SimTIE-Math: A Simulation-Game on Technology Integration for Mathematics Learning

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Abstract

This article describes the application of instructional design theories and game design principles in the creation of a paper prototype for a simulation game on technology integration in education (SimTIE-Math). The study employs a design and development research design in which artifacts that resulted from that design process are examined, including design documents, iterations of game components and rules, e-mail exchanged by the designers, notes from meetings, reports from playtesting sessions, and other related documents. The purpose of the study is to formulate principles for the use of instructional design theory in game design. By exposing and examining the design process, we intend to contribute to design knowledge in instructional systems design.

This article describes the application of instructional design theories and game design principles in the design and development of a paper prototype for a simulation game on technology integration in education (SimTIE-Math). We begin with a brief explanation of design and development research, the approach used in this study. Next we describe the purpose of this study and the methodology. We then describe the iterative design process of paper prototyping and playtesting and how the findings influenced revisions of the game components and rules. Finally, we reflect on lessons learned from the experience and formulate design principles for the use of instructional design theory in game design.

Design and Development Research

Richey and Klein (2007) define design and development research as “the systematic study of design, development and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and non-instructional products and tools and new or enhanced models that govern their development” (p. 1). This approach has a pragmatic orientation in that it seeks to improve practice through evidence-based claims about the design and development of instructional products. The study of the design process and its artifacts can elucidate the ways in which designers apply theories, principles, and methods to attain satisfactory results in naturalistic settings. This design knowledge may be characterized by “common examples, patterns, and principles, and by the expertise required to apply these generalities in specific settings” (Design-Based Research Collective, 2003, p. 9). At the same time, it can also contribute to theories of teaching and learning, although generalizability can be problematic because context is often a significant factor in the enactment of an intervention (Hoadley, 2004).

Purpose of the Study

One of the major challenges to teacher education is to provide pre-service teachers with enough practice in teaching before they graduate. It is costly to place them in real classrooms, and if they make mistakes there are real consequences to the students they teach during practica and student teaching. Simulations are routinely used in a variety of professions (e.g. business, healthcare, engineering, military, law enforcement and fire fighting, etc.) to prepare people for real-life situations that they are likely to encounter. SimTIE is intended to provide pre-service teachers with opportunities to make planning decisions for selecting student learning activities, and then to experience the consequences of those choices. To succeed in the simulation, teachers will need to give up the notion of "sage on the stage" and adopt a "guide on the side" perspective. Moreover, teacher or student choice of learning activities that integrate information technology will be necessary in order to provide individualized learning experiences for simulated students to work at their own pace on activities suited to their skills and knowledge.

The purpose of this study is to examine the design process and decisions made during the development of a paper prototype for a simulation game on technology integration in education. In particular, the focus is on the ways in which instructional design theory informed the decisions regarding simulation, game, and pedagogical elements (Aldrich, 2005). We have sought to answer the following design and development research questions. First, how can instructional design theories be applied in the game design process? Second, what design principles may be formulated from a retrospective analysis of the design and development process and artifacts?

Methods

Participants

The design and development of the paper prototype was undertaken in an advanced design class within the context of an Instructional Systems Technology (IST) graduate program at a large midwestern university. The class consisted of five residential students and one distance student. Four of the students were nearing completion of their Master's degrees, while the other two (including the first author) were beginning their doctoral studies. The second author was the instructor of the class and also played the role of the client who was contracting the team to design the instructional product.

The second author had previously led a team of students in adapting a board game, the Diffusion Simulation Game (DSG), for online use (Frick, Kim, Ludwig, & Huang, 2003). A few of the students in the current study had some limited experience in designing board games, card games, puzzles, and digital games. To prepare for the project, the students created and tested some simple games from Thiagarajan's (2003) book on game design. Thiagarajan also came to speak with the class about game design.

Procedure

Klabbers (2006) has argued that the analytical sciences employ a variable approach (based on variables and the correlations among them) as a mode of explanation while the design sciences should employ a process approach (based on events and the processes that connect them, cf. Maxwell, 2004) because causality is purposefully designed into the utilization of artifacts with the ultimate goal of changing existing situations into preferred ones (cf. Simon, 1969).

> Evaluating games (and simulations) from the viewpoint of an analytical scientist is distinct from assessing games (artifacts) from the position of a design scientist. Design scientists (game designers) build their artifacts to function in well-defined contexts of use for intended audiences. The artifact should be assessed from that viewpoint, in principle taking on board the option of "causality from single cases." Key questions in the design sciences are, Does it work? Is it usable in this context for this audience? (Klabbers, 2006, pp. 167-168)

The design process for SimTIE-Math utilized rapid prototyping (Tripp & Bichelmeyer, 1990) to create and evaluate prototypes in an iterative and systematic manner. This study employs an examination of artifacts that resulted from that design process, including design documents, iterations of game components and rules, e-mail exchanged by the designers, notes from meetings, reports from playtesting sessions, and other related documents. During the design process, these artifacts were posted to a learning management system (LMS) that was accessible to all designers. All e-mail was exchanged through this system as well. Furthermore, the first author, who served as lead designer during the development of the paper prototypes, saved intermediate iterations of game components and rules that had not been posted to the LMS. The authors, who have continued to refine the game while seeking funding for development of a digital version, retrospectively analyzed these artifacts to create a chronology of the origins and evolution of the game to its present state. As designers, we tried to determine if the game met the stated goals; as researchers, we are interested in *how* and *why* the game did or did not meet those goals. By exposing and examining the design process, we intend to contribute to precedent in instructional systems design (Boling & Smith, 2008).

Description of the Project

A review of the literature related to the use of games and simulations for learning indicated that while there is an increasing amount of research in this area, much of it has been anecdotal rather than empirical (Dempsey, Rasmussen, & Lucassen, 1996; Hays, 2006; Randel, Morris, Wetzel, & Whitehill, 1992; Van Sickle, 1986). Furthermore, little research has been done regarding the application of instructional design theories to the development of games and simulations for learning (Aldrich, 2003; Van Eck, 2007). In this project, instructional design theories are explicitly used to increase the probability that the game will promote the desired learning outcomes.

The decision to design a game as opposed to some other medium of instruction was driven in part by the desire to increase motivation (Garris, Ahlers, & Driskell, 2002; Malone, 1981), engagement (Dickey, 2005; Egenfeldt-Nielsen, 2005) and academic learning time (ALT; cf. Berliner, 1990; Brown & Saks, 1986; Kuh, Kinzie, Buckley, Bridges, & Hayek, 2007; Rangel & Berliner, 2007) by providing an authentic learning experience (Cannon-Bowers & Bowers, 2008; Galarneau, 2005; Magnussen, 2005; Ruben, 1999). We know from research on ALT that successful student engagement in tasks that are similar to those they are later expected to perform is positively correlated with objective tests of such performance. In addition, the design of the game system and game components was informed by the elaboration theory (Reigeluth, 1999), first principles of instruction (Merrill, 2002; Merrill, Barclay, & van Schaak, 2008), theories of intelligence and learning styles, cognitive load theory (Sweller, 1988; 2008; Sweller, van Merrienboer, & Paas, 1998), and research on differentiated instruction (Hall, Strangman, & Meyer, 2003; Tomlinson, 1999).

Initial Conception of the Simulation Game

The second author's idea for the project was to create a simulation game that would enable pre-service teachers to practice integrating technology into their teaching and to experience the consequences of their decisions. The project developed such that each player would manage a simulated classroom in which she or he must facilitate individual student engagement and learning achievement by identifying activities and resources most appropriate for each student. The player would succeed by most efficiently guiding the simulated students' mastery of curriculum standards during a fixed period of time. The underlying game logic would reward the selection of activities that complemented students' learning needs, styles, and preferences while utilizing appropriate technologies.

The broad goals of the project are to provide a means for radically improving pre-service teachers' ability to individualize instruction through the use of appropriate technology and to advance research on effective and efficient development of instructional games and simulations. While the players' objectives changed as the designers refined the game, the initial learning goals as defined by the second author persisted:

1. Given an existing education system, players will make changes in that system over time that lead to effective technology integration in that particular system.
2. Through repeated engagement with the game, players will begin to understand systems concepts and apply systems thinking to the problem of technology integration into education.

Description of Design Process

The designers initially met with the second author for several hours over two days to clarify needs and define deliverables and a timeline. They chose to follow an iterative process that is commonly used in game design as well as in design-based research which consists of cycles alternating between rapid prototyping, playtesting, evaluation, and revision (Brathwaite & Schreiber, 2009; Design-Based Research Collective, 2003; Reeves, 2000; Salen & Zimmerman, 2004). An iterative process is useful not only for improving the emerging intervention but also for identifying reusable design principles (Reeves, 2006) and creating models to inform design practice (Ma, Williams, Prejean, & Richard, 2007). The designers decided to produce at least two paper prototypes, playtest each prototype, and use the formative evaluation results to modify the subsequent prototype. The final playtest would also include an assessment of the players' learning.

Given the paucity of empirically-tested design theories for instructional games, the designers decided to take an eclectic approach in which theories of learning and instructional design would be selected initially to guide design decisions and subsequently whenever they seemed applicable to ensure that the game promoted learning.

An initial brainstorming session resulted in a general structure for the game system and a list of design constraints to help focus the design problem. The designers originally envisioned a hub-and-spoke model with the main game as the hub with optional side games designed to teach and reinforce relevant concepts and processes (i.e., supportive instruction to help the players do better in the main game). However, they soon switched to a model based on the elaboration theory (Reigeluth, 1999). Using this approach, the game would begin with a level that offered the simplest version of the whole task (the epitome); subsequent levels would become increasingly more complex—an approach common to videogames—with opportunities for review and synthesis. The list of constraints identified by the designers included:

- Limit the beginning cast to one teacher and 3-5 students;
- Identify core areas in which students must achieve proficiency;
- Identify elective areas in which different students must reach varying levels of achievement, depending on the particular student's attributes and goals;
- Determine relevant student attributes (which may include intelligences, learning preferences, attitudes, behaviors, personal goals, etc.);
- Provide many student models so that there is some variety in the challenges the player must meet;

- Identify technologies (hard and soft combined) and resources available to the player;
- Require that the player use appropriate technologies to affect student engagement (academic learning time) and student achievement;
- Ensure that the player has a generous amount of resources in order to simplify learning and encourage success in this initial epitome game.

A couple of key ideas emerged during the initial brainstorming session that persisted throughout the development of the game. The first suggestion was to limit the context of the game to a particular grade level. Even though this approach might reduce the relevance as perceived by the target audience, the designers envisioned the computer version of the game as a shell capable of accommodating content for different grade levels. The second suggestion—which foreshadowed a vexing design problem that persists to this day—was to incorporate lesson plans in the game. Initially this was considered too complicated, but the designers later reformulated the idea in more abstract terms, not as specific, detailed lesson plans but as a more general game mechanic for framing the use of instructional objectives, activities, and resources. With the goals and constraints defined, the designers decided to work individually on concepts for the game and then meet several days later to compare ideas and achieve consensus on next steps.

Initial Iterations

Two designers returned with descriptions of possible games, and the other designers contributed ideas for game rules, components, and mechanics. Topics of discussion included whether the players would act individually or in teams and whether they would compete or cooperate with each other. One designer suggested that players take turns acting as teacher and students. However, others felt it would be better for all players to stay in the role of teacher. While discussions about the structure and mechanics of the game continued, there was general agreement on the need for some sort of student model, a curriculum model, an instructional activity model, a method for evaluating the success of an activity with one or more students, and a method for tracking student achievement.

The original conception of the student model was to incorporate Gardner's multiple intelligences (1999) with student attributes like socio-economic background, strengths, interests, preferences, anxieties, experiences, and goals. However, the designers also explored Myers-Briggs type indicators (Pearman, Lombardo, & Eichinger, 2005), Keirsey temperaments (Keirsey & Bates, 1984), Hermann brain dominance instruments (Hermann, 1990), and the Felder-Silverman learning styles model (Felder & Silverman, 1988) before finally settling on Kolb's learning style inventory (Kolb, 1984), primarily for the practical reason that it is simple enough to model in a board game.

An early version of the *student information card* that the players would receive is shown in Figure 1 on the left along with the version that was used during expert review and playtesting on the right. These cards reflect the decision to narrow the focus from general skills to specific mathematics standards, which were color-coded on the *assessment log* (described below). Information on interests/hobbies and friends was not used in the paper prototype but was included because the designers thought it might be used in the digital version of the game.

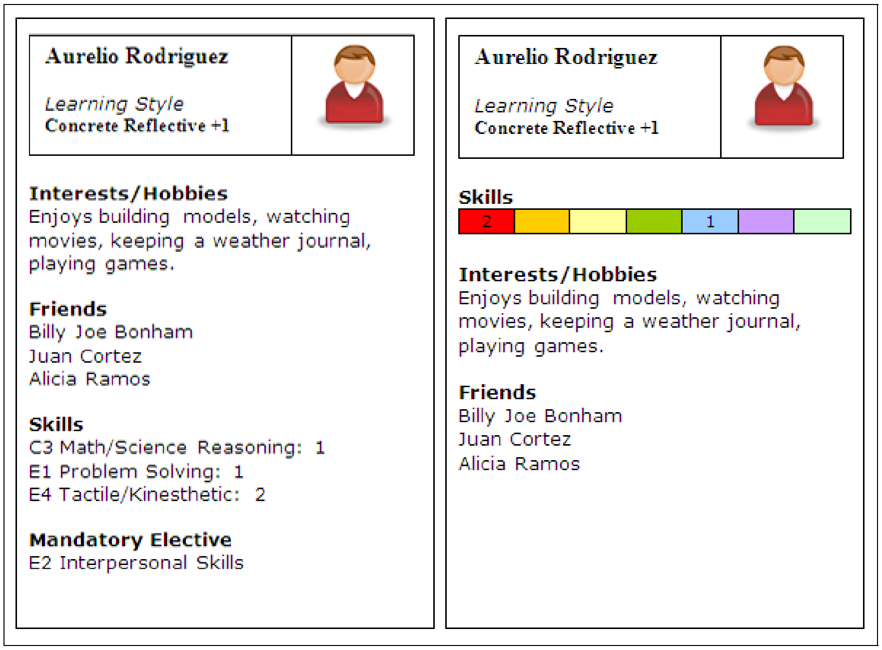

Figure 1. Two versions of the student information card.

The first author mapped Keirsey's temperaments and Myers-Briggs' types to Kolb's learning styles and then compiled lists of the kinds of activities that would appeal to each learning style. This map guided designers in evaluating the effectiveness of an activity for each learning style and assigning bonus points.

The initial curriculum model consisted of core competencies (reading comprehension, writing skills, math/science reasoning) and elective competencies (problem solving, interpersonal skills, technology skills, tactile/kinesthetic skills, naturalist skills, leadership skills) that are applicable across grade levels and subject areas. Players would be required to foster learning in the core competencies for all students, while the elective competencies would vary by student. After some debate, the designers decided to focus the prototype on mathematics at the fourth- to sixth-grade level. One reason for this decision was that there are well-defined state standards, adherence to which would be a criterion for evaluating the appropriateness of an activity. This would reinforce the real-world expectation that teachers help students to meet those standards. Another reason was the practical matter of eventually seeking funding to develop a computer version of the game. The designers thought that focusing on a high-priority subject area like mathematics would increase the chances of obtaining a grant.

Because the primary game mechanic was the selection of appropriate activities for students, the instructional activity model became a crucial element of the game's design. There was agreement on the need to provide a variety of activities, including poorly designed activities that would result in little or no learning for the simulated students. However, this meant that the players would have a large number of activities to search through. The designers struggled to define the salient attributes of an activity and express them succinctly to reduce cognitive load while maintaining fidelity to the real-world task being modeled.

The concept of fidelity in games/simulations seems to be a point of contention among instructional designers, and it was at the center of many discussions regarding SimTIE-Math. Fidelity is the degree to which a simulation is faithful to that which it simulates. Reigeluth and Schwartz (1989) theorized that the most fundamental aspects of a simulation should have high fidelity, while lower fidelity is appropriate for the more superficial aspects that may otherwise lead to cognitive overload and impede learning and transfer. They suggested that factors to consider include the complexity of the real world environment, the potential for transfer, the motivational consequence of high fidelity, and the expense of achieving high fidelity. More recently, Feinstein and Cannon (2002) examined numerous studies from the 1960s and 1970s that focused on the effects of fidelity on training and education. They report that greater fidelity did not result in greater learning and may in fact reduce effectiveness through unnecessary complexity and overstimulation. Similarly, Winn (2002) notes that a virtual environment does not need to simulate the real world to be useful for instruction, and that high fidelity may lead to constrained and inflexible understanding and make it difficult to transfer knowledge and skills to new contexts. Ultimately the designers working on SimTIE-Math decided that the learning objectives of the game determine the primary game mechanics, so those primary game mechanics should have the highest fidelity to real-world situations.

The earliest version of the *learning activity card* was an 8 ½ x 11 page that included information on the activity's type (e.g., group discussion, project), a brief description of the activity, the general skills addressed, the resources required (e.g., a computer for each pair of students, a calculator for each student, art supplies; the amount of teacher involvement was also specified), and an assessment matrix that indicated which learning styles would benefit from the activity. The designers found it difficult to search though the pages and decided to redesign to fit the information on a 4 x 6 index card. An example of the card used during expert review and initial playtesting is shown in Figure 2. This version addresses mathematics standards with colors corresponding to those on the assessment log (described below). During gameplay, the success of an activity was determined by rolling a special die that would result in 0, 1, or 2 points being awarded. Additional points were awarded as specified on the activity card if technology was being used effectively and if the activity corresponded to the student's learning style.

TIE Learning Activity low low low

Type: Problem Solving (Individual)—Shopping Spree

Resources:
- Teacher – partial involvement
- 1 Computer for every student
- Internet Access

Description:
Teacher tells students that they each have $100 to buy toys. Students' goal is to spend as much money as possible without going over $100. Teacher gives students URLs for online toy stores. Students may record purchases on paper or on a computer file, but they must record their purchases and present them to teacher.

Assessment Bonus: *Tech +1*
Abstract Active +1, Abstract Reflective +2

Figure 2. Learning activity card.

The designers created 76 activity cards based on lesson plans and activities found by searching the Web, most of which indicated which mathematics standards were addressed. The designers used the learning styles map described above to decide which learners would benefit most from each activity and assigned bonus points accordingly. A revised version of the learning styles map, which functioned here as a design tool, was provided to the players in the second playtesting session as a scaffold for selecting appropriate activities for students.

Scorekeeping in the game was done on an assessment log. Each time a student participated in an activity and was awarded points in specific competencies, the player updated the student's log to indicate the student's progress toward mastery. An early version of the assessment log, shown at the top of Figure 3, was based on the original approach of using core and elective competencies. If a student failed to make adequate progress by the end of the round (achieving from 1 to 7 points), he would become a dropout and be removed from the game with no points awarded to the player. If a student ended the round in the "Don't Graduate" section (achieving from 8 to 11 points), she would remain in the game for the next round; the player would acquire a new set of students in addition to any students who did not graduate, increasing the difficulty due to the greater number of students. If a student achieved from 12 to 14 points, he would graduate and be removed from the game, and the player would score 1 point in the "Score" column. If a student achieved 15 points, he would graduate and be removed from the game, and the player would score 2 points.

Student Name:																
Core	Dropout							Don't Graduate				+1			+2	Score
C1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
C2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
C3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Electives (Must score +1 in *two* or don't graduate)									+1						+2	Score
E1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
															Total Score	

Student Name:														Learning Style:											
Round			Standard	Low Mastery									Partial Mastery								Near Mastery				Player Score
1	2	3	Number Sense	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
	2	3	Computation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
	2	3	Algebra & Functions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
		3	Geometry	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
		3	Measurement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
		3	Problem Solving	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
		3	Data Analysis & Probability													13	14	15	16	17	18	19	20	21	
																								Total Score	

Figure 3. Two versions of the assessment log.

The version of the assessment log used during expert review and the first playtest is shown at the bottom of Figure 3. The shift from general competencies to mathematics standards is evident, with the addition of color coding that is also used on the student information cards (to indicate a student's beginning achievement level in each standard) and on the activity cards (to indicate which standards are addressed by the activity). Three rounds are indicated with difficulty increasing through the addition of standards in each round. That is, in the first round (the epitome, in terms of the elaboration theory) only Number Sense is addressed, while in the second round Computation and Algebra & Functions are added; in the third round all standards must be met. At the end of the third round, the player would tally points for each student/standard, with no points for Low Mastery, 1 point for Partial Mastery, 2 points for Near Mastery, and 3 points for Mastery. Therefore if a student achieved Mastery in all 7 standards, the player would receive a total of 21 points for that student.

Student achievement progression changed to mastery levels so that the student was required to achieve mastery (21 points) in each standard. However, there was some debate among the designers regarding the handling of students from round to round. One option was to have the player retain the same students for each round, so that the only change was the addition of standards. Another option was similar to the first, but the player also received some additional students to increase difficulty. A third option was to tally the player's points for each student at the end of a round, and then begin the next round with a new and larger set of students. This decision remained unresolved, in part because neither playtesting session went beyond the first round.

A week before the first scheduled playtesting session, a full paper prototype was produced. One designer used poster boards to create individual "classrooms" for each player as well as a shared "computer lab." The first author printed student information cards on 3 x 5 index cards, activity cards on 4 x 6 index cards, multiple resource cards on 8 ½ x 11 paper that was then hand-cut, learning styles maps, and job aids that described the sequence of events in a turn. Small wooden cubes were used to create custom dice, and play money was borrowed from a Monopoly game.

Expert Review

Once a playable paper prototype was assembled, the designers wanted some reassurance that the game would serve the needs of instructors in teacher education. Two faculty members who teach education technology classes for pre-service teachers agreed to conduct an expert review (Richey & Klein, 2007) which consisted of a structured walkthrough of two turns with feedback and discussion of strengths, weaknesses, and design alternatives. Each reviewer was paired with a member of the design team and together they examined their students' attributes, selected instructional activities, and scored the results. Other members of the design team observed and made notes. The reviewers, who were experienced school teachers before becoming professors, were impressed by the decision making required of the players and the fidelity to real-world teaching with technology. In addition to numerous minor suggestions regarding the design of game components, key suggestions for revisions included:

- Emphasize the assessment of technology integration in the selected activities to diminish the "pervasive attitude of not needing technology" to teach.
- In addition to numeric feedback indicating the success of a selected activity, provide narrative feedback describing the outcome to increase engagement.

- Include an assessment matrix for each activity to increase variability of outcomes, including the potential for technical problems and reward for anticipating such problems and arranging a contingency plan.

Because the first playtest with representatives of the target audience was scheduled for five days later, the designers decided not to attempt any major changes in the interim. The first author agreed to create a prototype of an activity card with an assessment matrix and narrative feedback that might be shown to playtesters at the end of the session.

Playtesting

Playtesting is a methodology commonly used throughout the game design process to systematically test "gameplay, systems, balance, and interface to find all the errors, inconsistencies, or issues and report them to the design team" (Brathwaite & Schreiber, 2009, p. 12). A playtest may be a full or partial play session and, depending on the development stage and the objectives of the playtest, may include the designers, their friends and family, experienced gamers, or "tissue testers," people who have never seen the game and are only used once (Schell, 2008). Playtesting is similar to usability testing, although Schell (2008) considers the former to encompass the overall experience of the game and the latter to focus on whether the interface and systems are easy to understand and use. The playtesting protocol for this project consisted of observation of the players combined with prompts to think aloud (Preece et al., 1994) during gameplay. Playtesting sessions ended with informal questioning of the players and the solicitation of freeform comments. Further details regarding each playtesting session are provided below.

Playtesting session 1. To prepare for the first playtesting session, the designers used several approaches to recruit participants. One of the faculty who participated in the expert review session was teaching an undergraduate teacher education class, and she offered her students extra credit for participating in the playtesting. In addition, one designer contacted several faculty who were teaching sections of an undergraduate class on technology integration and asked them to encourage their students to participate. Nevertheless, only three playtesters were recruited: two male pre-service teachers in social studies (one freshman, one sophomore) and a female graduate student in math education.

The primary goals of the first playtesting session were:

- to test the game mechanics for usability, cohesion, and "luck/skill balance" (Brathwaite & Schreiber, 2009, p. 112);
- to test the scoring for usability and timing;
- to get a sense from the playtesters as to whether they found the game engaging.

At this point the designers had a sense of how the game should be played and had even drafted a set of operational rules (Salen & Zimmerman, 2004); however, rather than spend time assessing the effectiveness of the written rules (which would surely change through iterations of the game), they decided it would be best to explain the game and basic rules and then let the players begin playing.

The first playtesting session was scheduled for one hour on a Tuesday evening near the end of the semester and was held in a classroom in the School of Education. One designer served as facilitator of the playtesting session while three other designers observed, took notes, asked questions, and occasionally prompted the playtesters to think aloud while playing. The sophomore and the graduate student played as a team (Team 1) against the freshman (Team 2). The facilitator explained the goal of the game and the basic game mechanics and components. The game began at 6:32 p.m. and ended at 7:34 p.m.

Each team took seven turns, but the seventh turn was perfunctory as each team had two students at mastery level with the third student one or two points away from mastery level. Excluding the seventh turn, the average duration for a turn was 4:45 minutes, with the first turn being 10 minutes. Team 1 earned a total of $580 from the Resource die and spent a total of $290 on four resources. Team 2 earned a total of $500 and spent a total of $220. Both teams bought Calculators and Art Supplies. Team 1 used the Computer Lab 5 times with 8 students. Team 2 used the Computer Lab 2 times with 5 students.

Results of playtesting session 1. One playtester said that the overview of the game scared him because it seemed like there was a lot involved. However, after a couple of turns he realized that it wasn't that difficult. He suggested (and the others agreed) that the game should start with a very short round (maybe three turns with Number Sense as the only standard) to introduce the game, then move on to a second round with multiple standards. The players on Team 1 thought that having two people on a team was helpful, and the player on Team 2 agreed that having a partner would have been useful, in particular to avoid making mistakes when matching students with activities. Both teams felt that it was too easy to get money and suggested raising prices for resources or somehow making resources more difficult to obtain. Both teams noted that they were never too concerned about having access to the Computer Lab, but they saw how it would be more of a concern with three or four teams playing.

There was a significant amount of discussion regarding scoring and scorekeeping. One playtester suggested that when a student moves to the next mastery level, he should stop at the beginning of the level. For example, if a student is near the end of Low Mastery and receives three points for a Low Mastery activity, he shouldn't receive any Partial Mastery points. This recommendation is consistent with the idea that students don't receive points for participating in activities that are outside their current mastery level. Another playtester suggested making the Near Mastery level longer. Her team had enough success on an activity near the end that a learner went from Partial Mastery to full Mastery. Both teams thought that playing a digital version of the game would be more enjoyable because they wouldn't have to spend so much time on scorekeeping.

In general, the playtesters characterized the prototype as a matching game. The activity cards showed the bonuses for particular learning styles and the student information cards showed the students' learning styles, so they simply had to pair them while paying attention to the standards and mastery levels addressed by the activities and the resources required. In other words, players were not required to think about the nature of the activities. One playtester clearly realized this after a few turns and developed the strategy of first searching for activities that matched one or more of his students' learning styles, and then choosing from that subset an activity that also specified a technology bonus. When shown the next proposed iteration of the activity card, which would hide the activity's association with learning styles and the technology bonus until the scoring phase of the turn, the playtesters thought that the change would increase difficulty but also make the game more realistic (i.e., enhance fidelity of the primary mechanic).

Playtesting session 2. To prepare for the second playtesting session, the designers revised several of the game components and developed an assessment of learning to be administered to the playtesters before and after the session. The activity card (see example in Figure 2) now had the results on the back, with a greater variety of results that nonetheless were more likely to reward the selection of an appropriate activity for a given learning style (see Figure 4).

TIE Learning Activity | low | low | | | | low | |

Type: Problem Solving, Practical Application—Shopping Spree

Resources:
- Teacher Involvement: Partial
- Computer for every student
- Internet Access

Description:
Teacher tells students that they each have $100 to buy toys. Students' goal is to spend as much money as possible without going over $100. Teacher gives students URLs for online toy stores. Students may record purchases on paper or on a computer file, but they must record their purchases and present them to teacher.

TIE Learning Activity Results | low | low | | | | low | |

Die Roll	Feedback	Activity Points	Tech Bonus	Total Points			
				Con Act	Con Ref	Abs Act	Abs Ref
1	Computer problems prevented students from finishing.	0	0	0	0	0	0
2	The activity went as planned.	1	1	3	2	3	3
3	Students had difficulties and needed assistance. Con Act and Abs Act get frustrated and receives no bonus.	1	0	1	1	1	2
4	The activity went as planned.	1	1	3	2	3	3
5	Students had difficulties and needed assistance. Con Act and Abs Act get frustrated and receives no bonus.	1	0	1	1	1	2
6	Some students were motivated to go beyond the parameters of the assignment to explore alternatives.	1	2	3	2	3	4

Figure 4. Revised activity card (front and back).

Furthermore, there was now narrative feedback for each result and a single number for each combination of result and learning style, eliminating the calculations required in the previous version and simplifying scorekeeping. Players would be told not to look at the backs of the cards until they had paired students with activities and rolled the die for results. Overall, the designers thought that these changes would reward players who learned to associate certain types of activities with learning styles and who learned to recognize appropriate use of technology resources.

A revised version of the learning styles map, which initially functioned as a design tool for evaluating the appropriateness of an activity for each learning style, was used in the second playtesting session as a scaffold (Wood, Bruner, & Ross, 1976; cf. Vygotsky, 1978) to assist players in identifying potentially successful activities for their students' learning styles (Figure 5).

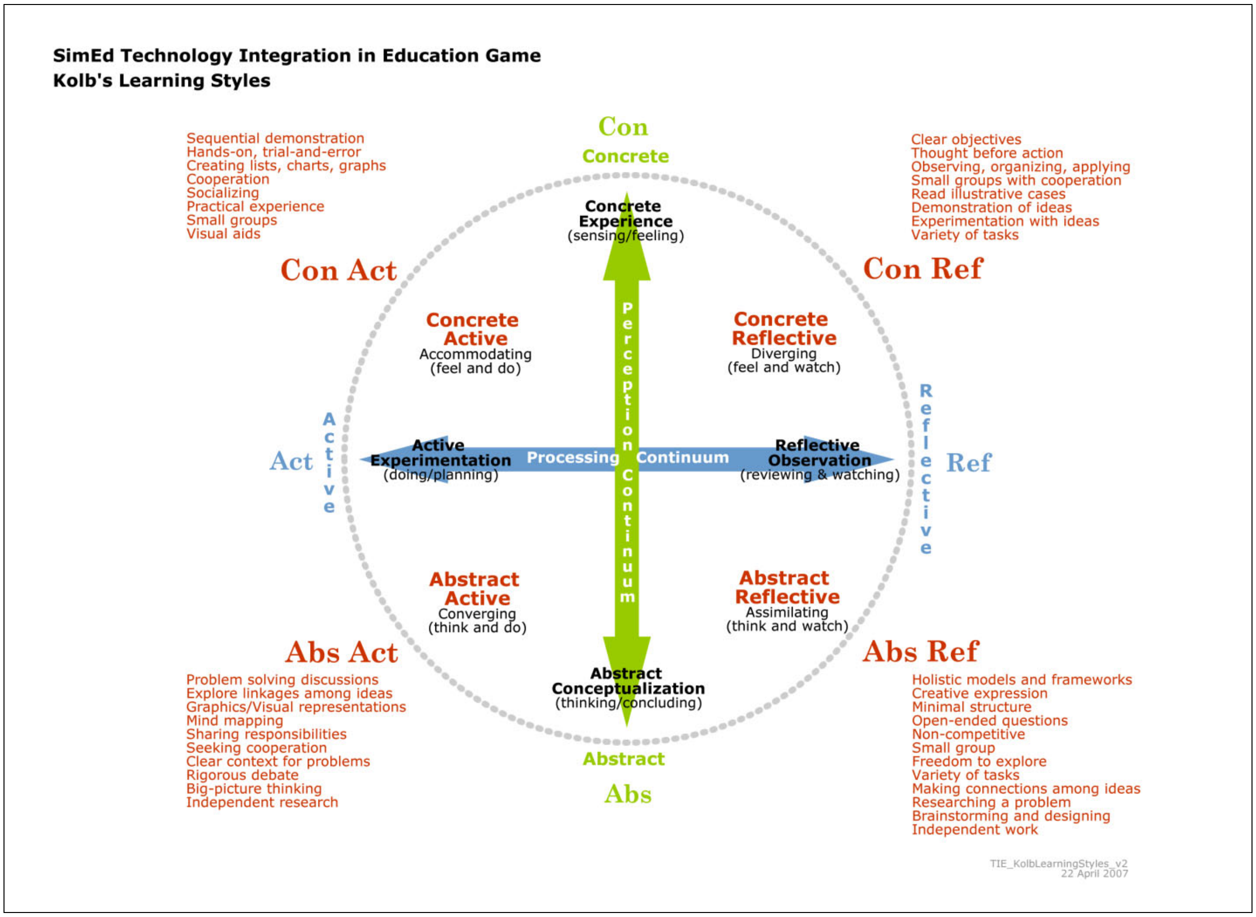

Figure 5. Learning styles map.

The descriptions of experiences amenable to each learning style suggested—but did not specifically duplicate the text of—particular types of activities. The designers thought that this approach would replace the simple matching that occurred in the first prototype with more deliberate analysis of activities, which would be more likely to transfer to real-world practice. Some minor changes were made to the assessment log (Figure 6) based on the results of the first playtesting session. The Near Mastery section was extended and the Mastery section was clearly labeled and assigned a score of +3. An extra round was added so that a practice round of a few turns with one standard (Number Sense) and three students would serve as a tutorial at the beginning of the playtesting session.

Student Name:														Learning Style:				Concrete Active					Concrete Reflective			Abstract Active			Abstract Reflective	
Round				Standard	Low Mastery +0									Partial Mastery +1									Near Mastery +2						Mastery +3	Player Score
1	2	3	4	Number Sense	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
	2	3	4	Computation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
	2	3	4	Algebra & Functions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
		3	4	Geometry	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
		3	4	Measurement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
			4	Problem Solving	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
			4	Data Analysis & Probability													13	14	15	16	17	18	19	20	21	22	23	24	25	
																													Total Score	

Figure 6. Revised assessment log.

For the second playtesting session, the designers hoped to recruit eight playtesters to form four teams. One designer made flyers which were posted around the School of Education. Flyers were also distributed to faculty who taught technology integration classes for undergraduates and to the Dean's advisory council, a group of student leaders in the School of Education. In addition to specifying details about the playtesting session, the flyers promised pizza, cookies, and beverages for participants. A few days before the scheduled playtesting session, two designers spent a couple of hours in the School of Education's atrium distributing information about the session to potential participants.

The second playtesting session was scheduled for two hours on a Wednesday evening two weeks after the first session and was held in a classroom in the School of Education. Six undergraduate students participated: three females (two of whom were sports marketing majors while the third was a pre-service teacher) and three males (all of whom were pre-service teachers).

The primary goals of the second playtesting session were to test the revised game components and rules, and to see if playtesters learned about learning styles and differentiated instruction through the appropriate integration of technology. Several designers collaborated on the development of an instrument to assess the players' knowledge of technology integration gained from playing the game. They intended to use this playtesting session as a pilot test of the instrument, which would then be refined for use with subsequent prototypes. Space precludes a detailed description of the instrument and analysis of the results.

The playtesting session began with brief introductions of the participants, who were encouraged to help themselves to the food and drinks that were provided. The facilitator for this session was the same designer who facilitated the first session. The administration of the pre-test took approximately five minutes. The playtesters formed three teams with the help of the facilitator, who then spent approximately 30 minutes guiding the playtesters through a couple of practice turns and answering their questions. The playtesters then played the game for 45 minutes, completed the post-test, and spent approximately 25 minutes discussing the game.

Results of playtesting session 2. In general the playtesters found the game to be enjoyable and challenging. As might be expected (and desired), the pre-service teachers obtained better results in the game than students who were not studying to be teachers. The revisions to the game components and rules, along with the practice turns, seemed to reduce the amount of confusion regarding scorekeeping. Because there were three teams this time instead of two, each team had a little more time between its turns to search for activities. However, selecting activities was more difficult because the results were on the backs of the cards. Instead, the playtesters used the learning styles map to infer which activities might be appropriate for their students, a process that took more time and effort. The designers did not take detailed notes regarding the duration of turns or resources used.

Discussion

We began this study by positing two questions that we thought could be answered through the design and development research approach. The first was, how can instructional design theories be applied in the game design process? We based the structure of our game on the elaboration theory as a way of ensuring that our players were engaging in whole tasks that increased in difficulty as they progressed. While we only partially tested gameplay to validate this approach, it is so commonly (if unknowingly) used in game design that it seems a natural application of the theory. However, given a game with different goals, a different theory may be suitable. A potential line of research might consider how game genres align with learning objectives and with instructional design theories.

We applied Merrill's first principles of instruction and Kolb's learning styles to evaluate the quality of learning activities and their effectiveness with given students. We would conclude from this that instructional design theories and learning theories are applicable as models for game components, including scoring mechanisms.

We drew upon cognitive load theory to make decisions about the design of game components and the amount of information players need to make successful decisions in the game. We are still struggling to resolve issues regarding the balance between cognitive load and fidelity in the design of activity cards. Instruction that embodies Merrill's first principles should describe how the learner's prior knowledge will be activated, how demonstration and practice will be provided, and how integration of the new knowledge and skills will be facilitated. This is more textual information than games generally require players to manage. Furthermore, at least in our current conception of the game, players must search through a large number of activities in a short time to keep gameplay moving forward. There may be a technological solution that would be difficult to incorporate in a board game, such as an interface for specifying desired criteria that retrieves only satisfying activities. That approach would simplify the primary game mechanic of selecting appropriate activities by splitting it into two steps: specifying criteria and examining in detail the applicable subset of all activities.

Our second question was, what design principles may be formulated from a retrospective analysis of the design and development process and artifacts? It is clear that we intuitively decided that our primary game mechanic—the selection of activities that complemented students' learning needs, styles, and preferences and that utilized appropriate technologies—needed to be aligned with our primary learning objective. We might conclude that designing core game mechanics that are aligned with learning objectives is a fundamental design principle for instructional games. In other words, if someone needs to be able to do something in the real world, design a way for him or her to practice that action and receive feedback in the game. Furthermore, the primary game mechanic should have high fidelity to real-world practice to facilitate transfer. Our initial attempt at this was flawed and resulted in a simple matching game; we provided too much guiding information on the activity cards whereas in a real-world context those data would not be so explicit. However, by focusing on the learning objective, we were able to redesign the components of the game—in this case the learning activity cards and the student information cards—to require the player to practice the real task.

Based on our experience in using models to design game components, we would suggest that when designing a scoring mechanism based on the relationship between two models (e.g., the relationship between learning activities and learning styles), and further when multiple designers are collaborating on evaluating components of those models, that the process be treated as a matter of inter-rater reliability. In our case, we created a map to assist designers in making this judgment, and we had one person serve as final arbiter of all scoring decisions. It is worth noting that we ended up giving a version of that map to players as a scaffold. This suggests that there may be a relationship between design tools and learner scaffolds that merits further investigation.

As we reflected on our design experience, we noted the similarities between playtesting and participatory design (Carr-Chellman & Savoy, 2004). Our playtesters gave us several creative and concrete suggestions for improving our game, and this highlights the usefulness of combining rapid prototyping with playtesting. It is increasingly common in game design to playtest frequently (cf. the designers' commentary included in the videogame *Portal*, 2007; Barnett, Swift, & Wolpaw, 2008), while in instructional design the formative evaluation of products seems less frequent and in many cases less open to design suggestions from participants.

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