they understand why. This may be a missed opportunity for learning to help clarify why one-third is not closer to one-fourth for these players.

Player Content Focus

Spatial and Math

None of the 4th grade players and three of the 5th grade players (58, 518, & 519) referenced spatial reasoning as their sole reason for making an in-game decision. One 4th grade player (49) and seven 5th grade players (51, 54, 57, 510, 514, 516 & 519) cite math reasoning as the sole reason for making in in-game decision. None of the 4th grade players and four 5th grade players (54, 58, 59, & 517) cite both spatial and math reasoning simultaneously as a motive for making in-game decisions. These numbers indicate that the 5th grade players were more focused on math content than the 4th graders.

Math and Spatial Struggle

Two 4th grade players (45 & 49) and five 5th grade players (57, 515, 517, 518, & 519) indicated math struggle during Level 6-1. Two 4th grade players (45 & 49) and four 5th grade players (51, 54, 58, & 514) demonstrated math struggle during Level 6.1.

Level 6-1 Summary

As noted in 5-2 reducing the complexity of the spatial problem by removing benders, places emphasis on using the splitters. In order to use the splitters successfully, it would appear the player must take into consideration the value (or power) of what each type of splitter will produce.

As with previous levels, players who breeze through levels like this already have a grasp of the math and spatial requirements to complete the level. Yet those who struggled with selecting the three-splitter first don't necessarily receive any just-in-time feedback or corrective guidance as to how they are thinking about the space.

In addition, there is an alternative strategy for solving this level that involves counting the lasers rather than focusing on splitting. A player may make their selection by looking at the number of ships (4) rather than their value (1/4). The question remains whether or not this strategy counts as math thinking and if so, how can we shift the attention of this type of player from counting lasers to focusing on the size or value of the laser?

Level 6-2

In level 6-2 the laser is labeled “1” and there are two ships labeled “1/4” (Image 61). There are no benders, three two-splitters, and one three-splitter. The boulders are not placed as direct obstacles to the ships.

Image 62. Level 6-2 start screen.

There is only one possible sequence to successfully solve this level. The player must choose the correct directional two-splitter (funnel facing left), followed by the remaining two-way splitters on either laser (Image 63). Though the play pattern (using two, two-splitters in a row) is the same as level 6-1 it is different because players are directing the laser into two ships, rather than four.

Image 62. The only viable solution to Level 6-2.

Level 6-2 Player Data & Discussion

Interviewer Intervention & Play Strategy

Of the original eight 4th grade players, three (45, 48 & 49) made it to Level 6-2 and one player (48) required one interviewer intervention. Of the original 16 5th grade players 12 (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, & 518) made it to Level 6-2 and none of them required any interviewer intervention.

Two of the 4th grade players (45 & 49) and four 5th grade players (57, 58, 510, & 514) used trial and error as part of their strategy to solve Level 6-2.

First Choice

Two players (45 & 48) selected a three splitter and one player (49) selected a two splitter as their first choice. All three selected a piece with a funnel that was facing the correct direction. Three of the 5th grade players (57, 58, & 510) selected the three splitter and nine players (51, 52, 54, 59, 514, 515, 516, 517, & 518) selected a two-splitter. All 12 players selected a funnel that was facing the correct direction.

Player Content Focus

Spatial and Math

None of the 4th grade players and one of the 5th grade players (518) reference spatial reasoning as the sole reason for making an in-game decision. One 4th grade player (45) and four 5th grade players (57, 58, 59 & 510) cite math reasoning as the sole reason for making in in-game decision. None of the 4th grade players and four 5th grade players (51, 52, 54, & 514) cite both spatial and math reasoning simultaneously as a motive for making in-game decisions. One 5th grade player (54) wasn't clear when asked how he solved the level he explained "*Like looking….Looking and like seeing it*".

Math and Spatial Struggle

None of the 4th grade players and two 5th grade players (516 & 518) demonstrated math struggle during Level 6-2. One 4th grade player (45) and two 5th grade players (510 & 517) demonstrated spatial struggle during Level 6-2.

Level 6-2 Summary

In the last three levels, including 6-2, there is an increase in trial and error play strategy and decrease in interviewer intervention. Players started to demonstrate a behavior where they use part of the game space to test out different combinations in order to arrive at the correct answer, then move the pieces so the laser goes into ships. This is an interesting strategy because it shows their thinking through the problem solving but that they don't want to commit to the solution, even though there are no consequences to playing it on the regular space. They still just want to avoid doing it wrong.

As suggested in the previous level, there may be player strategies that involved counting the number of lasers rather than focusing attention on the value or size of the laser. By reducing the number of ships from four to two, the conditions of this level may guide players attention away from counting and matching the number of lasers to ships and towards the size of the lasers and the number on the ships.

Level 6-3

In level 6-3 the laser is labeled “1” and there is one ship labeled “1/6” (Image 63). There are two benders, two two-splitters, and two three-splitters. The boulders are not direct obstacles to the ships. This is the first level, outside of the embedded assessment, where the player must create a 1/6 size laser.

Image 63. Level 6-3 start screen.

Given the available benders and splitters, this level can be solved with more than one combination of splitters and benders. For example, the following sequences successfully complete the level (placing benders and splitters in the order listed): 1) bender, bender, three-splitter, two-splitter; 2) bender, bender, two-splitter, three-splitter; 3) three-splitter, two-splitter; 4) two-splitter, three-splitter. Since there is only one ship and with any of these combinations, there are multiple lasers created that are not directed into any ships.

Level 6-3 Player Data & Discussion

Interviewer Intervention & Play Strategy

Of the original eight 4th grade players, one player (48) made it to Level 6-3. Player 48 completed Level 6-3 and required one interviewer intervention. Player 48 used trial and error as part of his strategy to solve Level 6-3.

Of the original 16 5th grade players 12 (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, & 518) made it to Level 6-3 and one player (516) required one interviewer intervention. Three 5th grade players (51, 52, & 58) used trial and error as part of their play strategy. Three 5th grade players (51, 514, & 518) came across an accidental discovery that helped them solved Level 6-3.

First Choice

Player 48 selected a piece with a three splitter with a funnel that was facing the correct direction as a first choice. Two of the 5th grade players (52 & 58) selected the two-splitter and ten players (51, 54, 57, 59, 510, 514, 515, 516, 517, & 518) selected the three-splitter as their first choice. All 12 players selected a piece with the funnel facing the correct direction. Since there are multiple correct first choices for this level that allow the player to successfully complete the level, it is less important what the player chooses to focus on (bender or splitter) as their first choice. Though the flexibility in designing multiple first choices may allow players to play to their preferences, which will be covered in more detail in the *Discussion and Implications* chapter.

Player Content Focus

Spatial and Math

Player 48 did not reference spatial reasoning as the sole reason for making an in-game decision but three of the 5th grade players (57, 516, & 518) did. Player 48 did not cite math reasoning as the sole reason for making in in-game decision but ten 5th grade players (52, 54, 57, 58, 59, 510, 514, 516, 517, & 518) did. Player 48 did not cite both spatial and math reasoning simultaneously as a motive for making in-game decisions but one 5th grade player (515) did.

The one 4th grade player (48) who made it to Level 6-3 did not cite math or spatial as a basis for making his decisions. Instead, this player cites using the color of the lasers to make his decisions. The unique success of this 4th grade player will be covered in detail in *Discussion and Implications* chapter.

Math and Spatial Struggle

Player 48 demonstrated math and spatial struggle during Level 6-3. One 5th grade player (51) indicated math struggle and seven 5th grade players (51, 52, 58, 510, 515, 516 & 518) demonstrated spatial struggle during Level 6-3.

Level 6-3 Summary

A unique design feature of Level 6-3 is that it further challenges players who may be counting lasers needed instead of looking at the size of the laser to match the ship. This is because a player needs to use multiple splitters (creating many extra lasers that aren't in use) to get one correct sized lasers. When these players first discover not all the lasers have to be used, it focuses their attention on the size of the ship, rather than the number of ships. Once counting lasers has been established as an unsuccessful play pattern, the play pattern of not counting lasers has been established, then it is clear to the player they shouldn't worry about extra lasers.

Level 6-4

In level 6-4 the laser is labeled "1" and there is one ship labeled "1/9" (Image 64). There are two benders, two two-splitters, and two three-splitters. The boulders are not direct obstacles to the ships. This is the first level, outside of the embedded assessment, where the player must solve for one-ninth (1/9).

Image 64. Level 6-4 start screen.

The design of level 6-4 is nearly the same as 6-3 with the same number of benders and splitters and the boulders are not placed as direct obstacles. The starting direction of the laser is different but doesn't pose any additional difficulty but the size of the ship (1/9) is different. The similarity between the two levels emphasizes the once difference, a new fraction to solve for.

Unlike Level 6-3 where there are multiple correct solutions, there is only one possible solution to this level. The player must place the three-splitter first (Image 65).

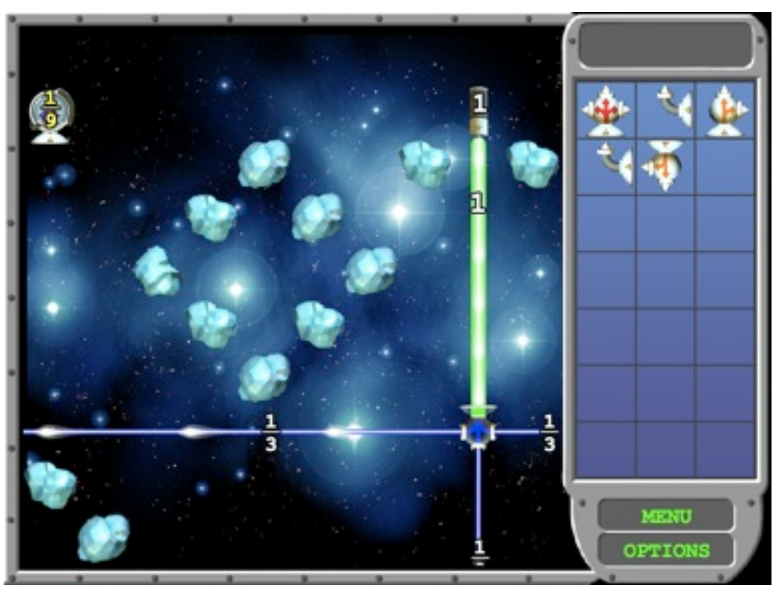

Image 65. The three-splitter is the only viable first choice to complete Level 6-4.

There is only one place along the trajectory of the laser that will work as all other spots along the laser will direct the laser into a boulder. The player cannot start with a bender because none of the benders are rotated in the correct direction (funnel facing towards the top). The player can start with a two-splitter but that will not create the correct size laser. To complete the level, the player must next place a bender, then another three-splitter.

There is another opportunity in Level 6-4, depending on the order in which the player places the splitters and benders, after the second move for the player to see another instance of "too-much-power" to the ship before placing the final three-way splitter (Image 66).

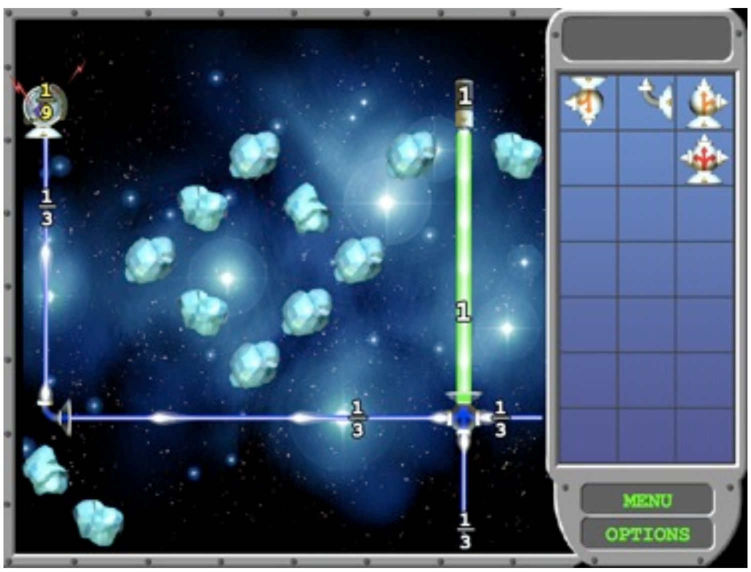

Image 66. "Too much power" animation.

Level 6-4 Player Data & Discussion

Interviewer Intervention & Play Strategy

Of the original eight 4th grade players, one player (48) made it to Level 6-4. Player 48 completed Level 6-4 and did not require interviewer intervention. Player 48 used trial and error as part of his strategy to solve Level 6-4.

Of the original 16 5th grade players 12 (51, 52, 54, 57, 58, 59, 510, 514, 515, 516, 517, & 518) made it to Level 6-4 and one player (518) required one interviewer intervention. One 5th grade players (510) used trial and error as part of their play strategy. One 5th grade players (52) came across an accidental discovery that helped solved Level 6-4.

First Choice

Player 48 selected a two splitter with a funnel that was facing the correct direction as a first choice. One 5th grade player (517) selected a bender as a first choice. Two of the 5th grade players (52 & 518) selected the two splitter and nine players (51, 54, 57, 58, 59, 510, 514, 515, & 516) selected the three splitter. 11 of the 12 5th grade players selected pieces with the funnel facing the correct direction but one player (51) did not.

Player Content Focus

Spatial and Math

Player 48 did not reference spatial reasoning as the sole reason for making an in-game decision. Two of the 5th grade players (58 & 518) referenced spatial reasoning as their sole reason for making an in-game decision. Player 48 and Eight 5th grade players (51, 52, 57, 58, 59, 514, 516, & 517) cite math reasoning as the sole reason for making in in-game decision. Player 48 did not cite both spatial and math reasoning simultaneously as a motive for making in-game decisions but three 5th grade players (54, 514, & 515) did.

The 4th grade player (48) continued to use color as one of his strategic focal points but added trial and error to make his way through the level, testing and strategically making next choices.

Math and Spatial Struggle

Player 48 did not demonstrate math struggle during Level 6-4 but one 5th grade player (518) did. Player 48 did not demonstrate spatial struggle during Level 6-4 and five 5th grade players (51, 54, 57, 514, & 515) did.

Level 6-4 Summary

This is not the first level where the solution requires two splitters even though it is the first time the player is being asked to solve for 1/9 in regular, untimed, game play. Based on the player's pre-exposure to using more than one splitter to solve for a single ship and without counting lasers, it might be possible to determine if students are able to deduce how to solve for 1/9 without; 1) knowing how to do so mathematically prior to the game, and 2) discover 1/3 split by 1/3 creates 1/9. In the video data.

Level Pack 7

Level 7-1

In level 7-1 the laser is labeled "1" with two ships, one labeled "1/2" and one labeled "1/4" (Image 67). There are three benders, two two-splitters, and one three-splitter. The boulders are not placed as direct obstacles to the ships. This is the first level, outside of the embedded assessment, where the player must solve for two different fractions on a single level.

Image 67. Level 7-1 start screen.

There is only one possible sequence and combination of splitters and benders to complete this level. The player must follow the following sequence; two-splitter, two-splitter, then a bender in order to create ½ and ¼ (Image 68).

Image 68. Correct sequence of splitters and benders to solve Level 7-1.

It is possible for the player to place a bender first but he or she will not be able to progress any further. Similarly, the player can place a three-splitter first but that will not create the correct sized laser.

Level 7-1 Player Data & Discussion

Interviewer Intervention & Play Strategy

Of the original eight 4th grade players, one player (48) made it to Level 7-1 and did not require interviewer intervention. Of the original 16 5th grade players, 9 (51, 52, 54, 57, 59, 510, 514, 516, & 517) made it to Level 7-1 and one of the players (51) required one interviewer intervention. One 5th grade players (510) used trial and error as part of their play strategy that helped solved Level 7-1.

First Choice

Player 48 selected a two-splitter with a funnel that was facing the correct direction as a first choice. Eight of the 5th grade players (51, 52, 54, 59, 510, 514, 516, & 517) selected the two-splitter and one player (57) selected the three-splitter as their first choice. All nine of the 5th grade players selected a piece with the funnel facing the correct direction.

Player Content Focus

Spatial and Math

Player 48 did not reference spatial reasoning but two of the 5th grade players (510 & 516) referenced spatial reasoning as their sole reason for making an in-game decision. Player 48 and five 5th grade players (51, 52, 54, 510, & 517) cite math reasoning as a sole reason for making in in-game decision. Two 5th grade players (52 & 57) cite both spatial and math reasoning simultaneously as a motive for making in-game decisions.

Math and Spatial Struggle

Player 48 did not demonstrate math struggle during Level 7-1 and one 5th grade player (57) indicated math struggle during Level 7-1. Player 48 did not demonstrate spatial struggle during Level 7-1 and six 5th grade players (51, 52, 54, 57, 510, & 514) demonstrated spatial struggle during Level 7-1.

Level 7-1 Summary

Some players could not tell that one-fourth (1/4) is smaller than one-half (1/2) and called it bigger still successfully completed the level. In addition, there was no corrective game content to help with their understanding.

Level 7-2

In level 7-2 the laser is labeled "1" and there are two ships, one labeled "1/3" and one labeled "1/6" (Image 69). There are three benders, two two-splitters, and one three-splitter. The boulders placed not as direct obstacles to the ships. However, the orientation of the ships in relation to the direction of the laser requires the player to direct the laser *around* the ships, unlike any previous levels.

Image 69. Level 7-2 start screen.

There is only one possible sequence to solve Level 7-2. The player must place (in the following order) a bender, bender, three-splitter, then two-splitter.

Though the boulders don't pose a direct obstacles to the ships, the orientation of the ships does increase the spatial problem difficult. It is the first instance where a player must direct the laser to enter through the furthermost (from the start of the laser) side of the ship (1/3 ship). However, because all of the splitters have the funnel facing the top of the screen, and the laser is pointing up, the only viable first move is to use one of the benders, with the funnel facing the bottom of the screen. Placement of the first bender along the lasers' trajectory is also important. The bender must be placed above the 1/3 ship in order for the player to be able to progress. (Image 70).

Image 70. The player must place the bender higher than the ships to complete the level.

If the player placed the first bender below the 1/3 ship (Image 71), he or she will not be able to complete the puzzle.

Image 71. Placing the bender in-between the two ships is not a viable solution.

The location of the three-splitter is also important as the laser must be directed directly into the 1/3 ship before placing the two-way splitter (Image 72).

Image 72. Exact placement of the three splitter is also important.

Level 7-2 Player Data & Discussion

Interviewer Intervention & Play Strategy

None of the 4th grade players made it to Level 7-2 or beyond. Of the original 16 5th grade players six (52, 54, 59, 510, 516, & 517) made it to Level 7-2 and none of the players required interviewer intervention. One 5th grade player (52) used trial and error as part of their play strategy.

First Choice

All six of the 5th grade players (52, 54, 59, 510, 516, & 517) who made it to Level 7-2 selected a piece with the funnel facing the correct direction for their first choice. Five of the 5th grade players (52, 54, 59, 510, & 517) selected benders as their first choice. One player (516) selected the three splitter as their first choice but placed it in the correct location, working backwards, instead of along the lasers' trajectory.

Player Content Focus

Spatial and Math

One of the 5th grade players (517) referenced spatial reasoning as their sole reason for making an in-game decision. Two 5th grade players (52 & 517) cite math reasoning as the sole reason for making in in-game decision. Two 5th grade players (54 & 516) cite both spatial and math reasoning simultaneously as a motive for making in-game decisions. One 5th grade player (510) worked backwards but was not clear whether her strategy was spatial, math or both. She explained "*Sometimes, I, like, if I'm working on a puzzle trying to get through, I work backwards and go from the end, from the end to…And sometimes it works, and sometimes it doesn't. And I was trying to think…how to get it to work…*".

Math and Spatial Struggle

None of the 5th grade players indicated math struggle during Level 7-2. Two of the 5th grade players (52 & 510) demonstrated spatial struggle during Level 7-2. Even though Level 7-2 is considered a higher level, the players who have made it this far don't indicate having any math struggle. The focus of any struggle continues to be spatial. This indicates players aren't being challenged to learn any new math concepts.

Level 7-2 Summary

The design of this level reinforces that sequence and placement are important but at the same time the design increases the level of difficulty for solving the directional spatial problem of the level. However, the difference from other levels being, instead of the boulders being used as visual indicators, the orientation of the ship combined with the limited number of first placement options, help guide the player.

Level Pack 8

Level 8-1

There is only one level in level pack 8, 8-1. This is the second timed, embedded assessment and it is exactly the same as the embedded assessment in level 2-1 (Image 73).

Image 73. Second embedded assessment.

Level 8-1 Player Data & Discussion

None of the eight 4th grade players played Level 8-1. Six of the 16 of 5th grade players made it to Level 8-1 and all of those players (52, 54, 59, 510, 516, & 517) successfully completed the level.

There were five 5th grade players (52, 54, 510, 516, & 517) who completed both embedded assessments. None of the players who *did not* complete Level 2-1 went on to successfully complete Level 8-1 (or get to the level). Two of the players (51 & 59) who did successfully complete Level 2-1 didn't make it to Level 8-1, their 20-minute play session ended.

These numbers indicates that those players who demonstrated math and game play understanding in the first embedded assessment were most likely to make it to the second assessment. More importantly, because there were no players who failed the first embedded assessment and went on to successfully complete the second embedded assessment in the 20-minute play session could mean the levels in between assessment did not adequately support the necessary math and spatial/visual learning required to progress efficiently.

Level Pack 9

Levels 9-1 through 9-4 represent alternate representations of fractions. For example, the laser is a cupcake tin that can be increased and decreased with the green arrows on either side of the laser source (Image 74). Given purpose of this level was to test players understanding of fractions using an alternate representation player data is not included in the final Discussion & Implications chapter. The full analysis of Level Pack 9 is included in *Appendix D*.

Image 74. Laser is a cupcake tin moving down the lasers' trajectory. The number of cupcakes can be increased/decreased with the green arrows.

Analysis Summary

This chapter included an overview of the game Refraction and a summary of the levels completed by players. The analysis included three components; the design walkthrough, player video data results and discussion organized by level. The design walkthrough includes a description of: what takes place on screen automatically without player interventions, game objects and user interface, what options and interactions are available to the players, what players are intended to do, what players can do (including subverting what they are supposed to do) and screenshots to illustrate descriptions. The detailed, play-by-play description captures the constraints and affordances existing within the game space and helps to categorize qualities of player actions that help identify game qualities and characteristics that may (or may not) contribute to learning.

The player video data presented in this chapter reflected the coding categories. This included data on interviewer interventions, play strategy, player's first choice, and content focus (e.g. Math). The player results were summarized and discussed in relation to the design of the level. Discussion points were focused on identifying new content or opportunities for learning and design implications for each level.

The next chapter, *Discussion & Implications*, includes a summary of the major themes that surfaced in the analysis and their implications in educational game design.

Chapter 5

Discussion & Implications

Discussion and Implications

The purpose of this research is to expose the range and complexity of how educational games support learning. In a more narrowed scope, the purpose is to develop a method to identify the qualities of educational video games that support learning by analyzing the design of the game and the relationship between the in-game representations of learning goals and objectives with game mechanics and game play. This work is to better understand how games for learning are working and identify opportunities to potentially improve them. I cannot stress enough the high quality and value of *Refraction* as an educational game. My intent is not to highlight design flaws or to critique it as an educational tool. If *Refraction* was anything less, the depth and richness of the analysis would not exist. Lesser educational games would not have required such a detailed analysis as the simplicity of their design would not support it.

The methods developed for this research were designed to address the following questions: What can the structure and design of games for learning reveal about the constraints and affordances of player learning in game play? More specifically, what do players' in-game decisions reveal about their learning? And how do the game design and the in-game representations of learning goals and objects constrain and afford player learning in educational games? In addition, there are four primary areas which the analysis is meant to address: 1) how learning goals and objectives are interpreted and incorporated into game content, game mechanics and game play, 2) how learning goals and objectives are represented visually (i.e. splitting lasers as representations of fractions), how learning goals and objectives are integrated into interactions, and how the game supports players to make sense of these visualizations and interactions, 3) unpacking how the game space creates a player experience which enhances a complex relationship between play and learning, 4) the contexts in which the games are played and the educational supports outside of the game to bridge learning and support transfer to out-of-game contexts (J. Bransford, personal communication, Feb. 14, 2013).

This research method includes two parts. The game analysis, or design walkthrough, is a step-by-step description of game play which accounts for all game content and potential player actions. Player videos captured both on-screen play activity as well as recording player think-alouds during game play. From the game analysis key moments, such as identifying when new content is introduced, are identified for potential player learning. Identifying when and how new content is introduced, combined with aggregated player video data by level, reveals what the game play sequence may mean to the player and what they may be learning. This method is also meant to capture not just what the player may learn regarding educational or domain specific content but also how players are learning to play the game.

The design walkthrough flags opportunities for learning by identifying moments when new content is introduced in each level. This means identifying when new material and content is introduced to the player as well as identifying how the game requires players to draw upon the cumulative understanding of the game to be successful at it.

This chapter presents a discussion of the findings and includes an overall summary of the main themes which emerged from the level-by-level discussion points in the *Analysis* chapter. These themes are presented in the following order:

1. Player Content Focus: Math, Spatial, or Both?
2. *Refraction* Play Strategies: Trial and error and accidental discoveries
3. Opportunities for Learning: Player struggle and interventions
4. Noticing and Awareness

5. Assessments
6. Level Design and Difficulty Progression
7. Summary

Player Content Focus: Math, Spatial, or both?

Introduction

In this section I review and summarize the player content focus during game play and discuss how what the player is focusing on reflects learning opportunities in *Refraction*. First I describe and summarize the primary game content categories, math and spatial content. Then, I describe and summarize the secondary game content categories, power and laser color. Finally, I explain how the patterns of player focus may or may not support the targeted learning goals and objectives.

Player Content Focus: Math and Spatial

Player content focus reflects the main categories the player is focused on during game play. The primary categories included, math, spatial, and math & spatial (solving for both simultaneously) as reflected in the coding structure (See *Methods* chapter and *Appendix C*). These categories indicate whether or not during a set of utterances and actions if the player is focused on solving for the math problem (i.e. creating the correct sized laser), solving for the spatial aspect of the puzzle (i.e. bending the laser around obstacles), or focused on both simultaneously (i.e. recognizing a specific size splitter will create both the correct sized laser and direct the laser in the correct direction). The player's focus can change as he or she plays through a level, shifting as the player become attentive to different aspects of the problems presented in each level.

Though it is not possible to be certain how the player is interpreting the contents of game play at all times the analysis revealed trends in how a player's focus shifts during a level. Table 1 depicts a sample of six players and their content focus across three levels. The purpose is to demonstrate the range and variability across players in the sequence and frequency of math and spatial content focus. Just as a reminder, each level does not take an equal amount of time to play as some students will complete a level more quickly than others. The sequence of their content focus appears in the order listed. For example, player 42 in Level 4-1 focused on spatial, math, math, then math & spatial.

	Level 4-1	Level 4-2	Level 4-3
42	S, M, M, M&S	M, S, S, S	M
47	S, M, S	S, S, S	S, M&S
49	S	S, S	S
52	M, M&S	M&S, S	M
54	M&S	S, M	S
519	S, S	S, M	S

Table 1. Sample of six player's content focus across three levels.

Table 1 demonstrates the variability of player focus within and across levels. It also demonstrates individual player tendencies, such as player 49's emphasis on solving the spacial part of the puzzle across all three levels. The degree of variability does not reflect poorly on the design of the game but rather is an initial indicator, to be taken into consideration with other factors, of what to look for in each level design as it relates to player learning and the intended learning goals.

The breakdown of what players are paying attention to in this early game level begins to expose the tension between the spatial and visual puzzle aspect of the game and the prominence of math and fractions learning. As players progress to later levels we can detect changes in focus per level. Table 2 is a sample of two players' complete play session of the frequency in which math, spatial or both were cited by the player.

Level	Players	
	49	52
1-1		
1-2		
1-3		Math
1-4	Spatial	Math
4-1	Spatial	Math Math & Spatial
4-2	Spatial Spatial	Math & Spatial Spatial
4-3	Spatial	Math
4-4	Spatial Math & Spatial	
5-2	Math & Spatial	Math
6-1	Math	
6-2		Math & Spatial
6-3	(*last level completed*)	Math Math Math
6-4		Math Math
7-1		Math Math & Spatial
7-2		Math Math Math

Table 2. Sample of two player's content focus for their complete play session.

Around Level 4-4 player 49 show signs of switching focus from primarily spatial to math. Player 52 remains consistently focused on math throughout the session. Looking more closely at what happened in Level 4-4 for player 49 we find that after solving for a spatial component of game play, he notices “too much/too little power” animation and then makes a selection while attentive to the math and spatial simultaneously.

To expand on the content focus trends further we can count frequency of occurrence for each level (Table 3). Frequency accounts for number of instances, which may be more than once per player, per level. Included are instances of math and spatial struggle to give a sense of frequency when all spatial and and all math categories are combined. Also, not all players made it to all levels so the decline in frequency is also be due to fewer players on the higher levels. See *Level Completion by Grade* in the *Analysis* chapter for number of players who completed each level.

Level	Math Only	Spatial Only	Math & Spatial	Spatial Struggle	Math Struggle
1-1	--	--	1	--	--
1-2	--	--	--	9	--
1-3	3	--	--	1	--
1-4	10	6	4	7	2
4-1	12	12	8	21	10
4-2	10	22	6	31	4
4-3	8	8	5	4	1
4-4	8	12	3	23	--
5-1	2	4	2	4	1
5-2	7	1	4	3	1
6-1	10	3	5	8	8
6-2	5	1	4	3	2
6-3	13	3	1	13	4
6-4	14	2	3	6	1
7-1	8	3	3	7	1
7-2	5	1	2	2	--
9-1	7	2	1	5	2
9-2	10	1	1	3	--

Table 3. Frequency of content focus per level.

These trends across levels indicate which levels emphasize math or spatial content. For example, Level 4-2 has more spatial and spatial struggle than math content whereas Levels 5-1 and 5-2 remained evenly distributed. As the numbers might indicate, looking back to the level design of 4-2, it is spatially significantly more complex than both Levels 5-1 and 5-2. Levels with minimal content focus recorded, such as Levels 5-1 and 5-2 were easily and quickly solved by most players without posing much of a challenge.

The variability in content focus by player reveal players are engaging in different play patterns and strategies to solve for levels. The trends by individual players support these play patterns but also reveal moments when player strategies change. Lastly, frequency of content focus occurrence by level indicates which levels appear to be spatial or math focused. All three of these factors can inform adjusting the level design to address content balance issues.

Player Content Focus: Power

In addition to the primary content focus of *Refraction* there were two secondary categories emerged from the player data; players who paid attention to "too much/too little" power animation and laser color. The animation indicating a ship was receiving too much power (red lightening bolts) or too little power (clouds of smoke) is a visual cue to the players that the ship was not received the correct size laser. The first time the player encounters both of these animations a pop-up message appears explaining "too much" or "too little" power. Neither pop-up message explains how to increase or decrease laser size using splitters.

Table 4 shows the frequency in which players referenced "too much/too little power" animation across levels. Only levels where there is an opportunity for players to view the animation are included (i.e. tutorial and assessment levels are excluded).

Level	Frequency
1-4	4
4-1	7
4-2	13
4-3	5
4-4	9
5-1	2
5-2	1
6-1	2
6-2	3
6-3	--
6-4	2
7-1	1
7-2	--
9-1	1
9-2	--

Table 4. Frequency in which players referenced “too much/too little power” animation by level.

The highest frequency of noticing occurs in the early, regular game play levels (i.e. non-tutorial or assessment). These numbers indicate which levels may need additional intervention for helping players interpret what “too much/too little power” animation means in terms of math understanding. However, noticing the animation helps players who are already approaching the level by focusing on math content and who possess some understanding of larger and smaller fractions. Players who may not be focused on math terms (i.e. the size of the laser and the number on the ship) may interpret the animation as an indicator something they did is wrong. These same players may not have the math understanding to interpret and identify why the size of the laser is smaller or larger than the ship.

For example, of the four players who noticed the animation in the early Level 1-4 one player made the observation when the level started and based subsequent choices off of that observation. Another player corrected his choice after noticing the animation and two players continued to use the bender (which still provided too much power) not recognizing initially that splitters changed the size of the laser. All players progressed through the level, but each player's interpretation of the animation did not guarantee they understood the mathematical consequences of their choices.

In non-tutorial levels where more players noticed the animation, such as Level 4-1, players used phrases such as "*it's pumping too hard*" (48), "*it couldn't fill up both of it*" (47), and "*I think it said you're putting too much of something into there*" (511). The other three players noted the animation and removed their pieces. All indicating they noticed something was wrong but did not use math terms to describe what it meant. Though the intent of the animation is to draw attention to the size of the laser, lasers fueling ships as a metaphoric representation of fractions is flexible enough that players can interpret it a number of different ways ("fill up both…", "pumping too hard", etc.) and not reach the necessary understanding to fulfill the learning goals.

The player understanding indicated in Level 4-1 is repeated in Level 4-2 and 4-3. In Level 4-2 this included utterances such as "*oops, no*" (41), "*Thought it would divide it equally, but it's too much*" (45) and "*that's not it*" (49) and immediately removing or repositioning a piece (42). One player (47) indicated some math understanding in relation to the too much/too little power animation with statements such as "*I just needed enough power—not too much and not too little power*". Another player noted the animation as a indicator (46) "*So, it was — it was like not working. It kept like, like getting sparks*" not indicating whether she understood the laser was too much or too little. One player knew the animation indicated the wrong power but didn't understand that it was too much power instead of too little (44).

Lastly, as revealed in the analysis, the "too much/too little power" animation is used inconsistently throughout the game. The animation is primarily used to indicate to the player the incorrect size laser is going into a ship. This generally means the player reconsiders and possibly changes their selections. However, in some levels (e.g. 4-3, 4-4) in order to solve the level the player must complete a specific sequence and placement and sequence of pieces that produces the animation (red lightening bolts indicating "too much power"). In these levels the player has to essentially ignore the animation and select the next piece (e.g. In level 4-4 the three-splitter) to complete the level. The sequencing and placement of pieces required to complete these levels requires the player to *play through* the discomfort of the "too much/too little power" feedback. Depending on player style and disposition some players were able to play through it while others removed the correct configuration because they took the animation to mean they had done something wrong.

Addressing the issue of clarifying why a laser is too much or too little for the spaceship in math terms can be approached in a number of different ways. For example, a redesign of the animation that demonstrates why the laser is or too much or too little power for the ship (i.e. demonstrate how one third is less than one half through images or numbers). Another approach is to design curriculum materials to supplement game play and "bridge" (J. Bransford, personal communication, Feb. 14, 2013) less than/greater than/equal to fraction learning with the in-game animation. However, the purpose of the game analysis isn't to provide prescriptive design solutions that can be applied uniformly to instructional animations. Rather, to be able to identify aspects in educational game design that need to be addressed.

Player Content Focus: Laser Color

Since the power animation is formally introduced to the player via the initial pop-up messages, it isn't surprising that players modified or changed their game play when they noticed it. However, the color of the laser is a surprising second category that emerged from player data. Player's who took into account the color of the laser in their game play was unexpected primarily because there was no tutorial or instructional material that explained the correlation between the color of the laser and the size of the laser.

There were only a few players who took into account the color of the laser as part of their decision making process. Table 5 outlines which players referenced color on which levels.

Level	Player					
	41	45	47	48	517	518	519
1-3	x	x					
1-4							
4-1		x		x		x	
4-2				x			
4-3			x	x			
4-4				x			x
5-1							
5-2				x	x		
6-1				x			
6-2		x		x			
6-3				x			
6-4				x			
7-1				x			

Table 5. Players who referenced the color of the laser per level.

Early in the tutorial level two players made mention they thought they were doing it wrong because their choices made a red laser. The interviewer explained that the red laser doesn't mean they got it wrong and the players self-corrected.

Some players noticed the color of the laser early in game play but then associated it with the size of the laser. For example, 518 made note of the color of the laser in Level 4-1 and made the association of the color with the size of the laser, "*Um, I was just thinking since it was red and usually it wasn't supposed to be red, but then I realized the one-half on it*." He didn't make mention of it for the remainder of the play session.

Another player relied heavily on the color of the laser as a cue to solve each level. Early in game play, layer 48 explains that the "*blue laser charges them up*" not indicating whether he was attentive to the size of the laser but using the color as a cue to what might work. This same player is the only 4th grader to make it as far as Level 6-3. Looking at the frequency in which he referenced the color of the lasers, his primary play strategy was using the right splitters to create specific color lasers and was successful in completing the levels.

In *Refraction*, the color of the laser is a game element used by some players to make sense of the game space. Though the laser colors correspond with laser size, this correlation allowed at some players to successfully complete levels without focusing on the math content. Players who focused on the color of the laser also demonstrate the range of details will take notice of as part of their problem solving and game playing strategies. Understanding how non-essential game content, such as the color of the lasers, influences player thinking and understanding will help narrow the player focus on game content essential to the learning goals and objectives.

Summary

There is wide variability as to what different players focus on during a single level of game play. Player focus includes primary content areas of math and spatial in addition to secondary content such as power animation and the color of the laser. The sample of six players across three levels revealed very different approaches to the same level. Looking at the full play session of two players, we can also see play preferences of individual players. One player indicated a change from spatial to math while the other remained primarily focused on math. Though math focus is a great outcome it may not necessarily point to learning gains as we'll see in the assessment section. Lastly, looking at the frequency of the math and spatial across all levels we can detect some levels lean towards spatially focused while other levels have limited content focus indicating they may not pose enough of a challenge to players. All of these components; player preferences in approaches, cumulative change in play patterns for individual players, and frequency of content focus across players are cues for investigating which levels could benefit from a redesign.

Evidence of secondary content focus changed player thinking and play behavior. The "Too much/too little power" animation influenced players' decisions but didn't sufficiently explain why one fraction is bigger or smaller than another to those who lacked sufficient math understanding. In other words, for those who understood one third is less than one half, players knew to adjust their splitters. For players who didn't have that understanding, they took the animation to mean they've done something wrong or didn't equate "too much/too little" with the size of the laser. Lastly, a few players used the color of the laser as a cue to successfully solve for levels bypassing the need to consider the size of the laser.

Trends in player content focus indicate an opportunity to revisit the design of a level to redirect player attention towards the learning goals and objectives (as well as to potentially improve game play). Some potential solutions might include increased level of difficulty and variety in the fractions presented for players who need more of a math challenge; tutorial levels, animations, or supplemental content to explain the math content to those not familiar with the values of the fractions used (i.e. players who don't know that one half is more than one third); and in-game hints available to players who struggle with the spatial problem solving component but know the math. These design suggestions are only a few of many options available.

Play Strategies

Introduction

From the player data two types of generic play strategies emerged; trial and error and accidental discoveries. Players were identified as using trial and error by utterances such as, "*First you put it on the side to test what it is*" and/or in-game actions such as randomly or methodically trying each piece available. Players who demonstrated accidental discovery include examples of accidentally selecting the correct piece while intending to select another or anticipating a three-splitter would make one half size laser and is surprised when it makes one third. In this section I present and review the frequency in which these player strategies appear across levels and discuss how these strategies may support learning.

Trial and Error

Trends of the use of trial and error seem to reflect the number of choices available on each level and increase with the complexity of the level. Table 6 shows the frequency in which players demonstrate trial and error across levels. Not all players made it to the same level. The last level completed by each player is indicated by a gray square.

Level	Player																	
	41	42	45	46	47	48	49	51	52	54	55	57	58	59	510	511	514	517	519
1-2																x			
1-3																			
1-4			x																x
4-1		x	x				x				x								
4-2	x			x	x	x													
4-3																			
4-4							x	x											
5-1																			
5-2																			
6-1							x					x	x						
6-2			x				x					x	x		x		x		
6-3						x		x	x				x						
6-4						x									x				
7-1															x				
7-2									x										
8-1																			
9-1																		x	
9-2										x					x				

Table 6. Frequency of trial and error by level and player.

The first instance of trial and error appears in the tutorial Level 1-2. For ten of the players there is an increase of trial and error as the player approaches their last level completed, indicating they engage in trial and error as the levels become more difficult for their ability. Also, trial and error doesn't indicate what the player is struggling with. The player could be testing the boundaries of the game to better understand game play or cycling through options because they don't know what the next best choice is. For example in Level 4-1, One player (49) cycles through the benders and splitters talking to himself to see which each one does. Another player (45) struggles with the funnel orientation and tries different benders and splitters to figure out which one will work while player (42) uses trial and error and accidentally discovers the splitter makes both lasers "*one halves*".

To better understand how players are making use of their trial and error play strategies we have to consider what they were struggling with or if the players were just exploring. Table 7 maps the content focus of a sample of players just before the time of trial and error.

Level	Content focus for each level with trial and error			
41	Spatial Struggle			
42	Power			
45	Math Struggle	Spatial Struggle	Math and Spatial	
46	Math Struggle			
47	Spatial			
48	Math Struggle	Spatial Struggle	Math	
49	Spatial	Spatial	Math Struggle, Spatial Struggle	Math Struggle, Spatial Struggle
51	Spatial Struggle	Spatial Struggle		

Table 7. Content focus of players just before trial and error.

As mentioned in the analysis of Level 4-1 trial and error as a play strategy isn't necessarily a bad thing as its another opportunity for player learning. Learning from failure is part of game play experience but to meet learning goals the learning has to be properly supported. Knowing what the player is learning from these attempts is another thing entirely. By looking at the content focus of their trial and error (what were they struggling with and what did they notice from their trial and error attempts) then we can determine if the emphasis is on math understanding or spatial problem solving.

We can also determine if trial and error is a strategy building tool. In levels where there is an increase in player choice (e.g. 4-1, 4-2, 6-2) and as players reach near their end game and presented with more challenging levels, strategically testing different pieces not only informs the player's next move but the player is able to use their learning in subsequent levels. Since the game content in *Refraction* focuses on math and spatial problem solving, this means learning about spatial and/or math depending on the complexity and direction of the level.

Accidental Discovery

There were fewer instances identified as accidental discovery than trial and error. However, accidental discovery is another way for players to learn from failure. Table 8 shows the frequency in which accidental discovery occurred by level and by player.

Level	Players							
	41	42	49	51	52	514	517	518
1-2								
1-3								
1-4	x							
4-1		x						
4-2		x						x
4-3								
4-4			x					
5-1								
5-2								
6-1								
6-2								
6-3				x		x		x
6-4					x			
7-1								
7-2								
8-1								
9-1							x	
9-2								

Table 8. Frequency of accidental discovery by level and player.

The instances of accidental discoveries provide insight as to what the player had misunderstood about the game, up until that point. For example, player (41) accidentally solved the level when she removed the bender and two-splitter from the play space (leaving the three splitter that happened to be located in the correct position). She discovered that the three-splitter created one third. Player 514 accidentally selected a two-splitter when trying to split the laser into one third (he meant to pick the three-splitter) but ended up solving the level. He discovered to pay attention to the number labeled on the ship to determine which splitter to choose.

From a design perspective these misunderstandings, if significant, can be addressed or revealed to the players in the tutorial levels (or in the early levels). For example, even though player 514 made it to Level 6-3, his accidental discovery clearly indicates that he wasn't certain which sequence of splitters would produce the size laser he wanted.

Summary

Trial and error and accidental discoveries are expected components of game play and are great opportunities for players to learn how to play the game. These are also opportunities for designers to better understand player misconceptions about the game and learning content. The intent is not to necessarily remove the opportunities for player's to direct their own learning and develop an understanding of the game through strategic trial and error. However, addressing misconceptions can reduce player's such as 514 from getting too far along in the game without comprehending a key component of the game.

Opportunities for Learning

Introduction

One attribute of games and game play is they afford a space for players to engage with different types of challenges. Overcoming challenges is not a singular quality of game play but is one of many conditions of a complex system (Salen & Zimmerman, 2003). In *Refraction*, the challenge of each level is to get the correct size laser to each of the spaceships. How players approach solving this challenge depends on their spatial and math abilities.

Identifying the moments when players are struggling with different types of game content isolates sequences where the player may potentially be learning. In the broadest sense players are learning how to overcome the challenge of the level but what the player is focused on varies by player. By identifying when players struggle with the spatial and/or math content of game play the goal isn't necessarily to make the game easier (perhaps, better) — we don't want to remove the fun of the challenge. We want to be able to identify why players struggle when they do and to determine if the struggles interfere with math learning and warrants a change in the design.

In this section I discuss two primary opportunities for learning during player struggle and interviewer interventions. First I review and summarize the player's who struggled with math content across levels, then review and summarize the player's who struggled with the spatial aspect of game play. Lastly, I present a summary of the frequency of interviewer interventions by level and frequency of interviewer intervention by player content focus.

Math Struggle

Players who demonstrated math struggle indicated such by their utterances and/or in-game actions. For example, expressing confusion if one fraction was larger or smaller than another, uncertainty what size lasers each type of splitter creates, and which combination of splitters to use for more complex fractions (one sixth and one ninth) to name a few (for a complete description of which utterances and actions qualified as math struggle see *Appendix C)*.

As initially shown in the *Player Content Focus* section, the number of players who struggled with math content by level indicates the level of math difficulty.

Level	Math Struggle
1-1	--
1-2	--

1-3	--
1-4	2
4-1	10
4-2	4
4-3	1
4-4	--
5-1	1
5-2	1
6-1	8
6-2	2
6-3	4
6-4	1
7-1	1
7-2	--
9-1	2
9-2	--

Table 9. Frequency of instances of player's struggling with math per level.

The first level after the tutorial and assessment, 4-1, had the highest occurrence. The second highest being Level 6-1 which was the first level (outside of the initial embedded assessment) where players had to use two splitters together to get the correct sized laser (i.e. use two two-splitters to make one fourth). Both increases appear to indicate the increase in math difficulty corresponds with the increase in math struggle.

Upon closer look we can see from individual players what type of math struggles were for each player in a given level (Table 10). For Level 6-1 players had to solve for four ships labeled one fourth, requiring them to use two, two-splitters to solve the level.

Player	Level 6-1
45	Starts off stating "*I know that these are halves*" but says "*that's too low*" referring to the one half size laser just created. Then later selects a three splitter and says "*too low*" again.
49	Uses trial and error to rotate through all the pieces. Is not making decisions based on the size of the laser.
57	Creates one ninth then explains its "*too big…I'm gonna put a lower one*".
515	When asked about picking a three-splitter explained "*Because it makes one-third and you want to make one-fourths*."
517	When asked to explain his thinking,; "*I picked this one because…[uses splitter]…one-third plus one-half…[selects two-splitter]…equals one-fourth…[uses splitter]*"
518	When successfully completed the level, was asked why he selected a two-splitter instead of the three-splitter he replied "*Um…[pause]…you know, I don't know. [chuckles]*"
519	Initially picks a three-splitter when she needs a "two-way"

Table 10. Indicators of math struggle in Level 6-1.

From these responses some players indicate they don't know which fractions are bigger or smaller than others. Other players are thinking in math terms but their descriptions are not quite accurate. While other players stumble upon or try different combinations. For player's who struggled with math content there is little or no in-game support to address their thinking. Yet all these player's successfully went on to complete the level.

Considering the design of the core mechanic (bending and splitting lasers) and the level design of 6-1 (creating one fourth lasers for four ships), it is difficult to determine if player's math struggle was a result of not understanding there are four one-fourths in a whole or if the struggle was in trying to find the correct combination of splitters. In other words, a recognizable math problem might have been achievable for some players whereas the visual representation of combining splitters may have been too far removed from a traditional math problem for players to calculate. For example, if an animation or part of the tutorial made explicit that 1/2 x 1/2 = 1/4 is the same as a two-splitter with a two-splitter creates one fourth, would players still struggle with Level 6-1 in the same way?

Spatial Struggle

The visual and spatial aspect of *Refraction* requires players to be aware of the orientation of the funnel (incoming laser) and the direction of the output. In addition, players have to sometimes navigate the laser around obstacles (e.g. boulders). Overall there was a higher frequency of spatial struggle than math struggle across most levels (Table 11).

Level	Spatial Struggle
1-1	--
1-2	9
1-3	1
1-4	7
4-1	21
4-2	31
4-3	4
4-4	23
5-1	4
5-2	3
6-1	8
6-2	3
6-3	13
6-4	6
7-1	7
7-2	2
9-1	5
9-2	3

Table 11. Frequency of spatial struggle per level.

This indicates that players spent a good deal more time problem solving for the spatial content of the game. For some players, like player 51, they know how to solve for the math content from the onset but struggled with both funnel orientation and navigating around boulders. These results shouldn't be considered an indication to make the puzzle less spatially challenging as for many players, the challenge is engaging and fun. Rather the question should be on the design challenge of ensuring that the time and effort spent focused on spatial content only, can be shifted to include math and benefit the player's simultaneous goal of learning fractions.

Interviewer Intervention

The interviewer determined when it would be appropriate to step in by how long the player remained inactive. If a player was struggling but was active and making a lot of selections then she would not intervene. If the player's actions not productive or led to repeated unproductive play patterns she would ask if the he or she wanted a hint. If the player was inactive and not making any actions or making very infrequent actions the interviewer would intervene sooner. The interventions were not direct instructions but focused the attention of the player on some aspect of game play that would lead them to the right selection. This provided an opportunity for players to reflect and learn from their actions. On rare occasions, especially in level 9-1, the interviewer would complete the level at the request of the player. Player's did not receive interventions on the assessment levels.

The frequency of interventions by level indicate the difficulty of the levels across the range of students (Table 12).

Level	Interviewer intervention
1-1	1
1-2	4

1-3	--
1-4	2
4-1	2
4-2	11
4-3	--
4-4	10
5-1	1
5-2	--
6-1	--
6-2	1
6-3	2
6-4	1
7-1	2
7-2	
9-1	6
9-2	5

Table 12. Frequency of intervention by level.

Levels 4-1 through 4-4 and Levels 9-1 and 9-2 appear to have the highest rates of interventions. These levels are both instances where the players are introduced to new math and spatial challenges. However, the skills needed to complete Level Pack 4 should have been covered in the tutorial levels whereas the content in Levels 9-1 and 9-2 was not. Looking more closely at a single level we can identify why the interventions occurred and see what caused players to get stuck (Table 13).

Player	Level 4-2 Interventions
41	Resets the level
44	Explains to player they have to use all the benders but don't have to use the two-splitter

45	Reminds player what a bender and splitter is and to use the third laser
47	Explains to player to use the third laser
49	Explains to player to go back to a previous configuration
53	Explains to player to adjust the location of a bender
59	Explains to player to go back to a previous configuration
511	Explains to player to use all the benders and to pay attention to the third laser
514	Explains to player to use all three of the lasers
518	Explains to player to use the third laser
519	Explains to player to keep current configuration and look for additional solution

Table 13. Types of interventions by player for Level 4-2.

This sample of a single level (4-2) shows a theme of player's struggling with the spatial configuration. Most of the players in Level 4-2 overlooked a third laser available for the third ship. Instead, players tried to use one laser for two ships without splitting it (see the detailed level description in the *Analysis* chapter).

Looking at the types of interventions that took place can also inform level design decisions. In this case, the sequencing and placement of the right combination of benders and splitters allowed some players to overlook an essential piece (the third laser) to solving the level. By either adding more pieces to allow for multiple correct pathways or changing the layout of the spaceships this early level in game play may be more accessible to some players.

Summary

Struggle and challenge is an essential component to game play. The goal is not necessarily to reduce or eliminate struggle but to understand where there is struggle in game play and why. By identifying the content focus of players we can not only determine what their attentive to but also identify challenges that may inhibit game play and interfere with learning goals. It is the balance of content and not overemphasis with the right amount of struggle that is conducive to learning. In the case of *Refraction*, focusing only on spatial struggle may inhibit players' access to math learning.

The role of the interviewer also acts as a mediator and an example of how an out-of-game resource can shape player decisions. The interventions can serve as a model for designing in- or out-of-game content to help mediate learning.

One last consideration in regards to opportunities for learning. Since the play sessions were restricted to 20-minutes players who would have been able to play for much longer, and repeat levels, may have been able to eventually complete the levels without intervention. Replaying levels allows for players to experiment and test different methods of problem solving. However, what they learn from their success would still need to be considered.

Noticing and Awareness

Noticing

Part of what makes well-designed digital games such a potentially powerful space for learning is how players learn to navigate and be successful in the game (Salen & Zimmerman, 2003; Gee, 2003). Cues and feedback mechanisms are designed into the play space as indicators for players to follow (Crawford, 2003; Rollings & Morris, 2004; Salen & Zimmerman, 2003). How well these feedback mechanisms are designed into the game help influence how many players take notice and incorporate their intended meaning into their game play.

Most importantly, at least for an educational game, are the players who can successfully complete levels without noticing the math. In Levels such as 4-1 there are opportunities to stress the size of the laser (paying attention to the fraction) as an essential part of game play. However, in some instances its possible to complete a level without requiring the player to pay attention to the math details.

As mentioned in the *Player Content Focus* section, players who noticed the color of the laser used this indicator as a way of making sense of the game space, more specifically, creating the right type of laser. Even though this strategy was successful, the intention of the design was for the players to be attentive to the size of the laser (fractions) rather than the color alone. Counting lasers was another strategy that was successful for some players in the early levels but failed in later levels. For those who focused on counting lasers, they may have missed the opportunity to learn from the progression of game content if they had focused on the fractions instead.

Anticipating how players will interpret non-essential details in the game space and use them to progress in game play is part of the play testing protocol. Not being able to predict how players will interpret all of the components of game play is a normal part of game development. Through play testing its possible to reveal and adjust the design earlier in the development process (Rolling & Morris, 2004; Rollings & Adams, 2003; Schell, 2008; Fullerton, 2008) to direct, or redirect, players' attention.

However, missing from the play testing protocol is understanding how a players interpretation influences learning. Noticing may not be sufficient as with some game content the player's interpretation of what's being noticed plays an important role on how the information is used. For example, "too much/too little power" animation was not consistently interpreted across players. Some didn't notice the initial pop-up message. Some didn't know what too little or too much was in relation to the fractions they were working with (i.e. they didn't know the math), others knew they were doing something wrong and interpreted it as a hint to make a different choice.

Even in the early tutorial levels it begins to become apparent that with more choices there is more opportunity to make mistakes (and learn from them). In the section *Opportunities for Learning* some players need guidance noticing particular aspects of the game. These moments of intervention are also indicators of what types of in-game prompts are needed to redirect the player's attention. These don't necessarily have to be in the form of instruction or direct hints but some indicator to the player to be attentive to another aspect of the game. In *Refraction* this may include addressing the following common occurrences; the relationship between the size of the laser and the size of the space ships, feedback mechanisms (such as snap-to-grid visibility), funnel rotation and misalignment, adjusting the position of one or more pieces to complete a level, and using all available lasers (instead of trying to use one laser to reach two ships without splitting it such as in Level 4-2).

Prioritization of content may also contribute to what players take notice of first. For example, in the tutorial levels introduction to the spatial problem solving component of game play came before the math component was formally introduced. Also, in levels where there is only one possible sequence and placement solution the first choice determines the frame in which the player must solve the level. If a bender is the required first placement, then the player must consider the spatial first, even if they know the math. Players who struggle with solving for the spatial will still try to start with a splitter, because they know the correct math, but disregard the orientation of the funnel (indicating spatial struggle).

Awareness

Though the player's in this study were aware *Refraction* is a math game, we begin to see differences in how players are interpreting what the game means and evidence of math talk as early as in the tutorial Level 1-3. Given the limited math instruction embedded in game play up to Level 1-3 the two 4th graders and two 5th graders spoke in math terms are demonstrating their knowledge of fractions prior to game play[4]. The two 5th grade players did so using their best terms. Sometimes the descriptions are accurate "*Oh, and it can divide into like halves and fourths and thirds and stuff*" and other times it could be math thinking but using the inaccurate terms "*You click that and then it goes on and separates it. [uses it; completes level] And then, they both get the equal amount that they need".* This early math talk indicates that in player awareness, at least for these players, *Refraction* is a game about math and is part of how they are trying to make sense of the game space. Though the player may know the game is about math there are no mechanics or player actions in place to measure how they are making sense of the math. In the example provided, "*goes and separates it*" and " *both get the equal amount*" are not strong enough indicators that the player knows there are three one thirds in a whole but in the context of game play, their math understanding is sufficient to complete the level.

The content or mechanics of the game itself does not require or press players to reflect upon their own understanding in this way. This type of intervention may be necessary to help students learn the math component of this game because 1) the mechanic does not support exploration and feedback on why they are successful or fail and 2) it is not possible to determine how the players are interpreting their own in-game actions or making sense of their choices.

Assessments

Introduction

There are two types of assessments included in this version of Refraction. Embedded assessments (Levels 2-1 and 8-1) and a regular assessment (Level Pack 3) (see *Overview of*

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[4] The 4th graders were asked indirect questions (not math specific, just to describe what they were doing) and the 5th graders were not prompted at all.

Refraction in the *Methods* chapter for level descriptions and corresponding levels in the *Analysis* chapter for the complete level analysis). For the purposes of this study I am not critiquing or analyzing the design of the assessment but rather reporting the results in relation to player performance. In this section I will summarize and discuss the results of the embedded assessment and regular assessment.

Embedded Assessment (Levels 2-1 and 8-1)

The first embedded assessment (Level 2-1) occurs immediately after the tutorial level pack, giving the player no regular game play time before taking the assessment. The embedded assessment presents math content not yet explored in the tutorial (i.e. solving for one sixth and one ninth).

None of the 4th grade players successfully completed Level 2-1 embedded assessment and none of them made it to Level 8-1 embedded assessment. Six 5th grade players successfully complete Level 2-1 (51, 52, 54, 510, 516, & 517) and six (52, 54, 59, 510, 516, & 517) successfully completed Level 8-1. Of the players who took both embedded assessments only one player, 59, didn’t complete 2-1 and went on to successfully complete 8-1. One player, 51, did complete Level 2-1 but did not make it to Level 8-1 to take the test.

This indicates that only players who grasp the mathematical meaning and purpose of the splitters were going to be successful in Level 2-1. This is because 1) the introduction of splitters in the tutorial levels does not cover splitting one into one sixth or one ninth, 2) the time constraint (two minutes) prevents player from using trial and error to solve the level. It should be too much of a surprise that those who successfully completed Level 2-1 also played more quickly (or were more successful) to make it to Level 8-1. However, making it to Level 8-1 is an indication of a players success, though not necessarily an indication of what they learned (math, spatial or both) to get that far in the game.

This raises some interesting questions about the standards of games and learning that reach beyond the scope of this study. It might not be beneficial to think all players should take roughly the same amount of time to play. It might be to the benefit of the learner to allow for more time without consequence. However, by doing so are games more or less efficient or effective than other methods? Or, is it that games used as a supplement can better serve those who need more time?

Assessment (Level Pack 3)

Level pack 3 (Levels 3-1 through 3-4) consisted of an assessment similar to what might be administered in a classroom (see corresponding levels in the *Analysis* chapter for the complete level analysis and assessment description). Looking at the same player's assessment results gives us some indication of their overall math understanding (Table 14).

Player	3-1	3-2	3-3	3-4
51	Correct	Correct	Incorrect	Correct
52	Skipped	Incorrect	Correct	Correct
54	Correct	Skipped	Correct	Correct
59	Correct	Correct	Incorrect	Correct
510	Skipped	Skipped	Skipped	Partially Correct
516	Correct	Correct	Incorrect	Correct
517	Correct	Correct	Correct	Partially Correct

Table 14. Number of correct, partially correct and incorrect answers for level pack three of the player's who completed the embedded assessments, Levels 2-1 and 8-1.

Players who did well on the embedded assessment appeared to do well on the regular assessment. Indicating they started the game with strong math skills to begin with. The remainder of the assessment scores for Level Pack 3 didn't reflect any player patterns. For example, a player who did poorly in Level Pack 3 focused primarily on spatial problem solving.

In addition, players didn't play another assessment level pack later on in the game to compare changes in scores.

Summary

A closer analysis of how each player answers each question may reveal their math thinking but this level of interaction analysis is beyond the scope of this research. The players who were able to finish the embedded assessments, not surprisingly, did well on the regular assessment levels as well. Though the assessment Level Pack 3 captured player's math understanding, without a second assessment it is difficult to determine if the player's math understanding improved from game play alone.

Level Design and Difficulty Progression

Introduction

Up until this point in the chapter I've focused primarily on summarizing and discussing the player data in relation to the design. For this section I focus on specific design implications of *Refraction* as they relate to learning. I summarize and discuss the level design progression in terms of math and spatial complexity, discuss the prioritization of introducing spatial problem solving over math content as part of the level design and game mechanic, and lastly, discuss the implications for learning on levels with one solution versus many solutions.

Difficulty Progression

Another attribute of a well-designed game is the fluidity of the natural build-up and progression of challenges and in-game difficulty (Salen & Zimmerman 2003; Schell, 2008). Though it is possible to included harder challenges earlier in a game, the necessary scaffolds must be designed in to help the player eventually reach success.

The two primary content domains of *Refraction*, spatial problem solving and math (fractions) should also progress in difficulty as the player moves further along. The introduction of new content or new challenge, by level, is an indicator of how much and what the player is being exposed through the progression of play. Table 15 breaks down the new content and challenges introduced by level.

Level	New content and challenges
1-1	Dragging and dropping objects is a primary game mechanic. The direction of the funnel and output arrow of the bender has significance. Snap to grid function.
1-2	Three aspects of the spatial component of game play; 1) the orientation of the funnel for where the laser enters the bender (or splitter, in later levels), 2) the orientation of the output of the bender (or splitter) and the output direction of the laser, 3) the sequence in which the benders (or splitters) must be used in order to direct the lasers to the correct location.
1-3	Players use a splitter for the first time. Boulders are present but do not directly block spaceships.
1-4	Magnifying glass First level to introduce one third. Introduction to “too much/too little power” animation
4-1	First level that is not a tutorial or assessment. Players are free to choose any piece and play in any order.
4-2	First level where a player needs to use a bender and splitter to get the laser to a single ship.
4-3	--
4-4	Boulders are direct obstacles for the first time. Player must use benders before splitters to solve the level. First time “playing through” power animation.
5-1	--
5-2	Splitters or benders are viable first choices (instead of one or the other).
6-1	First time using two splitters to create a fraction.
6-2	--
6-3	First time outside of the embedded assessment solving for one sixth. Level requires players create extra unused lasers.
6-4	First time outside of the embedded assessment solving for one ninth.

7-1	First time outside of the embedded assessment where the player must solve for two different fractions.
7-2	Orientation of the ships require the player to direct the laser around the ship in way unlike other levels up until this point.
9-1	Adjustable cupcake laser instead of single laser.
9-2	--

Table 15. Breakdown of new content and challenges by level.

The breakdown of new content and challenges introduced at each level indicates that more spatially focused materials are introduced in earlier levels than math. Different math choices appear later in game play. This can mean two things, perhaps an integration of new math content earlier in the game would better emphasize it as a focal point in the game given the time constraints. On the other hand, giving players more time would have allowed more players to reach higher levels and interact with more new math content.

<u>Prioritizing Spatial over Math</u>

Introduction to the spatial reasoning components of the game (sequencing and placement of benders) occurs before introducing concepts of splitting a whole into fractions. Even at the earliest tutorial level to use a splitter, there isn't a mathematical explanation of the what the player is being asked to do, rather its performed as a directional manipulation and explained in game terms.

The purpose of the game of directing lasers into spaceships is primarily a spatial problem. The game mechanic— benders bend lasers but don't create fractions—doesn't reinforce math thinking. Splitters can support math thinking because they create fractions, but don't always because the player can also use them for the purpose of bending lasers. This configuration reinforces a prioritization of spatial problem solving over math. In some levels, though players *can* solve for the math first they cannot solve the puzzle without tackling the spatial component first. As the breakdown of the level design in the *Analysis* chapter shows, the design of some of the levels polarizes players to think in terms of math *or* spatial, rather than math *and* spatial.

The number of players that toggle between focusing on math or spatial is higher than those players who consider both in their decision making and game play. Switching back and forth isn't necessarily contrary to learning math, it allows players the flexibility to think through the challenge based on their strengths and preferences while adding depth to the challenge of game play. However, when there is over-representation of certain types of game content, the game play becomes unbalanced. Players' spend more time focused on the preferred content. In *Refraction*, balancing the explanation of the math content to match the degree in which the spatial content is demonstrated and explained may restore that balance.

Level Design: One Solution vs. Many

Over time, toggling between content focus within a level may detract from player math learning for two reasons. One, the game content (spatial) and educational content (math) can become polarized instead of being meaningfully codependent. Two, this is further reinforced when levels only provide one possible solution (i.e. a player must identify the single sequence and placement of benders and splitters to solve a level). In some instances the correct first choice is a bender, emphasizing the spatial component of play, while on another level the correct first choice is a splitter (emphasizing both math and spatial).

In the overall game design of *Refraction*, levels that switch between only one available solution and multiple solutions is an interesting aspect of design. As shown in the game analysis, for some levels the player's initial problem solving approach is indicated by their first choice (i.e. selecting the bender or splitter to achieve a specific direction or choosing a splitter to create a specific size laser).

For levels with a single solution, what works for a player in one level may not work in the next level. So the player who prefers to choose splitters first to try to solve for math will not be able to do so in the subsequent level where the only viable first choice option is supposed to be a bender. Single solution levels emphasize precise sequencing and placement of benders and splitters as a necessary skill for completing the level. This design may support more complex challenges by narrowing the number of choices available to the player to complete the level. However, if a player does not meet or understand either the math or spatial complexity of the single solution then there aren't any alternatives to help them pass the level.

Multiple solutions for a single level allow for players to start with their preferred method of problem solving (splitter for math or math and spatial or bender for spatial), then proceed to the rest of the level and solve to their strengths. It also can give advanced players an opportunity to problem solve more creatively by using more options. However, for some players the number of choices may be too overwhelming if presented too early in game play.

Consistency, in this case, of either designing levels so there is only one correct first choice OR designing levels so there are multiple correct first choices may help in reducing player confusion on whether they should focus on spatial or math as they progress through levels. Increasing predictability in game play reduces the player's need to focus on non-essential aspects of developing game strategies. However, without appropriately scaffolded hints or feedback regarding how to achieve the correct sized laser, the player may get stuck in a loop where failure and exploration cannot support a learning progression. More importantly, if there aren't scaffolded hints or in-game feedback specific to math problem solving in relation to the spatial and visual puzzle, then its possible it is no longer important for the player to pay attention the math in order to succeed.

Summary

Emphasizing the spatial aspect of game play in early levels reinforces the math content is secondary to the spatial problem solving. Balancing the distribution of new math with spatial content in earlier levels may help reinforce math learning focus on later levels. In addition, adding the equivalently detailed explanations and examples of new math content that is used for introducing new spatial content may also reinforce the importance of math understanding in successfully completing future levels. Lastly, consistently using either single or multiple correct solutions for each level would provide a more consistent play experience allowing players to develop a play strategy that focuses on math *and* spatial rather than math *or* spatial content.

Discussion and Implications Summary

Of main themes that emerged from the analysis the question remains, what can we do with this information. Despite the use of a new hybrid method, the short play sessions of 20-minutes, and the difference in population (4th graders and 5th graders), I believe we can say that how learning objectives are integrated into game play through game mechanics matters. Not just in the quality of the player's play experience but in how the player understands the intended learning objectives. I believe this study answers, in part, the original research questions.

1) What can the structure and design of educational games reveal about the constraints and affordances of player learning in game play? We saw how the level design influences player thinking.
2) What do players' in-game decisions reveal about their learning? In-game decisions can reveal players thinking. Player approach levels differently and their understanding of what they are doing varies.
3) How do the game design and the in-game representations of learning goals and objectives constrain and afford player learning? Here we saw evidence of how spatial and math content

divided the attention of the players. Considering the consequences of game mechanics that didn't deter players from thinking in terms of spatial or math rather than supporting thinking of spatial and math.

This chapter included a discussion of the findings and summary of the four main themes which emerged from the level-by-level discussion points in the *Analysis* chapter. The first theme reviewed the frequency in which player's focused on math, spatial, or both during game play. This section highlighted the variability of what players focused on and revealed players' preferred play strategies for problem solving. These trends in player content focus indicate an opportunity to revisit level design to redirect player attention towards the learning goals and objectives.

The second theme included trial and error and accidental discoveries as play strategies. Without removing the fun and challenge associated with trial and error and accidental discoveries, the frequency of occurrence of these moments in game play indicate an opportunity to better understand player misconceptions about the game and the learning content. What players learn from accidental discoveries point to game and math content that could be better integrated in the tutorial or early game play levels. While still permitting (and encouraging strategic trial and error) understanding the moments that initially prompts players to use trial and error can inform design changes. Particularly to address those players who use trial and error to complete a level without necessarily learning why their choices were successful.

The third theme included a discussion on player struggle and interviewer interventions as opportunities for player learning. The frequency in which players struggled with math and spatial game content indicates the focus of their attention during game play. Looking across players we can see trends for levels that suggest some levels may be more spatially focused than math focused. These trends can serve as an indicator for how to better balance the game content with the learning content. Similarly, moments of interviewer intervention also serve as an indicator of which types of struggles players were not able to solve on their own. Detailed analysis of the particular intervention can serve as a blueprint for designing in-game support to address the particular issue.

Player's sensitivity to noticing different aspects of the game and awareness of their own learning and purpose of the game is the fourth theme. Players demonstrated noticing (or not noticing) a wide range of detail. Some of what was noticed was non-essential to math or spatial thinking (color of the laser) and other essential components missed (not using the third available laser). Prioritizing which content is presented to the player informs what players take notice of. Some players indicated they were aware the game was intended to teach math, and at moments, indicated they were learning. However, the think-aloud prompted these reflections not the game play. Incorporating mechanisms or content that promote player's to reflect on their choices and in-game actions can also support player learning.

The assessments from this study indicated that those who already possessed the spatial and math ability to complete the first embedded assessment were also able to get far enough along in the game to finish the second embedded assessment. Only one player who did not complete the first embedded assessment went on to complete the second. These same players also did well on the regular assessment levels. The results of the assessment indicate that those who were already high performing, both spatial and math, did well in the game.

Lastly, the design of each level and the difficulty of play progression can emphasizes or de-emphasizes the intended learning goals and objectives depending on how they are positioned within game play. Emphasizing the spatial aspect of game play in early levels reinforces the math content is secondary to the spatial problem solving. Balancing the distribution of new math with spatial content in earlier levels may help reinforce math learning focus on later levels.

Chapter 6

Conclusion

Conclusion

In this paper I've explored the unique challenges games for learning and educational games face. This includes; 1) Recognizing and taking advantage of the potential capability of game space while fitting with accepted pedagogical practices, 2) Supporting the learning goals and objectives desired, and 3) Creating meaningful game play that is conducive to targeted learning.

To address these challenges I examined three primary areas; 1) an account of the learning objectives and how they are taken-up, interpreted, represented and incorporated into the game; 2) an analysis of the game itself; game mechanic(s) and how game play and game mechanics are interpreted, taken-up, and incorporated in relation to the learning objectives (or not); 3) the player experience; player response to game play and learning goals. This also includes the contexts and conditions that support may or may not support transfer. The questions guiding this research include; what can the structure and design of games for learning reveal about the constraints and affordances of player learning in game play? More specifically, what do players' in-game decisions reveal about their learning? And how do the game design and the in-game representations of learning goals and objects constrain and afford player learning in educational games?

In addition to addressing the research questions, my aim of this research is to contribute a potential method of analysis to better understand why games for learning may or may not work, provide a foundation for evaluating the quality of educational games and games for learning, and to demonstrate the design of educational games and games for learning requires a hybrid design approach of both instructional and game design strategies.

I examined pivotal works that have influenced current pedagogical design strategies from both game design and educational research. The purpose is to better understand the strategies that underlie designing games for learning and reveal the theoretical and conceptual assumptions attached to successful (and less successful) games for learning.

The review of literature reveals that though there are a number of sources of research of games for learning there is very little that analyzes the games themselves and the design of these games in relation to the learning objectives. Many of the guidelines developed and shared in the game design community may not be taken up as hard, fast rules but as guidelines to be adjusted for innovation. Looking to e-learning or instructional design strategies, reveals these recommendations are too stringent to allow for creative game design as some recommendations are in direct conflict with game design principles.

The review of the literature also reveals the potential of digital games for learning has been widely explored and the process by which entertainment digital games are designed is well documented and supported. In addition, there exists a healthy variety of settings and context where games for learning are being researched. However, there is a lack of research that combines game design strategies with learning strategies as a way of understanding the quality of play and effectiveness of games for learning.

Lastly, there is a gap in the literature regarding methods for researching the viability of educational video games. The research lacks detailed content and interaction analysis of the game space and doesn't provide a comprehensive evaluation of how the design of the game affords and constrains learning that includes details of the game and the contexts it is being played.

For this research I have developed a method that combines an analysis of the design details of an educational game with video game play screen-captures and video recordings of player think-alouds. In short, the game analysis is a detailed design walkthrough of the game and outlines the full scope of game play options as they are made available to the player. In the game analysis procedures I focus particularly on capturing how the learning goals are represented both as in-game content and potential player interactions. The player videos afford insight into how the players are making sense of the representations and potential play options by examining how the players describe their play strategies through think-alouds and examining their in-game choices from the screen captures.

The analysis included three components; the design walkthrough, player video data results and discussion organized by level. The design walkthrough includes a description of: what takes place on screen automatically without player interventions, game objects and user interface, what options and interactions are available to the players, what players are intended to do, what players can do (including subverting what they are supposed to do) and screenshots to illustrate descriptions. The detailed, play-by-play description captures the constraints and affordances existing within the game space and helps to categorize qualities of player actions that help identify game qualities and characteristics that may (or may not) contribute to learning.

The player video data presented in this chapter reflected the coding categories. This included data on interviewer interventions, play strategy, player's first choice, and content focus (e.g. math). The player results were summarized and discussed in relation to the design of the level. Discussion points were focused on identifying new content or opportunities for learning and design implications for each level.

Discussion of the findings included a summary of the main themes which emerged from the level-by-level discussion points in the *Analysis* chapter. The first theme reviewed the frequency in which player's focused on math, spatial, or both during game play. This section highlighted the variability of what players focused on and revealed players' preferred play strategies for problem solving. The second theme included trial and error and accidental discoveries as play strategies. Without removing the fun and challenge associated with trial and error and accidental discoveries, the frequency of occurrence of these moments in game play indicate an opportunity to better understand player misconceptions about the game and the learning content. The third theme included a discussion on player struggle and interviewer interventions as opportunities for player learning. Detailed analysis of the particular intervention can serve as a blueprint for designing in-game support to address the particular issue. Player's sensitivity to noticing different aspects of the game and awareness of their own learning and purpose of the game is the fourth theme. Incorporating mechanisms or content that promote player's to reflect on their choices and in-game actions can also support player learning. The results of the assessment indicate that those who were already high performing, both spatial and math, did well in the game. The design of each level and the difficulty of play progression can emphasizes or de-emphasizes the intended learning goals and objectives depending on how they are positioned within game play. Balancing the distribution of new math with spatial content in earlier levels may help reinforce math learning focus on later levels.

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Appendix A: Definition of Terms

General Terms

In this research *digital games* refers to games played as a console, computer, handheld, mobile, or games that involve digital technology. *Educational games* and *games for learning* are close in definition and I use them interchangeably. The slight difference being educational games may imply games specifically developed for educational purposes, either to be used in a formal educational setting or structured with formal educational goals that may be played in informal settings. Whereas *games for learning* may included entertainment games used in either an educational setting or have been found to have some educational value in an informal setting.

Game mechanics is similar to *game play* and can refer to a number of different ways games work on many different levels depending on the altitude of analysis (Schell, 2008; Rollings & Adams, 2003). For example, a point-system is one of many game mechanics that track player progress and standing. Whereas, real time strategy (RTS) is a game genre which entails a number of standard (or player expected) game mechanics such as some component of strategically managing resources to overcome an obstacle.

The term *game content* refers to any component of the game in reference. Game content can range from in-game objects, such as a tree, to the narrative structure of the game play. *Educational content* is a term used to identify materials and concepts used explicitly for the purpose of teaching and learning and connotes a formal context. *Learning content* is a term used to identify materials and concepts either used explicitly for the purpose of teaching and learning or discovered and identified as potentially useful or beneficial to learn. This term indicates formal or informal learning environments. Much like *educational content*, *learning objectives* or *goals* refers to material and concepts explicitly identified as the take-away skills, understanding and/or knowledge the learner will develop after playing the game. *Learning objectives* are typically measurable and may have some form of either formal or informal corresponding assessment.

Instructional design definition draws upon e-learning and multimedia practices and guidelines as pedagogically sound approaches to technology integrated learning and refer to design understandings, approaches, processes, and practices specific to designing curriculum in virtual, electronic or other technology-mediated methods (Clark & Mayer, 2008).

Chapter 1: Introduction

ADDIE - An instructional systems design (ISD) commonly used for instructional design and development. The acronym stands for the five main stages: Analyze, Design, Develop, Implement, Evaluate.

First-Person Shooter (FPS) - First-person shooter refers to the player perspective (first-person) and the type of game play (shoot 'em up). FPS typically involves using guns or projectiles to do battle against computer generated non-player characters (NPCs) or other players.

Free-to-play game - A digital game that is initially free to play but to access premium content players must pay (or purchase in-game currency with real money) in order to access additional game content or play the full version of the game.

Side-scrolling adventure game - Side-scrolling refers to a game that is viewed from the side and the screen view moves left and right. Adventure games are typically are typically where they player is a main character in an interactive narrative but may also include puzzle and problem solving elements. See *Pitfall* (Activision, 1982) as an early example.

Chapter 3: Methods

Achievements - Achievements or achievement systems are rewards players receive for completing an in-game task or sequence of task. Generally these tasks are above and beyond the standard game play but not always. Achievements may reward players with access to new game content and in game rewards such as currency, powers, and gear, to name a few. Achievement systems can also allow players to track accomplishments completed above and beyond regular game play accomplishments. An example of an achievement system are badges used to mark player accomplishments.

Player vs. Environment (PvE) & Player vs. Player (PvP - Player versus Player refers to player-characters who engage in battles with other player-characters in multiplayer games. As opposed to player-characters who engage in battles with in-game, computer generated characters.

Appendix B: Initial Game Analysis Questions

Level Select Menu Did players access or explore levels from Level Select Menu other than initial start-up?

Level 1-1 Description of what the game play trends for this level.

Level 1-2 Description of what the game play trends for this level. Does everyone refer to the directionality of the laser? Does anyone talk about the size of the laser (1)? What were the missteps and how can we categorize those missteps?

Level 1-3 Look for degrees of noticing for each player. Do players read the instructions then play? Do players start moving stuff then read the directions? Look for how players completed the level. Is there evidence that the player understood a two-way splitter makes 1 into two 1/2? Or do players think two ships means they need two lasers? Do any players articulate that a two-way splitter makes two 1/2s? What are players paying attention to in this level? Are they noticing anything other than just following the instructions? In the video is there any evidence of how the players are making sense of the 2-way splitter? Does it just make two lasers? does it make 1/2? Does it just point the laser in a desired direction? Does the understanding of the splitter develop and change over time? Can we see the moments when the change occurs?

Level 1-4 Tally the number of students who noticed and/or commented that the level starts with showing where the three-way splitter goes but once they are able to make a move the three-way splitter is removed. Do players go straight for the three-way splitter? Are there any players that demonstrate they don't know that a three-way splitter means 1/3 at the beginning but develop an understanding after a period of gameplay? Mark here if we can tell if the player understands 1/3 or thinks it is directional or just makes 3 lasers. Tally how many students expressed discomfort, indifference, surprise, avoidance, or noticed the red lightening bolts of the over-powered ships (and those who didn't notice). How many players played around and tested the parameters of the game and how many tried to solve it as quickly and efficiently as possible.

Level 2-1 How many players noticed the timer right away? How many didn't notice at all until the researcher pointed it out? How many started experimenting right away because they didn't see the timer? What were first choices (benders or splitters)? is there any evidence as to why they made that choice? Is there any evidence of players who clearly do not know the math are just random trial and error? Is there any evidence of players who may know the math and are trying strategic trial and error? Is there any evidence the players know the math but are struggling with the directionality? Were there any players that experimented anyway after noticing the timer? Can you detect anything about play patterns from this level? did they ignore the timer after noticing it? Were there any players who tried to use all of the lasers (there should be three lasers and only two ships). In other words is there evidence of players counting lasers instead of splitting into 1/3?

Level 3-1 How many students accidentally clicked submit before answering the first question? Of those that did not click submit how many of them read the instructions first?

Level 3-2 How many players just started clicking before reading the directions or trying to figure out the math? After the first attempt how many just started messing around and testing the buttons? How many times were the instructions read? Is there any evidence to show that the players tried to figure out the math before clicking the buttons and were strategically trial and error or was it all random trial and error? How many times did the player start over.

Level 3-3 How many students picked decimals first? how many picked fractions? How many were trying to get exact location and how many did not (how many needed prompts that approximate location was okay)?

Level 3-4 Describe how each player tried to solve this level and see if there is anything interesting about the data. Look for signs of confusion (or not) or dislike (or not) or indifference about level pack 3 and summarize.

Level 4-1 Did any of the players use all three benders to solve this level? In other words did they use the most efficient solution or the one that used the most pieces? Insert description of video of players that intentionally placed pieces based on tutorial and number of players who appeared to be exploring or testing boundaries of what the game can do. Be sure to determine if it is impossible to tell but may need just to describe what happened instead. How many players tried to place three-way splitters? How many chose the two-way splitter? insert description of what happens in the video. How do most kids do this in the video? what are the first and second choices? can we see their reasoning through their choices? Since there are more choices were there more mistakes?

Level 4-2 Insert description of how students are figuring out the correct placement and sequence to get to the correct answer. include anything that may show trial and error. Is there evidence that some players solve through spatial reasoning and other through math? Is there is evidence of when a player realizes that they don’t need to use all the lasers? There appears to be evidence that the players don’t notice they have to use all the lasers.

Level 4-3 Insert description of how many players started with 1/3, ½ or a bender. Describe, if possible, what their thinking was for each of the groups of choices. Describe how many players had issues solving the spatial part of the puzzle without any help, if any. Also describe (and identify how many) players talked about the math to solve it and the number that did not.

Level 4-4 Describe how each player responds to the "too much Power" feedback, if they do. Describe the player first choices and how it relates to this design feature. Were they concerned with the math and did they have to shift focus? Were they concerned with the directionality of the laser (spatial problem solving) and so much with the math? How many solved for math first but had to re-strategize because that didn’t work with the sequence of the puzzle. Address each of the three design features above in detail.

Level 5-1 Describe how many players started with which shape and whether or not any placed two benders then a splitter. Not sure if there is a significance to this level or if this is one of those cumulative moments where the experience of the reconfiguration of the space and the new combinations of variables is just for fun.

Level 5-2 Insert any data on whether or not players noticed this or reacted to too much power feedback again. Does it decrease after initial exposure? Describe players first choices.

Level 6-1 Can we tell from the video data why students were making their choices? Was it math motivated or spatial motivated? Do any players focus on creating a specific number of lasers rather than focusing on the size of the laser?

Level 6-2 Describe video data. Are there any students who were counting lasers in the last level and tried to do it for this level, failed, then readjusted their strategy?

Level 6-3 Describe players first choices. Of all the ones who chose a splitter first, how many completed the puzzle without starting over? In the transcripts of these videos, did any players who selected the bender talk about math and/or direction?

Level 6-4 How many players struggled or did not struggle with figuring out how to create 1/9. May be able to figure out who already knew how to solve for 1/9 based on previous level performance.

Level 7-1 Insert description of the video data explaining how many players knew which splitter to start with, how many of them noticed the different numbers, and how many did not. Is there anything we can tell from the video about how they are thinking about the math versus the directionality or number of lasers?

Level 7-2 Describe players who struggled with the spatial problems and which ones struggled with the math problems. See if there is any way to tell why they struggled with either based on the design of the level.

Level 8-1 How many players noticed the timer? How many players solved the puzzle in the allotted time? How many of those players did not complete the previous embedded assessment and how many did? Of those that were able to solve, how many did so because of math and how many did so because they knew the spatial or right combo of splitters/benders (and is this possible to tell)?

Level 9-1 Did any of the players try to solve for the closest ship first? If so how long did it take for them to figure out it wasn't going to work? Describe anything that points to whether or not players who placed benders first were solving for the spatial problem – and if they were successful versus players who placed the splitter first – and if they were trying to solve for the math. Make note of any players that weren't able to solve the puzzle without help. Did students understand right away what the green arrows did? What were the first bender/splitters placed? How did payers react and make sense of this new configuration?

Level 9-2 Describe how students struggle, if at all. Describe in what ways they are struggling. Look for distributed cognition and how they use the game to help do the thinking for them. If players couldn't anticipate the final outcome based on their first placement, how many steps does it take before they do? How many successfully completed this level without help? With help? Where did players get stuck? Were there any patterns repeated even though they kept leading to the same dead end?

Level 9-3 How many players got to this level? How did they solve it? Did they start with benders and splitters? Did they need hints and help?

Level 9-4 How many players got to this level? How did they solve it? Did they start with benders and splitters? Did they need hints and help?

Appendix C: Complete Code List

	Type	Code	Description	Example	Why it is Important
Single Action Codes (may be coded from a single action or utterance)	First Choice	Correct Funnel	Funnel of the bender or splitter is facing the correct direction to receive the laser.	The first bender/splitter the player selects. The player doesn't have to place it on screen for it to count as the first one. These codes do not apply to levels where player's does not have a choice.	This code helps to determine if the player's incorrect first choice may indicate if they are focused on solving for the spatial or math problem. A correct first choice would indicate they are solving for both.
		Incorrect Funnel	Funnel of the bender or splitter is NOT facing the correct direction and the laser goes into the side of the bender or splitter.		
		Two-Splitter	Player chooses two-splitter		
		Three-Splitter	Player chooses three-splitter		
		Bender	Player chooses bender		
	Instructions & Pop-up Messages	Reads instructions	Reads on screen instructions or pop-up messages to self or out loud	You can tell instructions have been read in their entirety if a player say something like "oh, I see" or "I get it" after reading. There	This code helps to determine if players are incorporatin g this feedback into their play strategy.

				may also be evidence of reading instructions if they change their bender/splitter selection immediately after reading.	
		Doesn't read instructions	Glances, skims or ignores instructions or pop-up messages.	If a player doesn't respond to instructions or doesn't change their course of action after seeing instructions or pop-up message. Player may click through without reading.	
Multiple Action Codes (may be coded from a sub-set or sequence of actions and utterances within a level. Typical brackets of time might be for solving a single ship	Play Strategy	Trial-and-Error	Player appears to be randomly selecting pieces to test outcome. Incorrect placement and incorrect sequence of benders and splitters. An initial action may be random but subsequent actions may develop into a pattern of	A series of actions in succession that indicate the player is testing what results may occur from different choices. Actions may or may not clearly indicate math or spatial motives. May make verbal indications they are	This code identifies sequences of actions that may indicate player struggle with either math, spatial/visual problem solving or both. Used as an indicator to look closer at the sequence of actions and

or when there is a shift in player focus. For example, solving for one ship then trying to solve for laser size.)			discovery over time. Player may make selections based on previously observed information but may not know the outcome. Series of moves where the player learns and modifies actions based on previous move. Not mutually exclusive to spatial struggle or math struggle. Repeats patterns and incorrect actions. Player keeps trying the same action even when it doesn't produce different results.	connecting previously observed information such as "the last one was too much power, lets see what this one does". The player may use part of the game space to try things out before committing to a final configuration. Picks an incorrect funnel bender and repeatedly tries to place it along the same trajectory of a laser. Goes through a series of trying each of the pieces and when none of them work, tries the same pattern again.	utterances.
		Accident/Discover y	Player accidentally discovers a solution or solves a level.	Unintentionall y makes a move that solves for a ship or level. Accidentally moves a piece in the right	This code captures moments of potential player learning that may or may not come

				place. May state "I didn't mean to do that" or "oh!, I didn't know it would do that".	into play in future levels.
	Understanding (Player choices reflect what they are trying to solve for. The final, completing step of a level is not coded. Length of text and actions selected for these codes should include enough context to positively identify the code and not limited to one line or partial excerpts that do not provide enough context.)	Math	Player demonstrates math understanding through their description in the think-aloud and in-game actions. Self-corrects math problem-solving. A series of selections and decisions based on the size of the laser, the size of the ship, and/or the size of the splitter. Player uses math terms to talk about game or in think-aloud.	Player may say statements like “this ship needs ½” or “the laser needs to be smaller”. May include more than one action or utterance to indicate math understanding.	This code is important for identifying player actions and utterances motivated by math thinking.
		Spatial	Player demonstrates spatial understanding based on the correct selection and decisions of	May say "I need this to go here" or, after placing a bender or splitter may say "oh", self correct, and	This code is important for identifying player actions and utterances motivated

			funnel facing and laser output direction. Self-corrects errors regarding direction of funnel and lasers. A series of selections and decisions based on trying to get the laser to go to a certain direction regardless of the size of the laser or the size of the ship.	swap pieces. May use statements such as "I want this to go up there so it can go over here.". May get the laser in the right spot but may not make the correct size laser. May include more than one move or utterance to indicate spatial understanding.	by solving for the spatial/visual aspect of the puzzle.
		Math & Spatial	Series of correct actions and utterances that demonstrate an understanding of math (size of the laser, size of the ship, and/or size of the splitter) and, at the same time, makes correct decisions on the direction of the laser and	Correct placement, correct sequence solves for the ship or the level.	This code is important for recognizing players who solve for both the math and spatial/visual aspect of game play.

			maneuvering around obstacles.		
		Not Clear	It can't be determined by the actions or player utterances whether or not their choices are driven by direction (spatial) or solving for the ship (math).	Student may make utterances that aren't clear whether their actions are motivated by math or figuring out the spatial puzzle. For example, "I want it to go two ways" may indicate counting lasers or directionality.	This code is important to flag moments or sequences where it is not clear to the researcher if the player is motivated by math, spatial or both. This is to help remove the possibility of reading too much into an action or sequence of actions.
		Spatial struggle	Player pauses or appears indecisive when making a decision, is confused or doesn't know what to do. Pauses for longer intervals to make decisions. More than one attempt to get one laser to output in the desired	Player grabs a bender/splitter and hovers over a spot or can't decide where to place it. Can't decide which bender or splitter to choose. Places the wrong funnel direction or can't maneuver around obstacles. Repositioning a splitter or bender.	This code identifies which players are focused on solving for the spatial/visual aspect of the puzzle but struggle with finding the correct placement and sequencing of benders and splitters.

			direction. Places a bender or splitter with the funnel facing the wrong direction or directs the laser into the wrong side of another bender, splitter or ship.		
		Math struggle	Player pauses or appears indecisive when making a decision. Appears to get the directionality of the funnel and the laser but does not use the correct sequence to get the appropriately sized laser.	Player may make statements such as "I need to make this 1 into 1/3 [grabs three-way splitter}." or "I need to make this one smaller so I need to split it" May not choose the correct facing funnel or direction of splitters or benders. May make selections that do not support math understanding even though they are using math talk. Like noticing the size of the ship, size of the laser but	This code captures moments where players may or may not know there is math solution but can't figure out how to do so.

				not choosing the correct splitter. Can't figure out the right combination of splitters and benders to generate the correct size laser. This includes confusion or indecision about which splitter type to use in order to produce the correct sized laser for a ship.	
		Color	Player uses the color of the laser as a way of making sense of the space. Player uses the color of the splitters to make sense of the game.	Players may make statements such as "This laser is red and I think I want a blue one", "I need to mix an orange one and a red one"	This code identifies players who might pay attention to non-essential details of the game in and effort to try to make sense of the game space. This will also help in explaining if this strategy helps or hinders players' in game success.
		Power	Player notices	Players may make	This code identifies

			lightening bolts animation is a cue to the player to make a change or player notices the size of the laser states the ship is getting too much/too little power.	statements such as “that’s too much” or “that’s too little”. Player’s may also see animation and immediately remove the bender or splitter.	moments where players notice in-game feedback that helps indicate the size of the laser (math) and marks a moment to look at how players interpret this feedback.
Cumulative Action Codes (Summary of actions in an entire level)	Interviewer Intervention	Intervention	Interviewer asks a sequence of guided questions to help player think through a particular parts of a level or the entire level itself. Student asks for help or hint. Must be more than one statement or question from the interviewer. Note when the interviewer makes an intervention for each issue or each	A series of questions tailored for the player to help them notice key information they have overlooked. Questions such as “so how many ships are there and what size lasers do they need?”, “What happens if you try a different strategy?” and “try going back to the way you had it before”.	This code indicates moments where players couldn’t overcome math and/or spatial struggle and indicate an opportunity to investigate further what specifically prevented them from progressing on their own.

			scaffold.		
		One Intervention	Interviewer asks a limited number of guided questions to help player through a small portion or one aspect of a level. Student asks for help or hint that can be addressed with a limited number of guided questions or player only needs help ONCE in the level.	Interviewer asks one to a few questions on one topic (instead of a series of steps) to address a single specific issues. For example, “did you see that pop-up message? it said….” or “what happens if you move that one over just a little bit?”	This code identifies moments where a player may have normally completed a level without intervention but ran into a particular issue.
Level Specific Codes (These codes are specific to a level or level pack)	Level 3-1 through 3-4 Assessment	Correct answer	Answers level correctly		These codes track students math ability.
		Incorrect answer	Answers level incorrectly		
		Partial Correct	Answers part of the assessment level correctly		

Appendix D: Think-aloud protocol

The think-aloud protocol was developed and refined by our collaborating research teams led by Drs. Rachel S. Phillips, University of Washington and Carmen Petrick, University of Austin, Texas.

Student Think Aloud Protocol

I'm a member of the group that helped make Refraction, and I'm from the University of Washington. Before the student starts to play, tell him/her that you are studying how the game makes people think and feel in order to make the game better.

Ask them to "talk aloud" or "think aloud" as much as possible while they are playing. Use graduated prompting (i.e., use I prompts first, then II, then III).

I) If a student stops talking, remind them or prompt them to think out loud. You can ask questions such as:

1. What are you thinking right now?
2. Why did you make that choice/move?
3. Are you using a particular strategy when you play?
4. What kinds of things are you noticing about the game?

II) If a kid gets stuck:

1. 1. What are you trying to do right now?
2. 2. What is the problem that you're having?
3. 3. Does this make you feel frustrated? How come?

III) If a kid is really stuck, start giving some refraction specific teaching prompts:

1. 1. When you see that the ship is overpowered, what do you think and decide to do?
2. 2. If a student directs and inappropriate amount of power into a ship, ask them about the feedback. For example,

3. 3. Why did you use the magnifying glass?

4. 4. Would it be possible for you to move a bunch of pieces together?

5. 5. Do you think you have to start with a ½ and 1/3 splitter?

6. 6. Try putting it there and see what happens (over having them hover).

7. 7. What are ways that you could get to (insert fraction here)?